

Modern GIS technologies supporting land management in agricultural land consolidation

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Abstract. Ukraine has not conducted a comprehensive or systematic assessment of the effectiveness of spatial land consolidation processes, and the institutional framework supporting agricultural land integration remains limited. This study investigated the potential for rational land management through the application of agricultural land consolidation, focusing on the Liutenska and Petrivsko Romenska territorial communities. Geographic Information Systems (GIS) were employed to analyse spatial structure, land fragmentation, and opportunities for land-use optimisation. The methodological approach included geospatial analysis, systems analysis, graph-based generalisation, and normative-legal content analysis to evaluate fragmentation levels, ownership patterns, and spatial inconsistencies. The study found that land consolidation contributed to a reduction in land-use fragmentation, adjustments in land tenure structure, and improvements in the spatial configuration of agricultural areas. The integration of GIS tools supported spatial data analysis, enhanced transparency in decision-making processes, and facilitated the incorporation of ecological, economic, and social considerations. Parcel reallocation through equivalent exchange and consolidation planning supported more coordinated land cultivation, reduced transportation distances, and improved access to infrastructure. The findings suggested that spatial, legal, and institutional instruments need to be applied in combination to support land consolidation at the community level. These results can inform land management strategies for local authorities, agricultural producers, and stakeholders involved in rural development, particularly within the framework of ongoing land reform in Ukraine

Keywords: spatial optimisation; rural development; cadastral data; geoinformation analysis; sustainable agriculture; integration; fragmentation

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INTRODUCTION

The structure of agricultural land use in Ukraine remains highly fragmented and spatially inefficient. Historical processes of land distribution, partial reforms, and the long-standing moratorium on land sales have resulted in irregular and disjointed land holdings. These conditions impede the development of competitive agricultural production and hinder sustainable rural development. Land users often face limited access to tools that would allow them to plan, optimise, or consolidate land holdings, while institutional and technical frameworks for spatial land integration remain underdeveloped. In this context, Geographic Information Systems (GIS) present an opportunity for improving the spatial structure of land use, facilitating rational land management, and supporting more coordinated land reallocation processes at the local level.

Research by M. Malashevskiy & O. Malashevskaya (2022) focused on the modelling of land exchanges during the consolidation process. The authors developed a theoretical model for land plot reallocation based on the concept of spatial combinations, which provides the basis for optimising land parcel configurations during consolidation. In their study, the authors proposed a methodology for correcting land parcel boundaries to support consolidation efforts. They emphasised the need for accurate mapping and synchronisation with cadastral data, but did not address the practical implementation of GIS. A.M. Tretiak *et al.* (2025) analysed the consolidation of land shares (quotas) held by private owners, emphasising the need for legal clarity and a robust compensation mechanism to encourage voluntary participation in consolidation projects. Their findings suggest that transparent and legally secure frameworks are essential for stakeholder engagement. However, their research remains limited in terms of spatial or geoinformation modelling. N. Stoiko & O. Cherechon (2024) explored multipurpose land consolidation in the context of Ukrainian territorial communities. They examined how land integration could be used not only for agricultural optimisation but also to support environmental protection and infrastructure development. While their study offered a broad institutional perspective, it did not include spatial analysis or practical applications of GIS. A. Popov *et al.* (2020) introduced an alternative model to classical land consolidation, clustering agricultural lands according to production types. Their model was intended to improve the economic efficiency of land use, but the research did not include geoinformation technologies, and no case studies were provided to demonstrate practical outcomes.

J. Thomas (2023) provided a comprehensive handbook on rural land readjustment and consolidation in

Germany, commissioned by the Federal Ministry of Food and Agriculture. The publication outlined institutional, legal, and organisational frameworks that have enabled the longterm success of consolidation programmes, with particular emphasis on compensation mechanisms, voluntary participation, and integration with rural development policies. The German experience demonstrates how consolidation can be embedded within a broader territorial development strategy, offering valuable insights for countries seeking to modernise their land management systems. P. Leń *et al.* (2024) introduced a novel method for determining the urgency of land consolidation, which incorporates market value alongside traditional spatial and legal indicators. Their approach allows for a more nuanced prioritisation of areas requiring intervention, ensuring that consolidation not only addresses fragmentation but also reflects economic efficiency and land market dynamics. The study demonstrated the potential of quantitative assessment methods to improve the planning and sequencing of consolidation projects, thereby enhancing their practical implementation. M. Bijandi *et al.* (2021) employed multi-objective particle swarm optimisation in their study on land consolidation. They incorporated landowner preferences and legal restrictions into their reallocation models, offering a rigorous quantitative and technical approach. However, the applicability of their model to Ukrainian conditions remains uncertain due to differing institutional structures. Y. Wei *et al.* (2020) utilised GIS tools to assess land suitability for agricultural development based on environmental criteria. The study demonstrated the effectiveness of integrating spatial data into land-use planning but did not address cadastral or legal data, which are essential for formal land consolidation processes. S.P. Tunalı & N. Dağdelen (2023) compared different land consolidation approaches in Turkey, concluding that mixed methods – combining legal, participatory, and spatial tools – were the most effective. Their methodology included spatial simulations and field validation, demonstrating the practical application of GIS in land reform. These findings may be relevant to the Ukrainian context, though institutional differences must be taken into account.

