

ISSN 2518-7325 (Online), ISSN 2306-1677 (Print)
Land Management, Cadastre and Land Monitoring
Received: 10.09.2026; Accepted: 23.09.2026; Published: 30.12.2026;
<http://dx.doi.org/10.31548/zemleustriy2026.04.10>

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UDC 528.94:332.334(477.84)

CARTOGRAPHIC MODELING OF LAND OWNERSHIP AND USE INDICATORS BY HOUSEHOLDS WITHIN TERRITORIAL COMMUNITIES OF TERNOPIL OBLAST

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Abstract. *The article substantiates the relevance of implementing geographic information technologies for land resource management of territorial communities under the conditions of power decentralization in Ukraine. The research aims to provide a theoretical and methodological substantiation and practical implementation of approaches to the comprehensive cartographic modeling of land ownership and use indicators by households within the territorial communities of Ternopil Oblast. The methodological framework of the study is based on a systems approach utilizing statistical analysis, mathematical-cartographic modeling, and GIS*

technologies within the ArcMap environment. The key finding of the study is the development of an original cartographic model that integrates fragmented cadastral, demographic, and statistical data, visualizing the status of household land plots in the region (employing the methods of linear signs, choropleth maps, cartograms, and numerical indices). A pronounced mosaic pattern in the distribution of indicators without distinct zonal differentiation was revealed, and a decrease in the average size of land plots around large urbanized centers due to suburbanization processes was identified. The scientific novelty of the study lies in developing a methodology for fine-scale mapping of household land plots across the entire scope of the region's territorial communities, which allows for the simultaneous assessment of total land area, the number of households, and administrative-territorial structure parameters. The practical significance of the results consists in creating an effective analytical decision-support tool for local government authorities and land management services to optimize land taxation, audit land resources, and plan the spatial development of communities.

Keywords: *cartographic modeling, territorial communities, households, land management, ArcMap, Ternopil Oblast, land monitoring.*

Relevance

The reform of the land relations system in Ukraine and the decentralization processes impose new requirements on the quality, detail, and visualization of spatial data used for monitoring and managing land potential at regional and local levels. Households are a baseline element in the formation of the land fund and the socio-economic development of territorial communities, especially in agrarian-oriented regions. Efficient accounting, analysis, and strategic planning of the use of such lands require a shift away from traditional tabular forms of statistical documentation in favor of methods of comprehensive geospatial modeling.

In the context of geospatial analysis and land monitoring, a household is considered not only as a socio-demographic unit (a group of individuals living together and managing a common economy) but also as a primary economic and

legal subject of land use. The specificity of a household as a subject of land relations lies in the fact that it accumulates land tracts of various target purposes (for the construction and maintenance of a residential building, personal subsistence farming, gardening, etc.) held by the members of this household under the rights of private ownership (land tenure) or use (lease).

For Ternopil Oblast, which is characterized by a high density of rural population, an extensive network of settlements, and intensive personal subsistence farming, the issues of rational land plot use by households are critically important. Significant territorial differentiation in plot sizes, land fragmentation processes driven by leasing, and the need to optimize land taxation require the creation of integrated geospatial models that reflect the actual status of land ownership and use at the regional scale.

In this context, cartographic modeling of land fund transformation indicators by households within the territorial communities (TCs) of Ternopil Oblast serves as an effective tool for systems analysis. The application of modern geographic information systems (GIS) technologies allows for the transformation of fragmented cadastral, statistical, and administrative-territorial data into cartographic models. These models enable a simultaneous assessment of total land areas, the number of households, and average land plot sizes in direct relation to the number of settlements within each community. This provides land management authorities and local governments with an effective analytical toolkit for land monitoring, identifying spatial disparities, and justifying sustainable territorial development strategies.

Thus, the development and application of cartographic modeling for land plot indicators by households directly address contemporary demands in land management science and the practical needs of cadastral operations and land monitoring, highlighting the theoretical and practical significance of this study for ensuring the balanced spatial development of territorial communities in Ternopil region.

Analysis of recent research and publications

The issues of theoretical and methodological support for land management, state land cadastre administration, and land monitoring at various hierarchical levels of management are in the focus of attention of many leading Ukrainian and foreign scientists.

A significant contribution to the study of the transformation of land relations, rational land use, and the assessment of land potential under the conditions of decentralization and full-scale war has been made by domestic scientists Y. Dorosh, O. Dorosh, S. Ibatullin, I. Kovalchuk, A. Martyn, I. Novakovska, L. Novakovskyi, O. Sakal, A. Tretiak, and others [1-6].

