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USE OF LAND MANAGEMENT AND CADASTRE DATA FOR FORESTRY LAND MANAGEMENT

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Abstract
Analysis of land management and cadastre data to ensure efficient use of forest resources was conducted. Insufficient updating of data was identified, which leads to discrepancies between the records in the relevant cadastres and the actual state of the land. This complicates planning and management of both land and forest resources. Irrelevant or incorrect information has a negative impact on the ecological state of forest areas. The object of the study is the territory of Skrypai forestry in Chuhuiv district of Kharkiv region. The article highlights the shortcomings in the legislative framework that create space for legal conflicts and misunderstandings regarding the use and protection of forest areas. Limited access to cadastre information for the public and stakeholders restricts control and monitoring opportunities. The lack of effective integration between information systems makes it difficult to share and analyze data to make reasonable decisions. Technological limitations, such as insufficient equipment to handle large volumes of data, are another barrier to the effective use of information. Inaccurate cadastral and land management data, such as on plot boundaries or land classification, can lead to misuse of land resources. The discrepancies between the boundaries obtained as a result of cadastral and forestry surveys were analysed using the least squares and vector shift methods. The area measurement method and the polygon intersection method were used to analyze the discrepancies in areas in different data sets: cadastre, land management, open spatial data, forestry. Through a survey of specialists in the relevant field, GIS research of forest resources revealed manifestations of a low culture of using open remote sensing data. Comprehensive measures to address the above problems are offered: strengthening the legislative framework, transition to a unified state coordinate system, improvement of technological infrastructure, ensuring data accessibility to the public, development of interagency cooperation, and integration of information systems. This approach will help to achieve efficient forestry land management.
Key words: forestry land, GIS, land management, cadastre, remote sensing

Introduction

Merging land and forest cadastre data is an important factor in the development of a country. The potential need to follow specific procedures for handling special data and spatial information should be taken into account (Choi, 2020 et. al.; Kocur-Bera et. al., 2021; Çay, 2023). Integration of these two systems allows for a more complete and accurate picture of land resources, which contributes to more efficient planning and use of land, especially in the context of sustainable development and environmental protection. Clearly defining the boundaries of land plots, including forest areas, helps to avoid disputes and conflicts between different land users ("Про затвердження Інструкції..., 2010; Koshkalda, Stoiko et. al., 2023).

Forests play a key role in ensuring ecological balance and biodiversity. The integration of forestry documentation with land cadastre data contributes to better monitoring, protection and management of forest resources ("Про затвердження Порядку..., 2013).

On the other hand, land cadastre and forestry records are often maintained in different formats and on different platforms, which can make it difficult to combine and integrate them. It can also require significant financial and technological investments. Data merging may be resisted by the various administrative and legal authorities that have control over these databases (Koshkalda, Grek et. al., 2023; Koshkalda, Dombrovska et. al., 2023).

The scientists draw attention to the latest principles and innovations in the legal support of the State Land Cadastre in Ukraine (Forejt et. al., 2020; Станіславський, 2022). The author highlights the legal regulation issues of information interaction between the State Land Cadastre of Ukraine and the national geospatial data infrastructure. The author identifies the advantages of adapting the current legislation in the field of land relations (Сопов et. al., 2024).

The problems of the institutional environment of land and other types of cadastres were studied by a group of researchers (Третяк et. al., 2018; Mika, 2020; Cienciała et. al., 2021). They examined the issues of defining the state cadastre of territories and objects of natural resources use, as well as the specifics of maintaining the state forest cadastre in the forest code. The research covers not only the technological side of land and forest cadastre data integration, but also the legal, environmental and institutional components of this process, which is key to the successful spatial data integration (Khainus et. al., 2023; Dorosh et. al., 2024).

Methodology of research and materials

GIS software and statistical methods were used to assess the discrepancies in spatial data. The percentage of overlap between the coordinates of land plots from different information sources was calculated, which allows to quantify their similarity. For this purpose, GIS tools were used to automate the process: buffering, distance matrix, overlay operations.

Another way to quantify differences in data is to use a geometric metric such as Hausdorff distance, which measures how far two subsets of space are from each other. This metric is particularly useful for assessing the similarity of polygon shape (cadastral and forest management). The Hausdorff distance is a measure used to determine how much a set of spatial objects recorded in the land cadastre differs from those recorded in forestry records This metric is widely used in various fields, including mathematics and geographic information systems (GIS) (Hoptsii et. al., 2023).

