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Information and Analytical System Monitoring and Assessment of the Water Bodies State in the Mineral Resources Complex

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Abstract: Currently, one of the most pressing global issues is ensuring that human activities have access to water resources that meet essential quality standards. This challenge is addressed by implementing a series of organizational and technical measures aimed at preserving the ecology of water basins and reducing the level of harmful industrial emissions and other pollutants in the aquatic environment. To guarantee the necessary quality of water resources, monitoring is conducted based on selected parameters using various methods and means of technical quality control. From these results, suitable measures are formulated and applied to maintain water quality. Various scientific works extensively discuss different approaches to water quality management and compliance with specified requirements. Modern strategies for developing water monitoring systems leverage the capabilities of information systems that collect, process, store, and transmit information, enabling the resolution of issues in geographically distributed water bodies in real time. This paper proposes an approach that employs mathematical methods to identify the most significant factors determining water quality and to assess their interrelations using methods of a priori ranking, multivariate correlation regression analysis, and integral quantitative assessment. A hardware and software solution for the development of a unified integrated information and analytical system is proposed. This system enables continuous monitoring and assessment of water bodies based on a set of key parameters, addressing a range of critical tasks. This paper provides a detailed description of the software product, presents a demonstration using real-world data, and discusses the anticipated benefits of implementing such an information and analytical system.

Keywords: monitoring; modeling; water quality; information and analytical system

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1. Introduction

In modern conditions, ensuring the rational use of natural resources and maintaining environmental sustainability is a priority for various industries, including the mineral resource sector. Water bodies in this context play a critical role. Continuous monitoring and assessment of these water bodies are essential to prevent environmental pollution and ensure their ecological integrity.

The mineral–resource complex, as a complex entity that includes systems and methods for the extraction, storage, processing, and transportation of various natural resources, is a significant source of harmful emissions and pollution that adversely affect the environment. Moreover, the volume and quality of water resources are crucial not only for supporting the operational processes within the mineral–resource complex but also for the livelihood of populations relying on these resources.

Currently, the global community places considerable emphasis on solving issues related to environmental protection, ecology, and the reduction in harmful emissions and pollution resulting from human activities. A pivotal aspect of these efforts involves ensuring the necessary quality of water resources, achievable through systematic monitoring and the implementation of suitable organizational and technical measures to maintain the required water quality level. The modern state of information, computational, and telecommunications tools and technologies enables the deployment of comprehensive information systems that operate in real time for collecting, processing, storing, and transmitting essential information.

Thus, the development of a unified integrated system for continuous monitoring and assessment of water bodies based on the most crucial parameters represents a relevant scientific and engineering challenge.

Developing an information–analytical system that combines mathematical methods for analyzing water bodies allows for more accurate and substantiated decisions. This article is dedicated to creating such a system designed for monitoring and assessing the state of water bodies in the mineral resource complex. The system uses modern mathematical models, including methods of factor analysis, correlation, and regression, to identify and evaluate the most significant parameters affecting water quality. By refining the selection of key factors and improving the assessment process, the system aims to provide a deeper understanding of the mutual influence of factors on the state of water bodies, ensuring effective environmental management.

The development of innovative tools and methodologies for monitoring and assessing water quality is a crucial research area that concerns not only environmental sustainability but also public health and production efficiency. Instead of merely analyzing existing water quality, modern research focuses on creating advanced solutions that expand the capabilities of monitoring systems and improve decision-making processes.

For example, the article [1] discusses the importance of continuous monitoring and optimization of industrial effluents in wastewater treatment plants, but beyond the scope of conventional analysis, the focus shifts toward adaptive systems that operate in real time and are able to respond to changing water conditions. Similarly, the Nigerian Drinking Water Quality Study highlights the need for innovation in identifying public health risks and improving water safety, pushing the boundaries of traditional water quality assessment to include multivariate analysis of the physicochemical properties and concentrations of heavy metals [2]. An especially promising approach is described in [3], where models with bidirectional long short-term memory (Highway-BiLSTM) are developed, allowing for near real-time water quality monitoring. This system represents a leap toward integrating machine learning into edge computing environments, capable of detecting water quality fluctuations almost instantly and, consequently, providing proactive solutions for protecting ecosystems and human health. Innovative machine learning methods are also used in the analysis of groundwater quality in southwestern Algeria, where financial constraints on sampling are overcome through predictive modeling [4]. Such tools not only enhance the efficiency of water quality assessment but also enable continuous monitoring in resource-limited regions. Similarly, in the study of Egypt's El-Mex Bay and El-Umum Drain, a modified water quality index is presented [5]. Through multidimensional analysis and seasonal pollution data, this approach surpasses traditional methods, providing a more comprehensive understanding of water conditions and allowing for better resource management. Further progress is evident in studies like [6,7], where weighted arithmetic indices are used to assess water quality in reservoirs, offering local authorities more reliable tools to improve water conditions. The integration of geographic information systems and statistical models in water quality studies, such as in the Nador Canal in Morocco, reflects a growing trend toward interdisciplinary approaches that combine data from multiple sources to enhance accuracy and scale [8].

The examples presented above demonstrate the shift in focus from basic monitoring to the development of new technologies and methods aimed at optimizing water quality management.

The future lies in systems that not only evaluate but also predict and respond to changes in water quality, utilizing artificial intelligence, machine learning, and real-time data processing to ensure the sustainability and viability of water resource management.

Innovative approaches in water quality assessment are increasingly focused on developing advanced technologies and methodologies, rather than relying solely on traditional methods. In a study [9] dedicated to examining water quality in Rajasthan (India), a significant impact of anthropogenic activity is identified. Beyond determining pollution sources, the emphasis is on developing adaptive systems capable of dynamically responding to these human-induced changes. Similarly, in another study [10], the selection of crucial parameters for water quality indices is improved through machine learning and statistical approaches. These innovations allow for more accurate predictions and assessments, leading to the development of more rational water resource management strategies. A growing trend in water quality research is the integration of various objectives, such as using water quality indices to track pollution trends in rivers and other bodies of water [11–13]. Systematic data collection, as shown in [11], where 14 parameters were measured at multiple sampling points over several years, underscores the need to create automated and continuous water quality monitoring systems. This concept is also supported by studies [14–16], in which scientists advocate for developing tools that facilitate long-term environmental observation.

