Standardization of geodetic data for determination of boundaries of natural reserve areas

1 Introduction

The natural reserve fund is an important component of preserving the natural environment and biodiversity, and therefore ensuring sustainable development. Determining the location and boundaries of natural reserve zones is an important stage in the process of their creation and restoration. Geodetic methods allow for accurate and efficient determination of the location and boundaries of these zones, which promotes their conservation and proper use.
2 Regulatory framework for determining the location of Ukraine’s nature reserve zones
recreational and health forests, which include forest areas that perform recreational, sanitary-hygienic, and health functions, are used for tourism, sports, sanatorium-treatment, and recreation of the population;

- protective forests encompass forest areas that perform functions of protecting the surrounding natural environment and engineering objects from the negative impact of natural and anthropogenic factors;

- exploitation forests, which include forest areas that are not occupied by forests of nature conservation, scientific, and historical-cultural significance, recreational and health forests, and protective forests (categories of forests with a special regime of forest use). Exploitation forests are intended to satisfy the needs of the national economy for timber.

The nature reserve fund of Ukraine includes state reserves, natural national parks, reserves, natural landmarks, botanical gardens, dendrological and zoological parks, parks-monuments of garden and park art, and reserve tracts.

Article 3 of the Law of Ukraine “On the Natural Reserve Fund of Ukraine” outlines the classification of territories and objects belonging to the Natural Reserve Fund (NRF) of Ukraine. These include natural territories and objects such as nature reserves, biosphere reserves, national parks, regional landscape parks, nature reserves, natural landmarks, and reserved areas, as well as artificially created objects such as botanical gardens, dendrological parks, zoological parks, and park-monuments of garden and park art.

Depending on the origin and other features of natural complexes and objects that are designated as nature reserves or natural landmarks, as well as the goals and necessary conservation regime, the following are distinguished: landscape, forest, botanical, general zoological, ornithological, entomological, ichthyological, hydrological, general geological, paleontological, and karst-cave nature reserves, and complex, botanical, zoological, hydrological, and geological natural landmarks.

Differentiated conservation, reproduction, and use regimes for NRF territories and objects are established by relevant articles of the Law of Ukraine “On the Natural Reserve Fund”, in accordance with functional zoning. Article 18, for example, establishes the following functional zoning for biosphere reserves:

- protected zone - includes areas intended for the preservation and restoration of the most valuable natural and minimally disturbed anthropogenic factors of natural complexes, the gene pool of plant and animal life; their regime is determined in accordance with the requirements established for nature reserves;

- buffer zone - includes areas designated to prevent negative impacts on the protected zone from economic activities in adjacent territories; its regime and creation procedure are determined in accordance with the requirements established for protective zones of natural reserves;

- zone of anthropogenic landscapes - includes areas of traditional land use, forestry, water use, settlements, recreation, and other types of economic activities;

- within the territory of biosphere reserves, zones of regulated protected regime may be designated, including regional landscape parks, reserves, and protected areas, which adhere to the requirements for their conservation established by this law.

In the structure of natural complex territories and objects of national nature parks, the reserve zone, regulated recreation zone, stationary recreation zone, and economic zone are distinguished. Article 24 of the same Law notes that, on the territory of regional landscape parks, taking into account the nature conservation, recreational, scientific, historical, cultural, and other values of natural complexes and objects, their features, zoning can be carried out in accordance with the requirements established for the territories of national nature parks.

The relevant status and tasks are determined for natural monuments, reserves, botanical gardens, dendrological and zoological parks, and parks of garden and park art [1].
It is also necessary to indicate a number of laws that affect the determination of the location of natural reserve fund zones. This list includes a number of laws, regulations, orders, and other documents that regulate the determination, protection, and use of natural reserve fund zones.

In Ukraine, such documents include the Law of Ukraine "On the Natural Reserve Fund of Ukraine," the Regulation on the Natural Reserve Fund of Ukraine, Cabinet of Ministers of Ukraine Resolutions "On the Approval of the Procedure for the Organization and Conduct of Events to Determine the Territories of the Natural Reserve Fund" and "On the Approval of the Procedure for the Use of Objects of the Natural Reserve Fund," as well as orders and other documents of local authorities.

These documents establish the legal and organizational principles of determining and using natural reserve fund zones, including procedures for their approval, regulate the activities of government bodies and public organizations in this area, establish requirements for the organization and conduct of work on the determination of natural reserve fund zones, and indicate the need for their protection and preservation [2].

