# AI-powered information system for regional water and soil monitoring*

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### Abstract

This paper presents the development of an integrated online platform for monitoring soil and water resources, designed to enhance environmental management through real-time data collection, processing, and analysis. The platform addresses the increasing need for efficient environmental monitoring in the face of rapid urbanization and industrialization, which contribute to the degradation of natural ecosystems. The system architecture is based on a multi-tiered approach, employing Domain-Driven Design to ensure a clear separation of concerns and maintainability. The technology stack includes ASP.NET WebAPI for the backend, Angular for the frontend, and PostgreSQL for the database, complemented by Redis for caching to optimize performance. Key features of the platform include real-time data visualization, role-based access control (RBAC), and an intuitive user interface. The platform supports various user roles, such as super-administrator, owner, manager, supervisor, researcher, and guest, each with specific permissions and responsibilities. The system also incorporates automated testing using libraries like Moq, FluentAssertions, and Selenium to ensure reliability and robustness. The platform's architecture facilitates seamless interaction between the user and the system, providing tools for data input, editing, and analysis. The use of Leaflet for geospatial data visualization allows for real-time mapping of environmental parameters, enhancing the user's ability to monitor and analyze environmental conditions. This research highlights the potential of integrating modern information technologies to address environmental challenges. The developed platform offers a scalable and reliable solution for environmental monitoring, with potential for further development including the integration of artificial intelligence (AI) algorithms for predictive analysis and the expansion of environmental factors monitored by the system.

### Keywords

natural resources monitoring, online platform, modelling, artificial intelligence, prototype system, product development

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## 1. Introduction

In conditions of intensive urbanization and industrialization, environmental problems are gaining global importance. Degradation of natural ecosystems, increasing pollution of water and soil resources necessitate urgent measures at the local and international levels. Effective solution of environmental challenges is possible by increasing the environmental awareness of the population and intensifying its participation in environmental activities. Modern information technologies provide the creation of online platforms for the dissemination of environmental information and the involvement of citizens in environmental initiatives. Specialized applications are an effective tool for promptly informing about environmental violations, participating in environmental projects and obtaining information to reduce the individual negative impact on the environment.

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Traditional methods of data collection and analysis are characterized by significant labor intensity, high cost and limited space-time resolution. In this regard, the development of an integrated online platform for monitoring water and soil parameters is an actual and promising direction of scientific research.

The article presents the development of an online platform designed to optimize the process of making environmentally sound decisions based on data analysis. The system is based on the integration of the server part, user interface and databases, which provides a comprehensive solution for monitoring and managing environmental resources.

## 2. Formulation of the problem

The natural resources of each country, in particular water and land, are the most valuable, requiring constant protection and careful treatment. The need for operational control over the quality and quantity of water and soil resources, as well as the timely identification of negative trends, is a key factor for being ensured in environmental safety and sustainable development of the region.

Today, there is no comprehensive, integrated monitoring system that would provide operational and reliable monitoring of the state of water and soil resources at the regional level. Existing monitoring methods are often fragmentary, do not provide a complete picture of the ecological state, and also do not provide timely identification of negative trends. This complicates the process of making sound management decisions aimed at preserving and restoring water and soil resources, as well as reducing the effectiveness of environmental protection measures.

The implementation of the online system will ensure the continuous collection, processing and analysis of data, which will facilitate the adoption of sound management decisions and the development of effective measures for the protection and restoration of water and soil resources. In addition, the availability of open access to monitoring data will increase the environmental awareness of the public and its involvement in the decision-making process in the field of environmental protection.

The object of the study is an intelligent information system for environmental monitoring of key ecological components — particularly water resources and soils — under conditions of increasing anthropogenic load, industrial pollution, and climate change.

The subject of the study is the conceptual methodology, software architecture, and implementation details of an online platform, developed to support the collection, processing, storage, analysis, and visualization of spatial and temporal data concerning water and soil quality. The system enables the identification of ecological risks, detection of environmental degradation trends, and supports decision-making by relevant authorities and stakeholders in the field of environmental protection.

