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ANALYSIS OF CARTOGRAPHIC MODELS OF ECOLOGICAL STABILITY AND ANTHROPOGENIC LOAD OF THE ZHYDACHIV URBAN TERRITORIAL COMMUNITY

A. Pyrih, *PhD student*[1]
a.pyrih@ukr.net
ORCID 0009-0009-9321-4393
Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv

The article substantiates a methodological approach to the assessment and optimization of land use in territorial communities based on the integration of geoinformation analysis, environmental indicators, and cartographic modeling. The study was conducted using the example of the Zhydachiv urban territorial community, for which the current land-use structure was analyzed and the dominance of arable land (about 45%) was identified, leading to an increased level of anthropogenic pressure and reduced ecological stability of the territory.

A comprehensive assessment of the environmental condition was carried out using coefficients of ecological stability, anthropogenic load, and an integral indicator, which made it possible to quantitatively and spatially characterize the level

[1] Supervisor – Doctor of Economic Sciences, Professor Kovalyshyn O. F.

of landscape transformation. Spatial differentiation of the ecological condition of the territory was revealed, and zones with different levels of environmental tension were identified, in particular central urbanized areas as hotspots of increased pressure and peripheral areas as zones of relative stabilization.

A series of cartographic models was developed to reflect the land-use structure, the level of anthropogenic impact, and the integral ecological condition, which allowed for identifying spatial patterns of territorial transformation. A land-use optimization scenario is proposed, aimed at increasing the area of natural land, reducing plowing intensity, and forming an ecological framework. The obtained results can be used to support decision-making in the field of rational land use and to ensure the sustainable development of territorial communities.

Keywords: *land use; territorial community; ecological stability; anthropogenic load; cartographic modeling; GIS; integrated indicator; land use optimization; sustainable development*

Relevance. Rational use of land resources is one of the key conditions for ensuring the sustainable development of territorial communities. In the context of decentralization and the transformation of territorial governance systems, the issue of effective land-use planning, taking into account environmental constraints and economic needs, is becoming particularly important.

The current land-use structure of many territorial communities in Ukraine is characterized by a high level of plowing, fragmentation of natural ecosystems, and a decline in their ecological stability. This leads to land degradation, loss of biodiversity, and increased environmental risks. As shown in the study, the Zhydachiv territorial community is characterized by the dominance of agricultural land use, with a high degree of plowing and a significant level of anthropogenic pressure. At the same time, there is a need to implement tools that allow for a comprehensive assessment of the territorial condition and provide a basis for substantiating directions for its optimization.

Thus, the development of methodological approaches to the assessment and optimization of land use based on the integration of geoinformation technologies, environmental indicators, and spatial analysis is highly relevant.

Analysis of recent publications. The issue of assessing the ecological condition of territories and optimizing land use is widely covered in the works of domestic and foreign scholars. A significant contribution to the development of theoretical foundations of rational land use has been made by S.I. Dorohuntsov, A.M. Tretiak, and O.I. Drebot, who examined issues of environmentally balanced land use and the formation of sustainable land management models [1–3].

Methodological approaches to assessing the ecological stability of territories have been developed in the works of O.V. Kucher and P.H. Shyshchenko, where the use of a system of coefficients to characterize landscape conditions and determine the level of their ecological stability is substantiated [4, 5].

Modern studies actively use geographic information systems and remote sensing data for land-use analysis and environmental monitoring. In particular, the works of J. Malczewski consider the application of multi-criteria decision analysis (MCDA) in spatial planning, which allows the integration of heterogeneous factors in decision-making processes [6, 7]. Issues of cartographic modeling of environmental conditions and assessment of anthropogenic pressure are addressed in the works of P. Burrough and M. Goodchild, who substantiated the role of GIS in spatial analysis [8, 9].

Recent studies (2020–2024), indexed in Scopus, indicate the active development of integrated approaches to land-use assessment using GIS, remote sensing, and machine learning methods. In particular, the works of Liu et al. [10] and Zhang et al. [11] examine the use of satellite data to assess land-use changes and environmental risks. Studies by Rahman et al. [12] and Wang et al. [13] focus on the application of multi-criteria analysis and geospatial modeling for optimizing spatial planning. The works of Chen et al. [14] and Liu et al. [15] substantiate the use of integral indicators for assessing environmental conditions and supporting decision-making. Liu et al. [16] emphasize that effective land-use planning requires the integration of human activity models and ecological system responses, thereby substantiating the need for an integrated socio-ecological analysis to ensure sustainable territorial development.

