DOI: 10.30970/gpc.2026.1.5222; UDC 551.4+911.2

Topography and natural geoecosystems of Lviv Urban Territorial Community

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Abstract. Geospatial information on the natural landscape is essential for the ecosystem management of urbanized areas. This situation is particularly relevant for the Lviv Urban Territorial Community (LUTC), which is characterized by a diverse natural landscape and aims to achieve climate neutrality amid significant demographic and economic changes caused by the war. In this study, we applied a methodological framework and present the results of mapping the natural landscape of the LUTC as a natural morphogenetic geoecosystem (P-GES), with relief as its leading component.

In addition to literature sources and field information, we used large-scale topographic data, high-resolution satellite imagery, and a medium-scale map of Quaternary deposits to manually delineate two categories of P-GES – classes of macroecochores and individual microecoregions – at a scale of 1:50,000. Ecochores are associations of mesorelief forms, characterized with regard to surface deposits as well as probable properties of the natural land cover, including soil type, edaphic conditions, and dominant tree species. Ecoregions are third-order morphostructures, described by geological conditions and distribution of ecochore classes. We calculated the mean slope gradients and altitudes for ecochore classes and individual ecoregions.

Within the LUTC, four classes of ecochores were identified. Undulating (34.8%) and hilly (32.4%) interfluves predominate; they are composed of loess-like aeolian and eluvial–deluvial loams, on which mesic mesotrophic forests dominated by beech and oak could potentially develop on grey and dark-grey forest soils. Undulating interfluves formed by fluvioglacial sands – with natural sod-podzolic soils and oak-pine forests – occupy 13.0% of the LUTC area, while flat valley bottoms with alluvial deposits and peat, supporting hygric black alder and ash forests, account for 19.8%. These ecochore classes are distributed in varying proportions across the hilly ecoregions of the Lviv Roztochia and the Davydiv Range, as well as the undulating ecoregions of the Lviv Plateau, the Bilohorshcha Plain, and the Lviv Pobuzhia. The largest share of the LUTC area is occupied by the Lviv Pobuzhia (35.3%), while the smallest is the Davydiv Range (9.8%).

Keywords: Lviv Urban Territorial Community; natural landscape; natural morphogenic geoecosystem; topography; natural land cover; ecochore; ecoregion.

Рельєф і природні геоекосистеми Львівської міської територіальної громади

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Анотація. Геопросторова інформація про природний ландшафт необхідна для екосистемного менеджменту урбанізованих територій. Така ситуація особливо стосується

Львівської міської територіальної громади (ЛМТГ), яка характеризується різноманітним природним ландшафтом і прагне досягнути кліматичної нейтральності на фоні суттєвих демографічних і економічних змін, викликаних війною. У цьому дослідженні ми застосували методику та продемонстрували результати картування природного ландшафту ЛМТГ як морфогенної природної геоекосистеми (П-ГЕС), провідним компонентом якої є рельєф.

Окрім літературних джерел і польової інформації, ми використали великомасштабні топографічні дані, високороздільні космозображення та середньомасштабну карту четвертинних відкладів для мануального виділення двох категорій П-ГЕС – класів екохор та індивідуальних екорегіонів у масштабі 1:50 000. Екохори є асоціаціями форм мезорельєфу, які охарактеризували з огляду на поверхневі відклади, а також на ймовірні властивості природного наземного покриву – типу ґрунту, едафічних умов, переважаючих видів дерев. Екорегіони є морфоструктурами третього порядку, які описали з огляду на геолого-геоморфологічну будову та співвідношенням класів екохор. За допомогою цифрової моделі висот для класів екохор та індивідуальних екорегіонів розрахували середні значення ухилів і альтитуди.

