# Geodata Processing Methodology on GIS Platforms when Creating Spatial Development Plans of Territorial Communities: Case of Ukraine

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## ABSTRACT

The article offers a detailed expert analysis on handling spatial information of territorial communities amid administrative and land reforms. The authors have developed multiple methodological recommendations and justified the selection of efficient tools for contemporary GIS systems. It also delves into the essence of GIS technologies, the nuances of working with geodata, and provides a concise overview of the world's most prevalent GIS platforms. The paper outlines an algorithm for developing a land resource management strategy for communities in preparation for land reform. Through the analysis and visualization of spatial data, the paper highlights enhancements in economic valuation and the ability to pinpoint risks and infringements of property rights.

The study selects the Cadastr.UA system on the Soft.Farm platform, developed by Ukrainian company Quart Soft, as a notably user-friendly and promising GIS for land accounting and auditing. Research based on the experimental practical application of most functions of GIS Cadastr.UA indicates that this system aligns well with the needs for land plot accounting and auditing within the framework of Ukraine's Public cadastral map. The paper details the practical implementation of GIS technologies, using Cadastr.UA as a case study, and illustrates how to employ selected GIS tools in various scenarios and tasks.

**Keywords**: Territorial communities, Google Earth, GIS, geodata, Cadastr.UA, State Land Cadaster, land plots

## 1. INTRODUCTION

The administrative-territorial reform in Ukraine is among the most successful in Central and Eastern Europe, characterized by a substantial proportion of amalgamations based on the voluntary agreements of local authorities [1]. The primary objective of this reform in Ukraine is to empower local self-government bodies with more extensive authority (decentralization) and to modify the administrative-territorial structure [2]. Initiated in stages from 2015 to 2020, the implementation of this reform continues to this day across all Ukraine-controlled territories. Running concurrently, the land reform is anticipated to significantly impact the economy shortly. The connection between these reforms is strong since the principal resource of territorial communities, foundational to local production and activities, is the land. Land use and land cover change (LUCC) analysis in a given socio-economic region involves examining human interaction with land cover, based on the earth's surface's biophysical properties. Inherently interdisciplinary, LUCC research incorporates methodical approaches and methods from diverse fields, including economics, sociology, geography, geographic information systems (GIS), demography, and more.

In line with several legislative acts concerning land use planning and amendments to urban planning documentation, among others [3, 4], local self-government bodies are tasked with developing comprehensive spatial development plans for territories within the newly established territorial communities (TC). These processes have commenced in most TCs, yet only a minority have completed their spatial development plans. These comprehensive plans typically entail planning decisions for the future utilization of the entire TC territory, including:

1) The general plan of the settlement (city) – the TC's administrative center.
2) General plans of settlements and detailed plans of areas within the TC.
3) Boundaries of functional zones of the TC with development and landscape organization requirements.

The content of these comprehensive plans encompasses substantial volumes of specialized information, accumulated over time and now requiring consolidation, updating, and augmentation. These processes continue even under martial law in the country. Contrarily, most communities recognize their role in stabilizing the economy through existing resources, engaging in earnest development planning through discussion and diligent work. The current imperative is to audit and inventory all community resources: land, water, forests, and subsoil. This will uncover the community's potential and identify new revenue sources [5].

Work [6] presents empirical evidence of the impact of area, structure, and changes in land cover on the tax revenues of local budgets within TCs. The authors employed a mix of geospatial and econometric methods to examine the effect of land cover on these tax revenues. Their findings underscore the significance of land cover structure in shaping the financial potential of local self-governance, suggesting that local governments can boost tax revenues through effective land use management.

Many TCs currently lack sufficient intellectual resources to undertake tasks such as data collection, updating, and digitization for inclusion in these plans. A comprehensive plan is a compilation of specific data types, encompassing several sections, including:

1) Graphic (cartographic) materials from topographical and geodetic works across settlements at scales of 1:10,000 and 1:2,000 for all settlements;
2) General plans of settlements with zoning plans;
3) Detailed plans for specific areas;
4) Sanitary and ecological examination sections;
5) Engineering and technical measures for civil population protection during peace and special periods;
6) Land management aspects (including land inventory and setting boundaries of settlements), and other sections.