At the same time, despite the considerable number of studies, the issues of integrated land-use assessment at the level of territorial communities-taking into account the spatial differentiation of ecological stability indicators and anthropogenic pressure-remain insufficiently developed, which necessitates further research in this area.

Materials and Methods. The study utilized data from the State Land Cadastre, remote sensing data, topographic and thematic maps, as well as open geospatial databases. The methodological framework is based on the application of geoinformation analysis and cartographic modeling.

To assess the ecological condition of the territory, coefficients of ecological stability and anthropogenic pressure were calculated, followed by the determination of an integral indicator. Spatial analysis was carried out using GIS technologies, which made it possible to perform territorial zoning and identify patterns of transformation.

Results and Discussion. The developed cartographic models of land-use structure, ecological stability, and anthropogenic pressure made it possible to carry out a comprehensive assessment of the current state of the territory of the Zhydachiv urban territorial community.

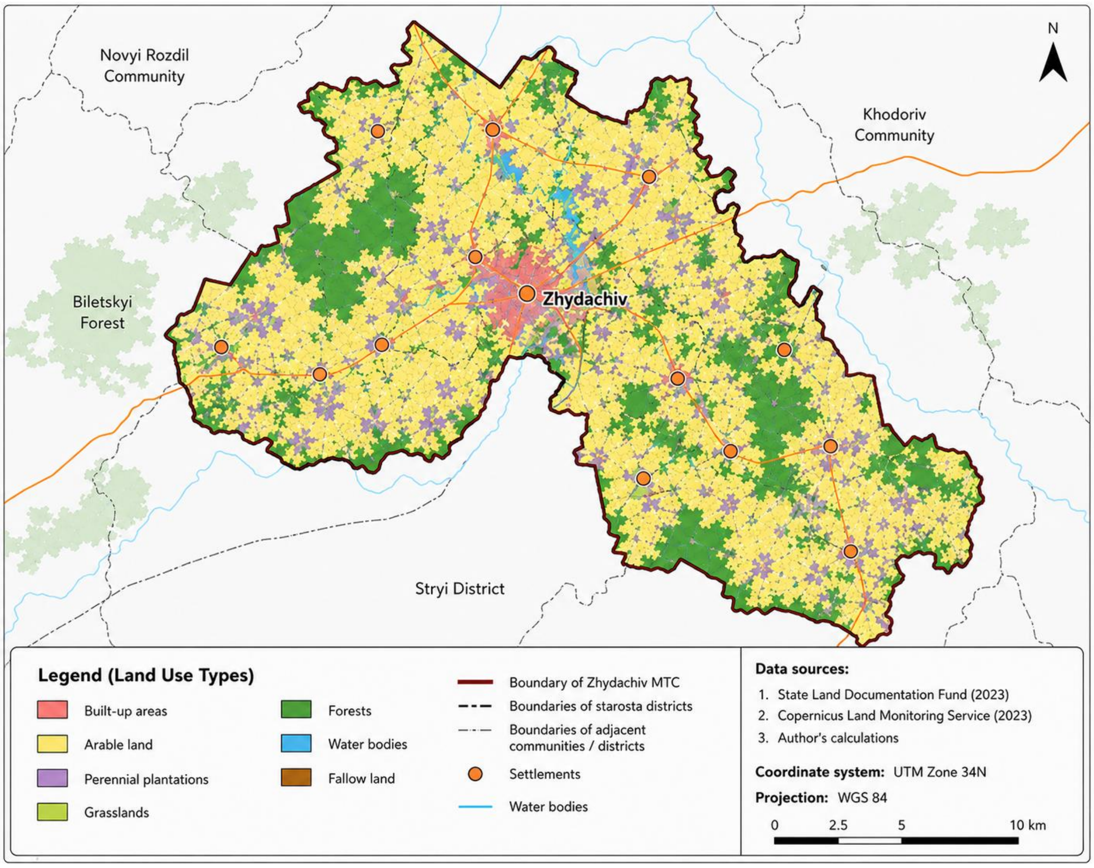

Fig. 1. Cartographic model of the structure of the Zhydachiv territorial community

The analysis of the land-use structure map indicates a clearly expressed agricultural orientation of the territory, as arable land is the dominant type of land use, accounting for about 45%. Spatially, arable lands are mainly concentrated in the central and eastern parts of the community, particularly within the Vilkhovets and Zarichne starosta districts, forming zones of increased anthropogenic pressure (Fig. 1). Table 1 summarizes the quantitative characteristics of land use.