The study of water pollution, often exacerbated by industrialization and population growth, is now being addressed using advanced machine learning methods [17]. These methods are being developed and applied for more accurate groundwater quality assessment in industrial zones.

In the pursuit of the most effective algorithms for assessing water quality, researchers have begun comparing various machine learning models, as described in studies [18–20], with a focus on identifying those best suited for determining key indicators. This shift toward algorithmic optimization not only improves water quality predictions but also creates a solid foundation for regional environmental initiatives aimed at protecting aquatic environments. Other innovative methodologies are emerging in studies of groundwater and drainage water. Principal component analysis, as shown in [21], is one such technique that helps interpret complex water quality data. In the context of natural sources, comprehensive monitoring and purification strategies discussed in [22] emphasize the need for effective policies promoting sustainable water resource management. In studies [23–26], systems for assessing drinking water using indicators such as the water quality index and the synthetic pollution index have been developed. The results are compared with global standards, such as those established by the World Health Organization, contributing to the improvement of both local and global water management practices. The article [27] illustrates the use of expert assessment methods, such as the Delphi method, to account for water level fluctuations. Similar studies in the USA evaluate urban river systems using pollutant tracking over time to refine water quality assessments [28]. As shown in articles [29–32], comprehensive mathematical models are being developed to analyze various water quality factors. These models, supported by advanced analytical methods, allow for a deeper understanding of how water quality changes over time, providing decision-makers with the tools needed to create more adaptive water resource management strategies.

It is also important to note that new challenges continuously arise, which are being addressed through novel methodologies that enhance the effectiveness of monitoring and evaluation [33–35]. These approaches contribute to the sustainable use of international water resources by providing more accurate data on their status, supported by continuous monitoring systems that are now a critical component of modern water resource management [36–38]. Traditional methods, long relied upon for their accuracy, are now giving way to more modern, integrated systems that offer real-time, cost-effective, and scalable solutions. While traditional methods yield certain results, they require significant resources and time, limiting their practical applicability for large-scale or continuous monitoring [39–41].

The future of water quality assessment lies in developing dynamic monitoring systems utilizing the most advanced technologies. Such systems are not merely passive data collectors but active components of environmental management strategies, designed to optimize water quality monitoring depending on specific goals, resource availability, and the unique characteristics of each water body [42]. For example, innovative sensor networks and automated data analysis platforms are being developed for continuous tracking of multiple water quality parameters, reducing the time and costs associated with traditional laboratory studies. The study described in [43] highlights the importance of developing monitoring strategies that align with desired environmental outcomes. By integrating real-time data collection with predictive analytics, these systems not only enhance the accuracy of water quality assessments but also improve the effectiveness of training programs and management decision-making by providing actionable insights.

From the foregoing, it is clear that a comprehensive approach to water resource management is crucial, and there is a need to develop effective tools for monitoring and analyzing the condition of the aquatic environment.

2. Problem Statement

This work is dedicated to the substantiation and development of mathematical methods that enable factor analysis of the main parameters of the selected water body, identification of the most significant factors, and exclusion of insignificant ones. It also facilitates the execution of correlation and regression analysis of the selected essential factors and, based on the multiple regression model, allows for the study of the mutual influence of these factors.

Traditional methods for investigating factor impacts, such as principal component analysis (PCA) and factor analysis (FA), are widely used to reduce data dimensionality and reveal latent factors. However, in PCA and FA, the resulting components or factors are often linear combinations of the original variables, which can make them difficult to interpret in a meaningful physical context for assessing water quality. Additionally, dimensionality reduction may result in the loss of critical information that is important for specific water bodies. Furthermore, PCA and FA methods do not incorporate expert knowledge about the system, potentially leading to the omission of key factors. The proposed set of mathematical methods is integrated into a unified information and analytical system. The developed unified integrated information and analytical system, along with the associated software product, should enable systematic monitoring and assessment of the state of the selected water body using a set of critical parameters. At the same time, the system offers the following capabilities: defining the number of study zones for a given water body, analyzing the current state of water parameters and constructing predictive models for each zone, and identifying the most probable source of contamination. The introduction of this information and analytical system—a combination of hardware, software, and information sources integrated into a single computer network—aims to enhance the accuracy and significantly accelerate the process of assessing changes in water resource characteristics.

This study focuses on water bodies, including natural and artificial water areas such as rivers, lakes, and reservoirs, whose water resources are utilized for various purposes, including drinking water supply, agricultural irrigation, fishing, recreation, tourism, and industrial use. In this context, particular emphasis is placed on water bodies where water quality is critical for environmental, economic, and public health concerns.

The objective of this work is to develop a unified, integrated information and analytical system for systematic monitoring and assessment of water quality based on selected parameters.

To achieve this goal, the following tasks are required:

- Justify and develop mathematical methods to conduct factor analysis of key water body parameters, identifying the most significant factors while excluding insignificant ones;
- Perform a correlation regression analysis of the essential factors, and use a multiple regression model to examine the mutual influence of these factors;

- Develop software that allows for data import from Excel, processes the information, and visualizes the results.

The novelty of this work lies in the creation of an integrated system that combines modern mathematical methods of data analysis with advanced information and communication technologies. This system enables continuous real-time water quality monitoring and supports informed management decisions. The innovative approach consists of integrating methods such as a priori factor ranking, multivariate correlation regression analysis, and water quality index calculation into a single system. This approach not only identifies the most significant parameters influencing water quality but also predicts their changes, accounting for the interdependencies between factors, thereby enhancing monitoring efficiency.

3. Mathematical Methods

3.1. Method of a Priori Ranking of Factors

The a priori ranking method is used to evaluate and rank factors based on the degree of their influence on the process under study. Unlike PCA and FA, which rely on statistical data analysis, the a priori ranking method incorporates expert opinion and domain-specific knowledge about the system [44].