Despite these contributions, several critical aspects remain insufficiently explored. Few studies demonstrate how GIS tools are applied in real-life consolidation projects in Ukraine. Most studies focus on legal or theoretical frameworks without presenting empirical findings or spatial models. Additionally, there is limited research integrating cadastral, legal, and geospatial datasets for community-level consolidation planning. The practical role of land users, local institutions, and digital tools

in land optimisation remains underrepresented in the literature. This study aimed to examine the potential for effective land management through the implementation of land consolidation in agricultural regions, using the Liutenska and Petrivsko-Romenska territorial communities as case studies. GIS technologies were applied to analyse the spatial structure, fragmentation, and land reallocation potential, with a focus on practical modelling and community-level integration.

MATERIALS AND METHODS

The research employed a multidisciplinary methodological framework to examine opportunities for rational land use through agricultural land consolidation, based on the case of the Liutenska and Petrivsko-Romenska rural territorial communities in the Myrhorod District, Poltava Region (Fig. 1). The approach integrated spatial, legal, and empirical methods to ensure analytical consistency and practical relevance.

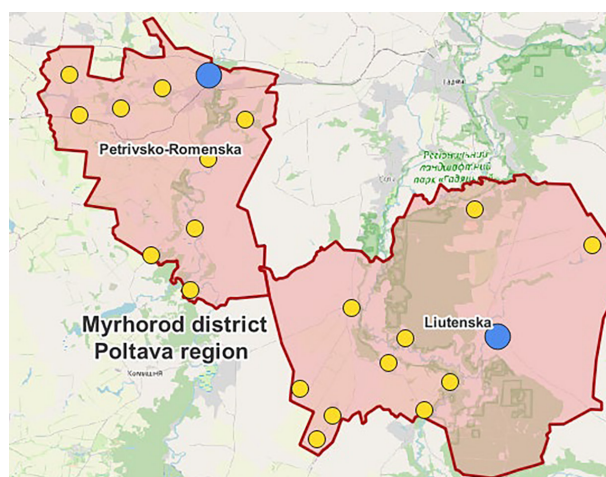


Figure 1. Schematic map of the Liutenska and Petrivsko-Romenska communities, Myrhorod District, Poltava Region

Source: created by the authors using OSM map and QGIS

The initial stage of the study involved a structural assessment of the land fund of the Liutenska and Petrivsko-Romenska communities, which cover 37,351.8 and 20,970 hectares respectively, as of 1 January 2025. Official cadastral records, archival materials, and land-use statistics were used to classify land by type (agricultural, forest, water bodies, wetlands, etc.) and by user category (households, enterprises, state institutions) (State Service of Ukraine..., n.d.). This classification allowed the identification of fragmentation patterns, ownership types, and spatial inconsistencies across village units. Geospatial analysis constituted the core of the research methodology. GIS platforms, including ArcGIS Engine and QGIS, were used to map the

existing land parcel structure, overlay thematic layers, and simulate alternative configurations for land consolidation. These simulations were conducted using actual cadastral data sourced from the State Service of Ukraine for Geodesy, Cartography and Cadastre (n.d.). Key attributes such as parcel size, ownership form, land designation, and soil quality were analysed to model spatial optimisation scenarios. The resulting digital maps provided a basis for visualising fragmentation and designing reallocation strategies. The spatial analysis was supported by graph-based generalisation, a method used to aggregate and simplify spatial data for further processing. This enabled the identification of consolidated land blocks based on proximity and functional use, and the modelling of equivalent exchanges between fragmented plots. These models were generated within the ArcGIS environment using custom scripts designed to process topological relationships among land parcels.

A legal and normative content analysis was conducted in parallel to ensure that proposed consolidation scenarios aligned with existing Ukrainian legislation. The analysis covered the Land Code of Ukraine (amended as of 7 February 2025) (Law of Ukraine No. 2768-III, 2001), national land policy strategies (Resolution of the Cabinet of Ministers of Ukraine No. 695, 2020), and selected presidential (Decree of the President of Ukraine No. 722/2019, 2019) and governmental decrees (Law of Ukraine No. 552-IX, 2020). Key legal parameters, including land ownership rights, servitudes, and equivalence of compensation, were reviewed and integrated into the consolidation models (State Service of Ukraine..., n.d.). To examine the actual application of GIS tools by land users, an empirical component was incorporated. "Agrofirma 'Dovzhenko'" LLC (2023), which manages around 85% of agricultural land in the community, provided access to its ArcGIS Engine-based land management system. The system integrates data with the national cadastre and supports boundary monitoring, sowing control, and fertiliser application. Smaller enterprises such as "Agro-Kray" LLC (2025) and other farms used software, including FEODAL, which allows for parcel tracking and basic land monitoring. These cases demonstrated the real-world integration of spatial data into agricultural management.