Each section has unique development specifics, approval procedures. To meet all requirements and achieve desired outcomes, TCs and working groups resort to paid digital survey tools and specialized information systems for processing geographical information, primarily GIS technologies.

The aim of this study is to conduct a thorough analysis of data processing capabilities and technologies in modern geoinformation systems, selecting methods for use in the spatial development planning of territorial communities.

The research focuses on technologies for working with geodata within geoinformation systems, specifically for auditing land resources of territorial communities. The subject of study encompasses geoinformation systems, their tools, functionalities, and methods for working with interactive maps.

The research employs a variety of methods: analytical, comparative, empirical, case method, and geodata visualization on interactive maps.

Subsequent sections showcase original approaches to the complex analysis and visualization of spatial data, as applied in the audit and management of land resources of TC and in developing practical application algorithms for GIS technologies and systems.

## 2. STATE OF ART

The United Nations has established the Sustainable Development Goals (SDGs) for 2030 as a global call to end poverty, protect the planet, and ensure peace and prosperity for all people [7]. Within the framework of SDGs, GIS technologies have played a critical role in addressing complex challenges, creating a structure for geographic design [8]. In 2019, Jack Dangermond, founder and president of Esri, suggested five sequential steps that the global GIS developer community could potentially undertake to achieve the SDGs [9,10]:

1) Collect information;
2) Visualize data;
3) Conduct spatial analysis;
4) Create geographic plans;
5) Monitor the implementation of development programs.

The first step focuses on improving decision-making by gathering, organizing, and managing various data. In the second phase, Esri, in collaboration with the UN, developed the Data Hub to visually represent the ongoing work on SDGs. The third step aids in identifying cause-and-effect relationships in specific phenomena by overlaying different maps and assessing the connections between them. The fourth step involves formulating a range of decisions about what and where actions should be taken. During the fifth step, users can fallow: examine connections, complexity, and patterns; outline various alternatives, and assess their benefits and risks to make the most informed decision [12]. Notably, Dangermond's fifth step highlights the importance of linking technology with policy at both global and community levels.

GIS are platforms that create, manage, visualize, and analyze various types of geographic data. GIS integrates location data (where objects are located) with all types of descriptive information (what these objects represent), linking data with maps. This integration forms the basis for mapping and analysis, used in scientific research and practically in all industries [12].

Interactive digital maps, created through computer programs, enable visualization and analysis of spatial data. These maps can be in various formats: vector, raster, 3D, or web maps. Interactive maps allow users to interact with spatial data, altering scale, orientation, filters, layers, and other parameters. They also provide additional information about map features, such as names, attributes, history, etc.

In terms of data types in electronic mapping, vector and raster data are predominant. Vector data depicts geometric objects (points, lines, polygons) using coordinates, while raster data represents spatial information via a grid of pixels or cells.

There is a significant number of special information systems for working with interactive maps. The most complete classification of GIS is given in works [12-13]. The class of systems by purpose takes into account the goals of using GIS. Thematic orientation takes into account the scope of the problem area. By territorial coverage - depending on the size of the worked territory [14].

GIS integrates many different types of data layers through spatial arrangement. Most of the data has a geographic component.

GIS data includes snapshots, discrete objects, and base maps associated with sheets and tables. The Esri company and its products are a recognized world leader in the software market for geographic information systems, geoanalytics, and mapping [9]. The main software product of Esri is the geographic information system ArcGIS [10]. ArcGIS is a powerful GIS technology that provides tools for collecting, viewing, editing, managing, analyzing, and sharing data in a geospatial context. It includes access to thousands of carefully selected data sets and maps that can be studied and used to analyze and gain valuable new knowledge. ArcGIS can be used in the cloud, on mobile devices, and on desktop computers to create maps, applications, dashboards, 3D scenes and models, and data science notebooks.