Emphasis is placed on the need to strengthen state control over land use, and the initiative to modernize the procedures and content of land monitoring is supported. [7]. Ways to increase the efficiency of state authorities' activities aimed at improving the entire land use management system are also substantiated.

In study [8], a comprehensive scientific and practical concept of the legal status of lands of destroyed settlements is proposed. The authors identified the signs of these territories losing their capacity for settlement restoration, developed a clear legal mechanism for their land management transformation, and substantiated the economic and organizational foundations of their future use.

The problematic issues of applying GIS, Earth remote sensing technologies, and implementing methods of geospatial and cartographic modeling to address tasks of spatial planning and territory monitoring are highlighted in numerous works.

Publications [9-14] are devoted to the theoretical and applied foundations of using cartographic modeling for strategic planning of territories. Cartographic models are presented as an analytical tool for integrating spatial data and substantiating management decisions. It is proposed to consider modeling as a cross-cutting element of the strategic process, and its functions at various stages of planning are analyzed. Emphasis is placed on the scenario approach, which combines spatial analysis, forecasting, and expert assessments. In conclusion, it is proven that cartographic modeling significantly increases the validity, adaptability, and efficiency of strategic management of territorial development.

In study [15], the methodology for comprehensive geospatial data collection, the integration of GIS, and Earth remote sensing (ERS) for the assessment and continuous monitoring of the state of natural systems and vulnerable landscapes is described in detail.

Research [16] demonstrates the synergy of using unmanned aerial vehicles (as an element of ERS), GNSS (Global Navigation Satellite Systems) observations, and GIS platforms. Utilizing the example of specific TCs, the work directly addresses the tasks of accurate mapping, spatial planning, and land management.

A methodological toolkit for the analysis and improvement of the land use structure of territorial communities (based on materials of Zhydachiv urban TCs) is proposed and substantiated [17]. The research is implemented through the integration of GIS technologies, cartographic modeling, and a system of environmental indicators.

In foreign scientific practice, modern approaches to the integration of cadastral data, the concept of "smart" land administration, and sustainable spatial planning have been introduced and are actively developing thanks to the works of such researchers as S. Enemark, I. Williamson, J. Zevenbergen (models of effective cadastre, sustainable development of land systems). The issues of cartographic and mathematical-cartographic modeling of spatial processes, assessment of land fragmentation, and analysis of small-contour rural land ownership, which are analogous to domestic households, are devoted to publications by European authors, in particular L. Mucsi (GIS analysis of land use), T. Noszczyk, A. Rutkowska, J. Hernik (modeling of spatial disparities of land plots in agrarian regions) [20, 21].

Despite a significant number of these thorough works, most existing research in the field of cadastre and land monitoring is oriented either towards the global macro-level (analysis of indicators for countries as a whole) or the micro-level of individual large agricultural enterprises. At the same time, the specifics of land ownership and land use of such a baseline socio-economic unit as private households, within the regional dimension of the entire set of territorial communities, remain fragmentarily studied.

To date, there are virtually no comprehensive scientific and methodological approaches to integrating and visualizing fragmented cadastral data alongside demographic and statistical parameters of the private sector (such as the number of households, total area, and average size of land plots tied to the administrative-territorial structure of TCs) using thematic mapping. The necessity of bridging this methodological gap and the requirement to create clear spatial models for agriculturally developed regions have determined the choice of the topic and the direction of this study.

The research aims to provide a theoretical and methodological substantiation and practical implementation of approaches to the cartographic modeling of land ownership and use indicators by households within the territorial communities of Ternopil Oblast to identify spatial patterns of their distribution and enhance the efficiency of regional land monitoring and management at the local level.

Materials and research methods

The informational and baseline data for the study were formed by the official statistical materials of the Main Directorate of Statistics in Ternopil region [22], forms of household accounting, and updated verified data of the communities, accumulated by the NGO "Portal "Decentralization" (demographic indicators, administrative-territorial structure, and borders of TCs as of the current period) [23].

The methodological framework of the study is based on a systems approach to the analysis of land resource potential. In the course of conducting the research and processing the baseline data, a complex of general scientific and special methods was applied, including:

- statistical and comparative-geographic methods – to group households by quantitative and qualitative indicators of land ownership and use, and to identify minimum, maximum, and average land plot areas within territorial communities;
- mathematical-cartographic modeling – for transforming tabular databases into geospatial objects and calculating derivative indices (average plot size per household);

- GIS-technology methods – for collecting, systematizing, spatial referencing, and geovisualization of the studied indicators.