The scientific newness of the research lies in the design and deployment of a comprehensive AI-powered platform that integrates modern technologies of environmental monitoring, geospatial data analysis, and machine learning. Unlike traditional systems that often rely on static reporting and fragmented datasets, online platform offers a unified solution that enables real-time acquisition of data from heterogeneous environmental sensors (IoT devices, remote stations, satellites, and manual field inputs). Also, IT project enables the application of machine learning models to detect anomalies in environmental parameters, forecast potential areas of risk, and identify patterns of degradation over time. Interactive visualization of environmental conditions through dynamic maps, dashboards, and reports to enable quick interpretation allows people to learn the functionality of the business logic quickly.

Furthermore, the system is designed with modularity and scalability in mind, allowing its future extension to other environmental domains (e.g., air quality and biodiversity monitoring) and seamless integration with national and regional environmental data platforms. Using AI in the monitoring workflow represents a productive and optimized in transforming environmental data into practical knowledge that can guide both local responses and strategic policy development for environmental sustainability.

Through its innovative architecture and actionable abilities, the online platform embodies a modern approach to environmental monitoring that addresses contemporary challenges while laying the foundation for proactive and informed environmental stewardship.

## 3. Analysis of recent studies and publications

In Ukraine, there is a significant degradation of soils caused not only by agricultural activities, but also by mining, military operations, construction and urbanization. This leads to such negative consequences as flooding, landslides, villages and other environmental problems [1].

The water monitoring system includes regular measurements of physicochemical, hydrobiological and radiological indicators in various water bodies, such as rivers, lakes, reservoirs and underground aquifers. The main tasks of monitoring are to identify and assess the anthropogenic load on water resources, to determine trends in changes in their state, as well as to predict possible negative consequences. The paper [2] provides a scientific generalization of legislative documents in the field of monitoring surface water resources in Ukraine, which has undergone significant changes, especially during the period of the Association Agreement between Ukraine and the European Union.

It should be noted that the State Agency of Water Resources of Ukraine provides information on programs of state monitoring of waters in the country, including diagnostic and operational monitoring. The article also contains a link to a web resource where you can find the results of surface water quality studies [3].

The authors of the study [4] analyzed the legal aspects of land monitoring in Ukraine, highlighted its tasks and prospects for improving land monitoring. In particular, attention is paid to the peculiarities of monitoring agricultural land.

Klymenko M.O. and others [5] focus on global environmental issues, emphasizing the relationship of climate monitoring with environmental monitoring, which requires a specialized observation system that can ensure the implementation of scientific and practical tasks, in particular, the provision of a wide range of climate information. Climate monitoring helps to identify critical environmental risks, develop strategies for the protection of natural resources and form a scientific basis for making environmentally and economically sound decisions at the planetary level.

Rational use of agricultural land in Ukraine requires an integrated approach for monitoring land resources. However, there is currently no unified system for continuous monitoring of land using modern remote sensing technologies [6].

Insufficient integration of data from different sources and the lack of a single platform for analysis of the natural resources make it difficult to assess the impact of anthropogenic factors on the ecological state of the region. Therefore, these justifications emphasize the relevance of developing a reliable digital platform for monitoring the state of soil and water.

## 4. Formulation of the purpose of the article

The article is aimed at developing an integrated online platform designed to provide real-time collection, processing, analysis, and visualization of data on the state of water and soil resources. The platform will incorporate AI-driven algorithms to enhance data analysis, provide predictive insights into environmental changes, and automate decision-making processes for proactive environmental management.

The study uses methods of software engineering, including object-oriented programming, the development of RESTful APIs, and the use of a frontend framework. The project is managed based on the principles of Agile development using GitHub and Jira tools. Data processing and integration are based on a relational data model implemented using PostgreSQL.

