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INFORMATION SYSTEM FOR DETECTION OF PARAMETERS OF DANGEROUS INDUSTRIAL FACILITIES BASED ON GEOINFORMATION TECHNOLOGIES

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Abstract. *With the development of industry, the issue of environmental safety of countries worldwide has become increasingly acute. Currently, there is a deficiency of information systems capable of effectively and comprehensively informing the public about the state of the environment, analyzing the dynamics of environmental indicators, and assessing regional disparities in terms of environmental safety. The objective of this study is to develop an information system for monitoring the environmental condition of a country's territory based on geoinformation technologies, considering emissions of pollutants. This system is conceived as a multi-regional monitoring system focused on industrial areas. It incorporates a geo-module for user location determination and data representation tailored to the user's location. Additionally, the system regularly updates information on hazardous enterprises and notifies the population in case of emergencies.*

Keywords: information system, geoinformation technologies, software architecture, cluster analysis, functional stability

SYSTEM INFORMACYJNY DO WYKRYWANIA PARAMETRÓW NIEBEZPIECZNYCH OBIEKTÓW PRZEMYSŁOWYCH NA PODSTAWIE TECHNOLOGII GEOINFORMACYJNYCH

Streszczenie. *Z rozwojem przemysłu wzrasta znaczenie problemu bezpieczeństwa ekologicznego i potrzeba doskonalenia systemów informacyjnych do jego monitorowania i analizy. W obecnych warunkach istnieje niedostatek takich systemów, które mogłyby jakościowo i dostępnie informować społeczeństwo o stanie środowiska, przeprowadzać analizę dynamiki wskaźników ekologicznych oraz oceniać regionalne różnice w tej dziedzinie. Celem niniejszego badania jest opracowanie systemu informacyjnego do monitorowania stanu ekologicznego obszaru kraju na podstawie technologii geoinformacyjnych z uwzględnieniem emisji substancji zanieczyszczających. Wspomniany system jest rozważany jako wieloregionalny i skierowany na monitorowanie stanu ekologicznego strefy przemysłowej. Obejmuje on moduł geograficzny do określania lokalizacji użytkownika i wyświetlania informacji zgodnie z tą lokalizacją. Ponadto system regularnie aktualizuje dane dotyczące niebezpiecznych przedsiębiorstw i informuje społeczeństwo w przypadku wystąpienia sytuacji nadzwyczajnych.*

Słowa kluczowe: system informacyjny, technologie geoinformacyjne, architektura oprogramowania, analiza klastrów, odporność funkcjonalna

Introduction

The issue of environmental safety has intensified since the inception of industrial development. Chemical and mechanical engineering industries, as well as energy production facilities operating worldwide, generate a significant amount of waste, polluting human habitats. Each year, the number of industrial enterprises grows, adversely affecting the entire planet's ecosystem.

Forest fires occur annually, with air and water pollution levels rising. Every summer and autumn, the population burns waste and dry leaves, significantly deteriorating soil fertility, while harmful substances harmful to respiratory health are released into the air [21].

Unauthorized burning of leaves can lead to a real catastrophe in the form of forest fires. According to data from the State Forest Agency, 75 percent of forest fires in Ukraine are caused by anthropogenic factors. Every year, about 300 fires occur in the territory of the Kyiv region, leading to the destruction of 60 hectares of forest [2]. Deforestation negatively impacts the entire ecosystem and can catalyze dreadful environmental disasters.

Additionally, irreversible damage to the environment is caused by transportation using diesel or gasoline fuel. In progressive and environmentally friendly countries such as Norway and Sweden, the population is encouraged to replace their old cars with new ones powered by electric motors. Encouragement is provided through tax incentives for purchasing cars, reducing parking fees, and other benefits.

It is worth noting that industrial enterprises remain the primary source of environmental pollution. The industrial sector holds an extremely important place in the economy of any country [4, 5]. Large enterprises create jobs, stimulate imports, and attract foreign investments. However, they also cause significant harm to the country's environment.

There is a clear and urgent need to create information systems that can analyze the state of the environment in specific areas where technologically hazardous industrial facilities are located [9, 17].

1. Analysis of latest researches and publications

In examining existing domestic projects and information systems based on search geoinformation technologies that identify the hazardous impact of technological and anthropogenic influences on the environment, it has been found that there are not enough such systems currently available.