Soil quality data were sourced from the Poltava branch of the State Institution "Institute for Soil Protection of Ukraine" (n.d.). Indicators such as pH, humus content, and available phosphorus, potassium, and nitrogen were used to assess agricultural suitability and potential for productivity improvement. These data informed the selection of parcels for modelling

consolidation alternatives. The research process followed a structured sequence: collection and classification of spatial and cadastral data; GIS-based mapping and fragmentation analysis; scenario modelling for parcel reallocation using spatial optimisation techniques; normative-legal assessment of consolidation procedures; empirical validation through case studies of land users; and integration of soil quality data into consolidation planning. The selected methods reflect the need for a holistic perspective that combines technical, legal, and institutional dimensions of land consolidation. This methodological integration enabled the development of consolidation models tailored to

local conditions and supported by empirical data and spatial analysis.

RESULTS AND DISCUSSION

As of 1 January 2025, the total land fund of the Liutenska territorial community was 37,351.8 hectares. Agricultural land accounted for 22,947.2 ha (61.4%), forest and forest-covered areas for 12,546.5 ha (33.6%), open wetlands for 783.9 ha (2.0%), built-up land for 690.6 ha (1.8%), water bodies for 329 ha (0.8%), and land without vegetation for 54.6 ha (0.1%) (Liutenska Village Council, n.d.). A detailed classification by village was conducted based on cadastral data (Table 1).

Table 1. Distribution of land by villages in the Liutenska territorial community (as of 01.01.2025)

Village	Total area, ha	Agricultural land	Forests and other forestcovered areas	Built-up land	Wetlands	Open wetlands	Barren land	Water bodies
Sosnivka	5,559.2000	2,960.2412	2,411.5024	106.7564	11.0600	19.1000	5.2000	56.4000
Rapynka	6,571.3000	5,648.2592	554.3000	113.8408	14.5920	144.2000	3.3000	107.4000
Lypivka	4,871.200	4,186.5231	379.8500	132.7269	40.6348	106.3000	4.9000	60.9000
Liutenka	20,350.100	10,152.2059	9,200.8681	337.2260	14.3940	514.3000	41.2000	104.3000
Total	37,351.8	22,947.2294	12,546.5205	6,905.501	80,680.8	783.9000	54.6000	329

Source: compiled by the authors based on cadastral records

The four villages – Sosnivka, Rapynka, Lypivka, and Liutenka – exhibited varied land-use distributions. In each case, agricultural land represented the dominant category, although forest land was particularly extensive in Rapynka and Liutenka (Fig. 2). The spatial structure was visualised using GIS-based land maps, and fragmentation

patterns were analysed using overlay techniques and attribute data queries (Fig. 3). The analysis revealed inconsistencies in parcel size and shape, frequent separation of plots belonging to the same user, and limited access to agricultural infrastructure. These spatial patterns contributed to lower efficiency of agricultural operations.

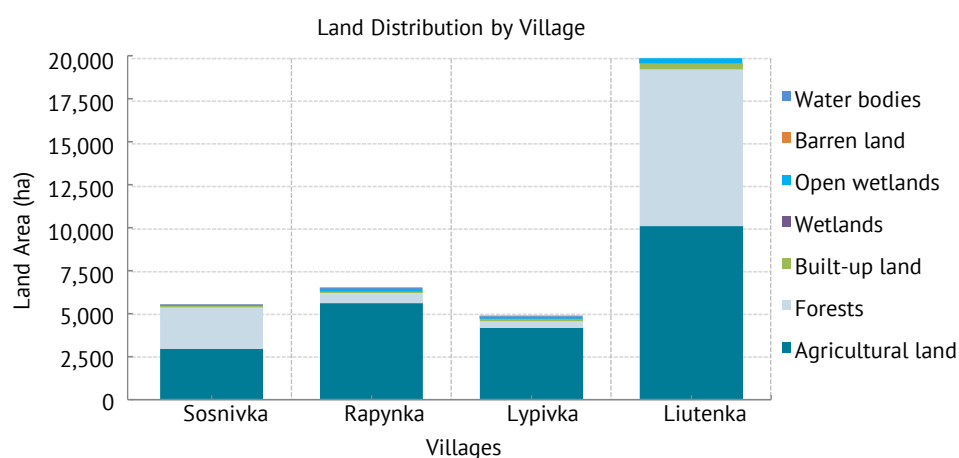


Figure 2. Distribution of land types by village

Source: created by the authors using ArcGIS Engine and QGIS, based on cadastral data



