INFORMATION SYSTEM FOR ECOLOGICAL MONITORING OF THE RESERVE TERRITORY

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Abstract. The article describes the issues of designing an information monitoring system for assessing the ecological state of the reserve territory. An information model of the system has been developed taking into account the parameters of the state of air, surface water, and soil in the "Roztochchya" nature reserve; in particular, attention is focused on the features of the biological diversity of the Vereshchytsky and Stavchansky branches of the reserve. The main components of the system have been designed and implemented, namely the logical model of the database and the geographic information system of the studied territory. A fuzzy logic model of the system was developed to assess the state of the environment based on selected assessment parameters, which allowed forecasting activities with sufficient accuracy for better control of the qualitative state of the environment. The developed system can be used by reserves for scientific research of environmental parameters and forecasting the characteristics of biosystems.

Keywords: ecology, information system, environment, forecasting, reserve, geographic information system, database, fuzzy logic.

1. Introduction

Currently, information systems forecological monitoring are used in society's various activities, particularly, in agriculture, urban planning, transport activities, and environmental protection projects. In the field of ecology, information monitoring systems are used to preserve valuable natural landscapes and protect rare species of plants and animals. It is worth noting that to research better and track the location of objects for monitoring, geographic information systems (GIS) are used.

Creating interactive maps and displaying the flora and fauna of the territory on them is one of the most common applications of geographic information systems in ecological research. GIS enablesusing various markers, showing the characteristics of different plants, interacting with them, and analysing the movement of animals. Working with a geographic information system will allow us to implement such functions as

– conducting ecological monitoring in a certain territory;
– ensuring the storage of various data;
– improving accessibility to information and the ability to analyse natural objects and data;
– visualizing the ecological system

The work focuses on monitoring the reserve territories. Recently, reserves have been facing various environmental problems that require constant monitoring.

Climate change has a significant impact on the reserve's natural ecosystems, causing changes in plant and animal communities, depletion of water resources, and an increase in the frequency of extreme weather patterns.

Illegal deforestation, unauthorized wood collection, and pest attacks lead to the gradual destruction of forests and their complete degradation, which constitute a threat to local species of flora and fauna.

The activities of agricultural enterprises and the discharge of polluting waste into rivers threaten the quality of the water resources of reserves and pollute the territory.

Tourist activity creates a load on natural landscapes and consists of the existence of recreational pressure, which leads to soil erosion, territory pollution, and disruption of natural processes in ecosystems [1].

Particular attention from the point of view of solving environmental problems and implementing a carbon-free economy in the world should also be paid to the development of information systems that allow collecting, processing, and analyzing data on carbon flows in reservoirs, wetlands, forests, and meadow ecosystems, and cities [2]. Such systems are developed following international methods, such as IPCC (Intergovernmental Panel on Climate Change), and they discover new opportunities for assessing the ecological state of territories, monitoring their changes, and predicting the consequences of anthropogenic impact. This allows for making environmentally sound decisions.

Geographic information systems are applied to collect data using automated and remote methods of remote sensing of the Earth from satellite images and displays from drones [3]. Remote sensing of the Earth provides high-resolution images with an assessment of the state of vegetation, soils, reservoirs, and atmospheric air. Satellite images provide data on large areas, creating opportunities for effective ecosystem change analysis and monitoring forests and other nature conservation objects. Drones can collect high-precision data in hard-to-reach places, in particular, to study changes in relief, vegetation, flora, and fauna, and assess the consequences of various natural disasters.

Currently, complex monitoring systems [4] are relevant, they combine data from sources, such as weather stations, sensors, drones, and satellites. Such systems provide opportunities for an accurate assessment of environmental risks and management of natural resources.

2. Drawbacks

The analysis of the subject area and known solutions for the development of an information system for monitoring the territories of the nature reserve fund involves the study and characteristics of the main aspects related to the environmental features of the regions. The currently existing monitoring methods do not involve processing large amounts of data, and the introduction of new information systems using rapid information processing technologies eliminate this problem. Information on the pollution of Ukrainian nature reserves is poorly visualized, so the use of developed geographic information systems and interactive maps creates new opportunities for forecasting and research.