The normative and legal framework also includes a number of international documents, including the Convention on Biological Diversity, which defines international obligations for the conservation and use of biodiversity, including protected areas.

Therefore, to determine the location of protected areas, we primarily rely on the classification and normative standards of the current legislation.

3 Analysis of geodetic methods for determining the location of natural reserve zones

The legislation norms regarding the placement of natural reserve zones describe these zones, while their exact location is determined by geodesy. Geodetic methods play a crucial role in determining the location and boundaries of natural reserve zones. Among the geodetic methods used, geodetic measurements, global navigation, and remote sensing methods can be distinguished.

Geodetic measurements are typically performed using instruments to measure distances, angles, and heights. These methods provide accurate results but may require significant effort and time to carry out. Global navigation, such as GPS, is also an important tool for determining the location of natural reserve zones. These methods provide speed and accuracy but may be limited by the availability of satellite signals in some areas.

Remote sensing methods, such as laser scanning and radar interferometry, allow for detailed data on natural reserve zones with high precision and speed. However, these methods may be limited by data processing and require significant costs.

In summary, geodetic methods are effective in determining the location and boundaries of natural reserve zones. The choice of a specific method depends on many factors, such as the availability of technical means, budget, and characteristics of the zone being studied.

In addition, an important aspect of using geodetic methods is their combination and integration with other methods, such as photogrammetry, satellite imaging, and geological research. This allows for a more complete and accurate understanding of the location and condition of the natural reserve area.

Finally, an important aspect of using geodetic methods is their impact on the environment. Some methods may require the use of transportation and large amounts of energy, which can have a negative impact on the environment. Therefore, when choosing a method, it is necessary to consider its impact on the environment and consider alternative methods that may be more environmentally friendly.
4 Practical implementation of geodetic methods for determining the location of natural reserve areas

The use of modern geodetic instruments, such as theodolites, global positioning systems (GPS), and laser scanners for surveying terrain.

Modern geodetic instruments such as theodolites, GPS, and laser scanners provide high precision measurements, allowing for detailed information about the territory. These instruments are used for surveying the territory’s contour, measuring the heights and coordinates of points, enabling the creation of accurate maps and identifying the location of protected natural areas.

To ensure the highest accuracy of measurements and obtain complete information about the territory, different surveying methods are used. For example, theodolites are used to measure angles and distances between points as well as heights of points. GPS is used to determine the coordinates of points using a satellite positioning system. Laser scanners provide detailed information about the terrain’s relief and the height of objects.

For instance, the Leica Nova MS60 1" theodolite is the world’s first MultiStation, allowing for all geodetic tasks to be performed with one instrument. It combines:

– the ability to perform high-class tachymetry;
– 3D laser scanning that allows scanning up to 30,000 points per second;
– ability to connect to GNSS;
– digital imaging based on point coordinates.

For example, the Leica GS18 I GNSS receiver allows inaccessible points to be determined in the field. The coordinates of these points are determined based on images using visual positioning technology, GNSS, IMU (inertial measurement unit), and camera technology. It solves problems such as:

– винесення в натуру об’єктів будівництва;
– measurement of land area;
– high precision measurements in road and bridge construction;
– engineering research;
– topographic surveying of the area.

As an example, companies FARO and Z+F have developed a device for simultaneous scanning and capturing images with subsequent joint processing of the results. The obtained data can be used to build a detailed cartographic database containing information on the location of natural reserve areas. This enables the efficient use and protection of these areas, as well as helps to ensure their long-term preservation.

In summary, the use of modern geodetic instruments, such as total stations, GPS, and laser scanners for terrain surveying, is a practical implementation of geodetic methods for determining the location of natural reserve areas. These methods provide detailed information about the terrain and ensure measurement accuracy, enabling the construction of an accurate map of the area and determination of the location of natural reserve areas. The obtained data can be used to ensure the efficient use and protection of these areas, and help ensure their long-term preservation. Thus, the use of geodetic methods to determine the location of natural reserve areas is an important step in preserving and effectively using natural resources [3].

The use of triangulation surveying to determine the coordinates of points on the terrain.

To perform a triangulation survey, control points with known coordinates must be established. These points can be set up using geodetic equipment such as a theodolite or GPS receivers.

To construct triangles on the terrain using triangulation surveying, the following steps must be taken:

1. Determine control points on the territory. These points should have known coordinates and be located in such a way as to cover the entire area on which measurements will be taken.
2. Establish measurement routes between the control points. The routes should pass through all the points that need to be measured and be located in such a way as to avoid obstacles and ensure maximum measurement accuracy.