It is understood that the assessment and ranking of factors involve ordering them according to their anticipated degree of influence on the process under study [45–47]. The significance of factors can be evaluated based on a survey conducted among a group of specialists (experts) [32,48,49]. The algorithm for a priori ranking of factors consists of six steps, as detailed in Table 1.

Table 1. Method of a priori ranking of factors (compiled by the authors).

No. Step	Name	Brief Characteristics
1	Determination of factors	Selection of a set of parameters (factors) characterizing the state of water, based on expert knowledge and the results of previous studies.
2	Assigning ranks	Assigning a rank to each factor on the basis of expert assessments, which allows for taking into account the specific conditions of the mineral–resource complex. Each factor is assigned a rank that reflects its expected impact on water quality. A questionnaire survey is one of the possible ways to obtain such estimates.
3	Assessment of the consistency of expert opinions	Calculation of the concordance coefficient W: - Unrelated ranks: $W = \frac{12\sum\Delta_i^2}{m^2(k^3-k)}$; - Linked ranks: $W = \frac{\sum\Delta_i^2}{\frac{1}{12}m^2(k^3-k)-m\sum T_j}$, where Δ_i is the deviation of the sum of the ranks of the j-th factor from the average sum of the ranks of all factors, k is the number of factors, m is the number of experts, t_u is the number of identical ranks in the group, $T_j = \frac{1}{12}\sum\left(t_u^3 - t_u\right)$.
4	Significance check	Statistically check consistency using the Pearson test. Comparison $\chi^2{}_B = m(k-1)W$ with a tabular value from the Pearson distribution ($\chi^2{}_t$). If $\chi^2{}_B \geq \chi^2{}_t$; then, the opinions of experts are considered agreed.
5	Calculating weights	Based on the ranks, the weights of the factors are calculated: $k = \frac{1}{R_i} / \sum\frac{1}{R_i}$, where R_i is the sum of the ranks of the i-th factor.
6	Selection of significant factors	Exclusion of factors with a weight below the specified threshold.

The advantages of this method include the following:

- It integrates expert knowledge, which is particularly important given the specific challenges of the mineral resource sector;

- Unlike the PCA method, the results are straightforward to interpret and do not require complex mathematical processing;
- It focuses on the most important parameters, excluding insignificant ones without losing critical information.

3.2. Multivariate Correlation Regression Analysis of the Main Indicators of Water Quality

After the identification of significant factors, a correlation regression analysis is carried out to study the relationships between the parameters and build a forecasting model [50–52].

Multiple linear regression model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n, \quad (1)$$

where is the factor under study; is n independent factors; is the coefficients for independent factors $y,\ x_1,\ x_2,\ \ldots,\ x_n \beta_0,\ \beta_1,\ \beta_2,\ \beta_n$ [31,49,53].

Correlation analysis is aimed at identifying and quantifying the relationship between random variables. Depending on the scale of measurement of variables, various methods for calculating correlation coefficients are distinguished. For quantitative variables, the Pearson correlation coefficient is used, and for ordinal data, nonparametric methods such as the Kendall and Spearman coefficients are used [54]. Correlation analysis is widely used in various fields due to its simplicity and ease of interpretation.

3.3. Water Quality Index

The works [55–60] describe various approaches to determining water quality. Various approaches to determining water quality have been described in the literature [1–6]. For instance, reference [55] presents a method of water quality assessment that includes evaluating chemical variables based on concentration, target quality indicators, and determining weights proportional to these evaluations. The result of applying this method is a water quality index whose values range from very good to extremely poor water quality. Reference [56] introduces a method that incorporates various tools and data sources, including a methodology for measuring water quality in the Tigris River and the process of collecting expert assessments. In reference [57], a system designed for assessing water quality in various water bodies is discussed. This method utilizes indices based on the characteristics of pollutants, which do not require specific information about water treatment facilities. The authors of reference [58] employ a water quality index to assess water quality, consolidating large volumes of data into a single value that determines the state of the water supply system. The water quality index serves as a valuable tool for assessing and communicating the condition of water bodies, which is crucial for sustainable development amid increasing urbanization and environmental stressors. Reference [59] provides the results of a comparative analysis of various methods for calculating the water quality index, highlighting their advantages and disadvantages. In reference [60], the results of a study aimed at refining the water quality index by adding new variables are presented, based on the analysis of water samples from 180 rivers. Particular attention is paid to the amount of precipitation and land use volumes in the catchment basins. The water quality index is shown to be an effective indicator of water quality, assisting in making informed decisions regarding water resource management. Based on their analysis and generalization, the calculation of the integral index indicator is carried out according to the following formula:

$$WQI = \sum_i RW_i \frac{C_i}{S_i} \cdot 100, \quad (2)$$

where RW_i is the weight coefficient of the i-th parameter determined by the method of a priori ranking, C_i is the measured value of the i-th parameter, and S_i. is the normative value of the i-th parameter.

The advantages of this calculation method include the following:

- The WQI index takes into account weights based on expert opinion, which makes the assessment more relevant to a particular water body;
- Ease of calculation and interpretation of results.

Numerical values of weight coefficients are calculated by the method of a priori ranking of factors, and standard values of parameters are taken from regulatory documents. The WQI classification is given in Table 2.

Table 2. Method of a priori ranking of factors (compiled by the authors).

Index Value	Condition Assessment
up to 50	"Excellent"
from 50 to 100	"Good"
from 100 to 200	"Bad"
from 200 to 300	"Very bad"
from 300	"Unsuitable"

4. Development of an Information and Analytical System

4.1. General Description of the System

The proposed system integrates hardware and software components to ensure continuous water quality monitoring (Figure 1).