## 5. Presenting the main material

In connection with the increase in public environmental consciousness, there is an increase in the popularity of environmental mobile applications. They contribute to the monitoring by users of their own impact on the environment, the formation of environmentally responsible behavior, and the consolidation of citizens around environmental initiatives. Similar applications are iNaturalist and Litterati, whose descriptions are given below.

iNaturalist is an application aimed at protecting biodiversity, allowing users to document their own observations of biological species, helping to deepen the understanding of local ecosystems. This project is of scientific and practical interest, as it ensures the involvement of citizens in the study and preservation of the natural environment [7].

Litterati is an innovative platform aimed at solving the problem of waste pollution by engaging the community and applying data analysis. With Litterati mobile applications, users can photograph, classify and dispose of waste, contributing to the formation of a global database that provides information on pollution trends [8].

Unlike Litterati, which focuses mainly on collecting data on waste pollution, the platform in question provides advanced functionality. The platform offers monitoring of the quality parameters of water, soil and atmospheric air, as well as the general ecological condition of the territory. The system will integrate AI algorithms to analyze environmental data and predict potential future changes in soil and water conditions based on historical trends and real-time information. The AI system will be able to suggest preventive actions or recommend areas that require immediate attention, providing more targeted insights for users.

The developed online platform for monitoring soil and water conditions provides uninterrupted interactive interaction between the user and the system, contributing to effective data management and environmental monitoring. The AI-driven platform will continuously learn from user interactions, data input, and environmental patterns to improve predictions and enhance overall system accuracy. The user interacts with a client application developed on the basis of the Angular framework, which provides interactive visualization of environmental data, as well as the ability to add new records, edit existing ones, and receive AI-based recommendations. The basic platform operation algorithm is illustrated in detail in Figure 1.

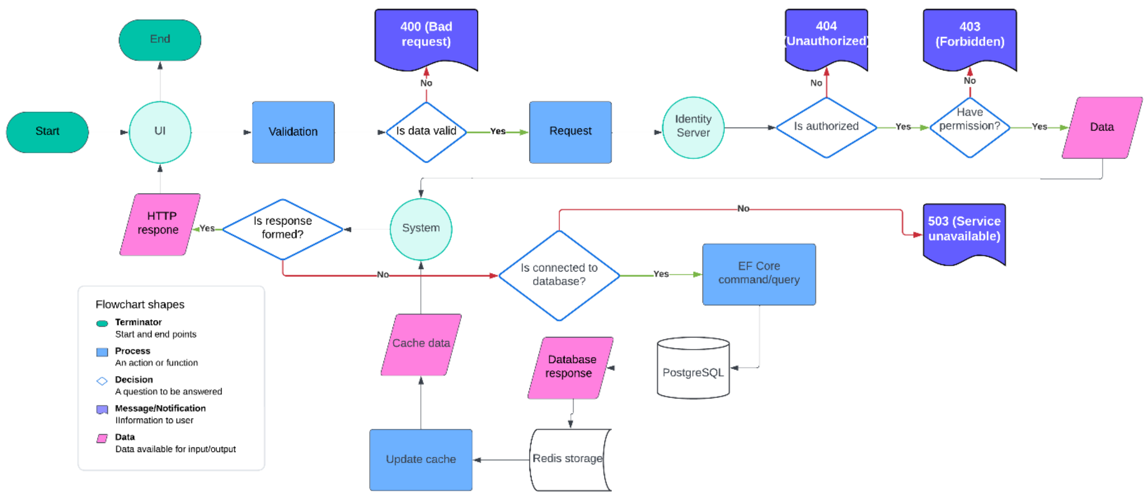


**Figure 1:** Platform flowchart.

After receiving the Identity request, the server verifies the user credentials and then sends the request to the host system to ensure the integrity and security of the data through additional validation. The functioning of the server is implemented using RESTful API endpoints developed on the ASP.NET WebAPI platform. The system initializes the necessary services and transforms the input data into the corresponding domain objects.

In order to optimize performance and reduce the load on the database, the system uses Redis distributed storage to cache frequently requested data. When receiving a request for environmental data, the system first checks for the presence of the corresponding cached results in Redis. In case of a positive result, the data is immediately transmitted to the client application, which ensures a reduction in response time. In the absence of the requested data in the cache, the system extracts it from the database, performs the necessary processing and saves the result in Redis for subsequent requests.