File formats for storing and exchanging geographic data are special standards that define how to store, structure, and transfer geodata between different programs and systems. Some of the most common geodata file formats are Esri Shapefile, GeoJSON (JavaScript Object Notation), KML (Keyhole Markup Language), GeoTIFF (Tagged Image File Format), and NetCDF. Each of these formats has its advantages and disadvantages, depending on the type, scope and purpose of using geodata. Depending on the tasks, other file formats can be used.

One way to improve image quality is to use basemap layers, each representing a specific type of data, such as terrain, climate, population, and so on. Layers can be layered on top of each other to create a complex image. Layers with different purposes are shown schematically in figure 1 [15].

Custom apps can create maps that dynamically display data as it's updated, so it's important to refer to the most recent data when making decisions.

The main layer is the so-called GIS base map (classical satellite map). Any layer can be used as the base layer. Base map layers provide a structure where dynamic operational information is displayed. Because basemap layers are relatively static and often don't change, their mapping can be calculated once and then reused many times. Different GIS use different formats and standards for storing and displaying electronic map layers.

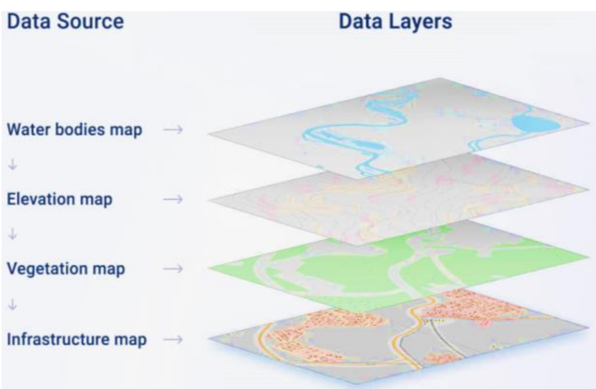


Figure 1 – Example of content layers of an interactive map [15]

In map development, maintaining high image quality without compromising performance is a key consideration. Basemap layers, representing different data types such as terrain, climate, or population, can be overlaid to create a comprehensive image. The choice of GIS software should align with user needs and interests, as different GIS platforms (like ArcGIS, QGIS, Google Maps, OpenStreetMap) offer varied layers and functionalities. ArcGIS uses the Shapefile format to store vector data, and QGIS uses the GeoJSON format. Also, different GIS can have a different number and set of layers that are available to the user. For example, Google Maps GIS has layers for the road network, satellite images, terrain, and 3D building models, while OpenStreetMap GIS has layers for the road network, public transportation, cycling routes, and historical landmarks. Users should choose the GIS that best suits their needs and interests.

## 3. THE MAIN ASPECTS OF THE USE OF GIS IN THE PROCESSING OF GEODATA FOR TERRITORIAL COMMUNITIES

In the context of tasks for territorial communities and comprehensive spatial development plans, the use of GIS is viewed from four perspectives:

1) Product: This refers to a specific information system designed for collecting, analyzing, storing, outputting, and distributing geodata and associated information. It serves as a comprehensive tool for handling various aspects of geospatial data.
2) Application Software: GIS includes application software equipped with a unique set of tools and special functions tailored for geospatial analysis and data management.
3) Data Source or Receiver: GIS can act as both a source and a receiver of data, playing a pivotal role in the gathering and dissemination of geospatial information. It serves as a central platform for data exchange and integration.
4) Analysis and Decision-Making Environment: GIS provides a staged environment for data processing, which involves data collection and processing, data editing, analysis, visualization of results using chosen methods, and decision-making [16-17].

This structured approach enhances the efficiency and effectiveness of spatial planning and decision-making processes. A team of researchers from the Center for Development Research (ZEF), University of Bonn, Germany, and the Central Island Agricultural Research Institute, Port Blair, India, identified eight primary applications of GIS in local self-government activities: recording, storing, supporting, analyzing, manipulating, displaying, and outputting geocoded information [18].