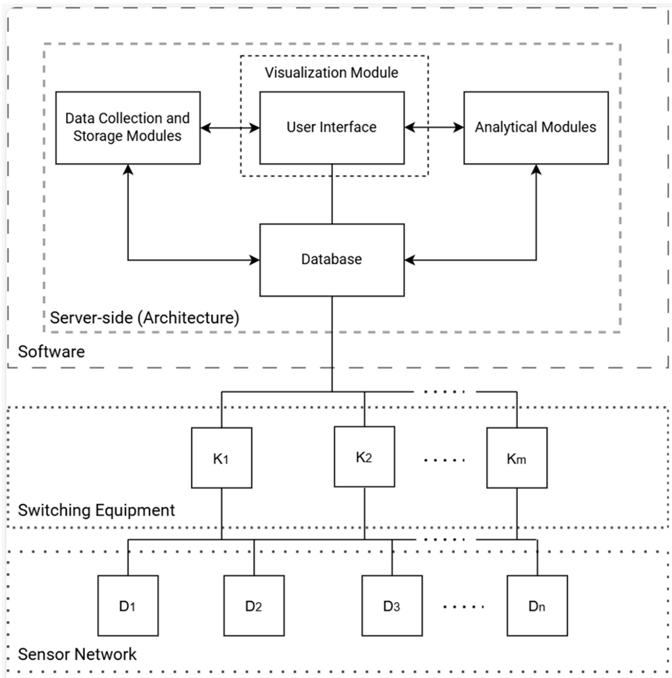

Figure 1. Generalized structure of the information and analytical system (compiled by the authors).

System components:

- Sensor network: measures water parameters across different locations;
- Communication infrastructure: transmits data in real time;
- Server infrastructure: includes a database and analytical modules;
- User interface: provides access to data and analysis results.

The system consists of the following key parts:

1. Hardware, which includes the following:
    - A sensor network that measures water parameters (turbidity, total suspended solids, water temperature, pH, conductivity, nitrate nitrogen, reactive phosphorus orthophosphate, dissolved oxygen) across various areas of the water body. The

    sensors are equipped with wireless communication modules for real-time data transmission;
  - Communication infrastructure that ensures real-time data transfer from the sensors to a central server.
2. Software, which includes the following modules:
   - Data collection and storage module: Responsible for receiving sensor data, performing preliminary processing, and storing it in the database;
   - Analytical modules: Implement mathematical methods for data analysis, including a priori factor ranking, correlation regression analysis, and water quality index calculation;
   - Visualization module: provides tools for visualizing data and analysis results in the form of graphs and tables;
   - User interface: allows users to interact with the system, configure monitoring parameters, view results, and generate reports.
3. A database that stores real-time and processed measurement data, analysis results, forecasting models, and other essential information.

Data from the sensors are transmitted through the communication infrastructure to the data collection and storage module. The analytics engine uses these data from the database to conduct analyses and update forecasting models. The visualization engine retrieves analysis results from the analytics engine and data from the database to display information to the user. The user interface provides access to the system's functionality, allowing users to configure monitoring parameters, run analyses, and view results.

The developed software also allows for the import of Excel files containing water measurement results for analysis using the methods outlined in Section 3. The core functionality is summarized in Table 3.

Table 3. Basic functionality of the information and analytical system (compiled by the authors).

No. Step	Functions	Short Description
1	Loading data	Import data from Excel files for different study areas
2	Data preprocessing	Check for omissions, outliers, and formatting
3	Data analysis	Application of the method of a priori ranking of factors and correlation regression analysis
4	Forecasting	Ability to predict the values of dependent variables based on the built models
5	Visualization of results	Construction of graphs and tables for visual presentation of analysis results

4.2. Research Areas

For detailed monitoring, a water body is divided into several zones, taking into account hydrological features and potential sources of pollution [61]. Each zone is equipped with the necessary number of sensors.

4.3. Data Collection and Processing

Data from the sensors are transmitted to a server, where they undergo preliminary processing: handling missing values through imputation or deletion depending on the volume and nature of the missing data (data cleaning), identifying and eliminating anomalous data points using statistical methods (outlier detection), and applying transformations to ensure comparable scales of variables, which is necessary for multivariate analysis (normalization). The preprocessed data are then stored in a database for subsequent analysis. The processed data are kept in a structured database, ensuring efficient retrieval and analysis.

The required data quality is ensured by implementing the following organizational and technical measures:

- Regular calibration and maintenance of sensors to ensure measurement accuracy;

- Implementation of data validation protocols for prompt detection and correction of errors;
- Continuous data collection and real-time analysis to enhance responsiveness to changing parameters of water composition and quality.

The innovation of the proposed schematic and technical solutions lies in the following:

- The use of modern sensors with high sensitivity and fast response time enhances system performance and reduces reaction time;
- The system allows for the prompt inclusion or exclusion of monitored parameters based on the set research objectives and expert evaluation results.

4.4. Software

The software is developed using the Python language and includes the following modules:

1. Data Acquisition Module: provides data reception and storage.
2. Analytical module: implements mathematical methods of analysis.
3. Visualization Module: provides tools for displaying data.

A block diagram of the algorithm for the operation of the software of the information and analytical system is shown in Figure 2.