На території ЛМТГ виділили чотири класи екохор. Переважають хвилясті (34,8%) та горбисті (32,4%) межиріччями, складені лесовидними еолово- та елювіально-делювіальними суглинками, на яких могли б рости мезофільні мезотрофні ліси з домінуванням бука і дуба на сірих та темно-сірих лісових ґрунтах. Хвилясті межиріччя, складені флювіогляціальними пісками, з природними дерново-підзолистими ґрунтами та дубово-сосновими лісами займають 13,0% площі ЛМТГ, а плаські днища долин з алювіальними відкладами й торфом під гігрофільними чорновільховими й ясеновими лісами – 19,8%. Ці класи екохор розподілені у різних пропорціях поміж горбистими екорегіонами Львівського Розточчя та Давидівського пасма, а також хвилястими екорегіонами Львівського плато, Білогорщської рівнини та Львівського Побужжя. Найбільшу площу у межах ЛМТГ займає Львівське Побужжя (35,3%), а найменшу – Давидівське Пасмо (9,8%).

Ключові слова: Львівська міська територіальна громада; природний ландшафт; природна морфогенна геоекосистема; рельєф; природний наземний покрив; екохора; екорегіон.

Introduction. Urban areas are primary human habitats with high concentrations of people, technogenic structures, significantly modified topoclimatic and hydrological conditions, and cultural / synanthropic biotic communities. Nevertheless, ecosystem-based management, which also considers underlying natural landscape conditions, remains the key approach for adapting urban environments to climate change and evolving socioeconomic circumstances (Brink et al., 2016). In western Ukrainian cities such as Lviv, these emerging socioeconomic conditions are driven by the relocation of populations and businesses from war-affected eastern regions, as well as by an increasing orientation toward European markets and logistics networks. Climate change adaptation has also become a central strategic priority; for instance, Lviv aims to achieve climate neutrality by 2050 (https://www.ucan-ukraine.eu/lviv. Accessed on 05.03.2026).

In Ukraine, information about the natural landscape is legally required as a prerequisite for different planning processes, like integrated development plans or air-quality monitoring programs. Thus, maps of natural landscape units are standard components of planning documentation. However, the absence of officially established methodologies for landscape mapping creates ambiguity, as multiple approaches exist for delineating landscape structures, which are essentially ecosystems with defined geographic boundaries (Angelstam et al., 2013). Therefore, the objective of this study is to develop and apply a methodology for natural landscape mapping, conceptualized as a morphogenic natural geoecosystem, whose spatial structure is primarily determined by topographic factors (Kruhlov, 2020). Furthermore, we propose this methodology as a standardized approach for the delineation of natural landscape units, suitable for subsequent integration into various planning documents. The Lviv Urban Territorial Community (LUTC) provides an appropriate case study, as it encompasses a diverse terrain.

Study area. LUTC is located at approximately 50°N latitude and 24°E longitude in Western Ukraine. According to official data, its area is 315.6 km² (https://city-adm.lviv.ua/lmr/lviv-community. Accessed on 02.01.2026). However, publicly available geospatial data from OpenStreetMap (https://www.openstreetmap.org. Accessed on 02.01.2026) indicate a slightly larger extent of 318.26 km²; this value was adopted in the present study. The LUTC comprises the city of Lviv, with a population of approximately 667,000 inhabitants, as well as 19 smaller towns, settlements, and villages, resulting in a total population of about 729,000 in 2025.

The study area occupies the western part of the Podillia Upland. Elevations range from approximately 230 m in the lowest valley bottoms in the east to 409 m at the High Castle hill – an artificial mound located on the highest ridge in the city center. In tectonic terms, the LUTC is situated along the western margin of the East European Platform, at its junction with the Central European Platform. Above the regional erosion base, Maastrichtian marls are developed, which are overlain – at altitudes exceeding 300 m – by sandstones, sands, and limestones of Badenian age. These bedrocks are largely mantled by unconsolidated Quaternary deposits, whose spatial distribution is generally consistent with the present-day topography of the area (DHS, 2009).