3. Goal

The purpose of this article is to analyse and research the developed information system for monitoring reserve areas, which will help people better understand the flora and fauna, discover new opportunities for a comprehensive analysis of natural processes and predicting their changes, and enable obtaining comprehensive data on the global state of the ecosystem of the region.

4. Development of an information system for monitoring reserves

Structuring a monitoring system

In the most general case, a monitoring system performs total and continuous monitoring of an object, a group of objects, and a certain real system, the key elements of which are objects, thanks to which the requested information can be obtained. Monitoring without control and management will not fulfil the assigned functions and tasks, since the concepts of control and management imply monitoring [5].

The structural diagram of the ecological system is shown in Fig. 1. Its main parts are large observation and forecasting blocks, information from which is transferred to the blocks for assessing the actual and forecasted state. Information from the monitoring system is transferred to the block for regulating the quality of the environment and responding to special cases [6]. Thicker lines indicate direct connections and thinner lines indicate reverse ones.

Any environmental monitoring system performs the following actions [7].

1. Special devices are placed in the studied area - sensors that measure temperature, humidity, air and water pollution levels, and radiation background.

2. Data from sensors are collected and transmitted to computers or servers.

3. Special programs analyse the collected data, compare them with standards, and detect deviations.

4. Based on the results of the analysis, decisions are made on the need to take certain measures, that is, a management process takes place.

The main examples of using reserve monitoring systems are air quality monitoring accompanied by measuring the level of harmful substances in the air to assess its impact on human health, monitoring forest fires and detecting fire outbreaks using satellite images and sensors, predicting natural disasters in the form of floods and droughts, taking into account the analysis of weather and climate change data [8].

To ensure protection against pollution, various methods of data collection and organization can be used, the description and purpose of which are given in Table 1.

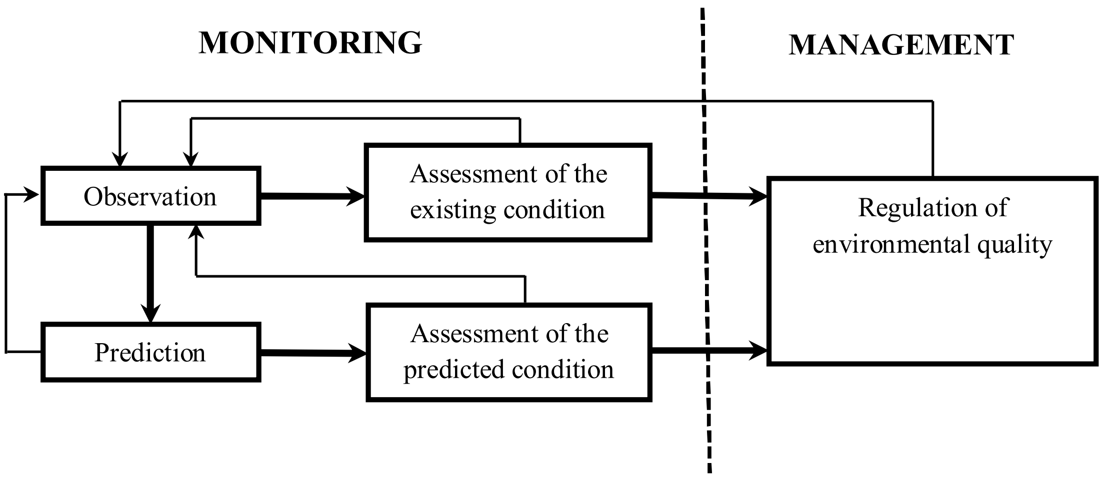

Fig. 1. Structural diagram of the monitoring system

Table 1. Methods and tools for data processing to ensure the ecological safety of the territory

Method	Description	Purpose
Biological monitoring	Tracking the vital state of various plant species	Identifying the impact of pollution on biodiversity
Air and soil quality monitoring	Sampling for analysis of pollutants in the form of metals and oxides	Identifying air and soil pollution
Water quality analysis	Sampling water to assess the content of chemical and toxic substances	Identifying the impact of pollution on water bodies
Field research	Monitoring the territory and sampling soil and plants	Assessing the state of plantations and ecosystem changes
Implementation of a geographic information system	Systematizing and storing data according to location	Creating interactive maps for monitoring the ecological state
Reports and data analytics	Using diagrams and trends to summarize data	Informing about the current state and changes in the environment

Information model of the research object

To create an information system for environmental monitoring, it is necessary to form an information model of the research object – the reserve territory, namely, to determine the input and output data of the system.