Considering the micro-level of territorial communities, GIS offers prospects for not only creating and regularly updating relevant maps but also for addressing other challenges. These include extracting geospatial data from geographical objects, integrating various databases (geographical, economic, medical, infrastructural, socio-demographic, etc.), visualizing geospatial statistical analytics by combining different data sources (surveys, statistics, raster images), and interfacing with artificial intelligence systems [19], among others.

### Selection of GIS tools and methods of use in the audit of land resources of territorial communities

In line with the objectives and tasks of forming spatial development plans for territorial communities, it is essential to devise an effective algorithm for conducting audits of land plots and organizing all data using specialized GIS. According to the Law [20], "A land plot is a part of the earth's surface with established boundaries, a specific location, and defined rights." The attributes of a land plot are illustrated in Figure 2. Attributes of a land plot include its boundary, area, cadastral number, and designated purpose. Additionally, legal and qualitative attributes such as soil cover, slope exposure, configuration, and climatic conditions are also determined. In the digital realm, each land plot must be identifiable by its cadastral number. According to the State Land Cadaster (SLC), a cadastral number is a unique sequence of digits and characters assigned to a land plot upon state registration and retained throughout its existence, ensuring individual identification across the entire territory of Ukraine [19]. Interaction with the state geo-information system, the Public Cadastral Map of Ukraine (PCMU), is based on this law. The PCMU contains data on all plots included in Ukraine's land cadaster [21]. Since its inception on January 1, 2013, the PCMU has marked a significant achievement in the realm of land relations. This computerized cadastral system has streamlined land transactions and bolstered land ownership guarantees. However, during the martial law period in Ukraine (initiated on 24.02.2022), the PCMU has been temporarily restricted from open access but remains operational for registered users.


Figure 2 – Set of mandatory attributes of land plots

Continuously updated with new data, the PCMU plays a critical role in facilitating administrative-territorial and land reforms. Its primary functions include:

1) Verifying the presence of a land plot in the State Land Cadaster.
2) Detecting errors and discrepancies in the representation of land plots.
3) Identifying plots without a cadastral number and processing requests for assignment (especially for plots with a state act prior to 2004).
4) Issuing official SLC certificates.

If a plot is listed in the SLC, it will appear on the public map, along with details such as cadastral number, ownership form, purpose code, and plot size (in hectares). Research on the content and quality of information in the cadaster revealed numerous errors and inaccuracies, indicating a need for significant improvements in its structure, legal and organizational foundations, and information processes [22]. Common errors include mismatches in the cadastral number searches, discrepancies in plot configurations, or boundary overlaps with other plots. Incorrect plot locations and overlaps with water bodies or roads are also noted. All these errors necessitate identification and correction through electronic applications to the relevant State Geocadaster bodies.

In the process of developing comprehensive plans, community resources such as land, forests, water, and minerals are inventoried. This inventory is essential for their effective and rational utilization. Reviewing the development strategies of urban and rural TCs of varying sizes and geographic locations reveals a focus on investment attractiveness, territorial development, improvement of citizens' living conditions, environmental enhancement, and resource provisioning. To achieve these goals and prepare for market conditions, communities are advised to follow a specific action algorithm developed by the authors. The solution to this complex task is broken down into a series of sequential, purposeful steps, schematically represented in a block diagram (Figure 3).

Each stage (step) of utilizing GIS in territorial communities involves a specific amount of time and is marked by intermediate productive activities, as represented by subroutine blocks in the flowchart. The ultimate goal is to complete the reform process and transition to the planned (sustainable) development of the community. Studies of various communities' experiences show that the initial stage typically involves working with documents and information about land plots, incorporating GIS technologies [6]. This initial phase often faces a common challenge: the disparity between programs and the lack of timely access to necessary information. Data sources include the Public Cadastral Map of Ukraine (PCMU), the State Land Cadaster website, paper documents verified with these systems, and Excel documents.

