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# HOW CAN GIS INTEGRATION IMPROVE LAND MANAGEMENT FOR SUSTAINABLE DEVELOPMENT IN TERRITORIAL COMMUNITIES

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**ABSTRACT**

Despite the increasing availability of open geospatial data and the widespread use of geographic information systems (GIS), there remains a significant gap in the literature regarding the systematic integration of GIS into community-level land management for sustainable development. Existing studies often focus on isolated applications or sectoral use cases, lacking a holistic framework for operational implementation in decentralised settings. This study addresses this gap by developing and validating a comprehensive concept of GIS integration into land management processes, tailored to the needs of territorial communities. The proposed approach covers the full analytical cycle: from the collection, cleaning, and normalisation of satellite and cadastral data to environmental sustainability assessment, spatial visualisation, and decision-making. Drawing on multi-source data (Sentinel-2, Landsat 8, public cadastral registers, crowdsourcing platforms), and using QGIS, ArcGIS, GeoDA, and Google Earth Engine, the study conducts a comparative analysis of software capabilities in spatial modelling, including the construction of NDVI, LST, and ESI indices, interpolation, regression, and scenario-based cluster analysis. A novel Environmental Sustainability Index (ESI) is introduced, integrating factors such as urbanisation, vegetation cover, erosion susceptibility, and anthropogenic pressure, and visualised as multilayer thematic maps. A metropolitan case study demonstrates the operational value of GIS in land use planning and provides an adaptable algorithm for community-level implementation. The results contribute new knowledge by establishing a replicable GIS integration model that enhances spatial accuracy, planning transparency, and environmental resilience. Key challenges identified include standardising data formats, expanding digital skills, and aligning with national legislation. This study offers both methodological innovation and practical tools for advancing sustainable land governance in resource-constrained environments.

**Keywords:** *GIS; Sustainable Development; Territorial Communities; Environmental Sustainability; Natural Resources*

## 1. INTRODUCTION

In the XXI century, digitalisation of management processes is becoming a prerequisite for the sustainable development of territories. Bondarenko et al. [1] emphasise the importance of GIS in strategic planning of state security, focusing on the role of informatisation in making informed decisions. In the border dimension, Hubanova et al. [2] show how GIS enhances the preventive management function, which is also relevant for planning in ATCs. In agriculture, according to Sumets et al. [3], GIS serves as a tool for assessing the sustainability of enterprises, taking into account socio-economic and environmental factors. Ramaano [4] addresses the issue of community involvement in management, pointing to the potential of GIS in the development of sustainable

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tourism and environmental management. Rahman and Szabó [5] demonstrate the effectiveness of GIS-MCDM in urban land use, which confirms the practical value of spatial analysis for making balanced decisions. Raihan [6] systematises evidence on using GIS in agricultural production in the rural sector, pointing to increased productivity through accurate monitoring. Basharat et al. [7] integrate the WQI with GIS to monitor groundwater, which is essential for environmental safety. Quamar et al. [8] focus on using UAVs with GIS, which opens up new opportunities for local monitoring of territories. At the same time, De Toro et al. [9] outline the key barriers to implementation: lack of quality data, limited finances, and digital illiteracy. Finally, Ahsan et al. suggest standardisation of cadastral profiles as a basis for digital transformation of land management [10].

While these studies illustrate the versatility of GIS in various sectors, they rarely address how to systematically implement GIS in community-scale land management under conditions of decentralisation, budget constraints, and non-standardised data infrastructure. Moreover, few of them propose adaptable algorithms that can be directly integrated into local decision-making workflows.

This research differs in both motivation and scope: it seeks not only to demonstrate the utility of GIS tools but to develop a fully replicable, step-by-step integration model for local governments. It explicitly connects geospatial modelling with administrative implementation, offering practical solutions for zoning, sustainability audits, and scenario planning.

Although the potential of GIS has been widely recognised across different sectors, there remains a critical lack of research dedicated to developing applied models for GIS integration at the community level, especially under the constraints of decentralised governance, limited resources, and fragmented data infrastructures. Addressing this gap is particularly relevant for countries undergoing land reform and administrative restructuring, where GIS can serve as a key enabler for evidence-based territorial planning and environmental resilience. Therefore, this study is timely and essential for strengthening land governance systems aligned with sustainable development goals.

Thus, integrating GIS into land management processes opens up new horizons for the digital transformation of spatial planning at the community level. The combination of cartographic modelling, environmental monitoring and index analysis contributes to informed decision-making, increased transparency and public engagement. This study will focus on analysing the theoretical foundations, reviewing current software solutions, developing a methodology for integrating GIS into land use management practices, and empirically analysing the use of GIS for environmental sustainability assessment, change forecasting, and natural resource management.

The study aims to substantiate the concept of integrating GIS into land management processes for sustainable development planning of territorial communities, to identify the application capabilities of modern GIS tools, to outline the stages of implementation and to analyse the potential of such solutions to improve the efficiency of spatial management. The structure of the study is as follows: Section 2 provides a brief literature review, Section 3 contains the problem statement, Section 4 describes the proposed GIS integration methodology, Section 5 presents the results and practical conclusions, and Section 6 concludes the study with the results and prospects for further research.

