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Environmental safety control in water reservoirs

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ABSTRACT

The ecological safety of drinking water in the Jeyranbatan Water Reservoir is shaped by the interaction of natural processes, anthropogenic impacts, and temporal variations in environmental conditions. Ensuring the stability of quality indicators requires continuous monitoring of key parameters, systematic data processing, and scientifically grounded management decisions based on regulatory requirements. The article integrates real-time water quality measurements with an extensive normative database covering national and international standards. Taking the time factor into account, periodic fluctuations, long-term trends, and irregular deviations caused by external influences are distinguished within the indicators. The obtained results provide a basis for the early identification of undesirable changes in water quality and support corrective measures aimed at reducing ecological risks. Comparison with normative values enables assessment of the current state and more accurate forecasting of potential hazards. As a result, aligning reliable measurement data with standardized criteria increases the reliability of management decisions, reduces uncertainty, and strengthens the overall level of ecological safety. The proposed approach can serve as a scientific foundation for advancing the monitoring of drinking water resources.

1. Introduction

In recent years, two parallel yet fundamentally different global challenges have emerged: on the one hand, a rise in sea levels is causing large areas of land to be submerged, while on the other hand, the problem of water scarcity is steadily intensifying. Global drought and the pollution of freshwater sources lead to the depletion of water reserves, the emergence of shortages, and the disruption of the natural water cycle. In recent decades, climate variability, the growing demand for water in agriculture, industrial discharges, and other related factors have been among the main drivers of water scarcity and even the exhaustion of water resources. Inefficient water management, unequal distribution, and contamination of available supplies further deepen the shortage of potable water. Addressing these issues requires effective and sustainable water management, efficient use of water resources, and the prevention of water pollution. International cooperation plays an essential role in solving water-related problems.

This issue is driven by multiple factors, including urbanization and population growth, climate change, water pollution, insufficient infrastructure, water governance, and regulatory limitations. According to United Nations reports, one in ten people worldwide currently suffers from water scarcity. Forecasts indicate that global water demand may increase by up to 70% by 2050.

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Azerbaijan is among the countries facing freshwater scarcity. Only 10% of the freshwater resources of the South Caucasus region fall within the territory of Azerbaijan. The country's potable water reserves are limited and unevenly distributed. Although the current surface water resources amount to 30-31 km³, during dry years this volume may decrease to 20.3 km³. Experts associate the decline in the flow of the Kura River with climate change, reduced precipitation, and the increasing frequency of drought periods.

Reservoirs may differ depending on their type, such as lake-type, river-type, or basin-type reservoirs. The physical characteristics of lake-type reservoirs are largely influenced by wind activity; river-type reservoirs are generally elongated in shape and the properties of their water mass resemble those of river systems. Basin-type reservoirs are comparatively small in volume and are typically used for irrigation, sanitary purposes, recreational activities, or aesthetic needs.

Reservoirs can be classified according to different characteristics, including their basin structure, water supply sources, geographical location, position within the river basin, methods of flow regulation, and other criteria. In terms of operation, the hydrological regime of a reservoir – namely, the parameters and technical measures required for its management – is controlled by human intervention. Despite their artificial origin, such reservoirs gradually become integrated into the overall hydrological cycle over time and function as a part of the natural system.

The Oghuz-Gabala-Baku water pipeline holds significant importance for Azerbaijan. Primarily, it delivers large volumes of clean potable water to Baku. Although a substantial portion of Azerbaijan's water resources is formed beyond the country's borders, the Oghuz-Gabala-Baku pipeline is a critical project entirely based on local sources. Construction of the pipeline began shortly after the country's first oil revenues were obtained. Experts acknowledge that without this pipeline, Baku's water supply challenges would be considerably more severe.

Additionally, the historical Takhtakorpu Reservoir should be noted, which has a substantial capacity of 270 million cubic meters. A new concrete channel was constructed from the Takhtakorpu Reservoir to the Jeyranbatan Water Reservoir (JWR). The Takhtakorpu Reservoir is particularly important because it collects water from the Samur River, naturally purifies it, and subsequently transfers the treated water through the newly constructed channel to the JWR (Fig.1).