Forest lands, which perform a key stabilizing function, occupy about 12% of the territory and are unevenly distributed. Their main areas are concentrated in the Berezhnytsia and Mlynyshche starosta districts, where they form a kind of ecological framework of the territory and ensure the maintenance of natural balance.

Meadow lands, represented by hayfields and pastures, occupy about 28% of the area (Fig. 2).

The ecological stability coefficient is calculated using the following formula

$$K_{ec} = \frac{\sum(S_i \cdot k_i)}{S_{tot}},$$

where S_i - area of a specific land-use type, k_i - ecological significance coefficient of the land-use type, S_{tot}- total area of the territory.

1. Quantitative indicators of land-use structure (Zhydachiv Territorial Community)

Land-use type	**Area, ha**
Built-up area	1030.22
Arable land	7552.06
Perennial plantations	143.32
Hayfields	2524.27
Pastures	2204.20
Non-agricultural land	648.16
Water bodies	686.73
Forests	2017.03
Total	**16805.99**

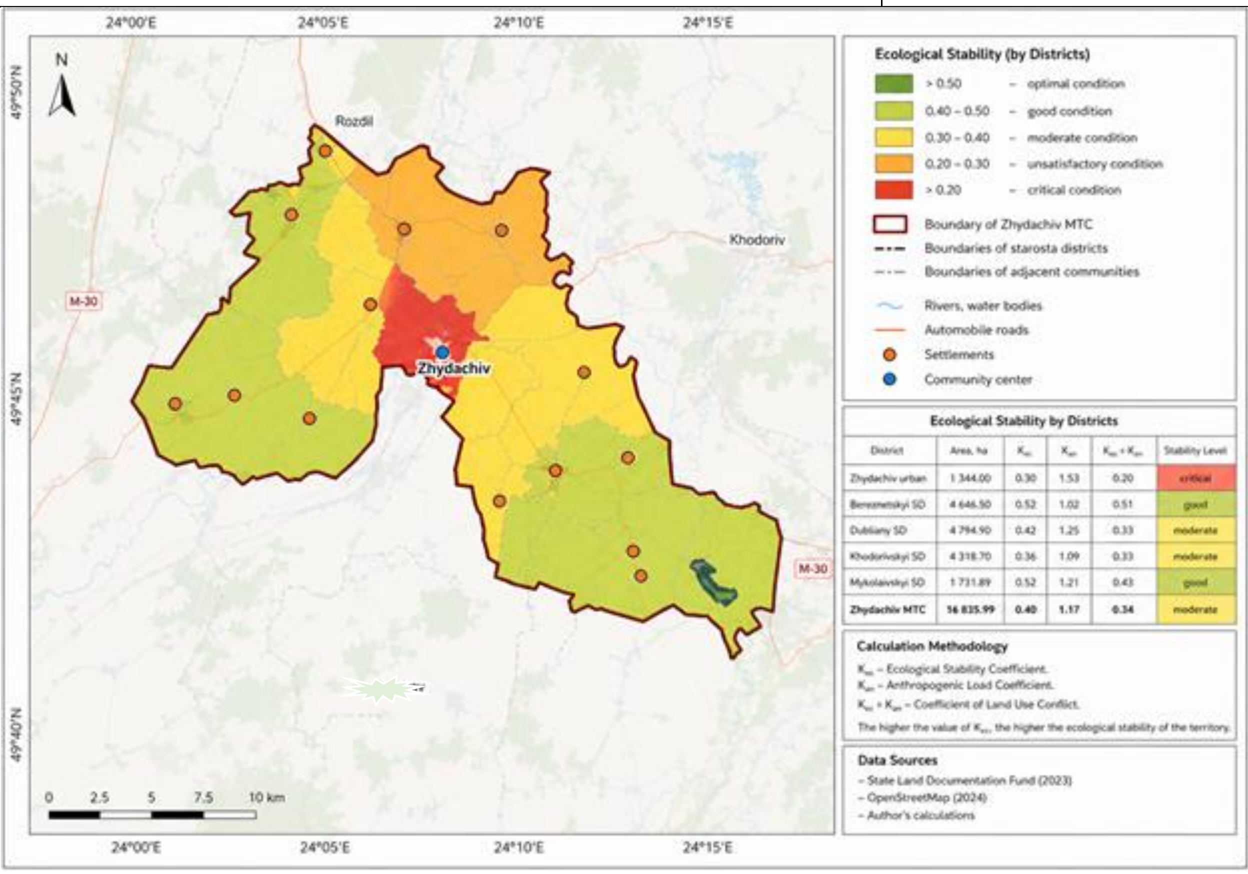

Fig. 2. Cartographic model of ecological stability of land use in the Zhydachiv territorial community