The Main European Drainage Divide traverses the LUTC, dividing it into drainage basins of the Baltic Sea and the Black Sea. The climate is temperate, moderately continental, and is classified as Dfb according to the Köppen - Geiger system (Peel et al., 2007), characterized by cold winters, no dry season, and warm summers. The mean annual air temperature is +8.3°C, and the average annual precipitation totals 769 mm (Круглов et al., 2024). The area lies within the natural range of beech and oak forests; however, the original vegetation has been largely replaced by anthropogenic land cover, including managed (cultural) vegetation, urban development, and other artificial structures (Kruhlov, 2015).

Conceptual framework. We conceptualize a landscape as a complex reality – a geospatially-heterogeneous area with all its tangible and intangible features, including topography, surface geology and soil, topoclimate, hydrological regime, vegetation cover, artificial structures, as well as associated social and economic characteristics (Angelstam et al., 2013). Given its inherent complexity, a landscape can be represented in a simplified form as a geoecosystem (GES) – a model that captures cause-and-effect (process) relationships among landscape properties as they evolve in two-dimensional geographic space (latitude and longitude) and, optionally, over time. GESs are delineated using GIS techniques and are visualized as geographic maps. Different complementary types of GESs may be delineated for the same landscape, depending on the underlying theoretical approach and specific research objectives (Kruhlov, 2020).

In this study we use morphogenic natural GESs (N-GESs), which are landscape models delineated based on similarity in their spatial form, particularly topographic (landform) characteristics. Such N-GESs reflect the geospatial differentiation of genetic relationships between the natural land cover as the dependent component (system output) and geological-geomorphological and climatic conditions as controlling components (system inputs). The natural land cover, in contrast to the actual land cover – which includes the real, existing biotic and anthropogenic formations of the Earth's surface – characterizes the potential biota (vegetation) and soil that would exist in the absence of human influence and other major disturbances (Kruhlov, 2020). The concept of natural land cover follows the notion of primary and potential natural vegetation (Moravec, 1998), which finds application in ecologically sensitive spatial planning and environmental restoration (Yang et al., 2025).

N-GESs are viewed as hierarchically organized geospatial units. Since topography (georelief) serves as the primary differentiator of environmental conditions in such genetic landscape models, its scale forms the basis for geospatial hierarchization. In this study, we examine N-GESs at the level of ecochores, namely macroecochores, which are essentially associations of mesorelief forms created by exogeneous processes and attributed with characteristics of other ecological components, such as surface deposits, topoclimate, and natural (potential) landcover. In addition, we considered N-GES at the level of small ecoregions (microecoregions) corresponding to elements of macrorelief – morphostructures of the third order as large landforms determined by bedrock geology and neotectonics (Kruhlov, 2020). We interpreted ecochores as typological units, while ecoregions – as individuals.

Material and methods. Several geospatial data sources were used to delineate NGESs. These included historical topographic maps at scales of 1:10,000–1:50,000, recent high-resolution satellite imagery provided by ESRI, and a 1:200,000-scale map of Quaternary deposits (DHS, 2009), which served as a supplementary source of information on the geological substrate. The FABDEM digital elevation model (Hawker et al., 2022) was applied to derive geomorphometric indices for the delineated NGESs. Additionally, field observations and published data on natural soils and vegetation previously collected in the vicinity of Lviv were incorporated (e.g., Kruhlov, 2012; Kruhlov, 2015; Mukha, 2003).

Paper maps were digitized and converted into raster format within a GIS environment. Ecochores and ecoregions were manually delineated as vector geodatasets through visual interpretation of large-scale topographic maps and ESRI satellite imagery. Attention was given to the accurate delineation of flat valley bottoms, using contour lines from topographic maps in combination with satellite image texture. The medium-scale map of Quaternary deposits provided information on the genetic types and textures of surficial deposits (parent material). The delineated landforms were subsequently attributed with data on the probable dominant natural soil types, their moisture and nutrient status, and the prevailing tree species, based on field observations and literature sources.