In addition, when adding new records, editing existing or any other modifications to the database, the system updates the corresponding cached data in Redis. This ensures that users always receive up-to-date information, taking advantage of the increased performance provided by the caching mechanism.

The response from the server is transmitted to a client application developed on the basis of the Angular framework, where it is processed and visualized for the user. The visualization may include an updated map display, a successful data entry message, or an error message if the operation fails.

The flowchart visualizes the architectural interaction between the user, client application, server services, database, and Redis distributed storage, demonstrating continuous communication, caching strategy, and platform feedback mechanism.

The development of the online platform is carried out using the Domain-Driven Design (DDD) architecture, which focuses on the core business area and its logic, providing a clear separation of problems and maintaining a high level of modularity. The architecture includes a layered structure that encapsulates functionality into manageable and cohesive components, contributing to scalability, testability, and an intuitive development process (Fig. 2).

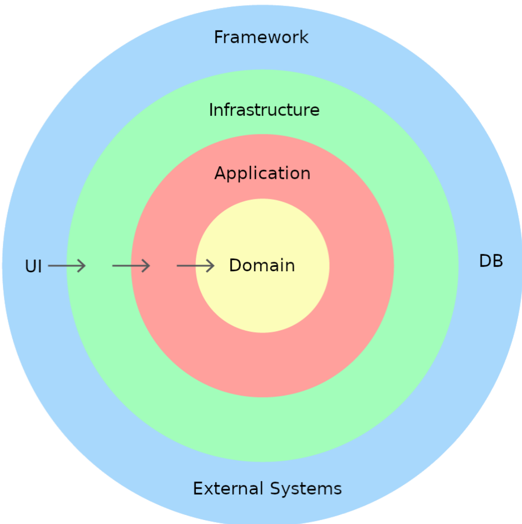


**Figure 2:** DDD-architecture.

Within the DDD architecture, the Presentation layer is responsible for the user interface and serves as an access point to the system. It includes a client application developed on the basis of the Angular framework, which provides a convenient interface for monitoring the state of soil and water. This layer interacts with the backend through RESTful API calls, providing relevant responses to the user.

The Application layer acts as an intermediary between the Presentation and Domain levels. It coordinates the execution of application tasks, causing operations with domains and following the rules of application. As part of this research, this level performs functions such as managing use cases, processing business logic and ensuring interaction between presentation layers and infrastructure.

The Domain layer is the central component of the system, containing business logic and rules that are directly correlated with the subject area. Domain object models, such as organization, laboratory, and location, enforce domain invariants in all operations. According to the principles of DDD, the domain layer retains independence from other layers, which facilitates its reuse and facilitates support.

Infrastructure provides the technical capabilities necessary for the operation of the application, including database access, sending electronic messages and integration with external APIs. In this study, the PostgreSQL relational database is used to store and retrieve data, and the ASP.NET server provides secure communication and data storage. This layer also includes entity mapping mechanisms for navigating to domain layer models with database objects, which facilitates efficient data storage.

In the DDD architecture, each layer is a stand-alone component with well-defined responsibilities and dependencies. The presentation layer interacts exclusively with the application layer, avoiding direct access to domain logic. The application layer acts as a gateway to the domain layer, providing the correct sequence and structure of operations. The infrastructure layer supports both the application layer and the domain layer, providing the necessary tools for data storage and external communication.

This project implements a system of differentiated user roles, including: super administrator, owner of the organization, manager, supervisor, researcher and guest. Authentication is a mandatory procedure for accessing the platform and involves the identification of the user's role. After successful authentication, the user is given tokens that determine his rights and opportunities for interaction within the system.