Research [2, 18] is dedicated to the assessment of temporal changes in forest stands and the development of an algorithmic-software complex for monitoring these changes. A comparative analysis of satellite images obtained through remote sensing by the Landsat 8 satellite system was conducted to determine areas affected by forest fires. Spectral analysis and calculation of the burn severity index were utilized during the classification process to identify burned areas. Correlation-regression analysis was employed to analyze changes occurring in forests due to fires. It was demonstrated that the area of post-fire sanitation cuts has the strongest correlation with the area of forest lands affected by fires. The practical outcome is the implementation of the developed system, enabling timely monitoring of forest stands after fires and assessment of affected areas.

Article [16] describes methods for assessing the fire danger of forested areas, which can aid in making informed decisions to prevent natural disasters. However, future forecasting of the occurrence of such natural disasters with subsequent consequences is not addressed.

In articles [1, 19], a method for assessing the impact zones using geoinformation technology based on the analysis of scenarios of emergency situations at gas stations has been developed. The methods for determining the accident scenario at a potentially hazardous facility and the capabilities of existing geoinformation systems for analyzing zones of technological risk have been analyzed, and the purpose and objectives of the research have been justified. Models of geodata for a gas station as a potentially hazardous facility and zones of technological risk from shock waves, spill fires, and fireballs have been developed. Methods for determining and visualizing geodata zones of technological risk in the event of an accident scenario have been developed.

Article [15] discusses the integration capabilities of a specialized GIS, which allows for a more comprehensive utilization of its capabilities for geoinformation mapping, environmental safety, and improving the quality of electronic maps.

In [14], optimal networks for environmental monitoring are substantiated for computerized environmental safety systems of territories. A comprehensive geoecological assessment of environmental components was carried out through computer processing of the analysis results, including the construction of databases and the generation of elemental ecotechnogeo-chemical maps based on them, followed by component-based maps. The use of modern remote sensing, IT, and GIS technologies allowed for the maximum automation of this process and the creation of computer-based multi-component continuously operating eco-technological models. The improvement of environmental monitoring systems is proposed based on the detailed analysis of satellite images using ground-based methods, which allowed for the identification of the morphology, structures, and origins of pollution spots from the city of Ivano-Frankivsk and the most powerful Burshynska Thermal Power Plant in western Ukraine. The necessary complex of environmental conservation measures has been developed, based on the overall environmental policy in the Carpathian region, encompassing both natural and anthropogenic environments.

For assessing regional risk in urban areas, researchers Zhao M. and Liu X. have developed and implemented a tool based on geoprocessing using GIS [20]. GIS technology process models have been created to determine vulnerability assessments, risk magnitudes, and mapping of these values.

The website SaveEcoBot [22], recently launched in the country, provides users with information on air quality and offers the possibility for users to invest in the installation of sensors to measure environmental pollution levels.

The website asm.kyivcity.gov.ua [23] displays data on air quality in the city of Kyiv. However, this project is in the development stage and is inconvenient to use as it does not provide sufficient information for detailed analysis.

Having analyzed existing computer systems that study the impact of harmful industrial facilities on the environment and determine techno genic risks, we observe that they are specialized, narrowly focused, and of limited practical use. Thus, it complicates the rapid and convenient determination of risk zones [8]. However, none of these resources provide the user with comprehensive information on environmental pollution and an objective assessment of the environmental state. Therefore, there is a need to create a resource that will satisfy users' need for complete and detailed information about the environment.

Establishing optimal connections between the sphere of techno genesis, its growing rates of development, and the state of the surrounding natural environment under the influence of external techno genic factors is carried out based on socio-ecological-economic models in the environmental monitoring and management system.

A significant portion of industrial enterprises in Ukraine are in poor condition. At the vast majority of these enterprises, filters and purification facilities, which should protect the environment from extremely hazardous emissions, have long been outdated and have not been replaced. This problem is partially responsible for the release of harmful substances such as carbon dioxide, sulfur dioxide, and nitrogen oxides into the atmosphere [24, 25]. These gases are highly stable and can persist in the atmosphere for up to 100 years, leading to their accumulation and an increase in their concentration in the air. These harmful components, when released into the atmosphere, mix with water vapor and return to the earth in the form of acid rain, disrupting the planet's ozone layer and causing various chronic illnesses, including damage to the upper respiratory tract. This can lead to the development of oncological diseases and acute respiratory illnesses.