Ecoregion boundaries were primarily defined using contour lines, with the Quaternary deposits map serving as ancillary information. Where appropriate, ecoregion boundaries were aligned with ecochore class boundaries. Each ecoregion was assigned a concise characterization of its topography and geological substratum, as well as a specific name derived from existing small-scale regionalizations (e.g., Kruhlov, 2012; Kruhlov, 2015; Mukha, 2003), with some modifications. Finally, the ecochore and ecoregion geodatasets were clipped to the boundary of LUTC. Zonal statistics were calculated to determine precise areas and geomorphometric parameters of the ecochore classes and individual ecoregions, including mean elevation and mean slope.

Results and discussion. We delineated four classes of natural ecochores and five individual ecoregions (Fig. 1; Table 1). Overall positional accuracy of the geodata is not lower than of a 1:50,000-scale map. The largest portion of the LUTC (34.8%) is occupied by the ecochore class of undulating interfluves with short slopes and shallow gullies composed of loess-like loam (class 3; Fig. 2). These are the most productive agricultural lands of the region with natural dark-grey forest soil (Phaeozem), but with moderate drainage owing to insignificant surface slope (Fig. 3). They are optimal for late-successional hygric–mesic eutrophic broadleaved forests composed of oak (*Quercus robur, Q.*

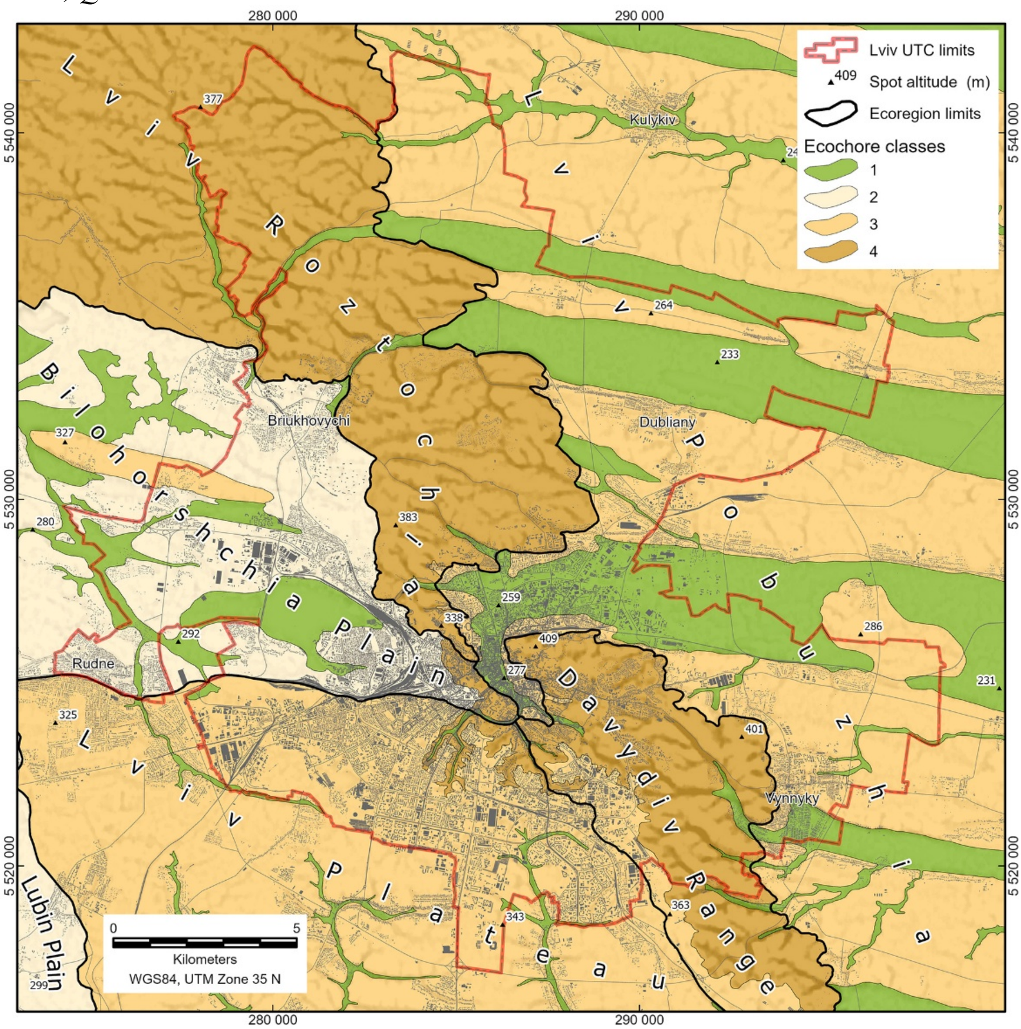

Fig. 1. Lviv Urban Territorial Community. Ecoregions and natural ecochores
Ecochore legend is in Table 1

Table 1. Lviv Urban Territorial Community. Natural ecochores (see Fig. 1)