Role permissions:

- Super Administrator: this role has the highest level of access and control over the platform. He is responsible for managing user roles, granting access rights and setting system-wide parameters.
- Owner: controls the monitoring processes in the organization. Owners have the right to assign roles to other users (for example, manager, manager and researcher) and control the overall activity of the platform.
- Manager: organizes and supervises teams of researchers and supervisors. They can analyze the collected data, create new monitoring sessions and manage the resources assigned to their team.
- Supervisor: this role is designed to oversee on-site activities, ensure data collection from specific locations, and report anomalies or irregularities.
- Researcher: is an authorized user responsible for entering and analyzing soil and water condition data. They can edit and submit flaws metrics based on their findings.
- Guest: has limited access to the platform, allowing it to view basic information such as general reports or public data without the need for authentication.

Role functions:

- The Super Administrator manages all aspects of the platform, including the creation and distribution of user roles, as well as monitoring organizational activities.
- Owners and managers are allowed to manage data collection processes, assign team responsibilities, and view reports created by researchers.
- The manager performs CRUD (create, read, update, delete) operations related to monitoring sessions, filling in forms, and solving shortcomings.
- Researchers can view assigned tasks, monitor and submit analytical data for specific places.
- Guests are limited to viewing public reports or general information about the capabilities of the platform.

After successful authentication, users are issued authorization tokens that determine their level of access to system resources. Unauthenticated users only have access to public data, while authenticated users have access under their assigned roles. The platform implements a role-based access control mechanism (RBAC), which guarantees that users perform only those operations that correspond to their role.

Figure 3 illustrates a UML use case diagram that describes functional and user-specific platform requirements.

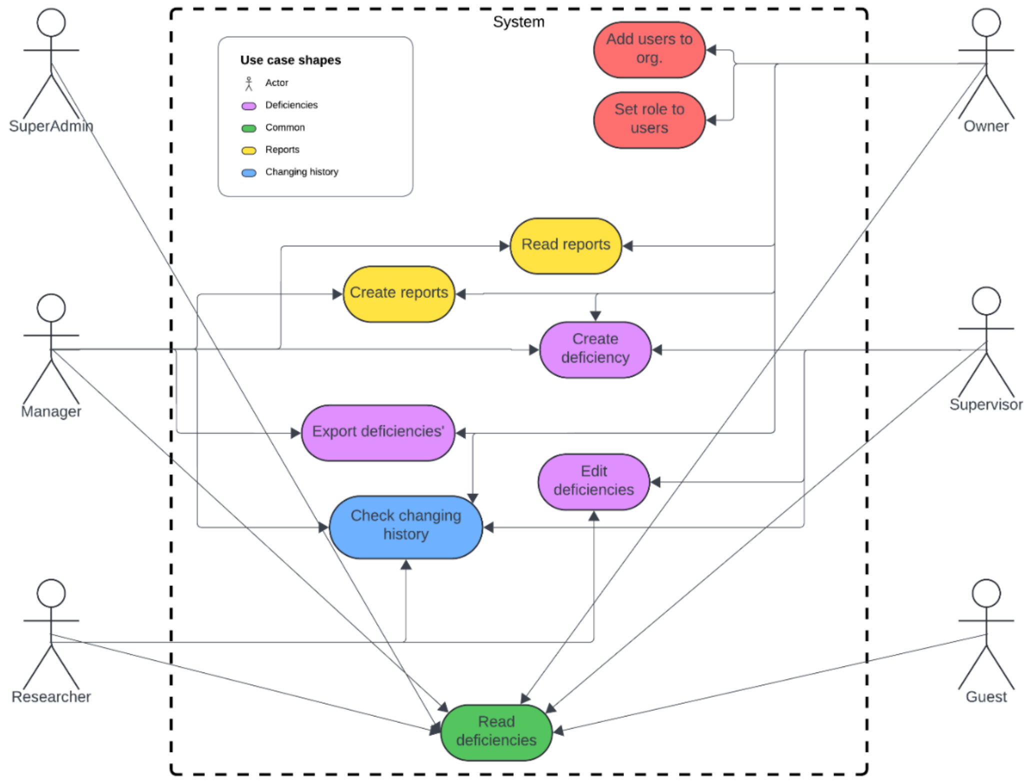


**Figure 3:** UML use case diagram.

The choice of a relational database is due to its high performance, scalability and optimization for processing structured data, which makes it the optimal solution for this platform. PostgreSQL was chosen as a relational database management system due to its wide range of functionality, reliability and support for complex queries. The development and administration of the database was carried out using tools such as the CLI pgAdmin and PostgreSQL utilities. To ensure seamless integration with the server side of the application, the Entity Framework Core was used as an object-relational mapping (ORM) tool.