3. Measure distances and angles between points on the measurement routes using geodetic equipment. Laser rangefinders, electronic distance meters, and other devices can be used to measure distances. Geodetic theodolites are used to measure angles with an accuracy of several seconds.

4. Process the data obtained using special software that allows for the construction of triangles and the determination of point coordinates on the earth's surface. Corrections that need to be made depending on the measurement conditions and soil conditions are taken into account during data processing.

5. Determine the location of nature reserve zones. After determining the coordinates of the points on the earth's surface and further processing them, the location of nature reserve zones can be determined. Special geographic information systems are used for this purpose, which allow for the creation of digital maps showing the nature reserve zones and other natural reserve objects.

6. Quality control of work. Various methods are used to control the quality of work, including checking the accuracy of measurements and data processing, comparing results with previously determined coordinates of points, as well as checking for errors and inaccuracies in the work.

4.1 Using Tachymetric Surveying.

Tachymetry can be used to determine the location of areas within a nature reserve or natural park by measuring the coordinates of points on the reserve's territory. With a tachymeter, distances and angles between points on the ground can be measured, which allows for the construction of a territory plan that displays the location and boundaries of the zones. Furthermore, a tachymeter can be used to measure elevations on the reserve's territory, enabling the determination of the area's relief. This is important for infrastructure planning and nature conservation measures.

4.2 Determination of the Boundaries of Natural Reserve Zones using Geodetic Methods

1. Trigonometric leveling. This method is used to determine the heights above sea level of points on the Earth's surface. By using trigonometric formulas, the height of a certain point is determined relative to other points, which allows for the determination of the boundaries of natural reserve zones, which are usually displayed on maps with absolute heights indicated.

2. Geodetic survey of the territory. For this, measurements of the coordinates of points on the Earth's surface are carried out using theodolites or the Global Navigation Satellite System. The obtained data is processed in special programs, which allows for the determination of the position of the boundaries of natural reserve zones.

3. Use of aerial photography and satellite imagery. These methods allow for obtaining high-quality images of the territory, which can be used to determine the boundaries of natural reserve zones. By using special image processing programs, it is possible to determine the coordinates of points on the Earth's surface and their heights, which allows for the determination of the boundaries of zones.

When determining the boundaries of natural reserve zones using geodetic methods, it is necessary to comply with the requirements of the legislation that regulates this process. It is
It is important to take into account the peculiarities of the territory on which the measurements are made, as well as to comply with the requirements for the accuracy of the measurement and data processing results. For example, when determining the boundaries of reserve zones, it is necessary to consider local ecosystem peculiarities, the size of the serviced area, and the possibility of its expansion in the future. The accuracy of measurements and data processing should also be sufficient to achieve the required accuracy of the results.

After determining the boundaries of natural reserve zones using geodetic methods, a map can be created showing the zones with different degrees of protection. This will ensure the rational use of natural resources and the preservation of the most valuable ecosystems for future generations [4].

Creating a digital map of natural reserve zones is an important step towards ensuring the rational use of natural resources and preserving the most valuable ecosystems for future generations. The first step in creating a digital map is to collect data on natural reserve zones. Various sources of information such as cartographic materials, satellite imagery, aerial photographs, expedition reports, and other sources can be used for this purpose. The collected data is then entered into a geographic information system (GIS) for further processing.

The second step is to process the data and create a digital model of the natural reserve zones. Different methods of geoinformatics such as digital image processing, interpolation, and data analysis are used for this purpose. One of the key stages in data processing is determining the boundaries of the zones and their classification according to their degree of protection.

The third step is to create a digital map of natural reserve zones based on the obtained digital model. This can be done using various GIS programs that allow the creation of cartographic products with different layers and elements. For example, maps can display the boundaries of zones, their classification and degree of protection, types of landscapes, and biodiversity. Maps can also be used to monitor the state of natural ecosystems and develop the tourism potential in natural reserve zones.

To process data from the territory survey and create a digital model (DM) for determining the location of nature reserve areas, various software tools and methods can be used. One of the most common methods for creating a DM is photogrammetry, which is based on processing images from different perspectives. This involves aerial photography or the use of photos from special drones. The obtained images are processed in special programs, where the coordinates of the image points and their heights are determined.

Another method is laser scanning of the territory. Laser scanners are used to measure distances to the surface with high accuracy. The obtained data is processed in special programs, where an accurate DM is created.