They play an important buffering role by separating intensively developed areas from natural ecosystems. However, their spatial distribution is fragmented, which reduces the overall effectiveness of ecological stabilization.

The spatial analysis of the ecological stability coefficient (Kes) showed that its values range from 0.30 to 0.53, corresponding to a low to moderate level of ecological stability. The most unfavorable conditions are observed in the city of Zhydachiv, where the indicator is approximately 0.30, due to the high share of built-up areas and significant anthropogenic transformation of landscapes. A similar situation is observed in the Zarichne starosta district (Kes ≈ 0.35), where intensive agricultural land use predominates.

The highest values of the ecological stability coefficient were recorded in the Berezhnytsia (Kes ≈ 0.53) and Mlynyshche (Kes ≈ 0.49–0.52) starosta districts. This is explained by a significant share of forest lands and natural forage areas, which perform the function of stabilizing the ecological condition of the territory. The Vilkhovets district is characterized by a moderate level of stability (Kes ≈ 0.41) and combines both stabilizing and destabilizing land-use elements.

The overall value of the ecological stability coefficient for the entire community is about 0.40, indicating a low level of ecological balance of the territory.

A cartographic model of anthropogenic pressure was developed (Fig. 3).

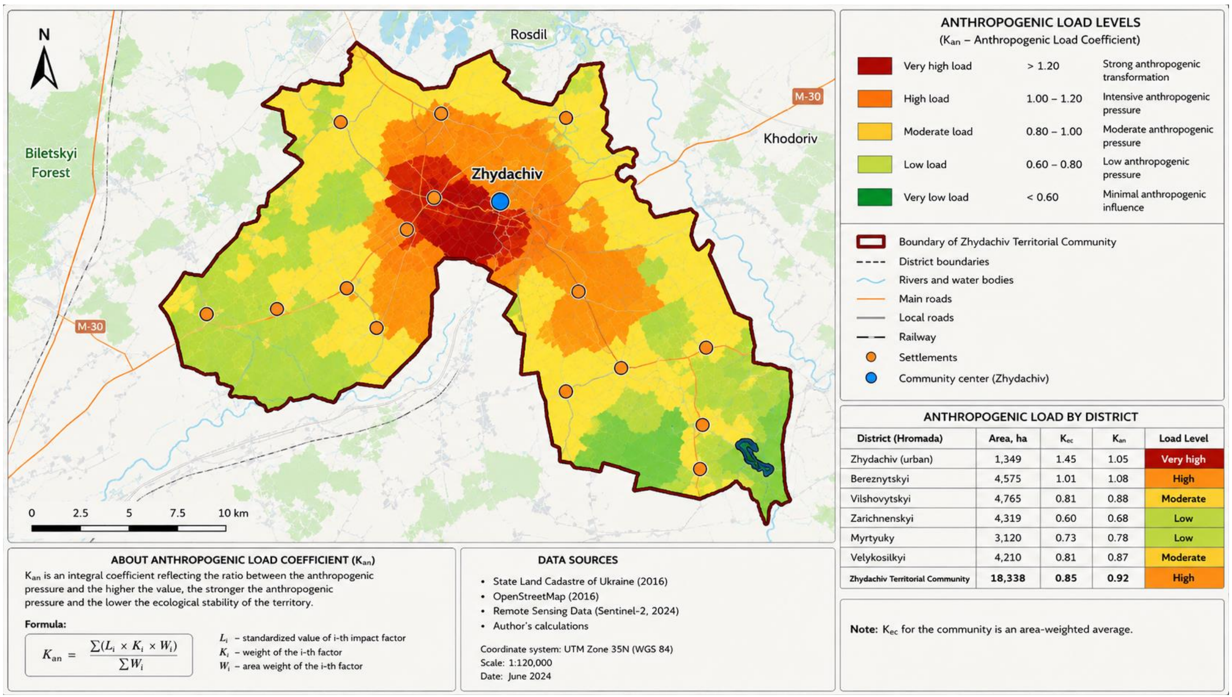

Fig. 3. Cartographic model of anthropogenic pressure in the Zhydachiv territorial community

This model reflects the spatial differentiation of the level of territorial transformation within the Zhydachiv urban territorial community and enables visualization of the intensity of economic impact within the starosta districts. Unlike tabular calculations, the map provides a holistic representation of the territorial structure of pressure and reveals spatial patterns of its formation.