Creating interim databases as Excel lists does not solve the core issue, as the final document storage should be in the PCMU and SLC. Therefore, the effective application of specialized GIS technologies involves data transfer in specialized formats and the selection of specific software for working with land data. Given that PCMU is not only indefinitely closed but also has significant deficiencies in its property database, each community is exploring alternative/additional tools.

For GIS technology software, two systems were considered: Google Earth and Cadastr.UA, developed on the Soft.Farm platform. Google Earth offers capabilities such as satellite imagery and geographic information systems [23]. It stores millions of satellite images of every Earth area in its global database, allowing users to view a specific locality in its real form. Google Earth tools enable tasks such as connecting detailed information about settlements and water bodies, placing custom markers, paths, and outlining areas on an interactive map, with options to set line color, captions, and descriptions.

Cadastr.UA, gaining significant popularity in Ukraine and becoming a bestseller among similar products in 2021 [24], is favored for being developed on the Soft.Farm platform, widely used by a large number of agricultural enterprises for managing production processes in precision farming [25]. Its geo-information tools were successfully utilized in creating a regional map of water bodies in the Poltava region [26].

Cadastr.UA fulfills all functions necessary for implementing land reform stages, as per the Land Law. Its main features:

1) Directly working with land plots on an electronic map: outlining contours, measuring area, attaching files.
2) Using a search bar for plots based on parameters like cadastral number, KOATUU code, geographical coordinates, or known geographical names.
3) Obtaining extracts from various registers including data from PCMU, the State Register of Property Rights, SLC, etc.
4) Separately storing search history and results.

5) Downloading and saving data in various formats: tables (xlsx), coordinates (kml, geojson), documents (pdf).
6) Convenient data filtering with map-displayed results.
7) Performing data analytics based on various criteria.

Cadastr.UA is essential not only for land managers but also for farmers, notaries, lawyers, and other professionals. Its importance for dozens of territorial communities of different sizes and types is increasingly recognized.