A nature reserve territory is considered a complex that includes the following main elements [9]:

- biological resources: flora, fauna, microorganisms;
- physical and geographical characteristics: relief, soils, water resources;
- climatic conditions: temperature, humidity, precipitation;
- anthropogenic factors: tourism pressure, agriculture, industry.
- The following information is used to create an information model:
- geospatial data: coordinates of territories, boundaries of protected areas, maps.
- ecological indicators: state of vegetation, air and water quality, pollution level.
- monitoring data: regular measurements from sensors (temperature, humidity, CO_2 level), satellite images, photographs.
- administrative information: name of the territory, status of the reserve, responsible authorities.

During the formation of the information model of the monitoring object, the following stages were carried out.

1. Identification of key objects of the system:

- nature reserve territories;
- protected species of plants and animals;
- infrastructure objects located within the territories;
- sources of impact on the ecosystem (industrial zones, roads, settlements).

2. Development of a logical data model:

- identification of the main entities, which are territories, environmental indicators, and objects of impact;
- establishment of relationships between entities.

3. Identification of data sources:

- primary data: sensors, satellites, field observations;
- secondary data: statistical reports, scientific research, geospatial maps;
- user data: information entered by administrators or ecologists.

4. Creating a conceptual model, namely the integration of all entities into a single system with a clear hierarchy and relationships.

Practical implementation of the information system for Roztochchya reserve monitoring

Development of the system structure involves content organization, page design, and navigation elements for searching for the necessary information. Initially, the purpose and target audience of the system were determined, which enabled the creation of the information system design. During the development of the map for the geographic information system, the structure of the system pages was visually implemented, helping navigation between them. The page content is arranged into logical categories and subcategories for the correct information structuring, considering the features of users' search for the necessary information.

New practical solutions were used in the development of the system, which permitted increasing the efficiency of the information system [10]. The interactive map of the reserve territory indicates places where rare plants grow, and hyperactive links are created in the markers on the map, through which you can find more information about a specific plant with its features of origin, how rare it is, detailed characteristics, and others. The created filter will help find the features of the reserve flora's existence by various parameters - where they grow, what soil they like, and how much moisture they need.

For convenient plant search and viewing of necessary information, a tab has been created where the user can see all plants available in the system. The window displays information similar to that in the tabs on the map – the appearance of a plant, where it grows, how rare it is, and detailed characteristics.

To obtain information about monitoring the reserve territory and familiarization with the reserve's ecological situation, a tab has been developed that shows pollution graphs. The user can see the visualization results, which will provide information about environmental problems in the territory [11].

In particular, it contains information about the types of pollutants most often found, and their impact on natural conditions in the reserve. Diagrams showing types of air pollutants provide an opportunity to find out where these pollutants come from, and what their quantity is, which helps to gain a clearer understanding of how these substances affect the flora and general ecology of the region.

The information obtaine denables the analysis of the environmental challenges in the monitoring territory and may allow scientists to nominate ideas for improving the ecological situation.

To process monitoring information, a logical model of the database of the environmental monitoring system was developed, and a database was created using the Postgre SQL database management system for storing and quickly accessing large amounts of information [12].

First, the entities that will be documented in the database are defined, namely the ideas about which information will be stored. Next, attributes are created for each object, and the specific data are defined which will be stored for it. After describing the connections between the objects, relationships are defined as direct, indirect, or multi-level.

The next step is to create unique primary keys, namely attributes unique to each record in the table. External keys will be defined by attributes to connect the tables. A logical database model (Fig. 2) is created for database documentation, using relationships and descriptions of entities, attributes, and relationships.

For the correct operation of the system and its correct filling, 7 tables have been created in the database: a table with general information about plants, a table with plant characteristics, a table with the location of plant placement on the map, a table with the relationship between plants and their places of growth, a table with pollutants, a table with pollution sources and a table with the relationship between pollutants and pollution sources.

The table "plants" (general information about plants) contains the plant's name, a photo, and a brief description of the species to which the plant belongs.