Soil quality analysis, based on data provided by the Poltava branch of the State Institution “Institute for Soil Protection of Ukraine” (n.d.), indicated that chernozem soils dominate the area. These soils have an average pH of 6.5, humus content of 3.08%, mobile potassium of 118.3 mg/kg, hydrolysable nitrogen of 112.7 g/kg, and phosphorus compounds of 117.1 mg/kg. These indicators confirm the potential for improved productivity under consolidated

land use. The largest land user, “Agrofirma ‘Dovzhenko’” LLC (2023), occupies around 85% of all agricultural land in the community and uses ArcGIS Engine for land parcel management. Smaller land users employ FEODAL software (Fig. 4), which offers limited functionality but supports basic monitoring and accounting tasks. The functionality of these systems was validated through structured interviews and software interface documentation.



A significant share of the remaining land is managed by the farms Mayak LLC and Promin Farmer's Enterprise (FE). The rest of the land in the village districts and the community is held by small farming enterprises: Lypky FE, Sirius-Agro FE, Berus FE, Velykoobukhivske Agricultural Production and Processing Enterprise, and Hnyda Sole Proprietorship. Some lands are cultivated by individuals engaged in personal subsidiary farming. Addressing the problems in Ukraine's agricultural sector is linked to the completion of land reform, the abolition of the moratorium on the purchase and sale of agricultural land, the inclusion of land in economic circulation, and the recognition of land capital on a par with other means of production. This requires modern

approaches to land management. As of 1 July 2021, the moratorium on the purchase and sale of agricultural land was lifted (Law of Ukraine No. 552-IX, 2020). This has contributed to strengthening and improving the financial standing of agricultural enterprises, as well as fostering effective ownership.

A fully functional land market is developing in Ukraine. Private individuals who own agricultural land plots have become sellers, but certain restrictions have been established on their purchase and sale. The law sets out restrictions for land plots owned by both individuals and legal entities. Land is considered in connection with joint ownership and shares in statutory capital, mutual investment funds, or legal entities

whose participants are individuals. The abolition of the moratorium does not apply to land plots owned by state and communal authorities, nor to lands located in temporarily occupied territories. A list of persons who are not entitled to acquire land ownership has been established: legal entities whose participant or ultimate beneficial owner is a non-Ukrainian citizen; legal entities for which agricultural land plots in state or joint ownership are demarcated in kind; legal entities whose participant or ultimate beneficial owner is a citizen of a state recognised by Ukraine as an aggressor or occupier; legal entities belonging to terrorist organisations; legal entities to which special economic or other restrictive measures (sanctions) have been applied in accordance with the Law of Ukraine No. 552-IX (2020); legal entities created under Ukrainian law but which do not cooperate in combating the laundering of proceeds from crime; and legal entities controlled by individuals or legal entities registered in states included on the Financial Action Task Force list (Law of Ukraine No. 552-IX, 2020).

Ukraine is in the process of forming market relations to implement effective mechanisms for land integration, as well as considering the positive and negative experiences of various countries in integrating agricultural land under different land use models. This is crucial at the current stage of developing market-based land relations and in overcoming the fragmentation and parcellation of agricultural lands resulting from land share distribution and privatisation. Consolidation of agricultural lands is the process of amalgamating plots of land to address issues of irregular configuration, size, structure, location, and boundaries, thereby improving land use, increasing economic efficiency, and optimising production organisation (Lupenko *et al.*, 2022). Land consolidation aims to eliminate obstacles associated with land ownership and land use that negatively affect agricultural organisation and the economics of agro-industrial complexes. This process unites the land of owners, farmers, and landholders, improves access to infrastructure and resources, and promotes their rational use. Land consolidation is considered the primary mechanism for rural land resource development, shaped by administrative-command methods such as nationalisation and artificial cooperation in plot amalgamation. At the core of the land consolidation procedure lies the principle of equal compensation for the plots whose boundaries are being demarcated. This principle stipulates that upon completion of the consolidation procedure, each owner should receive an equivalent value for their land plot or land use, matching the value of the land plot or land use they held before consolidation. During the land consolidation process, landowners

receive compensation for the right of ownership or use of the land being consolidated or redistributed. The principle of equal compensation (equivalence) ensures that landowners do not incur financial losses after consolidation, and their rights to land resources are protected in accordance with their previous value and restored from the perspective of property rights and economic relations after the land integration procedure. Participants should not be placed at a disadvantage compared with others.