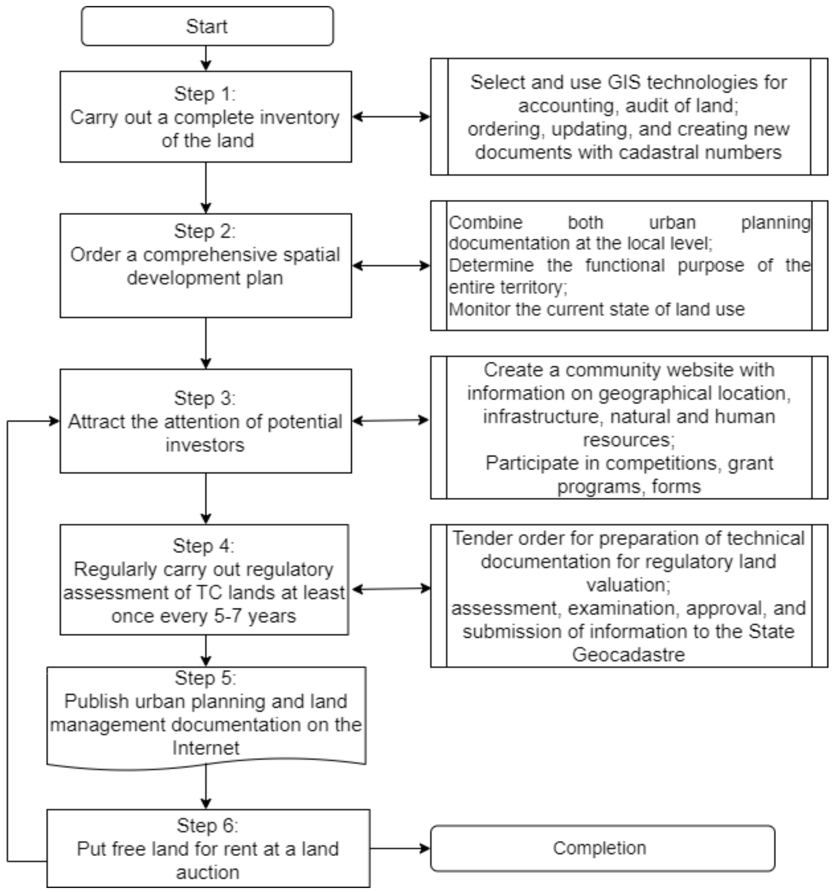


Figure 3 – Algorithm of actions for preparation for the land market in each TC

PSAU has established collaborations with many territorial communities in the Poltava region, providing consultations on system usage rules and integrating elements into the educational process in some disciplines [27].
To begin using the system, registration and personal account creation are required. The ultimate aim of the experimental part was to develop practical recommendations for effectively using GIS in territorial communities to meet their urgent needs.

**Applied Aspects of Working with Geozones on an Electronic Map and Data Processing Using GIS Cadastr.UA**
The use of the initial (starter) set of GIS technology tools in the Cadastr.UA uses data from the publicly accessible State Land Cadaster (SLC) and PCMU registers. Some data, such as the state register of real property rights, are restricted and accessible only after identity verification.
For example, methods for searching geozones are shown based on criteria like cadastral numbers and SCOATSU-codes, as well as capabilities for geofence searching using built-in tools followed by mapping the cadastral plot layer. An arbitrary location was chosen by pointing on the map at Tereshkivska TC in Poltava District. The first task was to analyze several plots in the selected TC for the presence of cadastral numbers and to compile a list of these plots. The contour of the experimental geozone on the map is outlined and linked to the mouse pointer, as shown in the example in Figure 4.

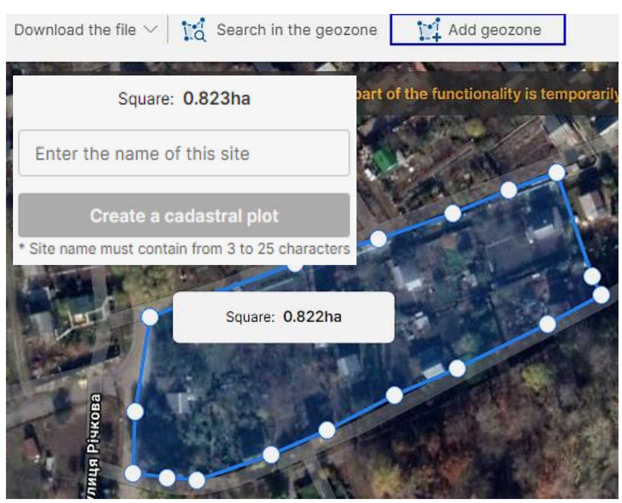


Figure 4. Plotting the first geozone in Cadastr.UA

The next step involves automatically dividing the circled geozone into cadastral plots. Within the outlined area, plot contours will be automatically highlighted based on their area and contours as recorded in the existing cadastral numbers. A list of all plots with numbers and other analytical data will appear in the program window (Figure 5), which will be saved. Multiple lists like this can be created and viewed sequentially.

Clicking on a plot on the map provides detailed information about the selected object according to the PCMU: cadastral number, form of ownership, designated purpose by code, geographical coordinates. For instance, Figure 6 highlights a 0.0851 ha plot designated for individual gardening in private ownership.