The practical implementation and construction of the comprehensive cartographic model were carried out within the environment of the ArcMap geographic information system (ESRI's ArcGIS toolkit). The chosen coordinate system is UCS-2000 / Gauss-Kruger, and the map projection is the conformal transverse cylindrical (Gauss-Kruger) projection. This approach allows for minimizing cartographic distortions and maintaining the familiar appearance of the territory's contours. The indicated scale is linear, which guarantees correct rendering during the transformation (enlargement or reduction) of the map base and contributes to the convenience of practical use. The spatial referencing of statistical information was performed to the vector layer of polygon objects – the boundaries of the territorial communities of Ternopil region.

To create a clear cartographic model in ArcMap, a combination of the following classic mapping methods was applied:

- 1) the line symbols method – for spatial localization, geographic referencing, and displaying the administrative boundaries of territorial communities, ensuring clear spatial structuring of the model;
- 2) the choropleth method – to display the differentiation of the total area of land plots held in ownership and use by households of each territorial community (by dividing the dataset into 4 interval classes ranging from less than 3,000 ha to over 9,000 ha);
- 3) the diagram thematic mapping method – for spatial localization and simultaneous display of two structural indicators within each community: the total number of households (4 interval classes from less than 2,500 to over 7,000) and the number of settlements (4 interval classes from less than 10 to over 30) that comprise the territorial community;
- 4) the numerical indices method – for direct cartographic display of the calculated average land plot size per household within each specific territorial community.

Such an integrated GIS approach allowed for ensuring a high level of generalization and synthesis of heterogeneous information on a single cartographic model, which creates the foundation for a deep spatial analysis of the studied phenomenon.

Research results and their discussion

Based on the integration of statistical data from the Main Directorate of Statistics in Ternopil region and verified information from the NGO "Portal Decentralization" within the ArcMap GIS environment, a comprehensive cartographic model was constructed (Fig. 1). It reflects the spatial distribution and interrelation of four key parameters: the total area of household lands, their number, the average plot size, and the number of settlements within the territorial communities of the region.