For rapid response to potential environmental disasters and the prompt implementation of measures, the creation of a specialized information system is necessary. Such a system should be capable of real-time data visualization on the environmental condition of the city where the user is located and display potentially hazardous objects. To conduct a more detailed analysis of the environment, calculators are needed to determine the degree of environmental pollution. With this data, it will be possible to identify which of the researched enterprises require upgrading their purification facilities, which city requires greening, and reducing the amount of non-ecological transport, and make the necessary management decisions to preserve the environment.

The purpose of this work is to create an information system for monitoring the ecological state of the country's territory based on geoinformation technologies with tracking the dynamics of emissions of pollutants.

To achieve this goal, the following tasks were set:

- develop a geo-module for displaying the environmental situation of the selected territory;
- develop emission calculators;
- conduct an analysis of the dynamics of changes in environmental indicators of the territory based on cluster analysis;
- visualize the most polluted areas in cities on an interactive map.

2. The study materials and methods

Many scientific works [3] are dedicated to the development of classifiers for data analysis and providing recommendations based on the developed classifier. The literature describes numerous applied tasks that are solved by applying cluster analysis methods.

Cluster analysis involves dividing n objects into m non-intersecting subsets that satisfy a certain criterion of homogeneity within clusters. The criterion is typically minimizing distortion. There are various ways to assess distortion, but in most applied implementations, the sum of the mean square Euclidean distances between a vector and the centroid of the cluster to which it belongs is used [6].

All clustering methods can be divided into two types.

1. Hierarchical methods, which include approaches such as:
   - Nearest neighbor method;
   - Farthest neighbor method;
   - Ward's method;
   - Unweighted pairwise average method.
2. Non-hierarchical methods, among which the most popular are:
   - K-means method;
   - PAM (Partitioning Around Medoids);
   - EM algorithm, and others.

Non-hierarchical methods are based on a predefined number of clusters or employ specific algorithms to determine their quantity.

Hierarchical methods are characterized by the construction of a hierarchical or tree-like structure, where objects are sequentially grouped or divided concerning other objects. In hierarchical clustering, smaller clusters are successively merged into larger ones, or larger clusters are divided into smaller ones [11].

In this study, for the analysis of territory based on environmental indicators, the following methods have been chosen:

- K-means method;
- Nearest neighbor method;
- Farthest neighbor method;
- Ward's method.

For the K-means method, the Euclidean distance is utilized [7]:

$$\rho(x,y)=\|x-y\|=\sqrt{\sum_{p=1}^{n}\left(x_p-y_p\right)^2},\ x,y\in R^n \qquad (1)$$

The distribution of objects into clusters boils down to finding the centroids of the respective clusters. The number of clusters is predetermined by the user.

At the initial stage, a centroid can be arbitrarily chosen as an object, and then all remaining objects are assigned to the clusters whose centroid is closest to them according to the chosen proximity measure. Then, the center of each cluster is recalculated according to the rule:

$$\mu_i=\frac{1}{S_i}\sum_{k^{(j)}\in S_i}x^{(i)} \qquad (2)$$

where μ_i is the centroid of a cluster, S_i is a cluster. This algorithm terminates when two identical centroids are encountered, meaning $\mu_i=\mu_{i+1}$.

For the nearest neighbor method, the two closest objects are found, forming the initial cluster [13]. Then, subsequent objects are assigned to the cluster to which they are most similar. Initially, a distance matrix is constructed, where the elements represent the distances between objects. At each step, the minimum value in the matrix, corresponding to the distance between the two nearest clusters, is identified. Then, the matrix is updated considering the new clusters. Next, similar to the first step, the corresponding objects that are closest to each other are identified, and the matrix is recalculated again.

When using the furthest neighbor method, the procedure for selecting objects for merging changes [10]. A new object is assigned to the cluster whose furthest element is closest to the new object compared to the furthest elements of other clusters. Initially, a distance matrix is constructed. Then, the minimum value in the matrix, corresponding to the distance between the two nearest clusters, is identified, followed by a recalculation. Subsequently, the nearest elements are found again, followed by another recalculation.

In the Ward's method, the within-cluster sum of squares is employed as the objective function, which is the sum of squares of distances between each object and the centroid of the cluster containing that object. At each step, two clusters are merged in a way that minimizes the increase in the objective function, i.e., the within-cluster sum of squares. This method aims to merge closely located clusters [12].