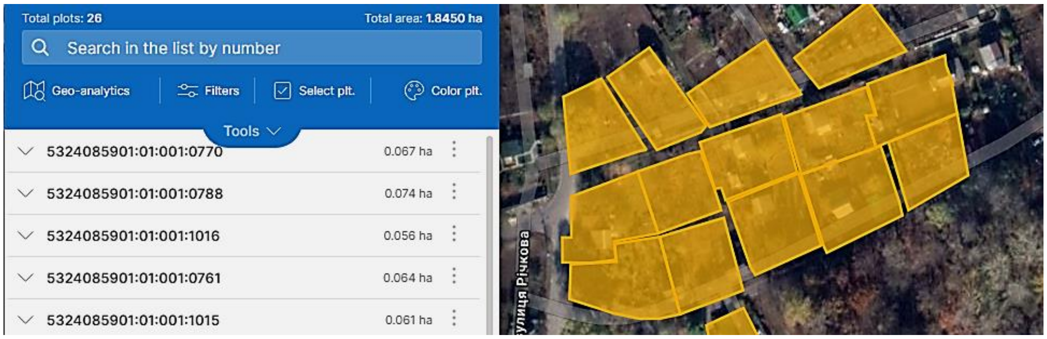


Figure 5. Automatic division of the geofence area into cadastral plots in the Cadstr.UA system

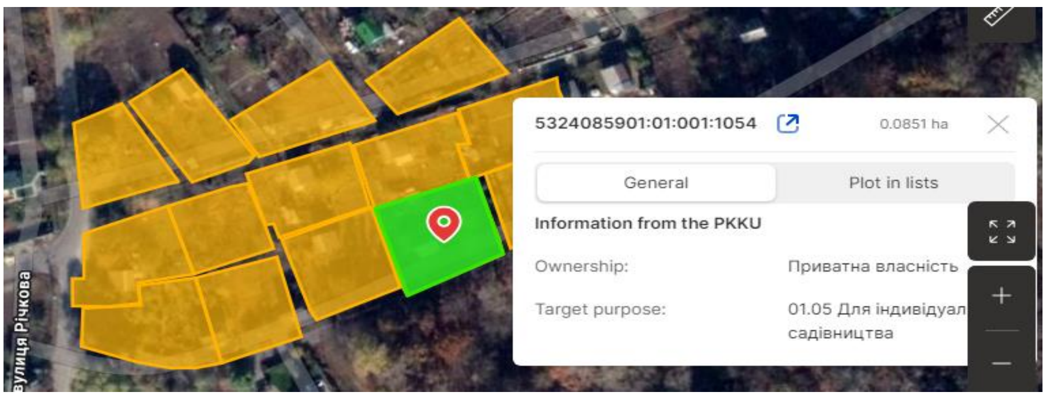


Figure 6. Data on a separate section from the list when selected on the map

In the data window for the selected plot, a special SCOATSU-code is highlighted - part of the State Classifier of Objects of the Administrative-Territorial System of Ukraine (SCOATSU), which is a component of the unified system for classification and coding of technical-economic and social information.

By conducting such analysis with many plots in the community, a completed map with clear contours of plots is obtained. This map can later be used to identify plots that lack numbers, are not used as intended, or encroach on additional lands.

As a modern GIS, Cadastr.UA works with files in KLM format. This format is based on the XML standard and uses a tag-based structure with nested elements and attributes.

**Audit Methods and Identification of Problem Areas**

During data processing in Cadastr.UA, users can retrieve data on plots according to state registers, measure areas of plots, verify existing documents, upload changes about the status of plots, perform searches from a list, and conduct geoanalytics.

A challenge in plot accounting is identifying discrepancies in data. For instance, when creating a geozone in Tereshkivska community, a list of cadastral plots with overlaps was discovered. Cadastr.UA indicates such overlaps. In legal practice, overlapping plots are controversial issues, and court proceedings are the only way to establish rightful property rights. After a specific procedure, these plots are demarcated, and changes must be entered into the PCMU. The system provides detailed information about overlapping plots based on their visualization in the PCMU (Figure 7).