The database was developed using the Code-First methodology, which allows developers to define the database schema directly in domain models. This approach provides an automated evolution of the database structure in accordance with business requirements and helps to reduce application development time.

Entity Framework Core uses Fluent configuration and annotation APIs to define relationships between entities, enabling the generation of optimized tables and data integrity constraints. Modeling of relationships between entities is carried out in accordance with the principles of DDD, using aggregates and value objects to represent concepts of the subject area.

In order to optimize the structure of the database, the principle of normalizing tables to the sixth normal form is applied. This approach involves decomposing tables into the smallest possible units while maintaining relationships. This improves system performance by storing keys instead of duplicating entire records, which reduces the amount of memory used. In addition, normalization minimizes data redundancy and eliminates anomalies associated with insert, delete and update operations, ensuring the integrity of the stored data. For database tables, the best way to optimize is to normalize them to the sixth form. This will divide the tables into the least possible parts, while maintaining their links. At the same time, the performance of the system will increase, since storing keys instead of direct records will reduce the amount of memory. Among the core tables in the database structure are NatLocations, OrgLocations, and Researches.

The NatLocations table stores information about natural observation points, such as lakes, rivers, forests, and other environmental features. It contains attributes like location name, type, GPS coordinates, and associated environmental parameters. This table is essential for linking environmental data with specific geographic areas.

The OrgLocations table contains data about registered organizational monitoring stations — typically those managed by governmental bodies, research institutions, or environmental organizations. It includes information such as organization name, location, contact details, and area of responsibility. This separation allows for clear distinction and control over data sources and access levels.

The Researches table stores records of conducted research and observations.

A physical database model showing the relationships between main tables and their attributes is shown in Figure 4.