According to FAO (2023), in addition to sublease mechanisms, land consolidation is carried out either in accordance with a land management project for consolidation or under contractual terms of land integration and cooperation. The development of land management projects for land integration and consolidation may involve the following actions: transfer for use and extension of lease agreements, sublease agreements, and land servitudes, as well as the conclusion of such agreements for a new term; consideration of legal restrictions and encumbrances, including property rights and servitudes; prohibition of boundary changes; and restrictions on the use of land plots located within arrays of agricultural land. The community is authorised to manage territorial community land, issue notices for violations and administrative offences by individuals and legal entities, and enforce compliance with land and environmental legislation. Specialists from departments of land relations, communal property, and housing and communal services continuously monitor lease agreements and supplementary agreements, ensuring that enterprises and activities comply with statutory requirements. However, only strategic management of land development – through consolidation, integration, and clustering – will ensure progress in the community's land management and bring about qualitative improvements. GIS technologies are available for the management and rational use of agricultural land, significantly facilitating the work of agricultural enterprises.

The development of modern information technologies, particularly the integration of internet tools, geo-information systems, organisational technologies, and mobile communication, has significantly reduced the perceived distance between remote locations, transforming the planet into a “visible” entity and making terrestrial objects and phenomena more “accessible”. Rapid communication and the ability to analyse spatial information have become essential for many categories of IT users. A wide range of online web mapping services and GIS portals (ArcGIS Online, QGIS Cloud, Google Earth, Google Maps, OpenStreetMap (OSM), NASA Worldview, Sentinel Hub (EO Browser), Wikimapia, Bing Maps, Here Maps, MapQuest, Leaflet, Mapbox, etc.) are

actively used not only in mobile navigation systems and GPS devices but also in everyday life by telecommunication users. Today, GIS tools are widely applied both to locate objects and phenomena on the Earth's surface and to analyse and select optimal routes across terrain. The evolution of GIS technologies, driven by the dynamic development of computer and internet technologies, is occurring at an extremely rapid pace, and even the boldest forecasts continue to hold true. While previously the development of such systems relied on a regulatory framework, today their use often extends into the online sphere, where, due to the lack of clear legal norms, user self-organisation is increasingly common.

Crowdsourcing is of great interest as a form of involving participants in the development of electronic or interactive maps. Thanks to the latest advances in cloud computing, GIS technologies are becoming accessible to an increasing number of users. GIS projects combine maps, photographs, crowdsourced data, social media resources, and other inputs. There is a shift from a geographically broad approach (aimed at accumulating information about geographical objects) to an analytically intensive approach, which involves expanding tools for processing spatial data and developing intelligent geoinformation systems. Digital knowledge is promising for the development of organisational technologies in agricultural land management. Large structures are managed using systems such as Material Requirements Planning (MRP), Manufacturing Resource Planning (MRP II), Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Supply Chain Management (SCM), and others. Decision Support Systems (DSS) are also widely used within these frameworks. However, the design features of such systems do not always allow for the full utilisation of spatial information regarding the location or movement of large numbers of resources. Management information often contains spatial or geographical components that cannot be ignored during operational data processing. The development of information technologies has made it possible to create GIS systems that enable the collection, storage, processing, access, visualisation, and dissemination of spatial data, and are capable of solving a wide range of management tasks related to objects with spatial references.

Land users in the Liutenska community widely employ GIS software for agricultural land accounting. For example, the agricultural enterprise "Agrofirma 'Dovzhenko'" LLC (2023) uses ArcGIS Engine software, which allows the management of a large volume of related data within a single software database. In practice, the software makes it possible to track the farm's land plots, determine their spatial location, synchronise

data with the state land cadastre, monitor cultivation boundaries, control sowing and harvesting, and apply plant protection products – among many other functions. The agricultural enterprise "Agro-Kray" LLC (2025) also uses ArcGIS software based on GIS technologies. The programme differs somewhat in its functional capabilities from ArcGIS Engine, but their core functions remain identical. Enterprises with a smaller land bank use FEODAL software. This programme offers more limited functionality but performs the main tasks of managing land resources and monitoring cultivation. New concepts for agricultural sector development should ensure balanced agricultural production, adapted as closely as possible to natural conditions. The implementation of these approaches requires measures for analysing land resources and organising rational land use in agricultural activity. It is necessary to transition to an adaptive development model that takes into account the ecological, social, and economic aspects of agricultural production. The organisation of the territory of agricultural enterprises plays a key role. The introduction of ecologically sound approaches to the organisation of territorial and land integration enhances land productivity, mitigates land degradation, improves crop yields, and ensures higher ecological and economic efficiency of production and economic activities.