## 2. LITERATURE REVIEW

Many studies have focused on using GIS as the primary tool for spatial analysis and territory management in achieving the SDGS. Kalfas et al. [11] analyse the role of GIS in achieving the SDGs through integrating environmental and urban planning, while Buba et al. [12] demonstrate the effectiveness of participatory GIS in reducing flood risk.

The review by Kuhaneswaran et al. [13] systematises modern approaches to combining GIS and AI and emphasises their potential for automating complex environmental tasks.

Kalogiannidis et al. [14] emphasise the importance of considering water resources in spatial planning, and Arifeen et al. [15] consider urbanisation impacts on land use transformation through spatial analytics. Barbosa et al. [16] dwell on the RUSLE model in GIS to prevent soil erosion, a key factor in agro-ecological sustainability.

An example of the integrated use of GIS in spatial planning and territorial management in Ukraine is the development of geoportals of regions (oblasts). Thus, in 2022, the Geoportal of Kherson Oblast was published for the first time in the country and a management tool was introduced. The geoportal presents 11 thematic sections containing 394 layers of geospatial data, consisting of 58,502 objects and demonstrating 309 indicators [17].

Jebur [18] identifies the main areas of GIS application – from environmental monitoring to urban studies, and Wang et al. [19] demonstrate its effectiveness in locating energy hubs. Lin et al. [20] use multilayer GIS models to identify areas of spatial conflict, which is relevant for Ukrainian communities.

Xia et al. [21] integrate GIS with BIM in the concept of a "digital city", while Minasi et al. [22] emphasise the importance of GIS in planning tourism infrastructure. Moharir et al. [23] propose using GIS and AHP to identify aquifers, which is critical for planning in water-dependent communities.

Puchol-Salort et al. [24] propose the concept of green-blue infrastructure, which, through GIS modelling, can increase the sustainability of the urban environment. Villacreses et al. [25] demonstrate the use of MCDM and GIS in placing SPPs adapted for strategic energy planning.

Calka and Szostak [26] explore GIS's potential in monitoring territories' environmental state, focusing on GIS's ability to quickly detect changes in the landscape, particularly those related to environmental degradation, urbanisation, and anthropogenic pressure.

In turn, Gabriele et al. [27] focus on using GIS and remote sensing technologies to detect landscape degradation caused by climate factors. The study is based on the example of the Basilicata region in Italy. It demonstrates how the systematic use of satellite data and geo-analytics allows monitoring the processes of desertification, soil erosion and reduced bioproductivity, which is critical for agricultural and mountain communities.

Mathenge et al [28] conducted a large-scale systematic review of GIS applications in agriculture. The authors point out the key role of GIS in making evidence-based agricultural decisions: crop rotation planning, water management, determining land productivity and risk zones. The article emphasises that GIS integration balances increasing yields and reducing the environmental impact on agricultural landscapes.

Islam et al. [29] study the urban transformation of residential areas in Bangladesh, using GIS tools to identify patterns of increasing building density, land use change, and infrastructure expansion. The authors argue that GIS provides a high level of spatial accuracy in predicting the impact of urbanisation on social infrastructure, transport network and the ecological balance of the urban environment, which is extremely important for developing small and medium-sized cities.

Ahamed et al. [30] propose an innovative approach to using GIS in micro-level rural planning with a gender perspective. The study demonstrates how mapping tools can identify unequal access to resources between men and women in agriculture, including land distribution, access to water and infrastructure. Finally, Kazemi and Hosseinpour [31] develop a comprehensive model for assessing land for urban agriculture, considering environmental pollution. The study synthesises data on soil contamination, water access and spatial characteristics to identify environmentally safe and productive zones. Thus, the current scientific discourse points to the expanding role of GIS in solving problems of spatial planning, risk assessment, ensuring ecological balance and formulating policies for sustainable resource management.

In summary, prior works provide a strong technical foundation but often overlook the institutional, procedural, and governance barriers that inhibit practical GIS adoption at the community level. This study addresses those gaps by combining methodological clarity, environmental modelling, and policy-oriented implementation strategies within a unified framework adapted to decentralised systems.

It maps the evolution of GIS research and critiques its limitations, while introducing a model that is not only technically sound but also institutionally viable and policy-relevant.

## 3. PROBLEM STATEMENT

The sustainable development of territorial communities is directly linked to the rational, scientifically based use of land resources, based on accurate spatial data, systematic monitoring and forecasting of land-use changes. However, traditional land management and territory planning approaches remain largely fragmented, paper-based, and lack tools for rapidly analysing large geodata arrays. In such conditions, decisions are made without considering complex environmental, demographic, and economic factors, which significantly limit the effectiveness of spatial management.

Despite the rapid development of geoinformation technologies, their integration into municipal land management in Ukraine faces several systemic challenges. In particular, according to Kalfas et al. [11] and Kalogiannidis et al. [14], many regions lack up-to-date digital cadastral maps, geospatial data are fragmented, and their storage and exchange standards are not unified. This creates barriers to the formation of a unified digital spatial planning system.