The analysis of the cartographic representation indicates a clearly expressed center–periphery gradient of anthropogenic pressure. The maximum values of the indicator are associated with the central part of the community—the city of Zhydachiv, which serves as the core of economic activity. Here, a zone of very high anthropogenic pressure has formed, associated with the concentration of built-up areas, transport infrastructure, and industrial facilities. Spatially, this zone is compact and clearly separated from the surrounding territories.

Around the central part, a belt of increased pressure is formed, covering mainly the Vilkhovets and partially the Mlynyshche starosta districts. These areas are characterized by a combination of intensive agricultural land use and a developed settlement network, which leads to the formation of zones with moderately high anthropogenic impact. Spatially, these territories act as a transition zone between the urbanized core and more natural peripheral areas.

The peripheral parts of the community are characterized by lower levels of anthropogenic pressure. In particular, the Berezhnytsia starosta district shows a relatively lower level of pressure, which is associated with a higher share of forest and natural lands. A similar tendency is observed in the Zarichne district, where, despite a significant share of arable land, the overall level of pressure is moderate due to lower concentrations of built-up areas and infrastructure.

An important feature of the cartographic model is that it allows not only the identification of general pressure levels but also the morphology of its spatial distribution. In particular, anthropogenic impact spreads along transport corridors and zones of economic activity, forming linear structures. At the same time, natural landscape elements such as forests and water bodies act as local areas of reduced anthropogenic pressure.

The resulting cartographic model also demonstrates the fragmentation of the territory by levels of anthropogenic impact, which is a characteristic feature of intensively used agricultural landscapes. The absence of large continuous natural areas results in low-pressure zones being local in nature and not forming an integrated ecological network.

Thus, the cartographic interpretation of anthropogenic pressure makes it possible to identify spatial patterns of territorial transformation in the Zhydachiv territorial community, distinguish cores of maximum impact and peripheral stabilizing zones, and justify the need for a balanced spatial land-use structure. Unlike numerical assessments, the map provides an integrated analytical perspective, which is essential for decision-making in spatial planning and environmental safety.

The constructed cartographic model of the integral ecological condition (Fig. 3), based on the relationship between ecological stability coefficients and anthropogenic pressure, reveals the spatial structure of ecological quality within the Zhydachiv urban territorial community. Unlike numerical assessments, the presented model reflects not only the level of indicators but also the nature of their spatial combination, allowing the ecological condition to be interpreted as a result of interactions between natural and anthropogenic factors.

The cartographic representation demonstrates the formation of a concentric-gradient structure of the integral ecological condition, in which the central part of the community represents the zone of the highest ecological tension. The city of Zhydachiv clearly stands out as an area of critical condition, due to the high intensity of anthropogenic impact and insufficient share of natural stabilizing elements. Spatially, this zone is compact and acts as a core of negative influence, from which ecological pressure gradually decreases toward the periphery.

Around the central part, a belt of territories with a medium level of ecological condition is formed, covering the Vilkhovets and Zarichne starosta districts. These areas are characterized by a combination of significant anthropogenic pressure and the presence of individual stabilizing elements, which prevents the formation of a high level of ecological quality (Fig. 4). Spatially, these territories serve as a buffer zone between the critical core and the more stable peripheral areas.