Another method used to study the similarities and differences between land and forestry data was to compare the coordinates of land plot vertices. This was done by calculating the root mean square error between the corresponding points of the two plots.

In order to measure the vector shift in coordinates of land cadastral and forestry survey plots, coordinates were transformed to a common system. Next, we selected steady reference points (333 pairs) that are present in both sets of polygons. These points served as the basis for measuring the shift. Statistical methods were also used to compare the distribution of geometric characteristics (side lengths, angles, centroids) of the boundaries of the two spatial data sets.

Each of these methods was applied to achieve a more detailed understanding of the similarities and variations in the boundaries of the land cadastre and forestry spatial datasets (Koshkalda, Sadovyy et. al., 2023).

Remote sensing data from various available geoportals and online services were also used. Remote sensing combined with GIS are interrelated and complementary modern technologies that, when combined, can improve the processes of monitoring, mapping and management of forest resources. Today, these two tools cannot be considered separately from each other, and the choice of a particular method of obtaining remote sensing data and software depends on the tasks set for monitoring the use of forest resources (Siedov et. al., 2023; Sadovyy et. al., 2022).

Discussions and results

The object of the study is the territory of the Skrypayivka Educational and Research Forestry of the State Biotechnological University, which is located in the central part of Kharkiv region in the Chuhuiv administrative district. According to the forestry report, the area of the two forestries is the following: Mokhnach forestry covers 4555.0 hectares and Skrypayi forestry covers 3716.0 hectares. The total area of both forestries (forestry) is 8582.0 hectares. This information can be used to analyze the distribution of land resources between forestries, plan the use of forest resources, protect nature and other purposes related to the management and conservation of forest resources.

The cartographic (geodetic) basis for the preparation of forest management plans was the materials of the previous forest management, as well as the materials of the state act on the right to use the land. In other words, the modern geodetic basis was formed not as the latest cadastral survey with modern instruments of the actual use of forestry lands, but as a long (34 years) process of forestry and cadastral spatial information integration. Where old mistakes, inaccuracies and gaps in the methodology were overlaid on top of each other over the course of time.

For the forest inventory, spectral-zone aerial photographs of satisfactory quality, flown in 1990, at a scale of 1:10000 were used as auxiliary data. As of 2000, the discrepancy in area with the previous forest inventory was +17.0 ha. This was due to the correction of land areas when drawing up the State Act on the right to use land.

The external boundaries of the forestry, forestry districts, administrative districts, and forest boundaries are shown in figure 1.

