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Landscape-Ecological Analysis for Sustainable Rural Development

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SUMMARY

Sustainable development of rural territories in the context of contemporary climate, socio-economic, and war-related challenges requires a shift from an administrative to a functional approach to their spatial identification and planning. The aim of this study is to explore the potential of landscape-ecological analysis for identifying Functional Rural Areas (FRAs) at different hierarchical levels of organization as objects of planning and revitalization for sustainable development. The research methodology is based on landscape-structural, landscape-functional, and landscape-organizational principles, employing a geoinformation approach, geospatial analysis of a digital elevation model and land-cover structure analysis. For territories dominated by fluvial processes, such as the Area of Interest, a hierarchical model for the spatial identification of FRAs is proposed, in which the paradynamic district corresponds to the Rural Region level, landscape tiers to Rural Areas, and landscape belts to agricultural landscapes. The approach was tested in the Inhulo-Verevchynskyi paradynamic district, covering an area of 3,430.92 km². Geospatial analysis revealed the dominance of agricultural land (45.27%) and grassland-meadow vegetation (35.14%) in the land-cover structure and enabled the identification of the internal spatial differentiation of the study area. The proposed approach provides a functional-landscape basis for spatial planning, the restoration of war-affected agricultural landscapes, the development of green-blue infrastructure, and the implementation of nature-based solutions as components of sustainable development of FRAs. Territorial communities located within FRAs are identified as subjects of economic cooperation and strategic decision-making for Sustainable Rural Development.

Keywords: Landscape-Ecological Analysis; Functional Rural Area; Rural Region; Rural Area; Agricultural landscape; Sustainable Rural Development.

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Introduction

"A Long-term Vision for the EU's Rural Areas – Towards Stronger, Connected, Resilient and Prosperous Rural Areas by 2040" (European Commission, 2021) (hereinafter referred to as the Vision) significantly broadens the traditional understanding of rural territories which are considered not merely as spaces for agricultural production, but as multifunctional socio-ecological systems that contribute to the resilience of the European Union. Rural territories are identified as a spatial basis for implementing the European Green Deal and the EU Biodiversity Strategy for 2030.

Since the European Commission considers rural territories as multifunctional natural and socio-economic systems, the assessment of their landscape structure, spatial configuration, fragmentation, ecological connectivity, and the condition of agrolandscapes becomes an essential scientific basis for implementing sustainable development policies.

Following Ukraine's acquisition of EU candidate country status, the harmonisation of rural development policy with European approaches to rural territories (specifically Rural regions and Rural Areas, and agricultural landscapes) have become one of the key directions in adapting the national agricultural policy. The Vision is regarded as a strategic framework for implementing a landscape-ecological approach to land-use management, restoring natural capital and ecosystem service potential, and enhancing the resilience of Rural Areas to climate-related and war-induced risks.

The Organisation for Economic Co-operation and Development (OECD) developed the report "Rural Well-being: Geography of Opportunities" (OECD, 2020), which provides a framework for assessing rural territories in terms of quality of life, natural capital, and ecosystem services. The document clearly defines the concept of *Functional Urban Areas* (FUAs), reflecting a shift from administrative delineation towards a functional approach to territorial analysis and spatial planning. The functional approach has subsequently been extended to other types of territories, including rural territories, contributing to the development of the concept of *Functional Rural Areas* (FRAs) in contemporary European regional policy. While FUAs are based on an FRAs currently remain primarily a conceptual and analytical approach applied in research and rural development policy documents and, unlike FUAs, are not yet underpinned by a single officially established methodological standard.

Landscape-ecological analysis (LEA) constitutes a scientific-research paradigm for the identification of FRAs, specifically, agricultural landscape, Rural Areas, and Rural Regions. The application of its principles, together with the tools provided by geographic information systems and geospatial technologies, is considered a pathway towards Sustainable Rural Development which is characterised by well-developed green-blue infrastructure, a high level of biodiversity, climate neutrality, a broad range of ecosystem services, and a high level of well-being in rural territorial communities.

In this study, we propose to examine the scope and role of LEA in identifying agricultural landscapes, Rural Regions as objects of spatial planning and integral components of Sustainable Development Strategies for rural territorial communities.

Method and Theory

The theory and practice of LEA accumulated research experience in addressing a range of issues, including the principles of landscape-ecological inquiry, spatial landscape-ecological modelling, the multiplicity of landscape territorial structures, landscape anthropisation, ecosystem service potential, landscape planning, precision agriculture, and nature-based solutions (NbS) for Sustainable Rural Development.