The table "plant_characteristics" (plant characteristics) is linked to the first table via an identifier and contains fields such as plant age, plant genus, plant family, plant origin, height, and width.

The location of plants on the map (the "locations" table) consists of the fields of the location name, latitude, and longitude of the location. Information about air pollutants ("pollutants") is the name of the pollutant and the percentage of pollution relative to the total pollution of the territory.

To monitor the territory of the reserve, information from the fields with the name of the pollution source and description of the pollution source of the pollution sources table ("pollution_sources") and the table of relationships between pollutants and pollution sources ("pollutant_sources").

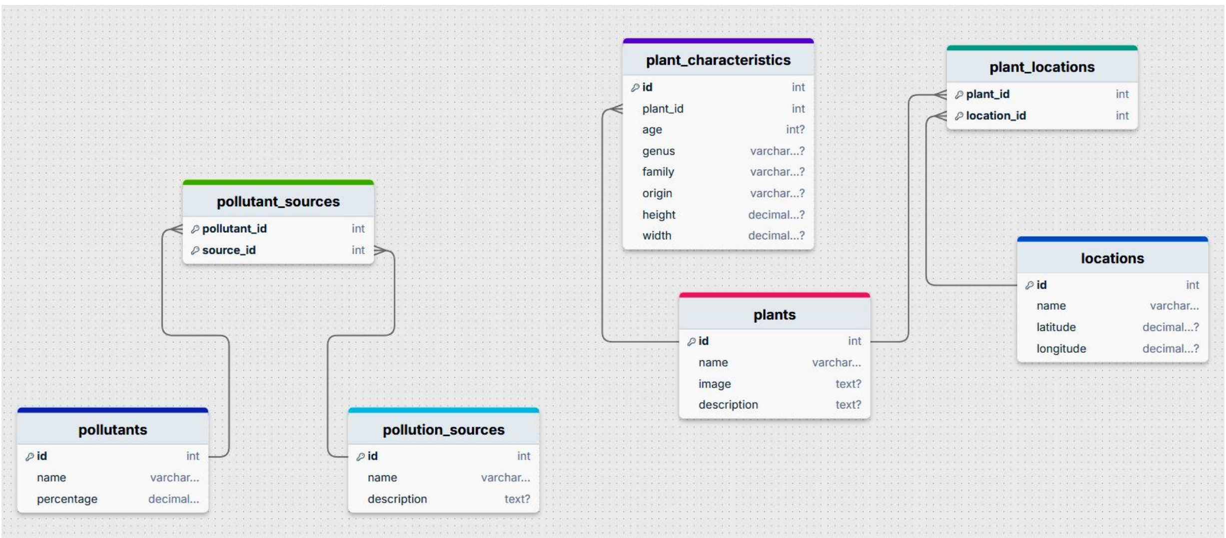

Fig. 2. Logical database model

To create a geographic information system, React (JavaScript) was used for the front-end part [13], Tailwind CSS for component styling, Node.js for the back-end part [14]. The following components were implemented on the server side:

– API settings for interaction between the frontend and the database;

– functionality for requesting information about flora, its ecological characteristics, and pollution data;

– integration with the Postgre SQL database for storing and quick access to large amounts of data.

An image of the page of the developed geographic information system of the Roztochchya reserve with enabled filtering by plant species of the reserve is shown in Fig. 3.