Currently, four methodological approaches to the territorial organisation of agricultural enterprises, which take into consideration ecological and economic factors, require special attention: agroecological, agrolandscape, adaptive-landscape, and ecological-economic. The organisation of agriculture and agricultural territories, their combination and coordination with the natural elements of the agrolandscape, largely determine solutions to tasks concerned with effective and ecologically balanced land and nature management in the country's agricultural sector. Ensuring the balanced development of the agricultural sector is necessary for adaptation to the prevailing natural conditions of the territory and for adaptive landscape land management, within which the territory of a specific agricultural enterprise is implemented. In the course of organising the agricultural landscape of a territory, the land fund, which has significant natural resource potential, is transformed. During this process, a significant number of tasks related to the organisation of production processes are addressed: an institutional production system is organised, the economic direction of the enterprise is determined in the context of production sectors, the structure of sown areas of agricultural enterprises of various production types is outlined, a crop rotation system is organised, and land management design is performed.

In addition to the land management works related to the formation of land plots through their consolidation, it is also necessary to include land redistribution measures, because consolidated territories may contain land plots with different owners, different land uses, and different designated purposes. Land consolidation involves reducing the number of landowners and reducing the number of land plots. Amalgamation to form land plots is possible only if the designated purpose is preserved, but during land consolidation, situations often arise in which the designated purpose of a land plot changes. Even if the first four methods of land demarcation (Law of Ukraine No. 2768-III, 2001) are used for land redistribution, such a procedure requires the preparation of separate land management

documents (land management projects and/or technical documentation for land management) for each individual case, which is a costly and lengthy process. A comparative case study was conducted for Berezova Luka Village (Petrivsko-Romenska community), where spatial reorganisation was modelled through land parcel consolidation. The area was characterised by elongated, narrow, and non-contiguous land plots, which led to increased transport time and inefficient field operation planning (Fig. 5).

Following spatial modelling based on equivalent land value exchange, consolidated blocks were formed to reduce fragmentation (Fig. 6). GIS analysis demonstrated reductions in the number of parcels per user and increased plot contiguity.

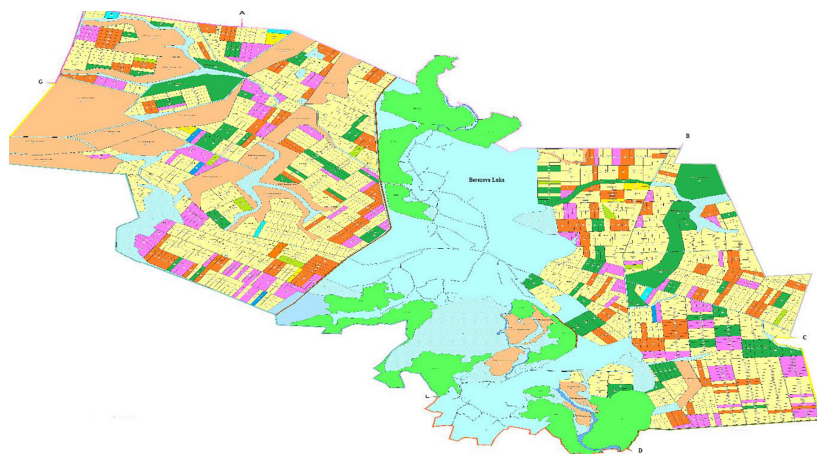


Figure 5. Plan of Berezova Luka (Petrivsko-Romenska community) before land consolidation

Source: created by the authors using an ArcGIS-based simulation

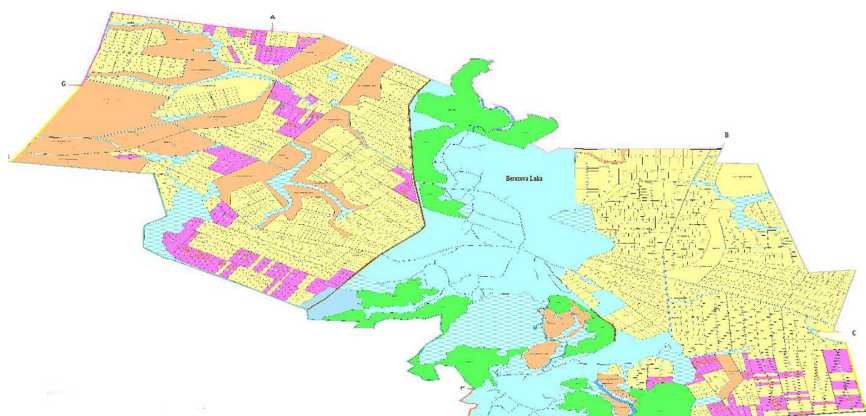


Figure 6. Plan of Berezova Luka (Petrivsko-Romenska community) after parcel reorganisation for one user

Source: created by the authors using an ArcGIS-based simulation

The application of GIS tools enabled precise measurement of changes in parcel boundaries, verification of ownership continuity, and assessment of potential impacts on agricultural accessibility. These results

support the operational feasibility of consolidation under the current legislative framework. In summary, this research constituted a scientific inquiry into methods and approaches for rational land management through

land consolidation, examined ways to improve spatial consolidation, and defined land use structures through legal and land management mechanisms.