Another challenge is the insufficient consideration of ecosystem and climate factors in land use decisions. For example, despite the availability of open satellite data, erosion risk models or changes in the Normalized Difference Vegetation Index (NDVI) are rarely integrated into municipal planning documents [16; 21]. Other countries' experience shows that using RUSLE-like models in a GIS environment can improve the accuracy of environmental forecasting, but in Ukrainian practice, such tools are rarely used.

At the same time, the latest technologies, particularly the combination of GIS and AI, open up new prospects for automated analysis of large data sets, building predictive models of land use change, and assessing risk vulnerability. However, as Kuhaneswaran et al. [13] note these approaches remain inaccessible to local communities due to technical complexity, the need for high computing power, and limited access to qualified personnel.

Given the above, there is an urgent need to develop a concept of GIS integration into the land management system adapted to Ukrainian realities, which will include: (1) processing of open satellite data and geospatial layers; (2) application of methods of spatial statistics, cluster analysis and index assessment of the sustainability of territories; (3) development of land use change scenarios based on multifactorial modelling. This approach will create a toolkit that combines flexibility, analytical depth and accessibility for territorial communities, ensuring effective planning in the face of dynamic environmental and social changes.

Thus, the main problem is not only the technological lag or lack of digital resources, but also the absence of a holistic model of spatial management that would integrate the potential of GIS, modern software (QGIS, Google Earth Engine), open data and an ecological approach to planning. This study aims to bridge this gap by developing and testing a conceptual approach to integrating GIS into land management processes to achieve sustainable development goals at the local level.

## 4. PROPOSED CONCEPT OF GIS INTEGRATION INTO LAND MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

### 4.1. Collection and preparation of geospatial data

The basis for building an effective spatial analysis system in land management is high-quality and up-to-date geospatial data. Their collection should be based on a combination of different sources, including satellite imagery (Sentinel-2, Landsat 8), as well as cadastral, topographic, socio-economic, environmental and engineering information from open registers (in particular, the Public Cadastral Map of Ukraine, OpenStreetMap, Copernicus Open Access Hub, Global Land Cover Facility). To ensure the completeness of the analysis, it is also advisable to integrate data from field surveys and crowdsourcing initiatives. This multi-source combination of data is the basis for building a multi-layer GIS model, as shown in Figure 1: each thematic layer (e.g., territory maps, utility networks, routes, sensor points, environmental parameters) is formed separately and then integrated into a single spatial environment.

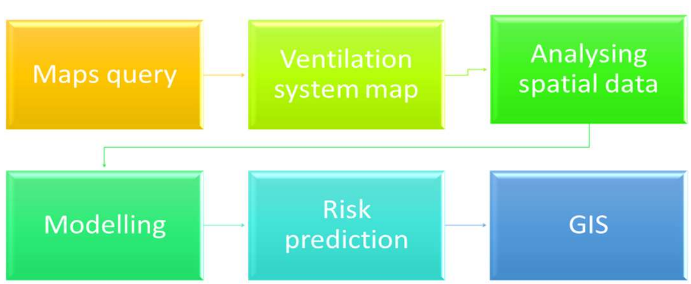


*Figure 1: GIS Data Process Cycle*
*Source: created by the author*

This allows querying individual layers, complex modelling, risk forecasting, environmental analysis, and management decision support. In this context, GIS serves as a core that integrates, structures, and ensures the interaction of all components of digital land management, forming a flexible spatial data-based management system.

The process of preparing geodata involves several key steps. Firstly, it is necessary to establish the exact coordinates of the study objects using generally accepted coordinate systems, such as WGS84, UTM, or local projections. Secondly, the data is downloaded in appropriate formats (GeoTIFF, Shapefile, KML, CSV) that are compatible with spatial analysis tools. Particular attention should be paid to the temporal relevance of the data, spatial resolution (e.g., 10 m for Sentinel-2 or 30 m for Landsat 8), and the availability of attribute information for each object.

When collecting data, it is also important to categorise it by thematic layers: land use (LULC), relief (digital elevation models - SRTM, ASTER), hydrography, road infrastructure, environmental constraints, administrative boundaries, etc. Forming such a multi-level structure allows for creating an integrated environment for further multifactorial analysis.

### 4.2. Cleaning, normalisation, geocoding

Once geospatial data is collected, it must be preprocessed, including cleaning, normalisation, and geocoding. These operations ensure heterogeneous information sources' consistency, correctness, and compatibility in a single analytical environment.

Geospatial data cleaning involves identifying and eliminating errors, missing values, duplicates, or abnormal coordinate points. For example, in the case of cadastral information, it is necessary to check the correctness of plot boundaries and the absence of topological errors (intersections, gaps, self-intersections of polygons) that can lead to distortions in further analysis. For satellite imagery, an essential cleaning stage is removing noise, cloud cover or scanning artefacts, which is achieved by filtering by spectral indices or using cloud masks (for example, QA bands in Landsat 8 or Sentinel-2). Figure 2 shows the sequence of actions applied to satellite images before they are used in spatial analysis.


*Figure 2. Stages Of Satellite Image Cleaning*
*Source: created by the author*

Basic metadata, georeferencing, and format checks are performed at the initial stage of satellite image processing. Next, clouds and artefacts are detected using masks, indices (NDVI, NDSI), and reflectivity thresholds. Problem areas are replaced or filtered through multi-temporal composites. The stage is completed by normalising the images and validating the results for further coverage or sustainability analysis, improving the data quality and land use models.