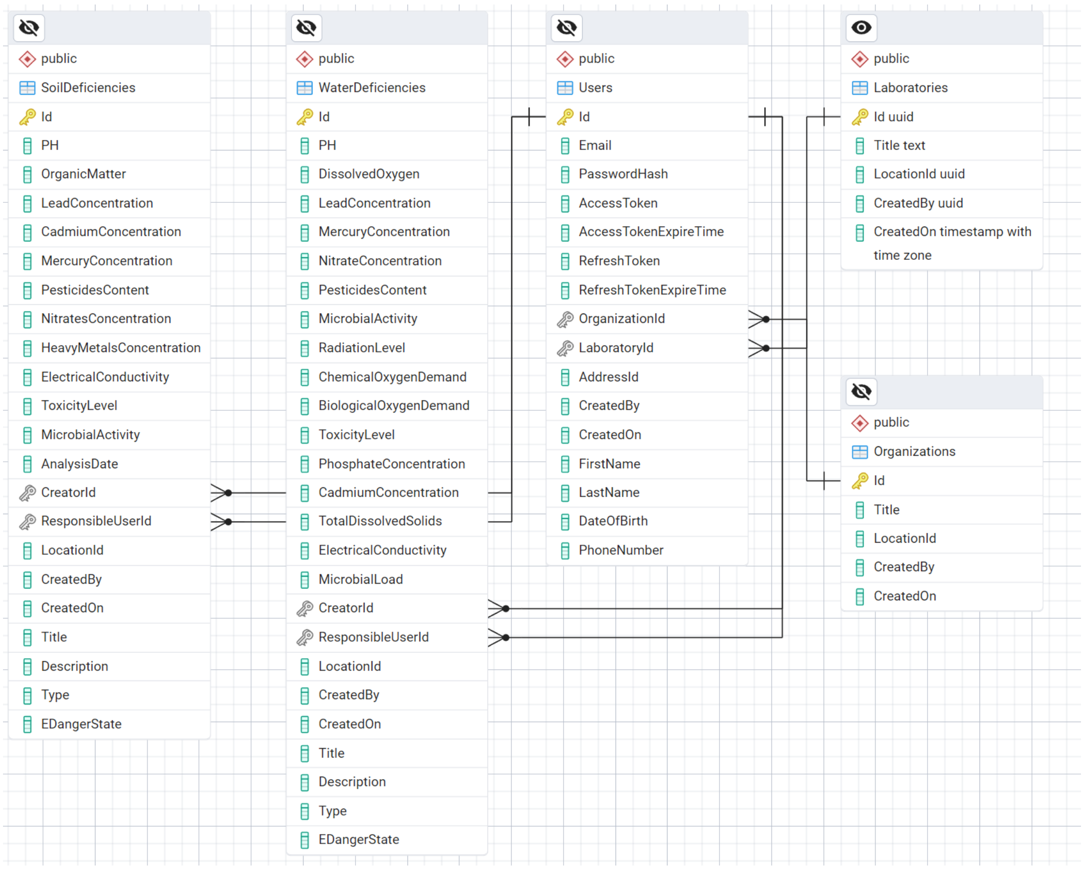


**Figure 4:** Physical database model.

The user interface of the web platform is implemented using the Angular framework. Angular's modular architecture provides clear code base organization, scalability, and low connectivity between components. To improve the user interface, as well as to speed up the development process, the Angular Material library was used, which provides a set of ready-made adaptive components.

The user interface of the platform is structured using several tabs, including: “Home”, “Deficiencies”, “Laboratories”, “Reports”, and “About us”. The horizontal navigation bar provides access to authentication functions, and the tabular data view provides the ability to switch between displaying data on water scarcity and soil condition through interactive interaction. To visualize geospatial data on the platform, the Leaflet library was chosen, which is characterized by ease, high performance and ease of use. Since the monitoring system requires an interactive display of environmental data in real time, Leaflet provides the optimal solution thanks to the rapid visualization of large volumes of point data and the possibility of using user map layers. In addition, its flexibility makes it easy to integrate a variety of geospatial data sources, which is especially important for a platform that handles dynamic parameters of soil and water conditions. Defect list visualization and mapping interface with online platform markers are shown in Figure 5.