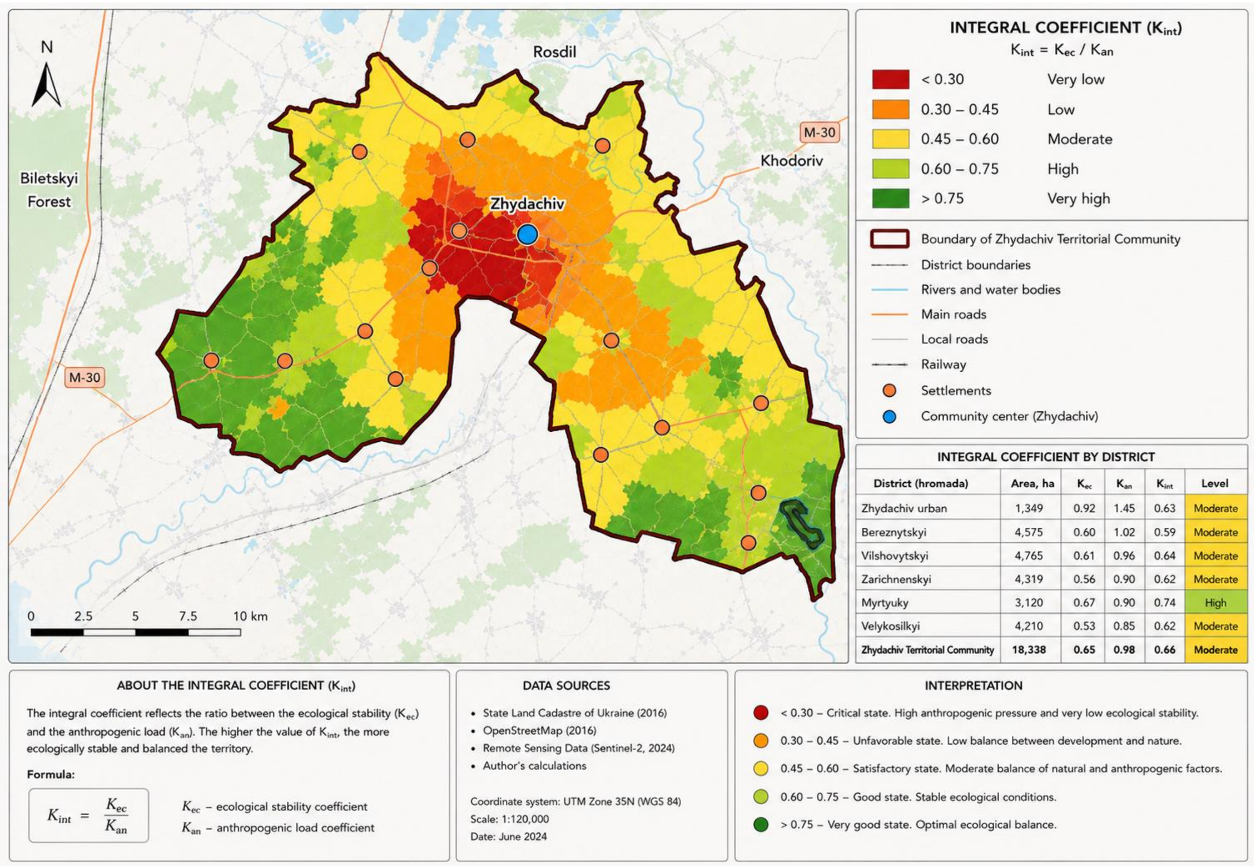

Fig. 4. Cartographic model of the integral ecological condition of the territory of the Zhydachiv urban territorial community (based on the integral coefficient)

The peripheral areas of the community are characterized by a more favorable ecological condition. In particular, the Berezhnytsia starosta district forms a zone of relatively high ecological quality, due to a significant share of forest lands and lower intensity of economic development. The Mlynyshche district occupies an intermediate position, showing an improved ecological condition compared to the central part, but still maintaining a certain level of anthropogenic impact.

A specific feature of the cartographic model is the representation of the spatial interaction between processes of landscape stabilization and destabilization. Natural areas form local centers of increased ecological quality, while urbanized and intensively used areas create zones of its decline. Such a mosaic structure indicates an insufficiently developed coherent ecological framework of the territory.

An important result is the finding that the integral ecological condition of the territory is determined not only by the share of individual land-use types but also by their spatial combination and configuration. This explains differences in environmental quality even under similar values of individual indicators.

Thus, the cartographic model of the integral coefficient allows the territory of the Zhydachiv territorial community to be interpreted as a system of interconnected zones with different ecological conditions, where central urban areas act as zones of high ecological tension, and peripheral natural areas serve as zones of stabilization. The obtained results can be used as a spatial-analytical basis for developing measures to optimize land use and improve ecological stability of the territory.

The cartographic model of the integral coefficient demonstrates a clear spatial differentiation of the ecological condition within the Zhydachiv territorial community, with a zone of critical condition identified within the city of Zhydachiv and relatively favorable conditions in the peripheral areas. It has been established that the combination of high anthropogenic pressure and low ecological stability forms centers of ecological tension, while natural territories perform a stabilizing function.