Class ID	Landform	Surface deposits	Potential natural soil	Moisture / nutrition status	Potential natural prevailing species
1	Flat valley bottoms	Alluvial sand & loam, lacustrine silt & peat	Alluvial & peat (*Luvisol & Histosol*)	Hydric & hygric / eutrophic	*Alnus glutinosa & Fraxinus excelsior*
2	Undulating interfluves	Fluvioglacial sand on glacial till	Sod-podzolic (*Albeluvisol*)	Hygric & mesic / oligo-mesotrophic	*Quercus sp. & Pinus sylvestris*
3	Undulating interfluves	Aeolian (eluvial)-colluvial loam	Dark-grey forest (*Phaeozem*)	Hygric & mesic / eutrophic	*Quercus sp. & Fraxinus excelsior*
4	Hilly interfluves	Eluvial-colluvial loam on bedrock sand, sandstone & limestone	Grey forest (*Phaeozem*)	Mesic & xero-mesic / mesotrophic	*Fagus sylvatica*

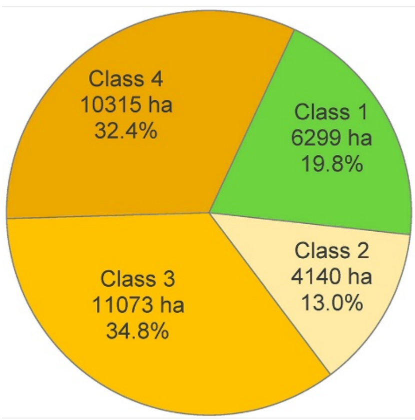

Fig. 2. Distribution of ecochore areas within LUTC (see Fig. 1, Table 1)

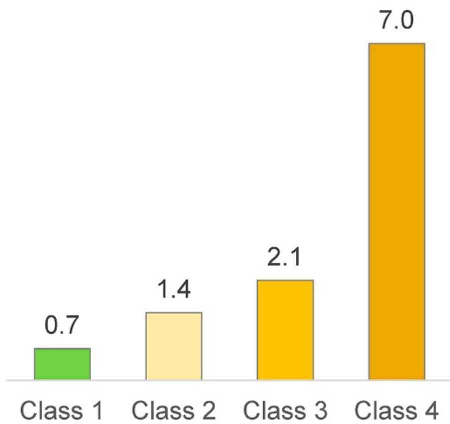

Fig. 3. Distribution of ecochore mean slopes (°) within LUTC (see Fig. 1, Table 1)

petraea), ash (*Fraxinus excelsior*), maple (*Acer platanoides*, *A. pseudoplatanus*), linden (*Tillia cordata*), hornbeam (*Carpinus betulus*) and other species. The ecochore class of hilly interfluves covered with loess-like loam and dissected by deep gullies (class 4) also has significant occurrence (32.4%). The soil here is somewhat less productive (grey forest), but drainage conditions are better due to greater slopes (see Fig. 3). Therefore, this class of ecochores is more suitable for mesic mesotrophic and eutrophic forests with prevalence of beech (*Fagus sylvatica*). It also has the greatest recreational potential.