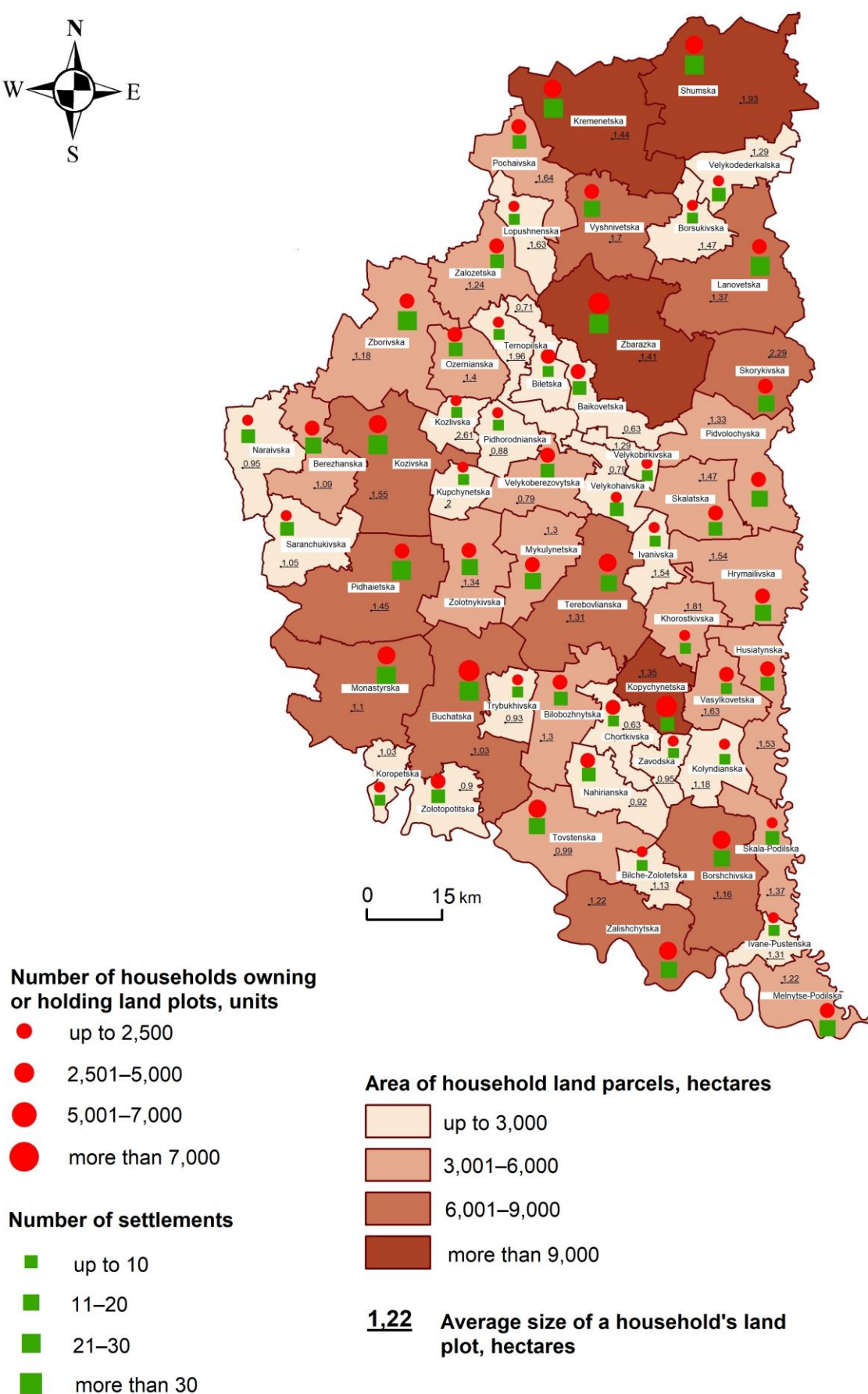


Fig. 1. Land plots of households within the territorial communities of Ternopil Oblast

Visual analysis and spatial interpretation of the developed model revealed a number of specific features across the territory of Ternopil region. First and foremost, a mosaic (dispersed) pattern in the distribution of indicators is captured, showing no clearly expressed zonal (north-south or west-east) trend. Communities with maximum and minimum parameters are more or less evenly scattered throughout the entire oblast.

Analysis of the integral indicator – the total area of land plots in household ownership and use (displayed by the choropleth method) showed that the majority of the region's territorial communities are concentrated within the middle interval classes (3,001–6,000 ha; 6,001–9,000 ha). At the same time, communities with the largest land fund (over 9,000 ha) do not form a single spatial cluster. Their localization directly correlates with two factors displayed on the map by the diagram thematic mapping method:

1. The effect of the community's scale and density of settlements. The highest values of the total area (over 9,000 ha) are characteristic of the TCs (Zbarazh, Kremenets, Shumsk), which include a significant number of settlements and, accordingly, a higher absolute number of households. In such communities, a large total land block is formed purely due to the effect of summing up thousands of small household plots. The lowest values of the total area of land plots (up to 3,000 ha) are traced in the TCs (Bilche-Zolotetska, Velyki Birky, Zavodske, Koropets), which also have the smallest number of settlements and households.

2. Local features of land share allocation (paiuvannia). In communities where high indicators of the average plot size per single household are registered (numerical indices on the map), an increase in total land areas is observed even with a medium and large number of settlements (Vyshnivets, Hrymailiv, Husiatyn, Kozova, Lopushne, Skoryky, Shumsk). This indicates an chronologically higher norm of land allocation (share size) during the reform of collective agricultural enterprises (CAEs) in these locations.

The analysis of the average land plot size deserves special attention. Cartographic modeling clearly illustrates the absence of a direct linear dependence between the number of households and the average area per household. Around large urbanized centers (the largest cities in the oblast are Ternopil and Chortkiv), a natural decrease in the average plot size is predominantly observed, alongside a high concentration of the households themselves. This is explained by the high investment attractiveness of land, the development of suburbanization processes, and the use of plots mainly for residential housing and gardening rather than for commercial agricultural production. Such a situation is inherently characteristic, in particular, of the communities adjacent to Ternopil TCs – Baikivtsi, Biletska, Velyki Hai, Pidhorodne communities, Chortkiv TCs, and its neighboring Zavodske and Nahiriianka communities. Ternopil TCs is not included in this list. Due to the relatively small area of the community and the predominant urban population, there are few households here that hold land plots in ownership and use. Conversely, in all northern and eastern peripheral communities, the average plot size is higher than the corresponding regional average (1.22 ha), indicating the preservation of the classical agricultural function of households as personal subsistence farms (PSFs).

The obtained results of cartographic modeling prove that tabular statistical reporting often levels out local spatial disparities. The synthetic GIS model demonstrates that the territorial communities of Ternopil region possess a significantly different structure of private sector land potential.

From the perspective of land monitoring and land management, the revealed mosaic nature of the indicators points to the necessity of a differentiated approach to TCs resource management. Communities with a large land area and a low average plot size (high fragmentation) require the development of land consolidation projects and the stimulation of cooperative creation. Conversely, TCs with a high average land plot size possess significant potential for the development of farming, but require rigorous monitoring regarding informal (shadow) leasing and the efficiency of land tax payments to the local budget.