Normalisation covers geodata (unified projections, coordinates, resolution) and economic indicators (unification of currencies, base years). Standardising attributes, such as names, land use types, and indicators, is also essential. If necessary, the data is aggregated or disaggregated to the desired scale, from quarter to region.

Geocoding (through Nominatim services, Google Maps API, or national platforms) converts textual descriptions into coordinates, allowing GIS data to be visualised. Reverse geocoding is also widespread, as it establishes administrative affiliation by coordinates for spatial automation.

### 4.3. Analysis tools: QGIS, ArcGIS, Google Earth Engine

After completing the cleaning, normalisation, and geocoding stages, the geospatial data is ready for further analysis using modern tools. The most commonly used platforms in land planning are QGIS, ArcGIS, and Google Earth Engine (GEE), each with functional advantages and application areas.

QGIS is free, open-source software with high flexibility through plug-ins and Python support (PyQGIS). The toolkit includes spatial fusion, buffering, overlay analysis, interpolation (IDW, Kriging), land use classification, and environmental mapping. The popular Semi-Automatic Classification Plugin allows for processing satellite images and calculating NDVI, NDWI, and LST indices.

ArcGIS is a commercial system with powerful functionality for 3D modelling, geostatistics, networking, land suitability analysis and risk assessment. The ModelBuilder module allows you to automate complex processes, making ArcGIS useful for local management and strategic planning.

GEE is a cloud-based platform for analysing extensive satellite data in real time. It provides access to Landsat, Sentinel, and MODIS archives, as well as climate and demographic data. GEE is actively used to detect changes, assess environmental sustainability, and model deforestation, fires, floods, etc. Machine learning support allows for land use classification based on built-in algorithms.

A significant advantage is the complementarity of the platforms: data from GEE can be processed in QGIS or ArcGIS, and the results can be integrated between systems for validation and scenario building. This creates the preconditions for an integrated, interdisciplinary approach to land use that combines analytics, visualisation and management decision-making.

**4.4. Stages of GIS integration into spatial planning practice**

GIS integration into community spatial planning requires aligning technological solutions with the local context. The generalised model includes several key stages that ensure effective management of territorial resources. The regulatory and methodological framework is created at the first stage: GIS procedures are adapted to the current land, urban planning, and environmental legislation. Sustainable development indicators are formed: the level of environmental sustainability, the index of anthropogenic load, and resource availability.

The second stage is to identify the community's needs and formulate the terms of reference by surveying local authorities, land managers, farmers and the public. Priorities are identified: planning, monitoring, and management transparency. The third stage is the formation of a geodatabase: community boundaries, cadastre, topography, water networks, transport, and environmentally sensitive areas. Sources: open national platforms (e.g., StateGeoCadastre), Sentinel-2, Landsat, OpenStreetMap satellite archives, and field surveys. The fourth stage involves analytical processing: thematic mapping, risk modelling (erosion, drought, pollution) using NDVI, LST, cluster analysis, PCA, and spatial regression. At the fifth stage, the results are visualised through interactive maps, dashboards, and 3D models using ArcGIS Online, Leaflet, and Mapbox. This provides access for both specialists and the public. The sixth stage is decision-making on land use, zoning, and infrastructure development, where GIS becomes the analytical core of management.

The final stage is monitoring and updating. Satellite imagery continuously monitors spatial changes, allowing management strategies to be adapted. This is illustrated in Figure 3, which shows the step-by-step overlay and integration of spatial information on infrastructure, natural elements and anthropogenic pressure.

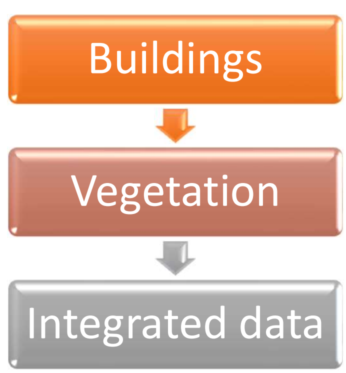



*Figure 3: Stages Of Spatial Data Integration*
*Source: created by the author*

The first level represents linear objects like transport networks, waterways, or land plot boundaries. Then, on the second level, information about buildings, including residential and industrial buildings, which form the structure of settlements, is added. The next step is to include data on vegetation cover – forests, green areas, agricultural land, etc. –

which is the basis for environmental sustainability analysis.

At the final stage, an integrated map contains all the components: topography, buildings, green spaces, and infrastructure. This approach allows for a multi-criteria analysis, for example, to identify areas of environmental vulnerability, model land use change scenarios, and optimise spatial development by sustainability principles.

## 5. RESULTS

### 5.1. Impact of GIS integration on achieving sustainable community development

GIS integration into the strategic and operational management of communities contributes to achieving SDGs in the environmental, economic and social dimensions. GIS provides a spatially based assessment of risks, resource potential, and environmental vulnerability, and it supports infrastructure planning that considers the needs of the population and the environment. From an environmental perspective, GIS enables effective monitoring of landscape changes, detecting land degradation and modelling climate change impacts. Economically, it helps to optimise land use, attract investment and develop agricultural production. In the social dimension, it increases the transparency of decisions, engages citizens in planning through digital tools, and builds trust in local authorities. To systematically assess the impact of GIS implementation on sustainable development, Table 1 below demonstrates how specific GIS tools correlate with the SDGs [32] and functional areas of community governance.