Flat valley bottoms are filled with alluvial sand–loam and lacustrine deposits (ecochore class 1), and they have a share of 19.8% within the LUTC. These are the most anthropogenically transformed ecological complexes occupied by urban development. We expect that pristine locations of this ecochore class could be occupied by hygric and hydric eutrophic forests with prevalence of alder (*Alnus glutinosa*) and ash. The smallest portion of the LUTC area (13.0%), in its western part, is occupied by undulating interfluves composed of fluvioglacial sand overlaying glacial till of the Early Pleistocene glaciation (ecochore class 2). Small surface slopes (see Fig. 3) and high groundwater table in combination with sandy substrate determined development of less productive sod-podzolic soil (*Albeluvisol*) with hygric oligo-mesotrophic conditions. The latter are suitable for late-successional mixed forests with prevalence of oak and pine (*Pinus sylvestris*).

The five ecoregions of the LUTC are: Lviv Roztochia, Davydiv Range, Lviv Plateau, Bilohorshcha Plain, and Lviv Pobuzhia. Proportions of their areas within the LUTC and the mean altitudes are presented, respectively, in Fig. 4 and 5. The Lviv Roztochia and the Davydiv Range, which form the northwestern and southeastern sectors of the LUTC, respectively, are hilly ridges with asymmetrical slopes. The steeper and more elongated slopes, dissected by stream valleys and ravines, descend eastward toward the lowlands of the Lviv Pobuzhia. The western slopes are less pronounced. Maximum altitudes of the Davydiv Range exceed 400 m, whereas those of the Lviv Roztochia exceed 380 m; minimum elevations range between 250 and 270 m in valley bottoms at the boundary with the Lviv Pobuzhia. The geological foundation of both ecoregions is predominantly formed by Badenian sandstones, sands, and limestones. However, Maastrichtian marlstone is exposed at altitudes of less than ~300 m in deeper valleys. The slopes and summits are predominantly covered by eluvial-colluvial loess-like loam.

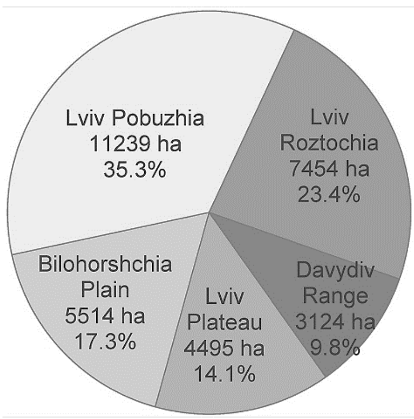

Fig. 4. Distribution of ecoregion areas within LUTC (see Fig. 1)

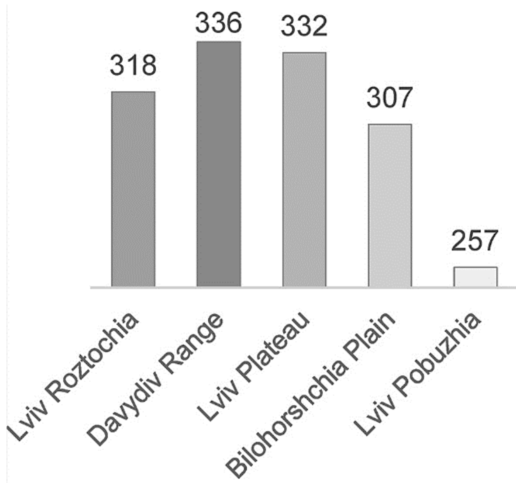

Fig. 5. Distribution of ecoregion mean altitudes (m) within LUTC (see Fig. 1)