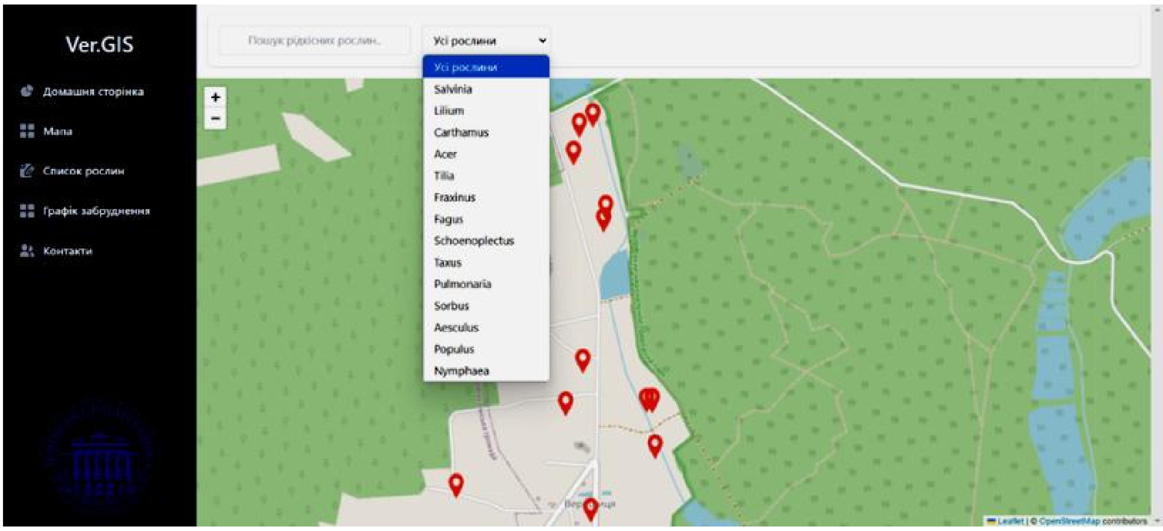

Fig. 3. View of the geographic information system of the Roztochchya reserve (filtering by plant species)

5. Experiments

Development of a fuzzy logic model and testing of a geographic information system monitoring model

Fuzzy logic is often used in developing nonlinear complex multi-parameter management solutions sinceit can describe systems using a combination of numerical and linguistic means. It measures the certainty or uncertainty of an element belonging to a set and is not very sensitive to environmental changes and erroneous or delayed rules [15].

For the research, a fuzzy logic model was developed, and this model was tested for an information monitoring system, the impact of air pollution on the flora of the Roztochchya reserve was determined.

Field studies, air and soil monitoring, water quality monitoring, and biomonitoring are considered among the data collection methods. The main type of pollution in the region is air pollution, which is determined by proximity to industrial zones and transport routes. Air pollutants affect plants, slowing down plant growth and reducing photosynthesis. Soil pollution due to heavy metals (lead, cadmium) accumulates in the soil, which causes reduced fertility. Water and dust pollutants can vary depending on external factors because of the seasonal changes, and the wind strength and direction.

Although the exact amount of different types of pollutants may vary, the four most dangerous ones for the flora in the reserve were selected for research. The fuzzy control model is designed for predictions based on four predefined parameters – carbon dioxide CO_2, nitrogen oxide NO_2, sulphur dioxide SO_2, and cadmium Cd.

The following stages were carried out to build a fuzzy logic system: determining input variables, fuzzification, formulating fuzzy inference rules and defuzzification. The clear input values are converted into fuzzy values using membership functions for each input.

The output indicator, which determines the pollution of the MPRT (monitoring of pollution in the reserve territory) territory, is estimated by the following values: good, moderate, sensitive, unhealthy, very unhealthy, and hazardous.

In fuzzy logic, rules define input and output membership functions, which are later used in the logical inference process. Fuzzy logic determines the degree of membership of certain membership functions, which are used in formatting logical inference to obtain a fuzzy conclusion [16]. To design the model, the limiting values of universal sets for input and output variables are determined. Fuzzy sets must be defined for the fuzzification process. Each variable is represented by three different fuzzy sets: “Low”, “Normal” and “High” (Table 2). Table 3 shows the boundary values of fuzzy sets of output parameters for predicting the pollution index of the reserve territory in the form of such a set as “Good”, “Moderate”, “Sensitive”, “Unhealthy”, “Very Unhealthy”, “Hazardous”.

Table 2. Boundary values of crisp and fuzzy sets for input parameters

Crisp input variables	Fuzzy input parameters	Boundary values for versatile sets	Parameters for input membership functions
CO_2	Low, Normal, High	0–1200	0–400, 200–1000, 400–1200
SO_2	Low, Normal, High	0–1100	0–200, 100–700, 200–1100
NO_2	Low, Normal, High	0–1000	0–300, 150–900, 300–1000
CD	Low, Normal, High	0–600	0–200, 100–400, 200–600

Table 3. Boundary values of crisp and fuzzy sets for output parameters

Crisp output variable	Fuzzy output parameters	Boundary values for versatile sets	Parameters for output membership functions
MPRT	Good, Moderate, Sensitive, Unhealthy, Very Unhealthy, Hazardous	0–600	0–100, 101–200, 201–300, 301–400, 401–500, 501–600

The air quality index prediction system model based on fuzziness was developed using Fuzzy Toolbox and Mamdani FIS, integrated into the MATLAB environment [17]. Fig. 4 shows the implemented air quality index prediction model based on fuzziness.