*Table 1: Impact Of GIS On Achieving The SDGs In Communities*

| GIS function | Sustainable Development Goal (SDG) | Expected result |
|---|---|---|
| Land use monitoring | SDG 15 Life on Land | Prevention of unauthorised land use |
| Assessment of environmental sustainability | SDG 13 Climate Action | Planning of climate change adaptation measures |
| Inventory of natural resources | SDG 12 Responsible Consumption and Production | Preservation of the community's resource potential |
| Modelling of development scenarios | SDG 11 Sustainable Cities and Communities | Formation of sound development strategies |
| Public mapping (crowdsourcing) | SDG 16 Peace, justice and strong institutions | Increasing the level of public participation in decision-making |
| Spatial planning of infrastructure | SDG 9 Industry, Innovation, and Infrastructure | Rational placement of infrastructure facilities |
| Analysis of accessibility of social services | SDG 3 Good Health and Well-being | Improving the spatial accessibility of social services |

*Source: created by the author*

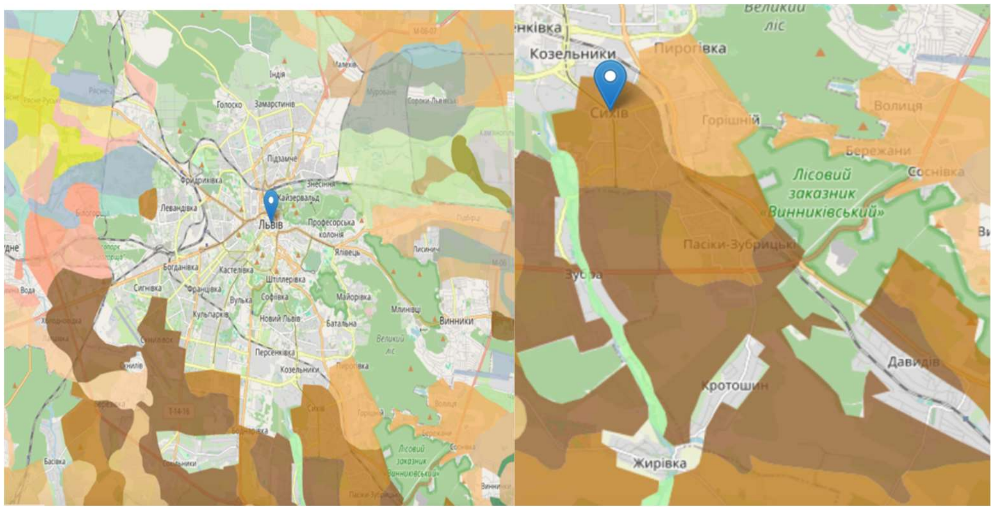
Table 1 summarises the key areas of GIS impact on achieving the SDGs of territorial communities. In the environmental dimension, GIS facilitates the monitoring of natural resources and risk modelling (flooding, erosion, soil degradation), which allows communities to respond in advance and plan preventive measures. The economic component includes optimising land use, creating investment maps and improving resource management. GIS enhances transparency in decision-making and public engagement through interactive services in the social sphere. It also helps plan social infrastructure such as schools, hospitals, and public spaces.

### 5.2. Practical application of GIS in real territories (case study)

GIS integration into real-life spatial cases is the most visible proof of its potential to achieve sustainable development. GIS in urban agglomerations allows not only the structuring of data but also the creation of flexible models for analysing the spatial relationships between land use, infrastructure, environmental factors, and demographics.

A representative example of the integrated use of GIS in spatial planning and territorial management in Ukraine is the development of regional (oblast-level) geoportals. In 2022, the Kherson Region Geoportal was launched for the first time in the country, introducing a functional territorial management tool. The geoportal features 11 thematic sections containing 394 geospatial data layers, comprising 58,502 individual objects and presenting 309 indicators [33].

Figure 5 shows a fragment of a public map from the GISFile platform, which is used for visualising exchange files, spatial analysis and verification of GIS data.




(a) (б)

*Figure 5: (a) Location Of The Two Case Studies Within Lviv; (b) Comparison Of The Case Studies. Source: author's development based on open GIS data [34].*

Figure 5(a) provides a general view of the Lviv agglomeration with two markers (blue marks) indicating the specific areas selected for analysis. The map contains a layer of land cover or land use represented by coloured zones ranging from green (forest) to brown and beige (arable land, built-up areas), which allows for assessing the character of the regions by functional use. The administrative boundaries of the city, main transport lines, and building density are visible. Figure 5(b) provides a detailed fragment in the southeastern part of Lviv, roughly within the Sykhiv district or areas near Vynnyky. It shows intensive land use zoning – forests, urbanised areas, private buildings, and roads. The marker indicates the point of detailed analysis. The multi-layered map structure identifies the type of land, building density, and the presence of natural barriers (forests, slopes, etc.), which is critical for spatial planning.