The Lviv Plateau occupies the southwestern sector of the LUTC. It is characterized by extensive, nearly flat interfluve surfaces and predominantly gentle, short slopes descending toward narrow stream valleys. Altitudes of interfluves rarely exceed 340 m, while valley bottoms generally remain above 300 m. The surface is covered by a several-meter-thick layer of loess-like eluvial-colluvial loam, underlain by a layer of fluvioglacial clay resting on Badenian sandstones and, locally, anhydrite bodies. As a result, karst features and subsidence microrelief forms occur in this area.

The Bilohorshchia Plain, located in the western part of the LUTC, occupies a somewhat lower hypsometric level than the Lviv Plateau. Maximum altitudes occur near its boundary with Roztochia and reach up to 350 m. However, the broad, undulating interfluve surfaces with poorly expressed slopes generally do not exceed 320 m. These are composed mainly of fluvioglacial and aeolian sands underlain by boulder clay (till). Only on a distinct ridge-like elevation, where the village of Kozhychi is located, does aeolian-colluvial loess-like sandy loam occur. Valley bottoms are very wide in their upper reaches and exhibit sharp narrowing downstream. Their altitudes range from 280 to 305 m, and they are filled with peat overlying glaciofluvial sands.

The Lviv Pobuzhia forms the eastern sector of the LUTC, as well as the northern and central parts of the city of Lviv. This ecoregion occupies the lowest elevation level; its geological basement consists of Maastrichtian marl, and its topography is characterized by a combination of wide valley bottoms separated by low ranges with gentle short slopes extending in a sublatitudinal direction. These ranges have flat interfluve surfaces not exceeding 290 m and are covered by aeolian-colluvial loess-like sandy loam. Altitudes of valley bottoms range from 270 m in central Lviv to 230 m at the eastern boundary of the community and are filled with peat and fluvioglacial sand.

The proposed subdivision of the LUTC into ecochore classes and ecoregions generally builds upon our previous study of the N-GESs of the city of Lviv (Kruhlov, 2012), while introducing several important refinements. The spatial extent of the mapped area has been expanded to encompass the entire LUTC, which is considerably larger than the city of Lviv alone. The positional accuracy of the geospatial datasets has been substantially improved, particularly regarding the delineation of valley bottoms and ecoregion boundaries, thereby providing a more reliable spatial framework for ecosystem-based planning, even at fine scales. At the same time, the number of ecochore classes has been reduced by merging landforms characterized by gradual or indistinct boundaries. For example, gentle slopes and undulating watershed surfaces have been combined into a single association of mesorelief forms representing undulating interfluves. This generalization results in a classification that is more practical for planning purposes, particularly for users without specialized expertise in landscape ecology. Nevertheless, the interfluve structure can be further refined, if necessary, through the incorporation of slope categories derived from digital elevation models. In addition, several ecoregion names have been revised to better reflect locally recognized toponyms; for instance, the terms *Bilohorshcha Plain* and *Lviv Pobuzhia* are introduced in place of *Lubin Plain* and *Ranged Pobuzhia*, respectively.

Conclusions. This study presents an approach to the ecological interpretation of topography and surface deposits, resulting in the delineation of integrated ecological landscape units – NGESs at both local (ecochores) and regional (ecoregions) spatial scales. The proposed approach is applicable for the characterization of potential natural landscapes, including areas that have undergone substantial urban transformation. The resulting map and descriptions of ecochores and ecoregions within the LUTC offer a concise, yet comprehensive and harmonized representation of its fundamental natural conditions. This integrated framework provides a robust basis for the sustainable management and planning of ecosystem services.

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Стаття надійшла в редакцію 17.04.2026
Прийнято до друку 29.04.2026
Дата публікації 19.05.2026