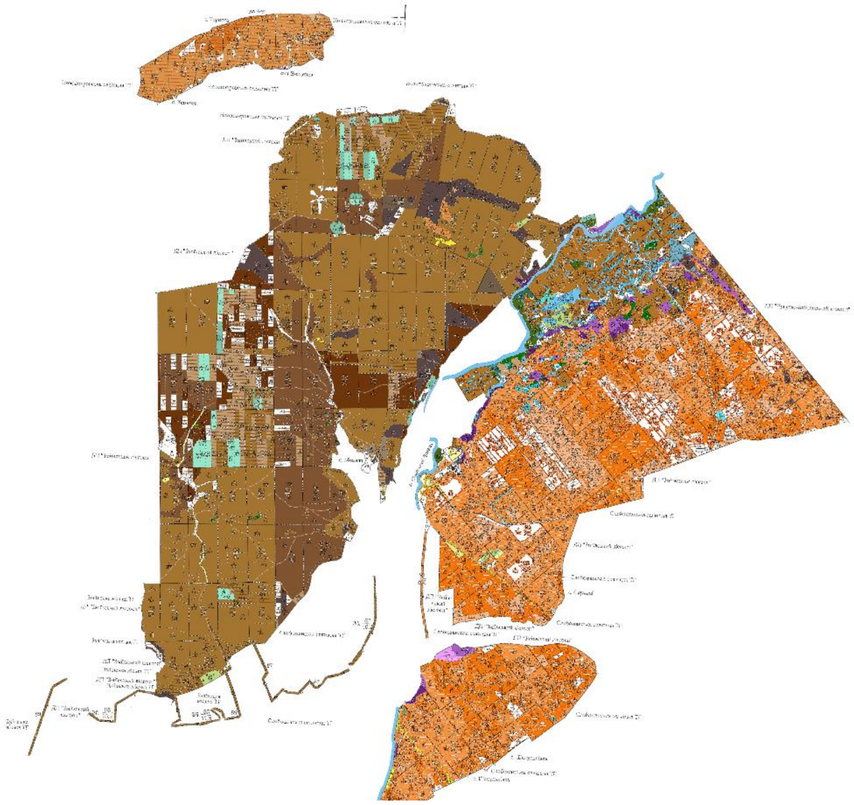

Fig .1. The territory of the Skrypayi Educational and Research Forestry

Figure 1 shows that the territory is divided into 226 quarters. The size of the quarters varies from 8.0 to 90.0 hectares, with an average of 38.0 hectares. Within these quarters, 2891 taxation blocks were defined. A taxation block is an elementary accounting unit in forest management that is homogeneous in terms of stand composition, age, fullness, productivity, forest type, etc. The average area of one taxation block is 3.0 hectares.

When analyzing the land resource potential of the Skrypayi Forestry in Chuhuiv district, Kharkiv region, we found shortcomings and inaccuracies in the classification of certain land categories. Such inaccuracies lead to incorrect accounting of available land resources, which complicates planning and management processes. Inconsistencies in the records are caused by both changes in legislation and natural and economic processes that occurred in a certain period, such as the expansion or reduction of forested areas, changes in the networks of forest roads, clearings and firebreaks. Most of these accounting gaps are the result of a lack of systematic monitoring.

Management decisions based on the use of outdated data can lead to misjudgements of forest resources and the risk of biodiversity loss, which in turn can lead to disruption of existing ecosystems and other natural processes. It should also be noted that outdated information can make it difficult to predict and manage the risks of natural disasters, such as fires, extreme weather or other natural hazards that can have a large-scale impact on the ecological state of forest resources.

The land cadastre plan focuses on registration, accounting and control of land resources, while the forestry plan focuses on forestry, protection, reproduction of forests and rational use of forest resources. Differences in the legal requirements for these documents can lead to uncertainties regarding the use of land plots, especially in the context of forestry land. Figure 2 shows what the study area looks like on the Public Cadastral Map (downloaded from QGIS).