To analyze the dynamics of environmental indicators in the region, calculations of specific emissions are used, based on the methodology for calculating emissions of harmful substances into the atmosphere from consumer service enterprises, approved by the Ministry of Energy and Environmental Protection of Ukraine [26].

One of the main sources of emissions of pollutants into the atmosphere is thermal power plants. The gross emission of the j-th pollutant E_j entering the atmosphere with the flue gases of the thermal power plant during the time period P, t, is defined as the sum of the gross emissions of this substance during the combustion of various types of fuel, including during their simultaneous joint combustion:

$$E_j=\sum_i E_{ji}=10^{-6}\sum_i k_{ji}B_i\left(Q_i^r\right)_i \qquad (3)$$

where E_{ji} is the gross emission of the j-th polluting substance during the burning of the i-th fuel during the time interval P, t; k_{ji} – emission index of the j-th pollutant for the i-th fuel, g/GJ; B_i – consumption of i-th fuel during the time period P, t; $\left(Q_i^r\right)_i$ – lower working heat of combustion of i-th fuel, MJ/kg.

The greatest damage to our air is caused by carbon dioxide CO_2, which is a greenhouse gas and is the main gaseous product of carbon oxidation of organic fuels. The volume of CO_2 emissions is directly related to the carbon content of the fuel and the degree of carbon oxidation of the fuel in the combustion plant. The carbon dioxide emission rate k_{CO2}, g/GJ, during the combustion of organic fuel is determined by the formula:

$$k_{CO_2}=\frac{44}{12}\cdot\frac{C^r}{100}\cdot\frac{10^6}{Q_i^r}\cdot\varepsilon_C=3.67\cdot k_C\cdot\varepsilon_C \qquad (4)$$

where C^r – mass fraction of carbon in fuel per unit working mass, %, Q_i^r – lower heating value of fuel, MJ/kg; ε_c – carbon oxidation degree of the fuel; k_c – the emission factor of carbon in the fuel, g/GJ. In the absence of data from a specific production regarding the carbon content in the fuel, a generalized emission factor of 15300 g/GJ is used [26].

There are also other methods for calculating emissions, which can be used to calculate:

- NOx emissions (nitrogen oxides);
- SO_2 emissions (sulfur dioxide);
- particulate matter emissions;
- heavy metal emissions;
- N_2O emissions (nitrous oxide).

3. Results of research

The developed information system features a simple interface, allowing users to work with it easily. The versatility of this development lies in its adaptive design, enabling its usage regardless of the technical specifications of users' devices. This system is a multi-regional environmental monitoring system for industrial zones, providing necessary information across all cities in the country. The created system has the following functionality:

- upon logging into the system, the geo-module will determine the user's current location and display the necessary information for that area;
- displaying comprehensive information with regular updates on hazardous objects in a specific region/city;
- quick and convenient calculation of air pollutant concentrations using calculators;
- analysis of the dynamics of environmental indicators based on cluster analysis (emissions of pollutants into the air, environmental protection expenditures);
- visualization of the most polluted areas in cities on an interactive map;
- prompt notification of the population about emergency situations in their locality.

Figure 1 shows the architecture of the developed software.

The information system consists of the following modules:

- geo-identification – comprises a list of cities where the system is already implemented. By default, when a user visits the homepage, they are directed to the subdomain of their city. If they wish to view information about the environmental status of another city, they can select it from the list provided;
- calculators – includes 6 calculators for determining the air quality. If users require additional environmental data, they can refer to the official website of the State Statistics Service of Ukraine;
- cluster analysis – consists of 4 methods for assessing regional differences in environmental safety indicators;
- online monitoring – presents a map of air pollution indexing. The SaveEcoBot website installs sensors to determine the air pollution index and aggregates this data into a unified view. Information from these sensors in different cities is obtained

through an API. Subsequently, the information is overlaid on a map to provide a comprehensive picture;

- enterprises – contains information about enterprises in the selected city (the most hazardous objects in the city, information about them, description of pollutants they emit).