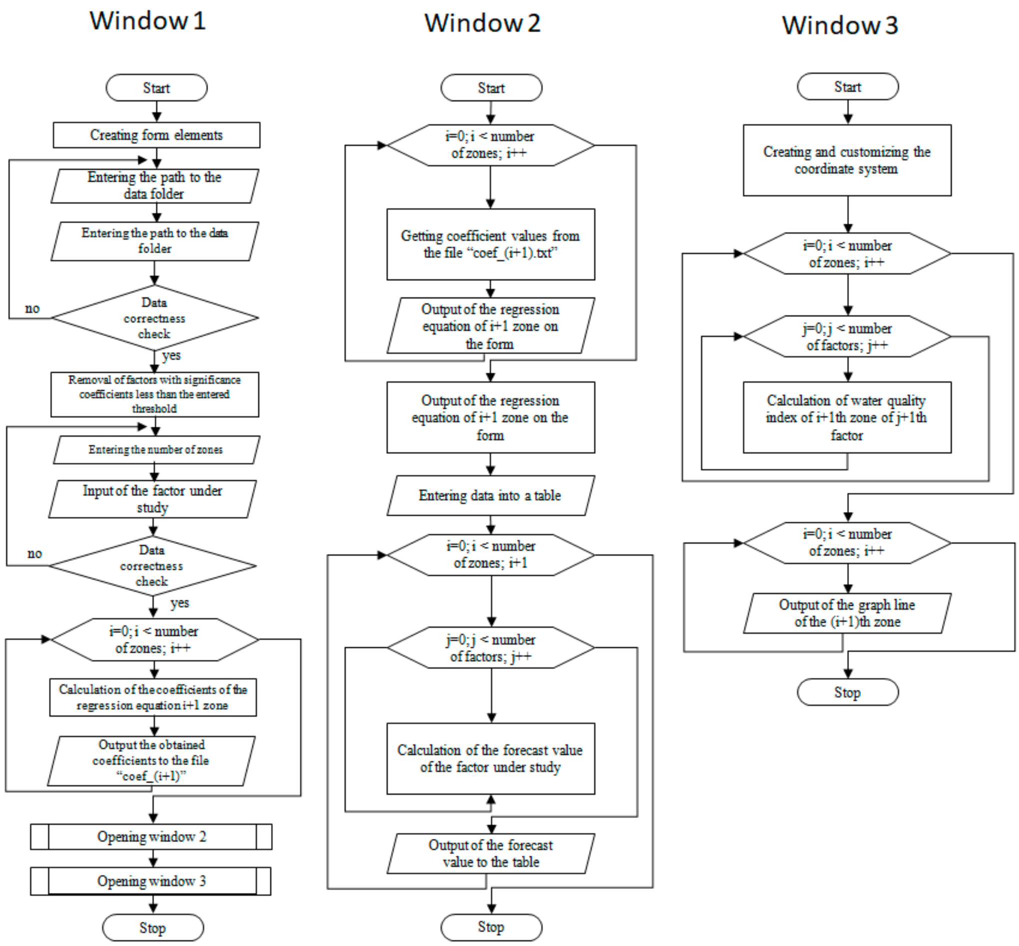

Figure 2. Block diagram of the algorithm of the software of the information and analytical system, where «Window 1» is the algorithm for entering information, «Window 2» is the derivation of the regression equation and the construction of a forecast; «Window 3»—Calculating the Water Quality Index (compiled by the authors).

5. Outcomes

5.1. Application of the System on the Example of the Laurel Creek River

To check the performance of the system, testing was carried out on the data of the Laurel Creek River, divided into eight zones [62]. Figure 3 shows a map with the designation of study areas [63].

Figure 3. Study zones on the Laurel Creek River [63].

The research process consists of three stages, containing five steps. Figure 4 illustrates the sequence of actions for water quality assessment.

In the first stage, users are prompted to create a folder that stores the water parameters, their weight coefficients (which users set independently, for example, by using a method of a priori ranking of factors), and the number of study zones. In the second stage, users are asked to set a significance threshold for the weights, which can range from 0 to 1. If 0 is selected, all parameters are included in the study; if a weight coefficient is below the set minimum value, the factor is considered insignificant and excluded. In the third stage, regression equations are derived using correlation regression analysis. These regression equations allow for predictions of the parameter values of interest to the researcher. Users can adjust the values of the indicators involved in the study. At the fourth stage, the program calculates water quality indices for each selected study zone based on the input data and the forecast results. In the fifth stage, these indices are displayed in both tabular and graphical formats (Figure 4).