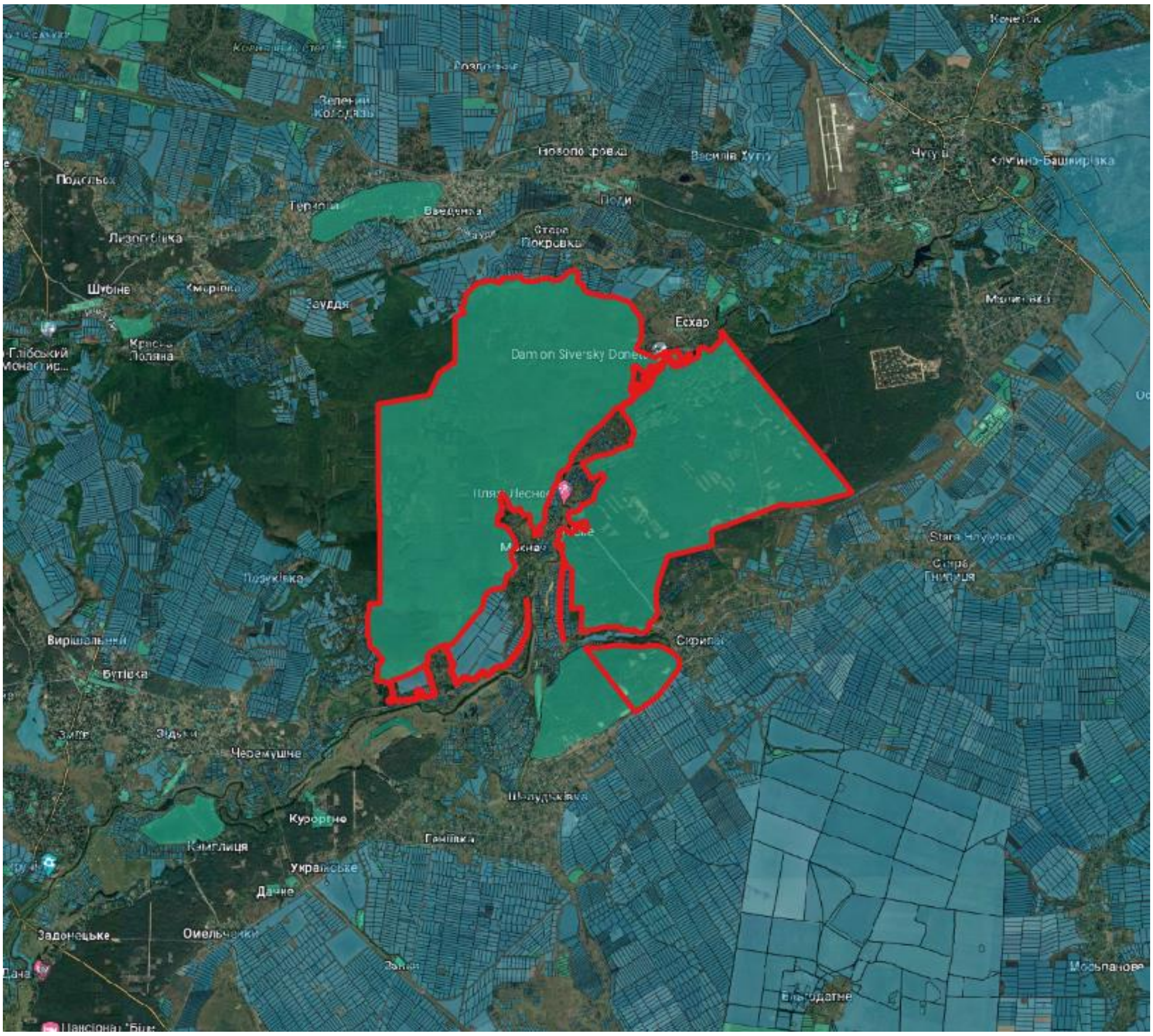

Fig.2. Public cadastral map and boundary of the study area

Figure 2 shows that the data of neighboring land plots along the perimeter of the study area have not yet been input into the State Land Cadastre database. This poses a potential threat of boundary disputes. It also shows that the forestry has a complex configuration, which makes it difficult to analyze its spatial characteristics. We can see the following land use deficiencies: inclusions, wedging, far-land, etc.

There are differences in the methodologies for collecting and processing spatial information, including requirements for mapping, geodetic data, etc., which may lead to conflicts in determining the boundaries of land plots. In our opinion, geospatial data of forestry enterprises should not only be open, but also displayed in various information systems. The lack of their effective integration complicates the exchange and analysis of data, which leads to conflicts when delimiting forestry lands, private property, nature reserve objects, etc.

Another factor that hinders effective data integration is the use of different coordinate systems in different organizations and agencies at different levels, which complicates the processes of monitoring, accounting and planning of forest resources use.

Integration of forest resources data into different geodatabases is possible only in a single coordinate system. Our study found that different systems are used in different sectors instead of one unified one. The coordinate systems SK-63 (land cadastre data), USK-2000 (state coordinate system) and UTM-36 (forestry plan data) were developed for different purposes and are based on different principles, which is why they do not coincide with each other.

Each coordinate system uses its own datum, which defines the position and shape of the Earth for that system. The SK-63 is based on the Soviet datum of 1942 (the Krasovsky ellipsoid), the USK-2000 uses the WGS-84 datum, and the UTM-36 is also based on WGS-84, but with a specific meridian (36 degrees) orientation. Projection defines how points on the Earth's surface are projected onto a plane. The SK-63 uses the Gauss-Kruger projection, while the UTM is a system that uses the transverse mercatorial projection.

These coordinate systems were developed to meet the needs of different geographical and administrative areas. Due to the use of different datums and projections, the methods of coordinate conversion between these systems also vary. This can lead to small or sometimes significant differences in the coordinates of the same geographic location.

In recent years, the forestry industry has been increasingly integrated into geospatial data analysis processes, such as mapping and remote sensing data. Processing large volumes of geospatial data usually requires powerful computing resources and efficient algorithms.

For effective forest management, it is necessary to take into account a variety of data on the state of forest resources, such as data on species distribution, health status, forest cover dynamics, etc. Large volumes of this data require an appropriate technical infrastructure for efficient processing and analysis.

It should also be noted that effective forest management may require rapid exchange of information on the state of the forest between different stakeholders, including foresters, scientists, governments, environmental services, etc.