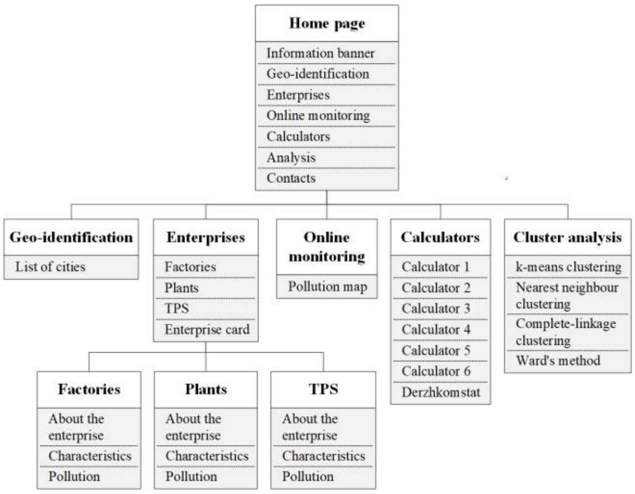

Fig. 1. The architecture of the software program

This system interacts with several external resources. Among them are resources for obtaining information about the user's IP address, the location of the system visitor, or a database of pollution sensors.

To ensure the stable operation of the information system, continuous monitoring of its operational status is necessary. One of the characteristics that should be present in its operation is functional stability. To achieve the goals of functional stability and ensure the reliability of the information system, it is important to select an appropriate system diagnosis algorithm. This algorithm should be developed considering the system's characteristics and its modules, allowing for the determination of whether the system modules are functioning properly. Such an algorithm enables the prompt detection of malfunctions and the implementation of appropriate measures to ensure the reliability and performance of the system.

Among the existing diagnostic methods, the method of test diagnosis of information system components was chosen. The algorithm involves organizing test diagnostics based on the principle of a wandering diagnostic kernel. This method allows for continuous system diagnostics at specified intervals throughout the entire operation of the designated object [17].

Figure 2 presents a diagram of use cases, illustrating the relationships between actors and use cases in the information system.

The administrator is responsible for populating the research objects, moderating existing ones, deleting outdated data, monitoring the system, and verifying the accuracy of calculations.

The user has the ability to view industrial objects, use calculators and online monitoring maps, assess the dynamics of environmental indicators using cluster analysis, and visualize the analysis results.

After logging in to the main page, the user will be redirected to the city subdomain of the site from which they logged in. If the system cannot determine the user's city, a list of cities for selection will appear.

The navigation menu of the system includes the following sections:

- Enterprises;
- Online monitoring;
- Calculators;
- Analysis;
- Contacts.

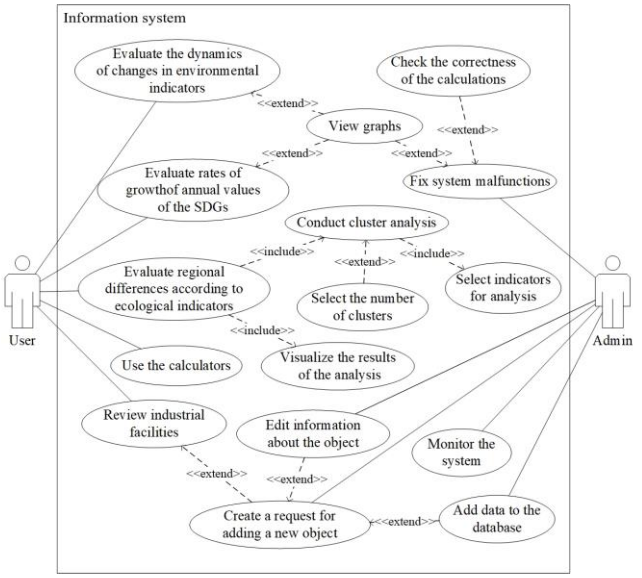

Fig. 2. The use case diagram of the system

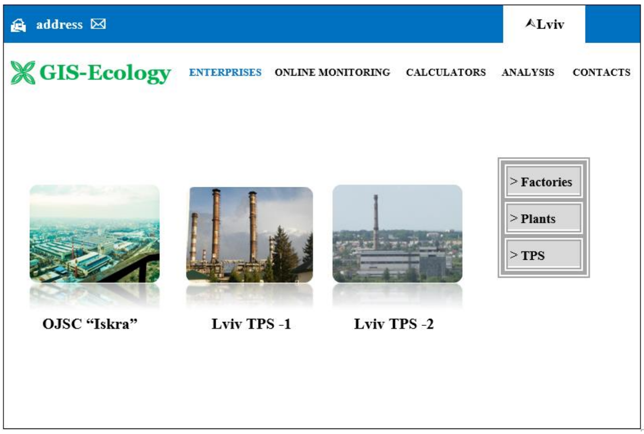

Fig. 3. Enterprises of the selected city

In the "Enterprises" section, users can familiarize themselves with a list of environmentally hazardous enterprises in their city (Fig. 3). On the right, there is a filter for easier navigation on the site, categorizing enterprises into "Factories", "Plants" and "TPS".