Fig. 1. Jeyranbatan water reservoir (Source: Google Earth)

Previously, the waters of the Samur River were directly channeled into the JWR. Without this large reservoir, it would not have been possible to supply Baku with potable water – a fact that is indisputable. Consequently, considerable efforts were undertaken to ensure the equitable distribution of the Samur River waters and the successful implementation of this project [1]. Furthermore, the project significantly increased the irrigated area in the Shabran, Siyazan, and Khizi districts, enabling the provision of water to approximately 30,000 hectares of previously unirrigated land and facilitating extensive agricultural activities in these regions.

The risk of contamination of potable water represents one of the primary threats to national security. Currently, the impact of global environmental issues on politics and international relations is steadily increasing. In interstate relations, environmental pollution and control over water resources play a significant role, and these factors have become instruments of pressure between countries. In this context, the issue of potable water has emerged as a crucial component of contemporary political relations. The concept of “water diplomacy” has been introduced to describe the use of water resources as a tool for political leverage on the international stage [2].

An illustrative example of this is Armenia’s occupation of the Sarsang Reservoir, which has been utilized as an ecological instrument of pressure against the surrounding regions.
In the Karabakh region, there are a total of 24 reservoirs, three of which are in critical condition. Of the 22 reservoirs used for irrigation purposes, seven are also utilized for fisheries. Additionally, two reservoirs serve as sources of energy production.

The data presented above highlights the necessity of establishing a unified management system to ensure the governance and safety of potable water in the country. This issue has a global dimension and requires the participation of numerous experts and the allocation of significant resources for its resolution. The development of such systems typically begins with the creation of a prototype. In this context, the JWR, which plays a crucial role in the potable water supply of the Absheron Peninsula, has been selected as a prototype.

2. Problem statement

Ensuring the ecological safety of strategic objects such as reservoirs directly depends on their protection as physical structures, the control of water inflow and outflow parameters, laboratory analyses, and expert evaluations. The objective of this work is to develop a centralized management system that oversees and controls these functions.

3. Solution

To preserve water resources from pollution and depletion, all water users must comply with the following general regulations based on water legislation:

- They must avoid causing harm to the environment and natural objects, and respect the rights of other water users;
- They should use water resources efficiently and economically, continuously improving water quality;
- Treatment facilities must be kept operational at all times, and their efficiency should be enhanced;
- Measures should be taken to completely prevent the discharge of wastewater containing pollutants into water bodies;
- The quantity and quality of water used and discharged must be recorded and analyzed.
- In addressing these issues, the following general requirements and standards should be considered:
- Potable water must be chemically safe in terms of epidemiology and radiation;
- Water that does not enter the distribution network must meet hygienic quality requirements;
- The composition of drinking water must comply with microbiological and parasitological standards [3,4].

In the Republic of Azerbaijan, the quality indicators of potable water supplied to consumers are determined based on the Interstate Standard adopted jointly by the CIS countries (GOST 2874-82). According to GOST 2874-82, drinking water is analyzed across more than 35 indicators, including organoleptic, physico-chemical, microbiological, parasitological, and radiological parameters.

Water quality analysis at the JWR is conducted based on samples collected from seven monitoring points (initially, in 2015 when the research began, samples were taken from 15 points; later, some points were decommissioned, and the most recent analyses are carried out at seven points). These points include the JWR, the Takhtakorpu-Jeyranbatan channel, the vicinity of the JWR water intake facility, the southern pumping station of the JWR, seepage waters at the southwestern dam, seepage waters at the southern dam, seepage waters at the northeastern dam, and the inlet of the JWR reclamation pumping station.