This confirms the need for a spatially differentiated approach to land-use optimization (Fig. 5).

The analysis of the anthropogenic pressure map (Kan) confirms the existence of an inverse relationship between the intensity of economic development and ecological stability. The highest value of the indicator is characteristic of the city of Zhydachiv (Kan ≈ 1.54), which is due to a high level of urbanization, infrastructure concentration, and intensive land use. Elevated levels of anthropogenic pressure are also observed in the Vilkhovets (≈1.25) and Mlynyshche (≈1.21) districts, where agricultural land use dominates. In the Zarichne district, the indicator is about 1.09, corresponding to a medium level of pressure. The lowest anthropogenic pressure is characteristic of the Berezhnytsia district (≈1.03), which is explained by a higher share of natural ecosystems.

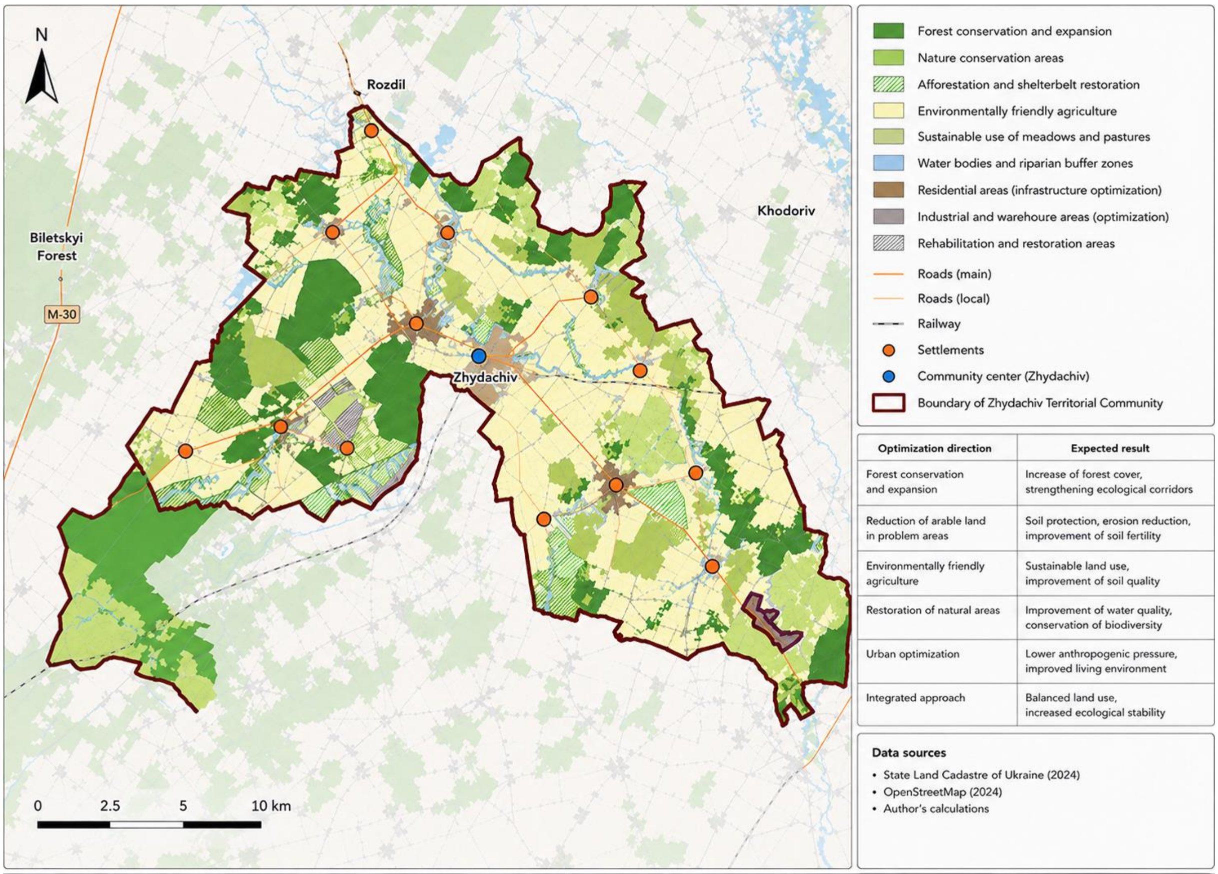

Fig. 5. Land-use optimization scenario

The average value of the anthropogenic pressure coefficient for the community territory is about 1.19, which corresponds to a moderately high level of landscape transformation. The combination of ecological stability and anthropogenic pressure indicators made it possible to perform an integral assessment of the ecological condition of the territory and identify functional zones.