Upon clicking on a specific enterprise, the user will be directed to its page. On the selected object's page, the user can review detailed information about it, read its characteristics, and view the latest data on environmental pollution by this object. With convenient navigation, the user has the ability to navigate to any page with minimal transitions, which will not complicate the operation of this system.

The "Online monitoring" section is designed to track air quality in the selected city in real-time (Fig. 4).

The map displays information from all air quality assessment stations located in the selected city. Each station is represented by a specific color:

- gray – currently no connection with this air quality sensor;
- green – good air quality;
- yellow – slight deterioration in air quality;
- orange – air quality is further degraded, people with respiratory illnesses are advised to avoid prolonged outdoor exposure;
- red – heavily polluted air, better to refrain from extended outdoor activities;
- purple – extremely polluted air, outdoor exposure is hazardous at this level;
- brown – air pollution index exceeds the norm by more than 6 times, indicating an emergency situation.

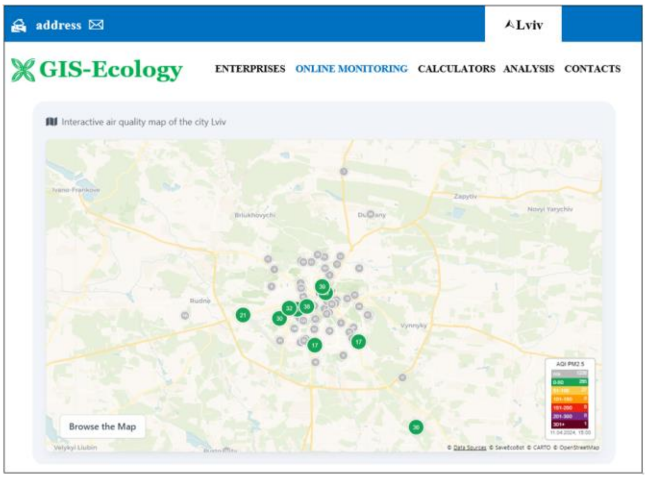

Fig. 4. Air quality online monitoring

Upon clicking on any sensor, the user receives information about the sensor's location, last update time, and the dynamics of air quality changes. Using an interactive menu, this information can be shared with anyone via messaging apps.

The "Calculators" section allows users to independently calculate emissions of pollutants into the environment. Users are provided with a list of emission calculators along with brief information about the calculation method and formula. If the formula contains constants, they will already be entered into the necessary field, but they can be modified if needed.

To track the dynamics of environmental indicators on the studied territory based on cluster analysis, information on emissions of pollutants into the air obtained from calculators is used. The rest of the data for analysis is sourced from the website of the State Statistics Service, namely waste management (generated, utilized, incinerated) and environmental protection expenditures (capital and current).

In the "Analysis" section, users can select the year (starting from 2015), indicators for analysis, and the clustering method. When the user clicks the "Analysis" button, and if the k-means method is selected, the program prompts the user to enter the number of clusters additionally. As a result, a message about creating the corresponding file with the results appears on the screen, followed by the display of the graph (Fig. 5).

The file with the results of the k-means method analysis is presented in table 1.

In the table containing the clustering results, the data is sorted by clusters. The number and labels of the clusters correspond to those shown in figure 5. If we compare the number of regions in each cluster, cluster 0 includes 14 regions, cluster 1 includes 2 regions, cluster 2 also includes 2 regions, cluster 3 includes 6 regions, and cluster 4 includes 1 region. Analyzing the clusters, we can draw the following conclusions:

- cluster 0 consists of regions where the values of all indicators are relatively low;
- cluster 1 is characterized by a very high level of emissions of harmful substances into the air and emissions of dioxide;
- clusters 2-3 are clusters with regions where the indicators are quite average relative to the entire country and do not differ significantly from each other;
- a distinctive feature of cluster 4 is the large amount of burnt waste.