Conclusions and prospects for further research

It has been proven that under the conditions of decentralization, land resource management of territorial communities requires a transition from traditional tabular forms of accounting to spatially coordinated models. The integration of official statistics, household accounting materials, and spatial parameters of the administrative-territorial structure provides a reliable baseline for a comprehensive assessment of the land potential of the private sector of the economy.

The methodology for constructing a thematic cartographic model within the ArcMap GIS environment was tested using Ternopil Oblast as a case study. The successful integration of the choropleth method (for land plot areas), the diagram thematic mapping method (for the number of households and settlements), line symbols (for TC boundaries), and numerical indices (for average plot sizes) made it possible to display the complex, multi-component structure of the household land fund on a single map.

Visual and spatial analysis of the model revealed a pronounced mosaic (dispersed) pattern in the distribution of land ownership and use indicators without clear zonal differentiation. It has been established that the maximum total land areas are present in communities with a high density of rural settlements due to a cumulative effect. At the same time, around TCs with the largest urban centers (Ternopil, Chortkiv), a regular decrease in the average plot size is observed due to suburbanization processes and changes in the functional purpose of lands.

The developed cartographic model serves as an effective decision-support tool for local government authorities and land management services. The obtained results allow for the differentiation of management approaches: in communities with high land fragmentation, it is advisable to implement land consolidation projects, whereas in communities with a large average plot size, it is necessary to enhance monitoring of land tax payment efficiency and identify latent land use reserves.

Prospects for further research lie in the development and integration of dynamic web mapping models (Web-GIS) at the level of individual territorial communities in Ternopil Oblast, with the capability of automatic real-time data updating. Another important vector for future inquiries is the study of the transformation of the

household land ownership and use structure under the influence of the agricultural land market, as well as the assessment of damage caused to the land potential of the private sector as a result of contemporary crisis and geopolitical factors in Ukraine.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process. During the preparation of this manuscript, the authors used Google Gemini for text translation, language editing, and formatting of specific bibliographic references in accordance with academic standards. Following the use of these tools, the authors thoroughly reviewed, manually verified, and edited all content to ensure accuracy and scientific rigor. The authors bear full responsibility for the content, scientific integrity, and final version of the publication.

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**КАРТОГРАФІЧНЕ МОДЕЛЮВАННЯ ПОКАЗНИКІВ ВОЛОДІННЯ
ТА КОРИСТУВАННЯ ЗЕМЕЛЬНИМИ ДІЛЯНКАМИ В РОЗРІЗІ
ДОМОГОСПОДАРСТВ ТЕРИТОРІАЛЬНИХ ГРОМАД
ТЕРНОПІЛЬСЬКОЇ ОБЛАСТІ**

***Анотація.** У статті обґрунтовано актуальність впровадження геоінформаційних технологій для управління земельними ресурсами територіальних громад в умовах децентралізації влади в Україні. Метою дослідження є теоретико-методичне обґрунтування та практична реалізація підходів до комплексного картографічного моделювання показників володіння і користування земельними ділянками в розрізі домогосподарств територіальних громад Тернопільської області. Методологічну основу роботи становить системний підхід із застосуванням статистичного аналізу, математико-картографічного моделювання та ГІС-технологій у середовищі ArcMap. Ключовим результатом дослідження є побудова авторської картографічної моделі, яка інтегрує розрізнені кадастрові й демографічно-статистичні дані та унаочнює ситуацію із земельними ділянками домогосподарств регіону (використано способи лінійних знаків, картограм, картодіаграм та числових індексів). Виявлено виражений мозаїчний характер розподілу показників без чіткої зональної диференціації та зафіксовано зменшення середнього розміру земельних ділянок навколо великих урбанізованих центрів під впливом процесів субурбанізації. Наукова новизна дослідження полягає у розробці методики дрібноконтурного картографування земельних ділянок домогосподарств у межах усієї сукупності ТГ області, що дозволяє одночасно оцінювати загальну площу земель, чисельність домогосподарств та*

параметри адміністративно-територіального устрою. Практична значущість результатів полягає у створенні для органів місцевого самоврядування та землевпорядних служб дієвого аналітичного інструментарію підтримки прийняття рішень щодо оптимізації земельного оподаткування, аудиту угідь та планування просторового розвитку громад.

Ключові слова: картографічне моделювання, територіальні громади, домогосподарства, землеустрій, ArcMap, Тернопільська область, моніторинг земель.