The simulated reorganisation in Berezova Luka further confirmed that consolidating disjointed parcels into contiguous blocks can significantly improve the efficiency of agricultural operations. The presented research aligns closely with recent investigations exploring the technical and practical benefits of land consolidation. For instance, the study of Z. Zhang *et al.* (2025) in the hilly and mountainous regions of China reinforces these findings by demonstrating that arable land consolidation is crucial for mitigating land fragmentation, particularly in facilitating the use of modern agricultural machinery. The elongated and narrow plots observed in Berezova Luka before the simulated reorganisation present precisely the kind of spatial inefficiency that hinders mechanisation. GIS-based modelling, which resulted in more compact and accessible land blocks, provides a practical validation of these principles. Similarly, the research by Y. Yang & T. Cao (2023), which utilised GIS for the optimal zoning of agricultural land, corroborates this methodological approach. Their focus on using geoinformation technologies to optimise regional land use mirrors the application of ArcGIS Engine and QGIS in this study for analysing land categories, soil quality, and ownership patterns to design effective consolidation scenarios. This parallel underscores that GIS is not merely a mapping tool but a critical analytical system for strategic land management, a conclusion strongly supported by the findings of this study.

The central role of digital technologies in contemporary land management, as highlighted in this study through the use of software such as ArcGIS Engine and FEODAL by local enterprises, is further elaborated by A. Koshel & D. Koshel (2024). Their analysis of modern digital tools in land resource management systems affirmed that the integration of spatial data is fundamental to improving administrative efficiency and production outcomes. The case study of "Agrofirma 'Dovzhenko'" LLC, which leverages its GIS to synchronise with the state cadastre and manage cultivation, serves as a concrete example of the advanced application described by these authors. However, the use of less functional software, such as FEODAL, by smaller farms indicates a digital divide that could hinder the universal adoption of sophisticated consolidation practices, highlighting a need for scalable solutions.

While the technical benefits are clear, the successful implementation of land consolidation is fundamentally dependent on a robust legal and institutional framework. The conclusion that spatial, legal, and institutional instruments must be applied in concert finds strong

support in Ukrainian legal scholarship. B. Derevyanko & O. Turkot (2024) explored the benefits and contradictions of current legislative drafting for land consolidation in Ukraine, pointing to the legal complexities that must be navigated. This study complemented their legal analysis by providing an empirical case of how these laws could be applied at the community level, emphasising the principle of equivalent compensation as a cornerstone for ensuring fairness and landowner participation. This principle is also a central tenet in broader European practice, as outlined in the FAO legal guide by T. Veršinskas *et al.* (2023). Their guide, based on regulatory practices across Europe, advocated legal frameworks that are flexible and participatory, aligning with the findings of this study on the need to integrate stakeholder interests. A comparison with the established land management system in Germany, as described by U.E. Chigbu *et al.* (2023), also shows that although the historical and legal context may differ, the main goal remains the creation of economically viable and environmentally sustainable land structures.

The broader socio-economic implications of the findings are reinforced by research from other post-Soviet nations. J. Looga *et al.* (2023) framed land consolidation in Estonia as an innovation policy instrument capable of stimulating rural economies, particularly for small agricultural farms. This perspective aligns with the conclusion that consolidation is a primary mechanism for rural development, capable of improving agricultural productivity and, by extension, the financial standing of agricultural enterprises. Furthermore, the study by W. Krupowicz *et al.* (2020) on implementing crowdsourcing initiatives in land consolidation procedures in Poland introduced an innovative participatory dimension. While the study focused on data from official cadastres and enterprises, the Polish experience suggests that engaging a wider community through crowdsourcing could enhance the accuracy of spatial data and foster greater transparency and public trust in the consolidation process, a key element highlighted in this research. The connection between rational land tenure and economic health was also underscored by N. Kantsedal & O. Leha (2022), who identified institutional stability as a prerequisite for the investment attractiveness of Ukraine's agricultural sector. By creating more orderly and efficient land holdings, the consolidation measures demonstrated in this study directly contribute to building this stability and making agricultural land a more secure and profitable asset.

Ultimately, the approaches and outcomes detailed in this research are in harmony with globally recognised best practices. The FAO (2023) generic master's course curriculum on land consolidation promotes an

integrated approach that combines technical skills in spatial planning with a deep understanding of legal frameworks, stakeholder engagement, and sustainable development goals. This study, by integrating GIS-based spatial modelling, normative-legal analysis, and empirical data from local land users, exemplifies this holistic methodology. The successful reorganisation of parcels to reduce transport costs, improve infrastructure access, and enable more coordinated cultivation directly supports the sustainable development goal of enhancing agricultural productivity and farmer incomes. The study confirms that GIS-supported land consolidation is not merely a theoretical exercise but a practical and effective strategy for advancing land reform in Ukraine, offering a replicable model for local authorities to overcome the legacy of land fragmentation and foster sustainable rural development.