After obtaining data from the territory survey, they are processed and combined into a single DM. The DM displays the height levels of the territory, allowing the identification of areas with a large number of slopes and other geomorphological features. As an example, a DM of a recreational area, processed on the lastofly.com resource, is presented (Fig. 1).
Fig. 1. An example of a digital model of a part of the recreational zone

The obtained digital elevation model (DEM) can be used to determine the location of natural reserve areas, plan roads and infrastructure, as well as study the geomorphology and natural conditions of the territory.

Geodetic methods can be used to monitor and protect natural reserve areas. For example, measuring the boundaries and monitoring their placement can be conducted using geodetic equipment, such as GPS receivers and theodolites.

Additionally, geodetic methods can be used to measure and monitor ecosystem parameters within natural reserve areas. For instance, using digital elevation models created from aerial surveys, the height of points can be determined and changes in topography can be tracked following natural disasters such as forest fires or floods.

Geodetic monitoring can also aid in assessing the impact of human activities on natural resources and ecosystems in natural reserve areas. The application of geodetic methods can help collect data on air, water, and soil pollution, and determine the causes of their occurrence.

When combined with geographic information systems (GIS), the possibilities of geodetic methods are further increased. The main advantages of using geodesy in GIS lie in the accuracy and spatial information that can be gathered using geodetic tools. Some possible applications of geodesy for monitoring and protecting natural reserve areas based on GIS may include:

1. Distribution maps of vegetation and animal species. Geodetic instruments can be used to create maps of the distribution of vegetation and animal species, which can be used to identify areas that require special protection. These maps can be created using geodetic surveys and additional information about the vegetation and animal life.

2. Monitoring changes in natural ecosystems. Geodetic methods can be used to monitor changes in natural ecosystems such as forests, swamps, and rivers. Geodetic points located on objects that require observation can be used for this purpose. The information collected through these points can be used to identify changes in ecosystems and develop measures for their conservation and restoration.

3. Control of development in natural reserve areas. Geodetic methods can be used to control development in natural reserve areas. For example, geodetic surveys can be used to create digital maps that display the location of buildings and infrastructure within a nature reserve or national park. Such maps can help preserve natural landscapes and ensure proper planning of infrastructure development to minimize the impact on the environment.
1. Monitoring water level and quality of water resources. Geodetic methods can help in monitoring the water level and quality of water resources such as rivers and lakes in the territory of a nature reserve or national park. Geodetic points can be established on the banks of rivers and lakes to collect data on water level, temperature, and other parameters. This data can be used to determine trends in changes to water resources and develop measures for their protection.

2. Land use monitoring. Geodetic methods can be used to monitor land use within protected natural areas. Geodetic points can be established at the boundaries of land plots to ensure accuracy and reliability of data on land use. This data can be used to ensure proper planning for the development of territories and protection of natural landscapes from unauthorized use.

As an example, figure 2 shows a digital map of the Chernobyl Biosphere Reserve.

Fig. 2. Map of vegetation green biomass density within the Chernobyl Radiation and Ecological Biosphere Reserve based on the Landsat-8 satellite data from April 24, 2019

5 Mathematical justification of standardization of eco-geodetic measurements of nature reserves
To bring them into a general view. To do this, mathematical methods of first-order logic and category theory can be used.

Category theory is used to represent the properties of relationships between objects of a certain field, represented in mathematical form, which do not depend on the internal structure of these objects. Geodetic data can be represented using Boolean algebra, and the connections between them can be represented using first-order logic based on category theory.

First and foremost, geodetic data will be represented as sets by the method of obtaining: 

\[ \pi \] – the set of «geodetic measurements»

\[ \sigma \] – the set of «global navigation»

\[ \delta \] – the set of «remote sensing methods of the Earth»

Next, these data need to be distributed by accuracy: low, medium, high. We will represent these sets of data as follows:

\[ \pi_{l} \] – the set of «geodetic measurements, accuracy: low»

\[ \pi_{a} \] – the set of «geodetic measurements, accuracy: medium»

\[ \pi_{h} \] – the set of «geodetic measurements, accuracy: high»

\[ \sigma_{l} \] – the set of «global navigation, accuracy: low»

\[ \sigma_{a} \] – the set of «global navigation, accuracy: medium»

\[ \sigma_{h} \] – the set of «global navigation, accuracy: high»

\[ \delta_{l} \] – the set of «remote sensing methods of the Earth, accuracy: low»

\[ \delta_{a} \] – the set of «remote sensing methods of the Earth, accuracy: medium»

\[ \delta_{h} \] – the set of «remote sensing methods of the Earth, accuracy: high»