To overcome these limitations, it is important to improve the technological infrastructure, use specialized information systems and integrate data processing technologies to ensure the effective use of information in forestry.

One of the methods of studying the turning points of the forest boundary is the satellite images analysis. Satellite imagery provides detailed information on the state of forest cover, detecting the loss of forest areas and changes in their size. Such analysis allows us to identify areas where there are problems with the loss of forest resources.

Aerial photography is another effective means of studying the turning points of the forest boundary. Aerial photography of forest areas has provided high-quality images that have been used to analyze the forest cover structure of the forestry enterprise, identify damage and changes in the landscape. This method can also detect illegal logging and other violations of forestry legislation.

Geographic information systems are also used to study forest boundary turning points. These systems allow merging data from different sources, such as satellite images, aerial photography, existing planning and mapping materials, and others, to obtain comprehensive information on the state of the landscape and forest resources.

Assessment of differences and similarities between land plot turning points (boundary marks) obtained from land cadastre and forestry surveys can be carried out by visual comparison of polygons using geographic information systems. This allows quick identification of obvious discrepancies in the contours and shapes of the polygons. An example is shown in figure 3.

Для більш інформативної оцінки відмінностей можна порівняння площі полігонів. Differences in area may indicate errors in measurement or data interpretation. The area measurement method and the polygon intersection method were used to analyse the difference in area between the land cadastre and forest management datasets.

The study used only a part of the forestry territory for which spatial information was available. According to the land cadastre, the area of the study is 7804.2978 hectares. According to the forest plantation plan, the area is 7840.4335 hectares, and according to the GIS overlay operation, the overlapping area of the plots is 7794.4820 hectares.

The spatial data of the land cadastre coincide by 99.87% with the data of the forest plantation plan. And, accordingly, the spatial data of forest plantations is 99.41%. Data integration should lead to the fact that not only the area (size) should be exactly the same, but also the spatial cadastral plan and the plantation plan should occupy the same space. And not differ by 0.13% and 0.39% of the area, respectively.

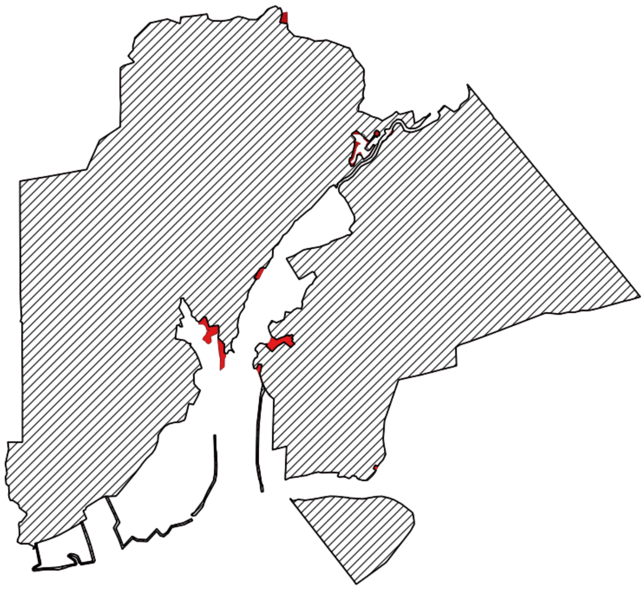

Fig. 3. Difference between the spatial location of land plots according to the land cadastre and the forestry plan

Figure 3 shows in red the fragments where the land plots do not completely coincide with the land cadastral information and the plan of forest plantations. The investigated parts of the plot boundaries (marked in red in figure 3) were not further analyzed, as the nature of the discrepancy is not related to the technical characteristics of geodetic objects: coordinate system, method of coordinating turning points or data processing. As noted above, forestry objects are characterized by some uncertainty regarding their boundaries. This is due to changes in legislation and business entities.

The next measure of difference was calculated using GIS Hausdorff distances. The Hausdorff distance provides a quantitative measure of the similarity or dissimilarity between two polygons, which is useful in analyzing geodetic data. The Hausdorff distance between two sets of points A and B is defined as the maximum distance by which any point in A can be removed from the nearest point in B, and vice versa. This means that it takes into account the largest of all minimum distances between points in the two sets.

Estimating the variations between the corresponding points and lines of two polygons. Calculating the average or maximum distance between points or lines helped to determine the degree of their variability.