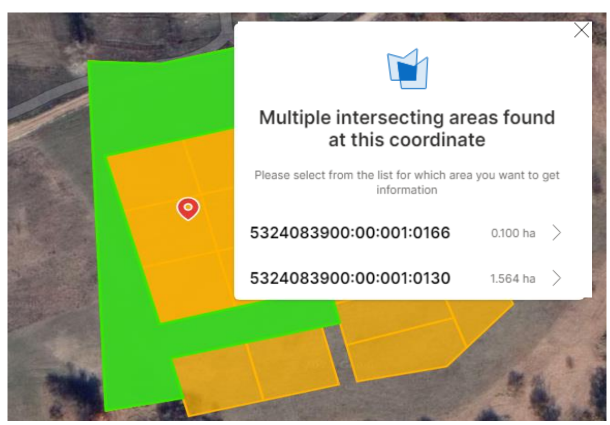


Figure 7. Visual confirmation of overlapping cadastral plots

The system features a robust tool for tracking changes in plot statuses. Cadastr.UA enables data analytics by comparing data lists over a certain period, as the accounting process is dynamic.
Results allow for review of changes in files over a period and downloading of Excel files.
The use of analytics is a distinctive feature of Cadastr.UA, setting it apart from other applications. The system automatically identifies plots that have undergone changes during the specified period.
Special attention is also given to identifying unaccounted plots. For example, Figure 8 shows plots without cadastral numbers in Machukhivska community against the background of cadastral plots and cultivated fields.
Data comparison enables precise measurement of differences and calculation of potential revenue losses to the community budget. As these cases are not isolated, organizing data in most communities is time-consuming.

Figure 8. Outline of unaccounted for plots on which agrotechnical works are carried out according to satellite data

Using GIS like Cadastr.UA is essential. GIS allows for analyzing spatial data, detecting land law violations, assessing risks and benefits of various land use options, and planning land use optimization and efficiency enhancement.
Economic efficiency formulas for using GIS in land plot audits can be derived by comparing costs and benefits associated with GIS use. Costs may include purchase, installation, maintenance, and GIS updating expenses, plus staff salaries. Revenues may consist of time and resource savings, improved audit quality and accuracy, reduced risks and errors, and enhanced audit firm reputation and competitiveness. Economic efficiency of GIS in land plot audits can be assessed using metrics like Net Present Value (NPV), Profitability Index (PI), payback period, etc.
Further research will be directed to the development of the technology of creating individual layers in the Cadastr.UA system based on current orthophoto plans of the territory of communities using drones, and recognizing the land's cover based on artificial intelligence [28].

## 4. CONCLUSIONS

Based on an analysis of the activities of the TCs in terms of preparing comprehensive spatial development plans, the provision of relevant information, and the timelines for completing assigned tasks, several methodological recommendations have been developed. The content of such plans, as mandated by current legislation, is based on numerous types of spatial data. These recommendations substantiate the choice of effective modern GIS system tools to assist in fulfilling the actual tasks of the TCs. The prospective development plan is presented in a block diagram format, detailing the content and sequence of work at each stage.
Comparative characteristics of GIS technologies available to users show a similarity in the basic toolkit for creating interactive maps, processing geodata, and performing imports and exports of data files in relevant formats (KLM and others), as well as data storage on local and virtual drives, and distinct means of data presentation and display. The Kadastr.UA system has been chosen as one of the most convenient and promising GIS for addressing tasks related to land accounting and auditing.
Experimental and practical research using most functions of GIS Cadastr.UA demonstrated that this system meets the needs for land plot accounting and auditing within the context of Ukraine's cadastral map. It is an effective tool for carrying out all necessary tasks. This GIS enables specialists to interactively measure input data about land plots on an electronic map - areas, boundaries, total perimeter, purpose, cadastral number, and compare all this with the data in the PCMU. Additionally, the GIS has an analytics module that enables automated analysis of changes in plot data over a specified period.
The rationale for the economic efficiency of using GIS for land plot audits lies in the technology's ability to provide precise and current information about the status, location, value, and legal status of land resources. Using GIS for land plot audits can reduce the costs of conducting surveys, shorten the time for processing and providing information, improve the quality and reliability of audit conclusions, and increase transparency and control over land transactions.

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