According to the standards established by the World Health Organization, drinking water is assessed across more than 50 parameters, whereas European Union standards specify over 75 parameters (data obtained from the Ministry of Emergency Situations). For the evaluation of JWR waters, normative databases were established for the measured parameters, and these standards were compared against current measurement results [5]. A functional model of the system has been developed to facilitate this evaluation [6].

$$\left\{\{I_{q_A}\};\{I_{q_B}\};\{I_{q_i}\};k\{I_{q_i}\};O\{P_q\}\right\}\xrightarrow{\{S_{O_q}\}\Rightarrow O\{P_q\}}\left\{(I_{q^*});k^*(I_{q^*})\right\},$$

$\{I_{q_A}\}$ – table of maximum permissible concentrations of factors in the water composition of the JWR;
$\{I_{q_B}\}$ – table of water composition standards according to GOST;
$\{I_{q_i}\}$ – table of current values of the composition of water taken from measurement point
i $(i = 1,2,\dots,6)$;
k$\{I_{q_i}\}$ – coefficient of comparison of current data $\{I_{q_A}\}$ with the norm of the JWR;
O$\{P_q\}$ – set of changes in the values of excited parameters;
$\{S_{Oq}\}$ – scale of values of impacting factors;
(*) – result of impact of operator $\{S_{Oq}\}$.

In this case, the conceptual model can be represented as shown in Fig. 2. [7].

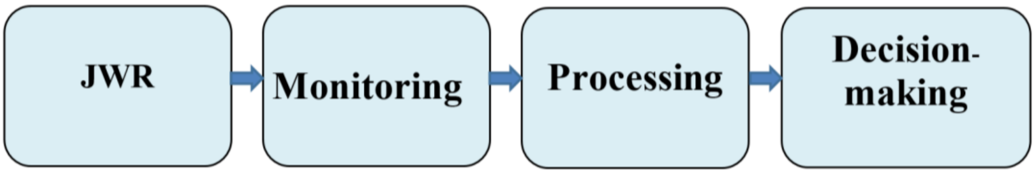

Fig. 2. Conceptual model of an intelligent environmental monitoring system for the Jeyranbatan water reservoir

The module developed for the JWR integrates all information related to the reservoir, ranging from its geographic location to the physical, chemical, organoleptic, and microbiological parameters of the water. The monitoring module ensures control over informative parameters, the implementation of measurement methods, and the formation of time series. The processing module enables the analysis and forecasting of time series based on various methods. The decision-making module generates recommendations based on the current state of the water and ensures compliance of the reservoir water quality with international standards.

Based on the functional and conceptual models, the structural architecture of the block responsible for monitoring the measured indicators in the reservoir has been developed (Fig.3).

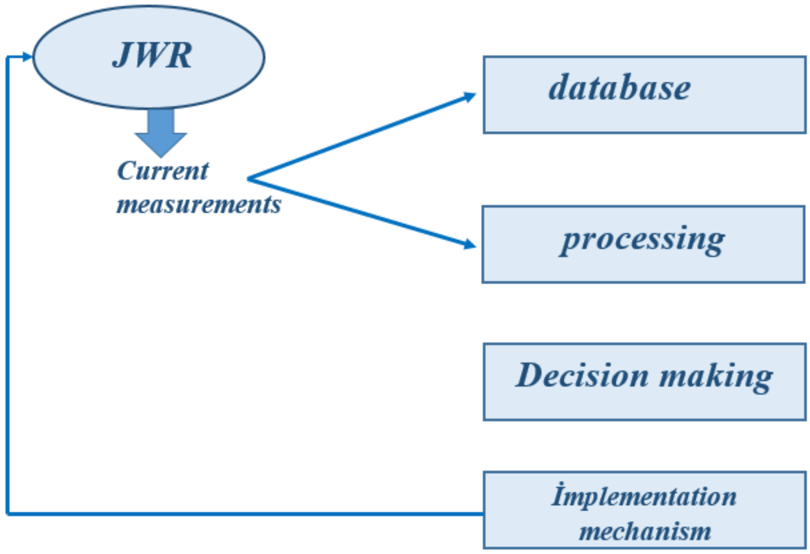

Fig. 3. Modul architecture of an intelligent environmental monitoring system for the Jeyranbatan water reservoir

The monitoring results for the JWR have been grouped into three periods: model validation, testing at new points, and the verification period starting in 2022. For each period, time-series data were generated across four respective databases. At the same time, the current water quality indicators are compared in real time with the established normative standards. Additionally, the current measurements can be compared with historical data collected in the information database, which is particularly valuable for forecasting purposes.