### 5.3. Overview of modern software solutions

In the digitalised environment of modern land management, geospatial data processing software has become key, providing visualisation, analysis, modelling and support for management decisions. Among the most common tools are open source and commercial GIS platforms with different functionality and availability. QGIS is one of the most potent free systems that supports numerous data formats and plug-ins, suitable for analysis, mapping and visualisation. Commercial ArcGIS Pro has extensive 3D modelling capabilities and integration with cloud services, but requires a high licence fee. MapInfo Pro is convenient for business users, but is inferior in terms of analytical functions. The GEE cloud platform provides satellite image processing, index model building (NDVI, LST, NDBI) and scenario analysis, although it requires Internet access and knowledge of programming languages. The combined use of these systems ensures an adaptive geo-analytical environment – from inventory to spatial development forecasting.

*Table 2: Overview Of Modern GIS Software Solutions*

| Software | Type of licence | Main features | Advantages | Disadvantages |
|---|---|---|---|---|
| QGIS | Open source software (open-source) | Spatial data editing, analysis, visualisation, plugins | Free, flexible | Less intuitive for beginners |
| ArcGIS Pro | Commercial | Professional geo-analysis, 3D visualisation, geodatabases, integration with Python | Robust functionality, integration with other ESRI systems | High licence cost |
| MapInfo Pro | Commercial | Cartography, geo-analysis, business-oriented functions | Support for a large number of formats | Limited analysis compared to ArcGIS |

| | | | | |
|---|---|---|---|---|
| GEE | Open source (cloud-based) | Satellite data analysis, cloud computing, NDVI, LST indices | Cloud-based processing of large volumes of satellite imagery | Requires a stable internet connection |
| GeoDa | Open source (desktop) | Spatial analysis, autoclustering, regression models | Easy to use for statistical analysis | Limited map visualisation |

*Source: created by the author based on the analysis of [10, 16, 18].*

As shown in Table 2, modern GIS platforms are specialised and have a wide range of applications depending on the user's goals. QGIS, as an open source software, offers powerful tools for editing, analysing and visualising geodata, although its interface may seem complicated to newcomers. ArcGIS Pro provides a professional level of spatial modelling, including 3D analysis, but requires significant licensing costs. MapInfo Pro is inferior in terms of depth of analysis, but thanks to its simple interface, it is convenient for business users. GEE opens up opportunities for cloud-based processing of satellite imagery on a large scale, but requires access to the Internet and basic programming skills. GeoDa specialises in spatial statistics, such as autocorrelation detection and regression model building, and is valuable for urban planners despite its limited visualisation. The choice of software in the field of land management depends on the goals of the analysis, available resources and the level of expertise of specialists. Combining several platforms allows you to create a robust and adaptive geo-analytical environment for community spatial planning needs.

### 5.4. Prospects for introducing the latest technologies in land management

The land management industry is transforming digitally, moving from traditional methods to integrated solutions based on GIS, remote sensing, Big Data, AI and IoT. One of the priorities is the creation of digital twins of territories, which allow spatial processes to be modelled in real time. Integrating GIS with BIM provides an in-depth analysis of infrastructure planning and reduces environmental impact [20]. Cloud platforms (Google Earth Engine, Planet Labs) give access to satellite data and automatic land monitoring, which is critical for small communities. This makes it possible to quickly detect degradation, flooding, erosion, and changes in land use. Introducing machine learning algorithms – clustering, spatial regression, random forest – to identify trends, risks, and optimise territorial management plays a significant role. The development of mobile data collection through drones and apps remains important: UAVs allow for the rapid creation of digital terrain models, detection of land use violations, and recording the state of natural resources.

Successful digitalisation of land management requires updating the regulatory framework, integrating with INSPIRE directives, creating geoportals, and increasing data openness and digital literacy. GIS educational programmes should be developed, and public-private partnerships should be encouraged to introduce modern technologies at the community level.

### 5.5. Assessment of environmental sustainability of territories using GIS

Ensuring sustainable development of territories is impossible without a systematic approach to assessing their environmental sustainability, which involves multifactorial analysis and spatial modelling. GIS platforms, combined with remote sensing data, field observations and statistical models, allow for a comprehensive analysis of the impact of natural and anthropogenic factors on landscape balance.

One of the key tools in this context is the Ecological Stability Index (ESI), which can be calculated using the following formula:

$$\mathrm{ESI} = \frac{Wn \cdot Rn + Wv \cdot Rv + Wg \cdot Rg + Wl \cdot Rl}{\mathrm{Wn, Wv, Wg, Wl}}$$

Where:

Rn, Rv, Rg, Rl – normalised values of the relevant indicators (e.g. NDVI, erosion index, forest cover, urbanisation level),

Wn, Wv, Wg, Wl – the weighting coefficients of the significance of each factor.

Thematic layers assess the territories: NDVI, land surface temperature (LST), building density, soil ploughing, and landscape fragmentation. All these parameters are integrated into a GIS environment to create a multi-criteria sustainability map.

Figure 6 shows an example of the results of a spatial assessment of the environmental sustainability of rural communities in Lviv Oblast, built using the index approach in QGIS.