Fig. 5 shows the graphs of triangular membership functions of the input variables CO_2, SO_2, NO_2 and CD, which determine the types of pollution processed by the information system for monitoring the reserve territory. The graphs for the output value, which determines the MPRT territory pollution index in the form of triangular membership functions, are shown in Fig. 6.

After modelling the system using fuzzy logic algorithms, it is possible to obtain the pollution index value for the specified values of the input variables. In Fig. 8, you can see the relationship between the input and the output variables, which is determined by the rule base.

The fuzzy logic method is applied to display input fuzzy values to the corresponding output fuzzy sets to generate inference rules. For the research, four variables were used, represented by four fuzzy sets, and 31 rules were generated in the rule base:

The rule viewer is used in the fuzzy inference diagram. It is used for diagnostics, active rules, or as a separate function to affect the results. Fig. 8 shows how the concentration levels of pollutants CO_2, SO_2, NO_2 and CD affect the pollution index of the territory. If $CO_2 = 600$ µg/m^3; $SO_2 = 500$ µg/m^3, $NO_2 = 800$ µg/m^3, and Cd = 300 µg/m^3, then the predicted MPRT = 475, which corresponds to very unhealthy pollution of the territory, “Very Unhealthy”.

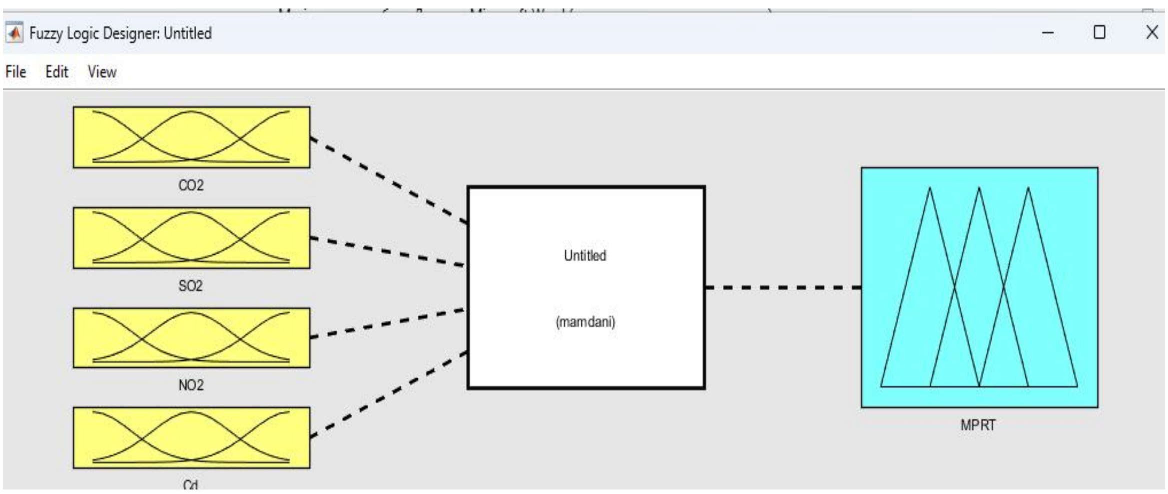

Fig. 4. Set of predefined system parameters

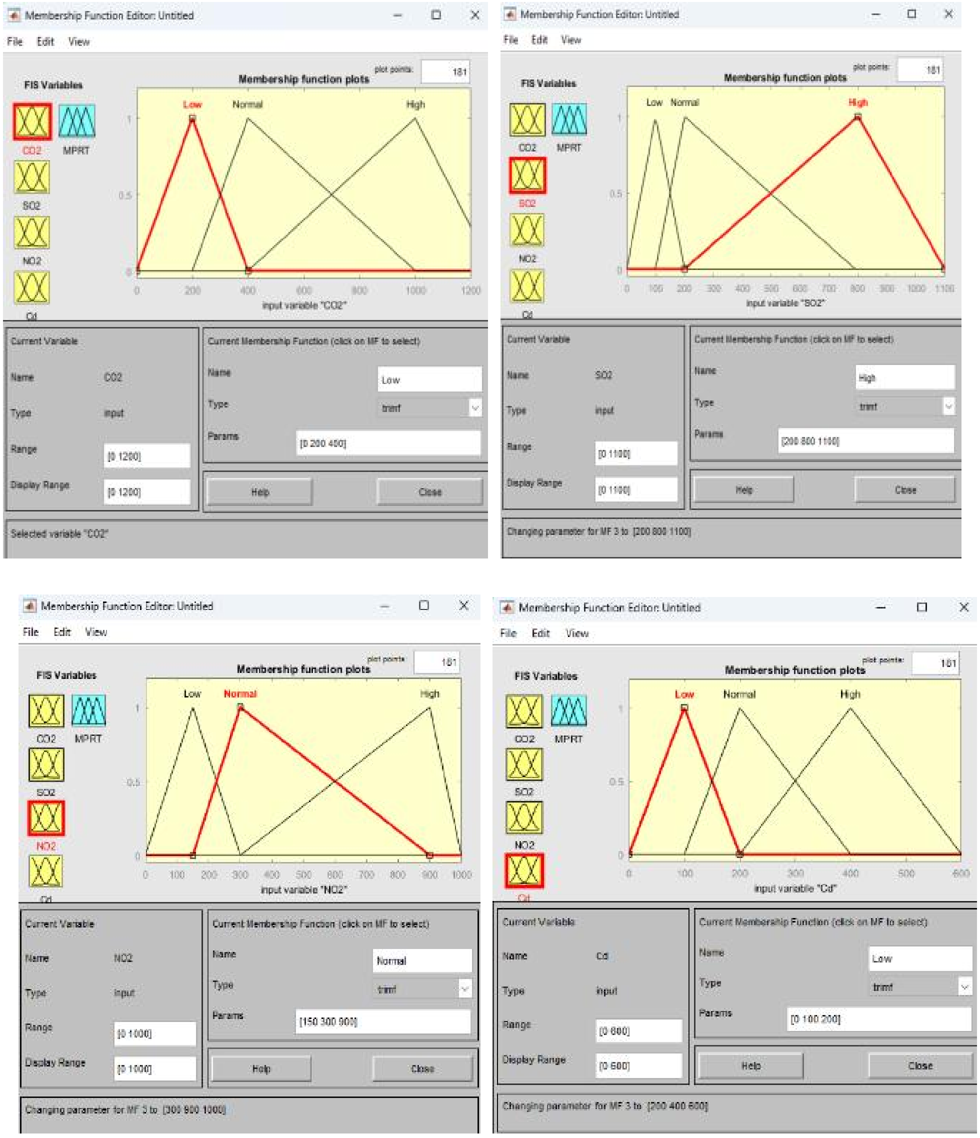

Fig. 5. Membership functions of input variables for pollutants:
carbon dioxide CO_2, sulphur dioxide SO_2, nitrogen oxide NO_2, cadmium Cd

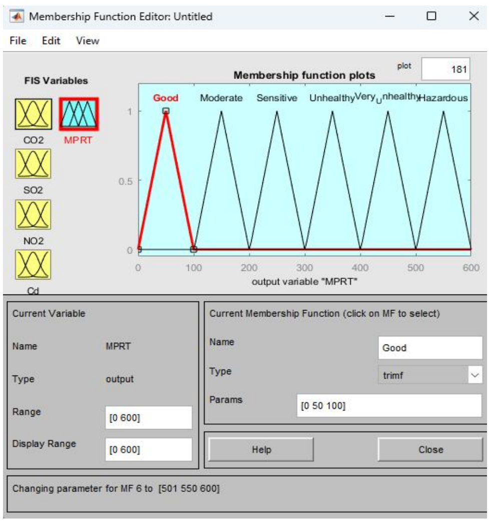

Fig. 6. Membership functions of the output variable that determines the pollution index of the territory