We will further distribute the data by storage method:

\[ \pi_{d} \] – the set of «geodetic measurements with low accuracy and numerical data storage»

\[ \pi_{e} \] – the set of «geodetic measurements with low accuracy and electronic map storage»

\[ \pi_{p} \] – the set of «geodetic measurements with low accuracy and paper map storage»

\[ \sigma_{d} \] – the set of «global navigation with low accuracy and numerical data storage»

\[ \sigma_{e} \] – the set of «global navigation with low accuracy and electronic map storage»

\[ \sigma_{p} \] – the set of «global navigation with low accuracy and paper map storage»

\[ \delta_{d} \] – the set of «remote sensing methods for soil probing with precision: low, storage method: numerical data»

\[ \delta_{e} \] – the set of «remote sensing methods for soil probing with precision: low, storage method: electronic maps»

\[ \delta_{p} \] – the set of «remote sensing methods for soil probing with precision: low, storage method: paper maps»
δ^e_a – the set of «remote sensing methods for soil probing with precision: medium, storage method: electronic maps»;

δ^h_a – the set of «remote sensing methods for soil probing with precision: high, storage method: electronic maps»;

δ^l_p – the set of «remote sensing methods for soil probing with precision: low, storage method: paper maps»;

δ^p_a – the set of «remote sensing methods for soil probing with precision: medium, storage method: paper maps»;

δ^p_h – the set of «remote sensing methods for soil probing with precision: high, storage method: paper maps».

Now the data is presented in a certain formalized format. Each set characterizes a certain block of data with its parameters. The number of parameters may increase, meaning that the number of data blocks will also increase.

The resulting data blocks need to be brought to a single standard. For example, each of the resulting data blocks will characterize spatial data according to one parameter – accuracy. This data needs to be averaged, reducing accuracy in some and increasing detail in others, that is, performing a certain complex of actions on each data block. This work can be presented as a category using category theory methods (formulas 1-4):

\[ \pi^d \xrightarrow{\mathcal{M}_d^\alpha} \pi^d \]

where \(\mathcal{M}_d^\alpha\) – the morphism that characterizes the complex of actions for transitioning data from the «low accuracy» block to the «medium accuracy» block.

\[ \pi^h \xrightarrow{\mathcal{M}_h^\alpha} \pi^d \]

where \(\mathcal{M}_h^\alpha\) – the morphism that characterizes the complex of actions for transitioning data from the «high precision» block to the «medium precision» block.

\[ \delta^a_e \xrightarrow{\mathcal{M}_e^\alpha} \delta^a_d \]

where \(\mathcal{M}_e^\alpha\) – the morphism that characterizes the complex of actions for transitioning data from the «storage method: electronic maps» block to the «storage method: numerical data» block.

\[ \delta^a_p \xrightarrow{\mathcal{M}_p^\alpha} \delta^a_d \]

where \(\mathcal{M}_p^\alpha\) – the morphism that characterizes the complex of actions for transitioning data from the «storage method: paper cards» block to the «storage method: numeric data» block.

As a result, we obtain standardized geodetic data for the purpose of determining the location of natural reserve areas (Formula 5):

\[ \{\pi^d, \sigma^d, \delta^d\} \]

These data can be further represented as a single electronic map of natural reserve areas (formula 6):

\[ \{\pi^d, \sigma^d, \delta^d\} \xrightarrow{\mathcal{M}_{EC}} EC \]

where \(\mathcal{M}_{EC}\) – the morphism that characterizes the complex of actions for processing standardized data to create an electronic map.

Overall, we will represent the formalized data in the form of a block diagram. (Fig. 3):
Fig. 3. Block diagram of the generalized process of standardizing geodetic data to determine
the boundaries of nature reserve zones

6 Conclusion
As a result of the research, an analysis of the regulatory documentation on the classification and delimitation of natural reserve zones was conducted. The main geodetic methods, which allow for the determination of the boundaries of natural reserve zones, were analyzed. The basic geodetic methods for practical implementation of work for determining the location of natural reserve zones were also structured and presented in the form of a list. Using mathematical methods of formalization, mathematical logic, Boolean algebra, and category theory, analytical and graphic models of standardization of geodetic data for determining the boundaries of natural reserve zones were developed. As today there is a great focus on information technologies and artificial intelligence, such tasks remain relevant.

References


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