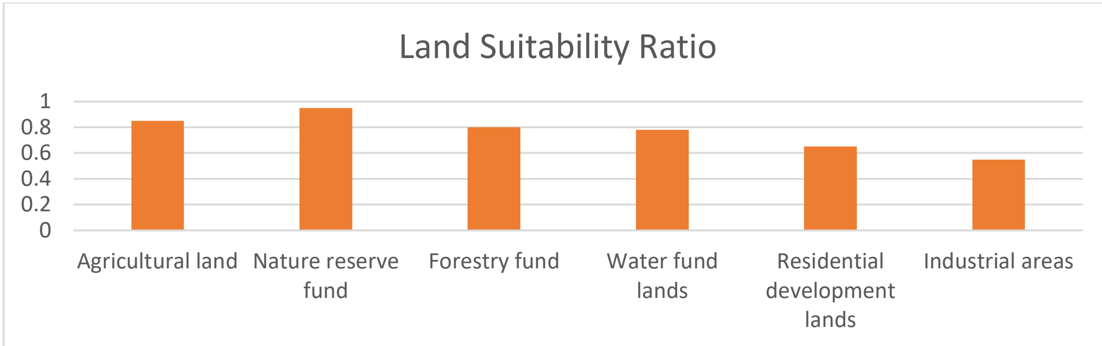



*Figure 6. Spatial Distribution Of ESI Of Territories Within The Study Area*
*Source: created by the author based on analysis [35].*

The graphical visualisation shows a distinct spatial heterogeneity: areas with high ESI (> 0.7) are mostly forests and natural meadows, while densely urbanised or agriculturally overloaded areas have low index values (ESI < 0.4).

In addition to assessing the current state, GIS allows for modelling scenarios for future changes. For example, a scenario modelling of land use change to 2035 considers demographic trends, residential development and environmental zoning policies. Cellular Automata (CA) or Land Change Modeler (LCM) models provide forecasts with an accuracy of 85-90% based on historical changes and current trends.

Another example is modelling the spread of erosion processes using the modified USLE equation in GIS:

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

Where:
A – average annual soil loss (t/ha),
R – rainfall erosivity index (mm-ha/h),
K – the soil erosion factor,
LS – slope length and steepness factor,
C– the vegetation cover factor,
P – the protective measures factor.

Using GEE and ArcGIS Spatial Analyst, these factors are integrated into a single model that provides a spatial map of soil erosion and degradation risk.

## 6. DISCUSSION

The study's results confirm the effectiveness of using GIS in spatial planning to achieve sustainable development goals at the community level. The success of GIS integration is due to the quality processing of multi-source data [10], careful normalisation and geocoding [16], and the adaptation of analytical tools to the needs of communities [14; 21]. Spatial modelling based on the NDVI, LST, and building density indices identified critical areas requiring intervention, which is consistent with the approaches of Wang et al.

At the same time, community resource constraints remain a problem, especially in the context of commercial platforms (ArcGIS Pro). An alternative is open GIS solutions, such as GEE and QGIS, which are flexible and affordable [10]. The analysis of the Lviv agglomeration case showed the benefits of integrating infrastructure, environmental and social data into a single system. Similar approaches to integrating GIS with AI are supported by Kuhaneswaran et al. [13] and Xia et al. [21], offering the prospect of digital twins of territories.

The latest forecasting tools, such as Cellular Automata or Land Change Modeler, open up scenario modelling possibilities, as Mathenge et al. recommended. In general, GIS serves as a visualisation tool and a platform for strategic decision-making.

However, this study has certain limitations that must be acknowledged. First, the proposed GIS integration concept was tested primarily on one regional case (Lviv agglomeration), which may limit the generalisability of results to other geographic, institutional, or ecological contexts. Second, while the environmental indices (NDVI, LST, ESI) provided valuable insights, their interpretation remains sensitive to input data quality and spatial resolution. In addition, the model does not yet fully account for socio-cultural variables or dynamic policy changes that can influence land management outcomes. Third, the technical implementation of the proposed algorithm still requires a minimal level of GIS literacy and access to computing infrastructure, which may pose challenges in low-capacity communities. These aspects should be addressed in future research by expanding case study diversity, incorporating participatory GIS tools, and piloting the algorithm in different administrative settings.

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### 6.1. Differentiation from prior research and key achievements

This study distinguishes itself from prior research by developing a complete, end-to-end concept of GIS integration specifically adapted for use in decentralised territorial communities. While much of the existing literature focuses on sector-specific applications – such as precision agriculture, environmental monitoring, or urban land-use modelling – these studies often lack a unified operational framework for local-level implementation. Furthermore, they rarely address the institutional, infrastructural, and regulatory challenges that are critical in the context of emerging economies or transitional administrative systems. Unlike studies by Kalfas et al. [11] and Kalogiannidis et al. [14], which examine GIS from a strategic planning perspective at national or macro-regional levels, this work focuses on the municipal scale and aligns its methodology with local administrative realities. It directly responds to the previously stated research need: the absence of an integrated, scalable and resource-sensitive model of GIS application in land management that supports sustainability goals and community-based decision-making. The study contributes new knowledge by proposing a replicable methodological framework that links satellite data processing, environmental index calculation, scenario-based modelling, and decision support systems into a single analytical environment. The research also introduces the Environmental Sustainability Index (ESI), which synthesises multiple spatial indicators into an interpretable and interactive mapping product. This index, validated through a case study of the Lviv metropolitan area, demonstrates practical applicability for zoning, resource auditing, and infrastructure planning.