The landscape-structural principle of landscape studies, from the standpoint of the concept of polystructural landscape-territorial organisation (Grodzynskyi, 2014; Shyshchenko & Denysyk, 2024), allows for the identification of different landscape systems and objects within a given territory, including genetic-morphological, positional-dynamic, basin, and other systems. Spatial analysis of digital elevation models, including morphometric and hydrological analysis, is a key methodological approach to GIS-based modelling of landscape territorial structures (Bilous et al., 2020).

The landscape-functional principle of landscape studies is fundamental to the study of the socio-economic potential of landscapes (Grodzynskyi, 2014; Shyshchenko & Denysyk, 2024), the level of landscape anthropisation (Samoilenko et al., 2025), ecosystem services potential.

The landscape-organisational principle involves the integration of structural and functional analyses to support planning decisions concerning the economic use and management of landscapes (Shyshchenko & Denysyk, 2024). Landscape-organisational analysis provides a fundamental basis for landscape planning and landscape architecture. Landscape planning is implemented at different levels of the administrative-territorial organisation of natural resource management. A landscape programme is developed for administrative regions (at a scale of 1:200 000–1:300 000), a framework landscape plan for administrative districts (1:50 000–1:100 000), and a landscape plan for territorial communities, small towns, urban districts, settlements, and villages (1:5 000–1:25 000) (Golubtsov, 2021).

The framework landscape plan serves as a level for identifying Rural Regions and planning Rural Areas. The landscape plan represents a level of spatial organization for agricultural landscapes and the development of Digital Farming Technology systems (Kokhan et al., 2020) and NbS for Sustainable Rural Development. Last one supported by NbS, has the potential to enhance food security, conserve biodiversity, mitigate pollution, and serve as an important mechanism for carbon sequestration (Sankalpa et al., 2026). An agricultural landscape is a complex system of elements with diverse functional purposes. Agricultural landscape features are small habitat elements embedded within agricultural landscapes, including woody features, field margins, ponds, ditches, stone walls, and other landscape elements. They support biodiversity and provide ecosystem services such as soil protection and pollination (Czúcz et al., 2022).

Results

Ukraine's food and environmental security depends on the systems and mechanisms for the revitalisation of war-transformed FRAs. To provide a scientific basis for their development and implementation, the spatial identification of FRAs is a priority task. For territories where landscape genesis is primarily determined by fluvial processes, the spatial differentiation of FRAs is shaped by the positional-dynamic characteristics of landscape organisation. To model the positional-dynamic landscape territorial structure (LTS) and conduct analysis at the hierarchical level of the framework landscape plan (1:100 000), and thus to identify Rural Regions and Rural Areas, Shuttle Radar Topography Mission (SRTM) data were used as the primary data source for generating a digital elevation model (DEM).

Using geoinformation methods and the GIS tools available in ArcGIS and QGIS, geospatial analysis of the DEM was performed to derive the positional-dynamic characteristics of the study area and to delineate the paradynamic region (PDR) and landscape tiers (LTs) (Fig. 1a, b). The PDR represents a functional spatial entity organised by a system of watersheds and bounded by a system of thalwegs and can be identified as an FRA at the Rural Region level. LTs are delineated according to the direction and intensity of fluvial processes and can be identified as FRAs at the Rural Areas level. For example, LTs 3 and 4 (see Fig. 1a) represent floodplain-terrace Rural Areas and can be considered as performing green-blue infrastructure functions.

For modelling landscape strips (LSs), which can be identified as FRAs at the agricultural landscape level, topographic maps at scales of 1:50,000 and 1:25,000 were used as the primary source data. These data were used to create a digital map of LSs for the Shevchenkivska Amalgamated Territorial Community (ATC), Mykolaiv Oblast (see Fig. 1a), which we identified as agricultural landscapes. The LSs were delineated based on slope gradients, elevation, and agro-production soil groups.
For the delineated Inhulo-Verevchynskyi PDR (3,430.92 km²), Corine Land Cover types were identified (see Fig. 1b). Cropland (crops) dominates the land-cover structure, accounting for 45.27% of the total

area. Grassland and meadow vegetation (grass) covers a substantial proportion of the territory (35.14%). Water bodies (water) account for 6.65%, built-up areas (built) for 5.00%, and tree cover (trees) for 3.14%. Other land-cover types include shrubland (shrub – 2.90%), bare soil and sand (bare – 1.39%), and small areas of flooded or waterlogged vegetation (flooded – 0.02%). The results of the analysis of the spatial structure of land cover allow the studied Inhulo-Verevchynskyi PDR to be identified as an FRA at the Rural Region level.