Similarly, as for the k-means method, graphs and files with the results of clustering using the nearest neighbor method, the furthest neighbor method, and the Ward method are created.

When comparing the results of all four methods, certain differences can be identified, but the main part of the objects and clusters to which they belong remains consistent. For example, in these methods, the Zaporizhzhia and Ivano-Frankivsk regions often belong to the same cluster, as do the Dnipropetrovsk and Donetsk regions, while the city of Kyiv forms a separate cluster.

Thus, this information system monitors the environmental state of the country's territory based on geoinformation technologies, tracking the dynamics of emissions of pollutants. This is crucial for analyzing the overall state of ecology.

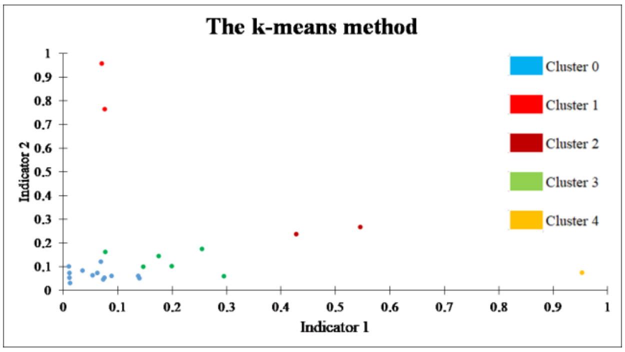

Fig. 5. Result of the cluster analysis using the k-means method

Table 1. The results of the k-means analysis

Region Name	Incinirated Waste Amount	Air Emission Amount	Diox Emission Amount	Cluster
Mykolaiv	26	15.8	1816.4	0
Kherson	24.4	8.9	352.6	0
Khmelnytskyi	1.7	18.3	2193.3	0
Odesa	18.4	26.1	3232.3	0
Chernihiv	11.2	33.9	1517.6	0
Cherkasy	4.7	57.9	2662.2	0
Chernivtsi	21.3	3.2	154.9	0
Kirovohrad	38.6	14.2	1012.1	0
Kyiv	20.5	78.1	4631.6	0
Transcarpathian	5.9	4.4	133.1	0
Zhytomyr	22.4	9.0	591.3	0
Volyn	40.1	4.7	445.3	0
Sumy	16.6	17.5	1244.5	0
Ternopil	2.2	8.5	364.4	0
Donetsk	21.9	917.6	3599.5	1
Dnipropetrovsk	23.4	723.9	25642.1	1
Ivano-Frankivsk	147.5	223.9	11575.3	2
Zaporizhzhia	116.1	193.7	13901.1	2
Vinnytsia	70.1	134.7	6462.1	3
Rivne	81.0	10.2	1245.0	3
Poltava	40.8	55.6	3314.9	3
Lviv	48.8	102.4	3399.2	3
Luhansk	22.5	115.2	6550.2	3
Kharkiv	55.2	53.4	5365.8	3
Kyiv	255.4	26.2	5125.1	4

4. Conclusions

The developed information system, based on geoinformation technologies, allows for the analysis and investigation of the environmental condition in any city across the country. All data are displayed in real-time, enabling users to access up-to-date information and make timely decisions regarding environmental improvement or mitigation of problems and consequences.

The system's universality lies in its adaptive design, which enables its use regardless of users' device specifications. This system serves as a multi-regional environmental monitoring system for industrial zones, providing necessary information across all cities in the country.

The developed system consists of four main blocks: geo-identification, calculators, cluster analysis, online monitoring, and enterprises. It interacts with several external resources, including resources for obtaining information about users' IP addresses, their location, and databases of pollution sensors.

Equipped with a geo-module for determining the user's city of access, the system displays data specific to that city. An interactive map of Ukraine visualizes data on air quality and pollution levels. Regional disparities in environmental safety indicators are assessed based on cluster analysis.

Potential users of this system could include ordinary citizens interested in monitoring environmental conditions, as well as professionals in the field of ecology and environmental conservation.

As for further research prospects, the integration of artificial intelligence for analyzing the dynamics of environmental indicators and visualizing the most polluted areas on an interactive map could be considered. This would enhance the accuracy and speed of obtaining results for prompt response and informed decision-making.

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