The findings confirm that the integration of GIS-based modelling, normative-legal frameworks, and empirical validation provides an effective foundation for advancing agricultural land consolidation in Ukraine. The application of GIS tools has enabled precise measurement of changes in parcel boundaries, verification of ownership continuity, and assessment of potential impacts on agricultural accessibility. These results support the operational feasibility of consolidation under the current legislative framework. This study constitutes a scientific inquiry into methods and approaches for rational land management through land consolidation, the exploration of ways to improve spatial consolidation, and the determination of land use structure through legal and land management mechanisms. The findings demonstrate that the application of modern GIS technologies is a crucial instrument for supporting agricultural land consolidation in Ukraine, leading to reduced fragmentation, enhanced spatial optimisation, and more rational land management within the Liutenska and Petrivsko-Romenska territorial communities.

CONCLUSIONS

This study has shown that the integration of modern GIS technologies is an effective tool for resolving the problem of agricultural land fragmentation in Ukraine, which arose from the land-sharing process. Unlike general assertions, this research has yielded

concrete results that confirm the practical effectiveness of the proposed approaches. The analysis of the Liutenska and Petrivsko-Romenska territorial communities, with total areas of 37,351.8 ha and 20,970 ha respectively, revealed significant spatial disparity and inefficiency in the existing land use. It was established that in the Liutenska community, agricultural land accounts for 61.4% of the territory. Approximately 85% of this land is cultivated by a single large agricultural enterprise, which uses advanced ArcGIS Engine software, whereas smaller farms employ less functional systems such as FEODAL. This finding indicates a digital divide that could hinder the comprehensive implementation of consolidation.

A key result of this research was the modelling of spatial reorganisation using the example of Berezo-va Luka village. The simulation, conducted based on equivalent land value exchange, clearly demonstrated the benefits of consolidation: a transition from inefficient, elongated, and fragmented plots to the formation of compact, functionally integrated blocks. This resulted in a reduction in the number of parcels per user, the optimisation of their configuration and, consequently, a decrease in transport costs and an increase in the efficiency of agricultural operations. Further scientific research should be directed towards several areas. It is necessary to develop scalable and accessible GIS solutions for small and medium-sized farms to overcome the identified technological divide. Pilot projects should be conducted to implement the developed consolidation models in practice, in order to verify their economic efficiency and social acceptance at the community level. Another promising area is the analysis of the adaptability of the proposed methodology to other regions of Ukraine, taking into account their unique agricultural landscapes and socio-economic characteristics.

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Сучасні ГІС-технології для підтримки управління земельними ресурсами при консолідації сільськогосподарських земель

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Анотація. Україна не проводила комплексну або систематичну оцінку ефективності процесів просторової земельної консолідації, а інституційна база, що підтримує інтеграцію сільськогосподарських земель, залишається обмеженою. Це дослідження вивчало потенціал раціонального землекористування шляхом застосування сільськогосподарської земельної консолідації, зосереджуючись на територіальних громадах Лютенська та Петрівсько-Ромська. Для аналізу просторової структури, фрагментації земель та можливостей оптимізації землекористування було використано географічні інформаційні системи (ГІС). Методологічний підхід включав геопросторовий аналіз, системний аналіз, узагальнення на основі графіків та нормативно-правовий контент-аналіз для оцінки рівнів фрагментації, моделей власності та просторових невідповідностей. Дослідження показало, що укрупнення земельних ділянок сприяло зменшенню фрагментації землекористування, коригуванню структури землеволодіння та поліпшенню просторової конфігурації сільськогосподарських територій. Інтеграція інструментів ГІС сприяла аналізу просторових даних, підвищенню прозорості процесів прийняття рішень та полегшила врахування екологічних, економічних і соціальних аспектів. Перерозподіл ділянок шляхом еквівалентного обміну та планування укрупнення сприяли більш скоординованому обробітку землі, скороченню транспортних відстаней та поліпшенню доступу до інфраструктури. Результати дослідження свідчили про необхідність комплексного застосування просторових, правових та інституційних інструментів для підтримки земельної консолідації на рівні громади. Ці результати можуть бути використані для формування стратегій управління земельними ресурсами місцевими органами влади, сільськогосподарськими виробниками та зацікавленими сторонами, що беруть участь у розвитку сільських територій, зокрема в рамках поточної земельної реформи в Україні.

Ключові слова: просторова оптимізація; розвиток сільських територій; кадастрові дані; геоінформаційний аналіз; стале сільське господарство; інтеграція; фрагментація