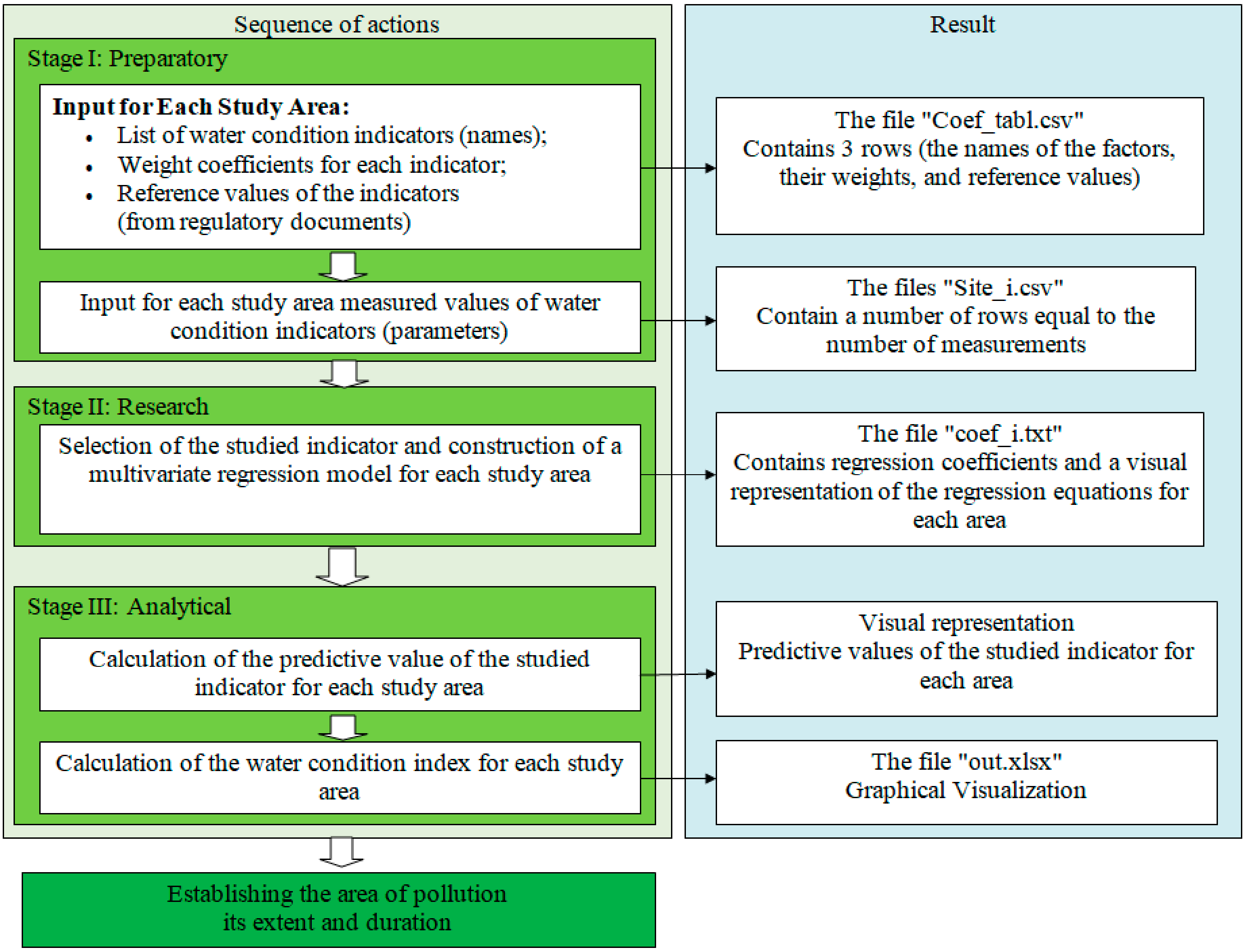

Figure 4. Sequence of actions for water quality assessment.

5.2. Operation of the Information and Analytical System in the Collection and Processing of Data

Data from the sensors are sent to the server, where they are pre-processed. The data are then passed through analytical modules, where the techniques described in Section 3 are applied.

Data from sensors installed in each zone are periodically uploaded to Excel files.

Data are collected using a network of sensors placed in different zones of the water body. The sensors measure various water quality parameters, including the following:

- Physical parameters: turbidity, total suspended solids, water temperature, flow velocity, average depth, wetted width;
- Chemical parameters: pH, conductivity, chlorides, nitrate nitrogen, reactive phosphorus orthophosphate, dissolved oxygen.

Flow velocity, average depth, and wetted width are dynamic parameters. They affect the concentration, dispersion, and transport of pollutants. Including them in the analysis provides insight into the hydrodynamic conditions influencing water quality [62]. Dynamic parameters are included in statistical models after appropriate normalization to account for temporal and spatial variability.

The data include measurements of the following parameters of the Laurel Creek River website [62]:

- Turbidity;
- Total suspended solids;

- Water temperature;
- Stream velocity;
- Mean depth;
- Wetted width;
- pH;
- Conductivity;
- Chlorides;
- Nitrate nitrogen;
- Reactive phosphorous orthophosphate;
- Dissolved oxygen.

Data preprocessing includes checking for missing values, eliminating outliers, and normalizing.

Before running the program, it is necessary to compile a list of all parameters, the values of their weighting coefficients, and their standard values in the "coef_table" file, as illustrated in Figure 5.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	factors	Turbidity_NTU	Total_Suspended_ Solids_mg/100ml	Water_Temperature _Celsius	Stream_ Velocity _m/s	Mean_ Depth_ cm	Wetted_ Width_m	pH	Conductivity _uS/cm	Chlorides _mg/L	Nitrate_ Nitrogen _mg/L	Reactive_Phosphorous_ Orthophosphate_mg/L	Dissolved _Oxygen _mg/L
2	coef	0.053	0.062	0.053	0.037	0.033	0.032	0.187	0.124	0.055	0.078	0.17	0.117
3	standart	2.6	0.0005	37.5	0.5	25	6.7	7.5	430	200	1.5	3.5	9

Figure 5. Contents of the "coef_table" file.

Thus, it is possible to increase or decrease the number of analyzed parameters depending on the goals of the study, as well as to establish their weight coefficients and their values accepted as references.

The file for each zone is saved in a separate folder in the "Microsoft Excel file" format, named "site_i", where i is the zone number. An example of the data inside each file is shown in Figure 6.

	A	B	C	D	E	F	G	H	I	J	K
1	N	Date	Time_(EST)	Turbidity _NTU	Total_Suspended _Solids_mg/100ml	Water_Temperature _Celsius	pH	Conductivity_ uS/cm	Nitrate_ Nitrogen_ mg/L	Reactive_Phosphorous_ Orthophosphate_mg/L	Dissolved_ Oxygen_ mg/L
2	1	2023_02_20	9:00	NaN	0.0056	9	8.1	836	12	0.21	11.6
3	2	2023_03_21	10:00	NaN	0.0071	9.8	8.02	758	9.96	0.089	10.6
4	3	2023_04_20	11:00	3.1	0.005	11.1	8.2	767	9.66	0.052	12.3
5	4	2023_06_08	12:00	2.2	0.0065	13.4	7.93	861	11.9	0.19	9.61
6	5	2023_07_21	13:00	7.5	0.0092	14.1	7.83	845	9.48	0.2	8.26
7	6	2023_08_14	14:00	4.3	0.0011	15.8	7.7	861	9.49	0.21	8.16
8	7	2023_09_06	15:00	5.2	0.0012	16.2	7.73	1003	14	0.32	7.96
9	8	2024_01_04	16:00	27	0.0033	7.9	7.96	643	8.28	0.059	10.8
10	9	2024_02_08	17:00	37	0.0059	6.9	7.92	622	7.07	0.091	11.3
11	10	2024_03_08	18:00	5.4	0.0011	7.7	8.06	747	9.28	0.053	11.4

Figure 6. Data folder.

5.3. Software of the Information and Analytical System

The program is developed using the Python programming language and includes the following functionality [64]:

1. Setting up research parameters and selecting significant factors;
2. Conducting correlation and regression analysis;
3. Forecasting parameter values;
4. Calculation of the water quality index for each zone;
5. Visualization of data and analysis results.