We examined 333 points in each dataset. At the first stage, we used GIS to ensure that the points in both spatial datasets matched each other in terms of order or identification. The points were ordered in such a way that the corresponding points represented the same locations (boundary markers, geodetic points) on both polygons (land plots).

The average distance between the coordinates of the points is 1.32 m. Although in fact these are the same points and in the same coordinate system, i.e. there should be no discrepancy (the distance should be 0 m). The standard error is 0.02 m, the median is 1.24 m, and the mode is 1.21 m. In general, this information indicates that the measured distances have a fairly consistent and predictable distribution with little variation. The mean distance is slightly higher than the median and mode, which may indicate that there are some larger measured distances that slightly increase the mean value. The minimum distance is 0.19 m and the maximum is 2.48 m. The small variability and large average distance indicates the presence of a systematic gross error in either the geodetic survey or the parameters of the conversion of coordinates from one system to another.

The next method of quantifying differences in spatial data is to calculate the root mean square error of coordinate increments. The difference in coordinates for the same geodetic points in different geodetic surveys should be equal to 0. The abscissa root mean square error is 0.94 m, and the ordinate is 1.97 m. A smaller value of the abscissa error indicates a higher accuracy of coordinate determination in the

X-axis direction (east-west direction) compared to the accuracy in the Y-axis direction (north-south direction).
To evaluate the accuracy and reliability of the results, you can calculate the standard deviation of the shifts for each coordinate. This step allows us to quantify the vector shift in the coordinates of land parcels in different datasets. The obtained values are used to analyze the differences in spatial data and to make appropriate adjustments when integrating them. The shift vector was calculated for each pair of points (333 pairs). It was found that 67.87% (226 pairs of points) have the same direction of displacement. This indicates the systemic nature of geodetic information distortion. The reason for this may be the use of different coordinate systems described above. The correlation between the modulus and direction of the shift vector of points pairs is 0.28, which indicates a rather weak relationship. The mixing of land plot centroids also did not reveal any patterns.
It would have been possible to prevent such a discrepancy in spatial data if the achievements of geoinformation technologies had been widely used at the initial stages of forming the state cadastre database: exchange files, a single coordinate system, remote sensing data, etc.
One of the ways to control and verify land cadastre and forestry planning data is to use open spatial data. Given that forest resources are open in space, most of the issues related to monitoring their condition and creating a dynamic and up-to-date database can be solved today by means of remote sensing (RSD), which is an essential source of input data for geographic information systems (GIS). The processes of obtaining remote sensing data and the capabilities of geographic information software are developing dynamically, which affects the quality of the information received and its processing; efficiency and its interpretation expands the possibilities of its availability and reliability. However, the level of specialist awareness in forestry enterprises regarding the use of these technologies is currently insufficient.
Today, one of the most effective, convenient and cost-effective methods of remote monitoring is the use of satellite data. The existing services EO Browser, Planet Explorer, Sentinel Playground (Sentinel Hub), Copernicus Open Access Hub provide free access to viewing, analyzing and downloading space observation data from medium and high resolution satellites.
The use of open remote sensing data makes it possible to conduct mapping operations, monitor forest condition, assess timber stocks, monitor changes in forest cover, assess the ecological state, plan forest management, forecast forest fires, promptly record illegal logging, etc.
One of the ways to solve the problem of low culture of using open remote sensing data is to conduct special training courses, engage relevant specialists, and integrate scientific and technical developments into traditional forest management methods.

Conclusions and proposals

Thus, the integration of land cadastre and forest records is a key step towards sustainable natural resource management, leading to social, economic and environmental benefits for society. In general, while there are certain advantages of integrating land cadastre and forest records, potential disadvantages and challenges should also be carefully considered before deciding to integrate them.
The reasons for the discrepancies in spatial data are the lack of perfect geodetic tools and the methodology of cadastre maintenance at the initial stages of land reform.
The study of spatial data from different related sectors of the economy is an important factor for decision-making on forest management and conservation. The results of such studies can be used to integrate data, set restrictions on landscape use and develop sustainable forestry.
Comprehensive measures to solve the above problems are proposed: strengthening the legislative framework, transition to a unified state coordinate system, improvement of technological infrastructure, ensuring data accessibility to the public, development of interagency cooperation, professional development of relevant specialists and integration of information systems. These approaches will help to achieve efficient forest management.

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