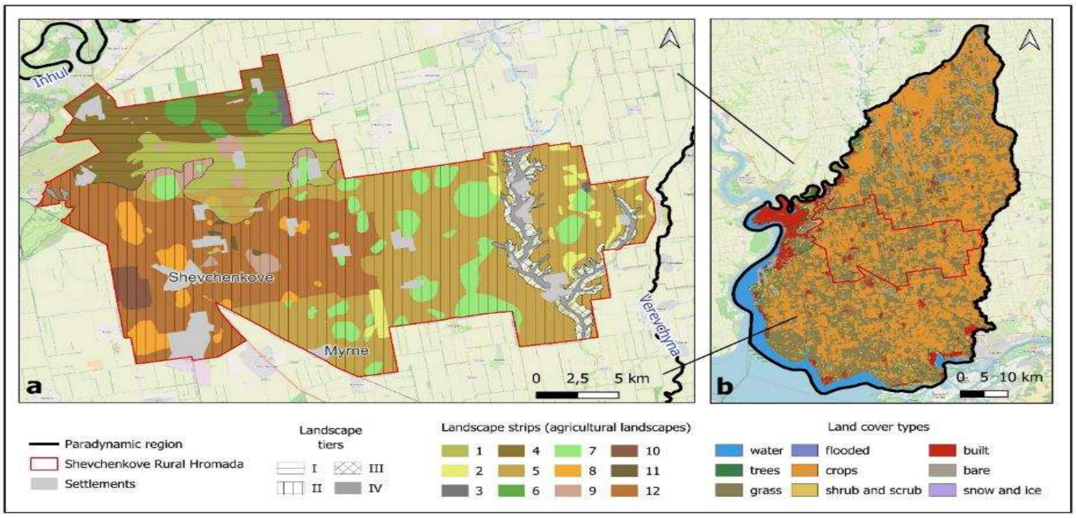

Figure 1. *Functional Rural Areas: (a) agricultural landscapes (landscapes strips) and Rural Areas (landscape tiers) of the Shevchenkivska Territorial Community (for the legend, see Denysyk et al., 2026); (b) land-cover types of the Inhulo-Verevchynskyi Rural Region*

The Inhulo-Verevchynskyi Rural Region was divided, based on the results of morphometric analysis of the DEM, into two relatively homogeneous Rural Areas according to the composition and structure of their agricultural landscapes: the Middle Steppe Subzone of the Steppe Zone of Ukraine (Black Sea Middle Steppe Region) and the Southern Steppe Subzone of the Steppe Zone of Ukraine (Black Sea–Azov Region).

The Inhulo-Verevchynskyi Rural Region and each of its Rural Areas comprise a specific set of territorial communities (TCs), which differ in the distinctive and shared characteristics of their agricultural landscape structures. An understanding by public authorities and local stakeholders (TCs) of their position and role within the FRA system (Rural Region, Rural Areas, and agricultural landscapes) is a key prerequisite for Sustainable Rural Development.

Conclusions

The results of this study confirm the relevance of landscape-ecological analysis as a scientific paradigm for the spatial identification and differentiation of Functional Rural Areas (FRAs). The proposed research principles – landscape-structural, landscape-functional, and landscape-organisational – together with the concept of polystructural landscape-territorial organisation and contemporary geoinformation approaches, enable the delineation of Rural Regions (PDRs), Rural Areas (LTs), and agricultural landscapes (LSs) as spatial entities for strategic cooperation among territorial communities in achieving Sustainable Rural Development. The analysis of land-cover structure provided a basis for the spatial identification and characterisation of the landscape-functional differentiation of FRAs. The Inhulo-Verevchynskyi Rural Region is characterised by the predominance of cropland and grassland vegetation.

The obtained results expand the potential of landscape-ecological research for the functional delineation of rural territories and for the development of a standardised methodology applicable to spatial planning, the revitalisation of war-transformed agricultural landscapes, the development of green-blue infrastructure, the restoration of ecosystem service potential, and the implementation of nature-based solutions.

Understanding the position and role of territorial communities within the hierarchical system of Rural Region – Rural Areas – agricultural landscapes creates a foundation for differentiated management decision-making and Sustainable Rural Development.

Future research should focus on testing and validating the proposed approach across other landscape types and regions of Ukraine.

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