The sequence of actions for assessing water quality consists of the following sequential steps:

1. Data preparation: creating data folders for each zone containing the measurement results of water parameters and their weighting coefficients determined through a priori ranking.
2. Parameter selection: setting a significance threshold for the weighting coefficients to include significant factors in the research process.
3. Model development:
   - Performing correlation regression analysis to determine regression equations for each zone;
   - Including dynamic parameters after normalization to account for their influence on water quality.
4. Forecasting: applying the developed models to predict the values of target water quality parameters.
5. Calculation and visualization of the water quality index:
   - Calculating the water quality index for each zone based on measured and predicted values;
   - Outputting and visualizing results using graphs and tables to identify problematic areas of the studied water body.

Figure 7 shows the initial interface dialog window that opens when the program is launched.

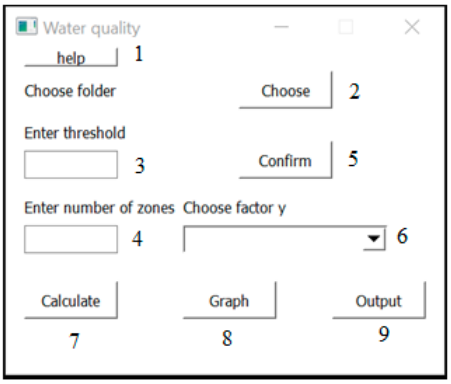

Figure 7. View of the initial interface dialog window.

The initial window displays the following elements:

1. Pressing the No. 1 "help" button provides detailed instructions for conducting the study, allowing you to familiarize yourself with the instructions for starting and working with the program.
2. The No. 2 "Choose" button is used to select the folder that stores data for each zone.
3. Field No. 3 "Enter threshold" sets the threshold value of significance (the minimum value from 0 to 1) for weight coefficients. This allows you to set the minimum value of the parameter weight to include in the study.
4. Field No. 4 "Enter number of zones Choose factor y" allows you to set the number of zones to be examined.
5. The No. 5 "Confirm" button starts the process of selecting data for the study and makes the No 6 field active.
6. Field No. 6 allows you to select the parameters to be studied from the drop-down list, which in our case are turbidity, total suspended solids, water temperature, PH, conductivity, nitrate nitrogen, reactive phosphorous orthophosphate, dissolved oxygen.
7. The No. 7 "Calculate" button starts the process of calculating and deriving the regression equation for each zone.
8. Button No. 8 "Graph" for calculating and displaying water quality indices in graphical form (Figure 8).
9. Button No. 9 uploads the numerical values of the indices for each zone to the Excel file.

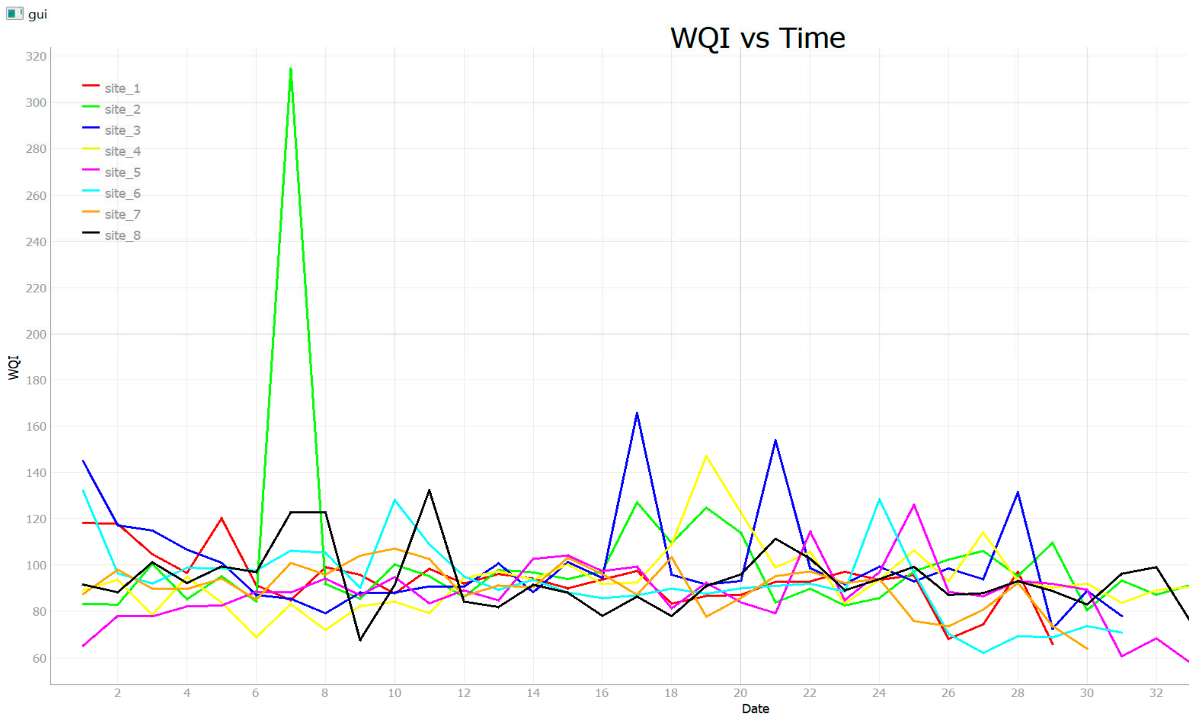

Figure 8. Graph of quality index values.

When you click the button ”Calculate”, a window with the calculated regression equations will open. The multivariate regression coefficients calculated for each study area are stored in separate “coef_i.txt” files. This window contains a table that allows you to predict the values of the selected parameter. For a forecast, you must fill in the columns of each parameter, except for the investigated parameter.

To verify the correctness of the program’s operation, multivariate predictive models were built in Excel. Comparison of the forecast results calculated using Excel and the information–analytical system for eight zones showed that the error was less than 1%.

5.4. Visualization of Results

By clicking on the “Graph” button on the first window, the values of the water quality indices will be calculated and displayed, as shown in Figure 8.

The graph shows a significant spike in the water quality index, indicating a substantial decline in quality. For a more precise analysis, the lines for specific zones can be hidden by clicking on their corresponding names in the legend. The graph can be zoomed in or out by scrolling the mouse wheel to adjust the scale. The numerical values of the indices are saved in tabular form in the file “out.xlsx”.