Relatively optimal areas include the Berezhnytsia district and partly the Mlynyshche district, where higher values of the ecological stability coefficient (Kes) and lower values of the anthropogenic pressure coefficient (Kan) are combined. Transitional zones are represented by the Vilkhovets and Zarichne districts, which require optimization of land-use structure. The most critical area is the city of Zhydachiv, where low ecological stability is combined with high anthropogenic pressure.

In order to improve the ecological condition of the territory, a land-use optimization scenario was developed, which provides for an increase in forest areas by 1,200 ha, an expansion of hayfields and pastures by 1,000 ha, a reduction of arable land by 1,800 ha, and the reclamation of disturbed lands. The implementation of these measures ensures an increase in the ecological stability coefficient from 0.40 to 0.55, corresponding to a 37.5% improvement, and a reduction in anthropogenic pressure from 1.19 to 1.02 (by 14.3%).

Spatial analysis of the projected state of the territory indicates a significant improvement in its ecological structure. After optimization, all starosta districts transition to the category of medium and high ecological stability, a coherent ecological framework is formed, fragmentation of natural landscapes is reduced, and ecological connectivity of the territory is improved. This creates prerequisites for increasing biodiversity and enhancing the resilience of the territory to anthropogenic and natural impacts.

Conclusions and prospects for further research. The conducted cartographic analysis confirms that the current land-use structure of the Zhydachiv territorial community is ecologically unbalanced. At the same time, the results of scenario modeling demonstrate the possibility of transitioning the territory toward a sustainable development model, provided that scientifically grounded land-use optimization measures are implemented.

Further research should focus on improving methods of integrated land-use assessment using high-resolution remote sensing data and UAV (drone) imagery, expanding the system of environmental indicators, and incorporating climatic factors. The application of multi-criteria analysis and machine learning methods is a promising direction for improving the accuracy of spatial modeling and forecasting changes in environmental conditions.

An important area of research is the development of land-use optimization scenarios that take into account land degradation risks, urbanization pressure, and spatial planning needs, as well as the implementation of research results into decision-support systems at the level of territorial communities.

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А.В. Пиріг

АНАЛІЗ КАРТОГРАФІЧНИХ МОДЕЛЕЙ ЕКОЛОГІЧНОЇ СТАБІЛЬНОСТІ ТА АНТРОПОГЕННОГО НАВАНТАЖЕННЯ ЖИДАЧІВСЬКОЇ МТГ

У статті обґрунтовано методичний підхід до оцінки та оптимізації землекористування територіальних громад на основі інтеграції геоінформаційного аналізу, екологічних індикаторів та картографічного моделювання. Дослідження виконано на прикладі Жидачівської міської територіальної громади, для якої проаналізовано сучасну структуру землекористування та встановлено домінування ріллі (близько 45 %), що зумовлює підвищений рівень антропогенного навантаження та зниження екологічної стійкості території. Проведено комплексну оцінку екологічного стану із застосуванням коефіцієнтів екологічної стабільності, *антропогенного навантаження та інтегрального показника, що дозволило кількісно та просторово охарактеризувати рівень трансформації ландшафтів. Виявлено просторову диференціацію екологічного стану території та виділено зони різного рівня екологічної напруженості, зокрема центральні урбанізовані території як осередки підвищеного навантаження та периферійні ділянки як зони відносної стабілізації. Побудовано серію картографічних моделей, які відображають структуру землекористування, рівень антропогенного впливу та інтегральний екологічний стан, що дало змогу встановити просторові закономірності трансформації території. Запропоновано сценарій оптимізації землекористування, спрямований на збільшення площ природних угідь, зменшення розораності та формування екологічного каркасу. Отримані результати можуть бути використані для підтримки прийняття управлінських рішень у сфері раціонального використання земельних ресурсів та забезпечення сталого розвитку територіальних громад.*

***Ключові слова*: *землекористування; територіальна громада; екологічна стабільність; антропогенне навантаження; картографічне моделювання; ГІС; інтегральний показник; оптимізація території; сталий розвиток.*