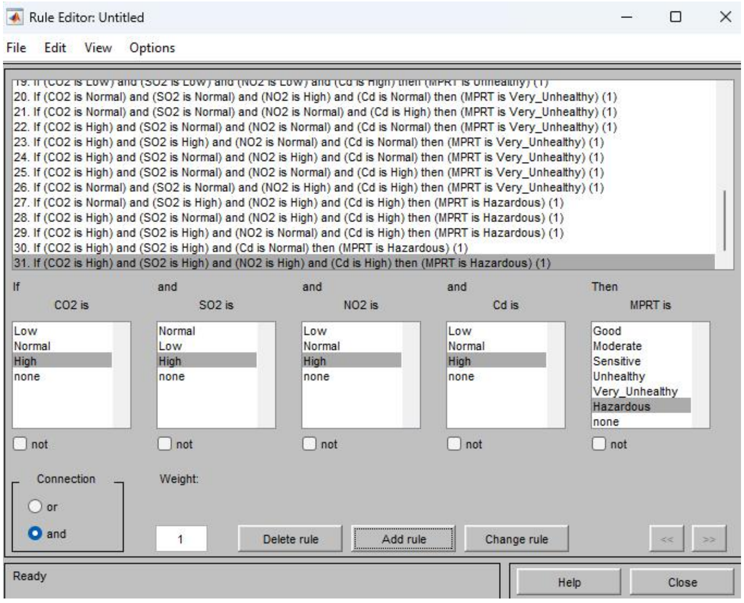

Fig. 7. Formed membership rules

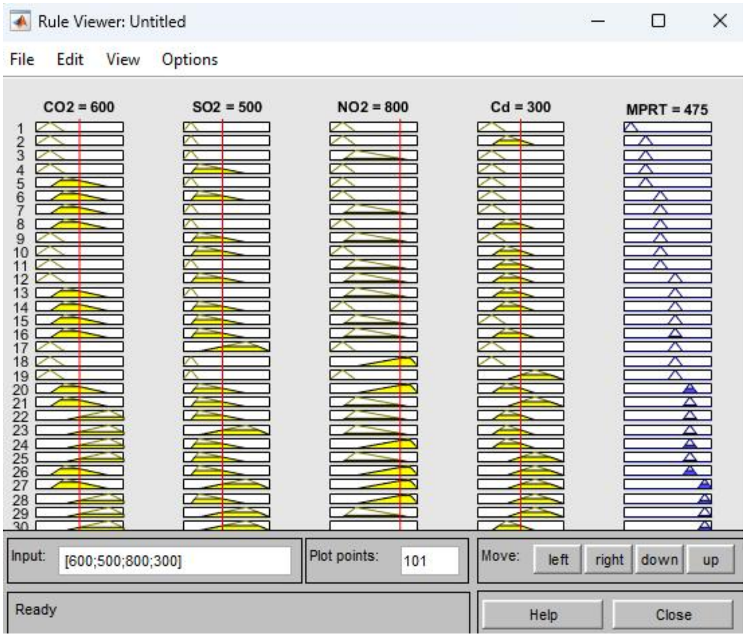

Fig. 8. Representation of fuzzy rules in the form of images

6. Conclusions

The environmental safety issues in the world were and remain in the first place because the population's well-being depends on their solution. Many documents and standards determining the transition to an environmentally safe society have been created recently. In these documents, the main attention is paid to air cleanliness, climatic conditions, soils, radiation pollution, biodiversity conservation, carbon-free economy, and the impact of transport. Modern information systems, which are used, in particular, for monitoring environmental indicators, play an important role in research on the ecological situation in the world.

The developed information system for monitoring the reserve territory allows for predicting the state of pollution of the territory based on the analysis of pollutants in the air in the form of carbon dioxide, nitrogen oxide, sulphur dioxide, and cadmium. The initial indicator, namely the territory pollution index, shows the state of pollution in the territory. To analyse the ecological situation of the territory, a geographic information system has been created, in which information about the state of pollution can be obtained at certain points on the map. Due to the application of modern information technologies for building a database and web technologies, the system provides high-speed data processing and visualization.

Conflict of Interest

The authors declare re no financial or other potential conflicts of interest regarding this work.

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