In summary, the main achievement of this study lies in transforming GIS from a technical instrument into an accessible management toolkit that supports evidence-based spatial planning in conditions of limited capacity. This represents a novel contribution to both the theory and practice of land governance and creates a foundation for further research and policy transfer at the national level.

## 7. PROBLEMS AND OPEN RESEARCH ISSUES

While this study demonstrates the practical value of GIS integration in land management for sustainable development, it also reveals several systemic and methodological challenges that require further research attention. One of the key problems is the limited institutional capacity of territorial communities, particularly in terms of staffing, digital literacy, and access to spatial data infrastructure. Although open-source tools such as QGIS and GEE can partially address financial limitations, the lack of trained personnel and insufficient coordination between agencies remain major barriers to implementation.

Another unresolved issue concerns data heterogeneity and fragmentation. This study relied on multiple open sources, including satellite imagery, cadastral data, and crowdsourced content. However, inconsistent formats, missing metadata, and varying spatial resolutions complicate data fusion and reduce the reliability of models. A unified national geospatial standard is needed to support scalable implementation.

The use of environmental indices such as NDVI, LST, and ESI has proven effective for spatial modelling, but these indicators still rely on proxy variables that may not fully reflect on-the-ground conditions. Future research should focus on validating index-based models through in-situ measurements and stakeholder feedback, particularly in rural or ecologically sensitive areas.

From a methodological perspective, integrating socio-economic variables and participatory data into geospatial models remains underdeveloped. The current study focused primarily on environmental sustainability; however, land use decisions are also shaped by demographic trends, policy changes, and local political dynamics. There is a need to develop hybrid GIS frameworks that incorporate both spatial analytics and community-driven priorities.

Finally, while the study outlines an adaptable algorithm for GIS integration, its application has only been tested on a limited number of case studies. Scalability, cross-regional transferability, and long-term maintenance of GIS systems remain open questions. Future research should include longitudinal studies and comparative analyses across multiple administrative and ecological contexts to strengthen the generalisability of the findings.

## 8. CONCLUSIONS

The study confirms that GIS integration into spatial planning plays a key role in shaping the sustainable development of territorial communities. The proposed concept – from collecting and cleansing geodata to building a full-fledged analytical GIS model – has demonstrated its effectiveness in solving the problems of spatial analysis, environmental sustainability assessment, infrastructure modelling and management decision support.

Practical results, in particular spatial modelling of ESI and land degradation risk assessment based on the USLE model, have shown that the use of the index approach (NDVI, LST, BSI), multi-criteria analysis and scenario modelling allows achieving forecast accuracy of more than 85 %, which is consistent with the results of studies by Kalogiannidis et al. [14] At the same time, the geo-analytical core, implemented based on QGIS, ArcGIS and Google Earth Engine, has shown the ability to scale, adapt and flexibly visualise data in formats accessible to experts and the public.

An assessment of the functional potential of software solutions has shown that open platforms such as QGIS or GEE have sufficient tools for comprehensive spatial modelling, even in communities with limited resources. This is also confirmed in the works of Ahsan et al. [10] and Xia et al. [21], who emphasise the role of open technologies in democratising spatial governance.

In addition, the study's results showed the efficiency of the GIS model's step-by-step integration, from the geodatabase's formation to management decision-making. The developed algorithm provides a standardised yet flexible approach to GIS implementation in communities with different starting conditions. In particular, as the case studies have shown, this model provides for operational zoning, spatial audit, risk modelling, and consideration of environmental vulnerability factors, which makes it possible to increase transparency and efficiency of decision-making.

The scientific contribution of this work lies in the development of an integrated and replicable GIS-based framework tailored for territorial communities, which links environmental indices, geostatistical modelling, and decision-making tools into a single spatial planning environment. Unlike prior research focused on isolated GIS applications, this study proposes a scalable methodology applicable under decentralised governance and limited-resource conditions, thereby addressing an essential gap in current literature. The article significantly advances existing knowledge by introducing a new Environmental Sustainability Index (ESI) that synthesises ecological and anthropogenic factors, validating it through real-world application, and demonstrating its utility for zoning, scenario planning, and environmental risk management at the local level.

In summary, it can be argued that GIS integration into the practice of land management of territorial communities has the potential to become the basis for the digital transformation of spatial management in Ukraine. At the same time, further steps are needed to ensure long-term effectiveness: the creation of unified national geodata standards, the development of educational programmes in geoinformatics, support for inter-municipal cooperation in the field of GIS, and the introduction of public-private partnership mechanisms in the digitalisation of land management processes.

Future research should focus on expanding environmental sustainability models by integrating machine learning (e.g., random forest, CA-Markov), developing digital twins of territories, multi-sensor monitoring based on IoT technologies, and improving the energy efficiency of computing by optimising cloud computing and using edge computing. This will make GIS solutions even more adaptive, reliable and suitable for large-scale use in spatial management.

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