From the results obtained in the example under review, it is possible to determine the following:

- Whether a discharge has occurred;
- The degree and type of contamination;
- The location of the contamination;
- The duration of the event.

Based on the results observed in Zone No. 2, it appears that there was a release of a non-toxic substance into the water. Since the parameter values returned to normal the following day, it can be inferred that this incident did not pose a serious threat to the environment.

The study tested the system’s performance on data from the Laurel Creek River for the following parameters: turbidity, total suspended solids, water temperature, pH, conductivity, nitrate nitrogen, reactive phosphorous orthophosphate, dissolved oxygen.

The use of the method of a priori ranking of factors made it possible to identify the most significant parameters for a specific research goal. Correlation regression analysis revealed the relationships between the parameters and made it possible to build models for forecasting. Correlations were identified between water quality parameters and dynamic factors such as flow velocity, average depth, and wetted width. Regression models were developed for each zone, exhibiting high coefficients of determination, which indicates good model quality. The predictive accuracy and reliability of the models were confirmed by comparing the predicted values with actual measurements. The error between predicted and actual values was less than 1%, confirming their adequacy. Including dynamic parameters improved the predictive accuracy and reliability of the models, underscoring the importance of accounting for hydrodynamic conditions in assessing water quality.

A water quality index was calculated for each zone, which made it possible to identify areas with degraded conditions and potential sources of pollution.

6. Discussion

The development and implementation of an integrated information and analytical system for monitoring and assessing water quality is a significant achievement in the field of environmental management and public health protection [65]. The research highlighted in this article underscores the critical role of data analysis and systematic monitoring in addressing ongoing water quality issues across various water sources.

Water quality directly impacts the ecosystem, human health, and economic activities [66]. Water bodies serve multiple purposes, including supplying drinking water, irrigating agricultural lands, supporting fishing, offering recreational opportunities, and facilitating industrial uses [67]. This underscores the necessity for continuous monitoring aimed at ensuring sustainable usage and preventing pollution. The findings of this study stress the immediate need for a comprehensive approach to water quality assessment that considers multiple factors and leverages modern technological solutions [68–70].

The complexity of obtaining data on water quality, due to the multitude of parameters that need to be measured and analyzed, creates serious problems for monitoring and assessing the state of water bodies. This study effectively addresses these challenges through the development of an information and analytical system that integrates hardware, information sources, and software solutions. This integration enhances the efficient processing and analysis of large datasets, ensuring timely and accurate assessments of water quality.

The extensive analysis conducted in this study has identified several key factors that most effectively characterize water quality. A notable methodological innovation is the development of a program for factor and correlation regression analysis [71,72]. This program enables the exclusion of less significant factors and the creation of a multiple regression model, which is essential for understanding the relationships between various water status parameters and predicting future water quality trends. The practical consequences of the developed system are very significant. The system increases the efficiency of localized monitoring, which in turn makes it possible to determine the number of study zones and analyze the current water parameters in each of the zones.

The ability to build predictive models and assess current conditions allows you to manage and quickly respond to potential problems related to water quality.

In addition, the system's ability to conduct a comparative analysis of different zones helps to identify potential sources of contamination, which is extremely important for targeted remediation work [73–75]. These capabilities not only help protect the environment, but also help maintain regulatory compliance and public health.

Although this study has laid a solid foundation for monitoring and assessing water quality, future research may aim to further improve the accuracy of the system's prediction and expand its applicability to different geographic regions and water bodies [76,77]. Collecting real-time data and applying machine learning algorithms can also improve the responsiveness of the system and its adaptability to changing environmental conditions. In addition, the joint efforts of government agencies, academic institutions, and local communities can increase the effectiveness of the system and promote its widespread implementation [78–81].

It is also worth noting that the development of this information and analytical system is the most important step toward integrated and effective water quality management. This study holds great promise for achieving environmental, health, and sustainable development goals. At the same time, this work touches upon the problems associated with the complexity of processing and obtaining data, and allows for a detailed assessment of specific zones.

Integration of mathematical methods with information and communication technologies makes it possible to timely identify changes in water quality, predict trends and potential risks, and improve the efficiency of water resources management.

The advantages of the system include the fact that it reduces the human factor and speeds up the analysis process, can be adapted for various water bodies, and provides access to information in real time.

The limitations of the system include the need for a stable communication infrastructure. It is also necessary to consider the possibility of expanding the functions of the information and analytical system by introducing machine learning methods to improve the accuracy of forecasting.

7. Conclusions

A program was developed that allows for using factor analysis to exclude insignificant factors and, using correlation regression analysis, to obtain a multiple regression model that allows you to study the mutual influence of factors and predict the values of the parameter under study. This program allows you to assess the current state of water in each zone, build multivariate forecast models, and make a forecast, building a graph of the dependence of water quality indices on time.

An information and analytical system for assessing and monitoring the state of water has been developed, which allows for the following:

- Establish the number of study zones;
- Analyze the current state of water parameters for each zone;
- Build predictive models for each zone;
- Assess the current state;
- Based on the comparative analysis of the obtained water quality indicator values across zones, identify the most probable pollution source.

This article demonstrates the functionality of the described approach, whose scientific novelty lies in the content of the algorithm for performing operations through multifactorial correlation regression analysis of primary water quality indicators, zoning of aquatic areas, and subsequent calculation and evaluation of the water quality index. The accuracy and reliability of the proposed method are determined by the number of zones and corresponding sensors, their distribution across zones, instrumental factors, and the volume of information obtained and statistically processed.

The main drawback of the proposed approach is the insufficient consideration of the non-stationarity of the processes of accumulation and changes in emissions and pollution over time, which could be addressed by developing a unified, spatially distributed information–analytical system operating in a unified hardware–software environment in real time. This would require a significant increase in the performance of monitoring hardware, volumes of processed information, and a corresponding increase in the performance of computing resources (sensor sensors, peripheral controllers, central server, etc.).

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