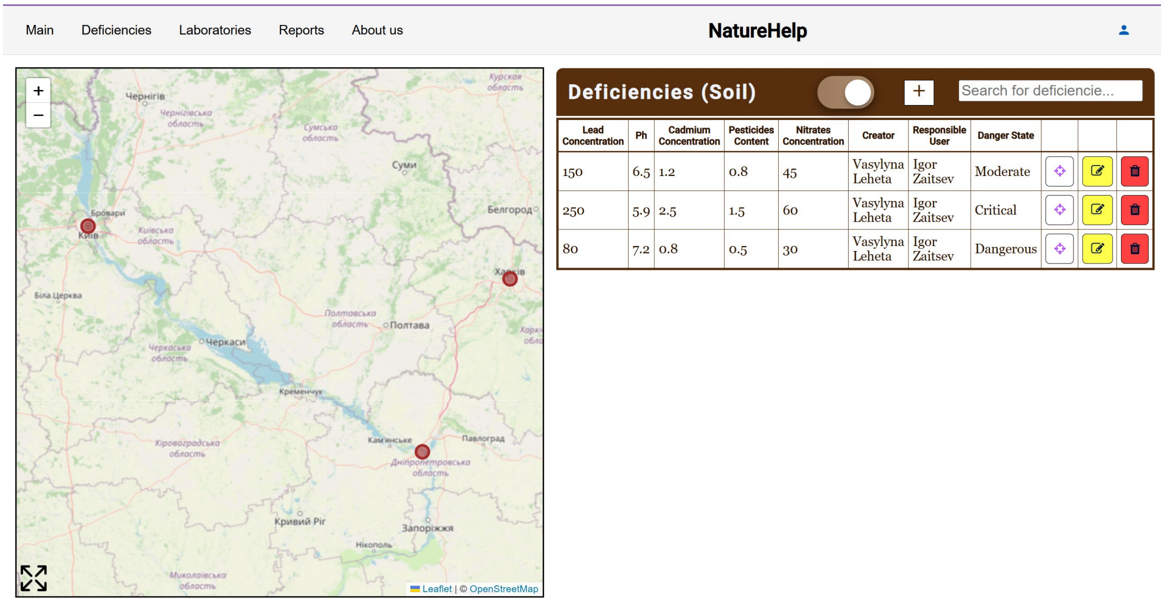


**Figure 5:** Online platform interface.

Software testing is a critical step in the development process. Automated tests have been integrated to ensure the efficient use of time and improve the accuracy of testing, with AI playing a key role in optimizing the testing process. Machine learning algorithms and AI-driven tools can be used to automatically generate test cases and predict areas of the application that are more at risk of failure. The main .NET libraries used for server-side testing, such as Moq, FluentAssertions, NSubstitute, and Selenium, are suited by AI-driven test automation tools that enhance test coverage and prioritize tests based on system behavior.

The online platform for monitoring the soil and water resources of the region demonstrates significant potential for further development by integrating artificial intelligence technologies. These technologies can be implemented to automate data analysis, predict environmental changes, provide recommendations for resource management and assist in testing and quality assurance. For instance, AI algorithms can be used to detect anomalies in monitoring data, predict soil and water pollution risks, and optimize water management processes. Additionally, AI can aid in continuous system testing by identifying changes in data patterns that could signal potential failures or performance issues, making the platform more resilient and reliable.

The improvement of the user interface is aimed at enhancing the usability of the platform and improving the visualization of data. AI can also be employed to dynamically adjust the interface based on user behavior, providing personalized views and recommendations. The development of intuitive interfaces, interactive mapping modules, and AI-enhanced data analysis tools will allow users to make better use of the platform's functionality. Expanding functionality by adding external modules — such as AI-based integration with laboratory management systems, weather forecasting systems, and water management systems — will enable the platform to better adapt to the specific needs of different organizations.

The high level of flexibility and scalability of the online platform makes it possible to adapt it to the various needs and limitations of users. AI can further support this adaptability by learning from user interactions and system usage patterns, allowing the platform to evolve over time. The web application architecture, supported by AI-powered testing tools and intelligent scaling mechanisms, makes it easy to add new functionality, integrate external systems, and scale the system to serve a large number of users without compromising performance.

Thus, the online system for monitoring the state of water and soil resources has significant potential for further development and adaptation to the diverse needs of users. By integrating artificial intelligence technologies for automated testing, improving the user interface, and expanding functionality, the platform's efficiency will be greatly enhanced, and its application will be expanded across various industries.

## 6. Conclusions

The development of an online platform for monitoring soil and water parameters demonstrates the prospect of integrating modern information technologies to solve urgent environmental problems. The application of the technology stack, including ASP.NET, Angular and PostgreSQL, provides a scalable and reliable solution for environmental monitoring.

The development and implementation of the platform confirms the importance of choosing technologies characterized by scalability, security and efficiency. The architectural flexibility of the platform makes it possible to further expand it by integrating customized interfaces and additional functional modules that meet the specific needs of various organizations. In addition, its adaptability to a wide range of subject areas of testing ensures high accuracy of knowledge assessment and data analysis, making it applicable in a wide range of practical applications.

When comparing deployment options, Azure cloud services are the best choice due to their integration with .NET and PosgreSQL technologies, the provision of reliable AI services, as well as support for modern development tools such as Kubernetes and Docker. Advanced Azure functionality provides accelerated project deployment, increased security, and simplified administration.

Therefore, the integration of a scalable platform architecture, efficient technology solutions and the choice of Azure cloud environment for deployment ensures the positioning of the platform as a reliable and promising solution for environmental monitoring.

Future areas of further development include the integration of machine learning algorithms for predictive analysis and expansion of platform functionality by including additional environmental factors.

## Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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