The increasing demand for potable water in Azerbaijan is one of the most critical issues. Existing reservoirs in liberated territories are being restored, and new ones are being constructed. Considering that the sources of rivers flowing through the country are located outside its borders, ensuring the security and continuous monitoring of potable water is essential. Therefore, the development of a unified approach to ensure the ecological safety of all reservoirs and the establishment of an integrated intelligent management system is necessary. In this context, the developed module is intended to be incorporated into the future unified system.

The software was initially tested using Python and several other programming languages. The most accurate and realistic results were obtained using the Visual Studio Code platform, along with HTML markup, CSS coding, and JavaScript programming. Front-end code was written using HTML markup, as it allows the creation of accessible and comprehensible content through elements such as lists, tables, and paragraphs. The headings, layout, fonts, and other visual effects of the program were implemented using CSS. The most effective way to ensure the correct execution of functions is through the application of JavaScript. Since JavaScript is a single-threaded scripting language, it executes code line by line, and the next line is not processed until the current one is fully completed. Below are fragments from the program. (Fig.4).

It is well established that water currently enters the JWR through the Takhtakorpu-Jeyranbatan channel from the Takhtakorpu Reservoir. Accordingly, the Takhtakorpu channel was chosen as the main control point for comparative analysis. Numerous experiments have been conducted. Initially, the adequacy of the software in relation to the process was tested. Trials were performed using measurements from 2014-2017 to verify the accuracy of the results. Testing continued for the period 2018-2021, and the verification phase of the system covered the years 2022-2024.

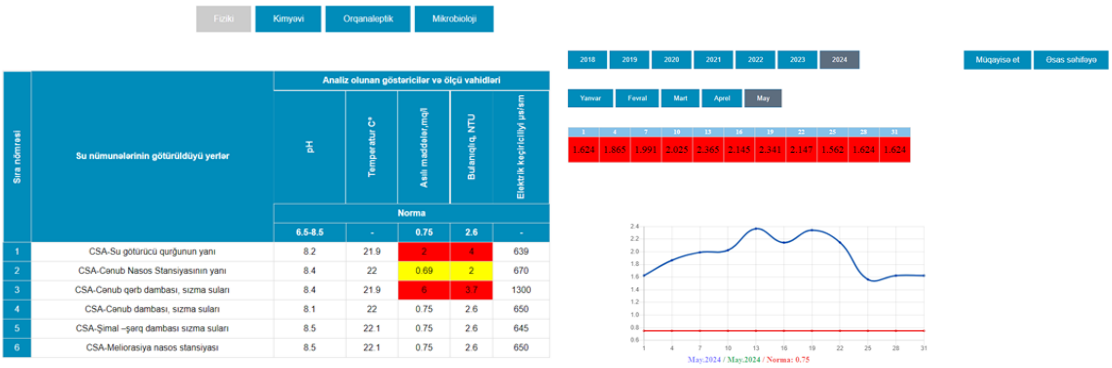

Fig. 4. Fragment from the comparison performed in the program

4. Conclusion

A module based on functional and conceptual models has been developed to monitor the safety of drinking water in the JWR. Measurement scheduling has been organized to define appropriate sampling times for parameters that remain stable throughout the measurement period, as well as for those that vary irregularly due to environmental factors. Forecasting has been addressed using variance analysis, mathematical statistics, and probability theory methods.

Considering that the sources of rivers flowing through our country are located beyond national borders, continuous monitoring of safety – particularly drinking water quality – must be ensured. Therefore, it is necessary to establish a unified approach and an integrated intelligent management system to guarantee the ecological safety of all reservoirs. The developed module can play a leading role in the implementation of such a system.

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