

ANALYSIS OF THE LANDSCAPE STRUCTURE AND OPTIMALITY OF THE CAPITAL REGION OF LITHUANIA

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Abstract

Problems related to landscape structure optimality typically involve challenges in balancing ecological, social, and economic needs while ensuring sustainability. The study utilized diverse scientific methodologies, including comparative analysis, grouping techniques, analytical approaches, statistical data analysis, and graphical representation. Formula calculations assessed natural and cultivated land proportions in Lithuania's Capital Region, evaluating deviation from the optimal ratio and determining optimality class. The study also examined landscape changes from 2004 to 2024. The analysis revealed that during this timeframe, the natural landscape expanded by 3.66 percent, the anthropogenic landscape increased by 12.55 percent, but the anthropogenized landscape decreased by 5.36 percent. When evaluating the composition of the Capital Region landscape, it becomes apparent that in 2024, the predominant portion of the country's terrain was characterized by natural landscape (47.89 percent), while the smallest proportion was attributed to anthropogenic landscape (7.43 percent), with anthropogenized landscape encompassing 44.68 percent of the Capital Region of Lithuania. Additionally, calculations were conducted, determining that the ratio of relatively natural land to cultivated land in the Capital Region, denoted as R_{ns} , equaled 1.99. Upon assessing the relative deviation of the Capital Region of Lithuania from the optimal ratio value (Dr), it was determined to be $Dr = 1.22$, indicating that the region falls within optimality class A2.

Keywords: natural landscape, anthropogenized landscape, anthropogenic landscape, landscape optimality.

Introduction

Nature has created remarkably consistent geomorphic patterns on Earth's surface, which are often attributed to the optimal functioning of natural processes (Paik & Kumar, 2010).

Landscape perception plays a crucial role in the field of landscape studies. Within this, landscape preference represents an integral aspect, reflecting the combined outcomes of various perceptual processes (Cai et al., 2022).

The importance of landscape structure in regulating biodiversity and ecosystem services in agricultural landscapes is increasingly recognized. It comprises two primary components: landscape composition, which pertains to the variety and quantity of habitats, and landscape configuration, which relates to the shapes and spatial arrangement of these elements. Together, these components interact to influence ecological outcomes (Ali et al., 2023).

The concepts of 'ecosystems' and 'landscapes' focus on the horizontal dimension of the Earth's surface and highlight the integration of structures, processes, and functions (Luo et al., 2019).

The landscape offers essential resources such as food, water, and materials to support societal development. It also plays a vital role in regulating various phenomena and processes within a region, while providing numerous cultural and recreational opportunities (Bechera et al., 2023).

When discussing the functions performed by the landscape, its multifunctionality should be mentioned. Multifunctionality refers to the diverse beneficial functions that a landscape provides, spanning from a particular site or neighboring areas (local scale) to an entire region (regional scale). It encompasses various sets of landscape functions related to production, cultural, or

ecological aspects. These functions represent a landscape's potential and capacity to sustainably meet fundamental, enduring, and socially validated material or non-material human needs (Galler et al., 2015).

The essential contribution of ecosystems to human well-being is broadly recognized, underscoring the importance of prioritizing the long-term conservation of multifunctional landscapes (Rodriguez-Loinaz et al., 2015).

The growing demand for land resources to deliver multiple benefits requires landscape strategies that optimize the provision of various ecosystem services. While previous research has primarily focused on changes in land use composition, the spatial configuration of different land use types also plays a key role in driving the supply of ecosystem services (Boesing et al., 2024).

Ecosystem service provision at any specific location within a landscape can be heavily influenced by its surrounding environment. Therefore, both landscape composition and configuration (the way various land use types are arranged) are essential in shaping multifunctionality (Duarte et al., 2018).

Environmental degradation has emerged as a major obstacle to sustainable development and global human well-being. Consequently, scientific efforts are directed at understanding the mechanisms behind environmental degradation and advancing sustainability. Critical Zone science and research on multifunctional landscapes are developing fields within Earth science that have the potential to support these efforts (Luo et al., 2019).

Research on landscape structure and its optimality is becoming increasingly relevant.

Landscape optimality is typically interpreted through a system of core anthropo-ecological criteria based on

land management methodologies. Landscape management is built on the creation of planning zones that apply different land use, protection, and management measures to achieve an optimal spatial structure. At the national level, the optimality of landscape structure should be assessed according to the alignment with strategic macro-zones, which are designed to balance ecological compensation and economic activity in accordance with the universal 'golden ratio' (~60:40) (Veteikis et al., 2016).

With the sustainable development of the modern world, the process of urbanization is accelerating. This urbanization has greatly altered the types and spatial structure of landscapes, leading to corresponding ecological impacts. During the development process, various challenges are often encountered, with ecological issues being among the most significant. These ecological problems are frequently caused by changes in the spatial structure of ecological landscapes. As contemporary urbanization continues to accelerate and deepen, the types and structures of ecological landscapes have undergone substantial transformations. However, these changes in the spatial structure of ecological landscapes inevitably impact the ecological environment (An, 2022).

To strike a balance between landscape conservation and the changing demands for land use and natural resources, it is essential to incorporate the ecological, socio-cultural, and economic values of the landscape into planning and decision-making. Landscape planning requires assessing various competing demands for often limited space. In this process, economic factors, especially financial considerations, tend to play a dominant role, often overshadowing ecological and socio-cultural values (De Groot, 2006). The object of article is landscape structure of the Capital Region of the Republic of Lithuania.

The goal is to evaluate the optimality of the landscape structure in the Capital Region of the Republic of Lithuania.

Tasks to be carried out:

1. to examine the transformations in the natural, anthropogenized, and anthropogenic landscapes of the Capital Region between 2004 and 2024;
2. to determine the ratio of relatively natural and cultivated land in the Capital Region (Rns);
3. to evaluate the landscape's optimality in the Capital Region of the Republic of Lithuania and its classifications.

Materials and Methods

To determine the optimality of the Capital Region landscape structure, an analysis of scientific articles related to the topic was conducted. The study provides a comparative analysis of changes in the areas of natural, anthropogenized, and anthropogenic landscapes between 2004 and 2024.

Using the grouping method, the components of these three landscape types were categorized, and changes in their areas were examined. The natural landscape

components include forests, water bodies, and wetlands, while the anthropogenized landscape encompasses areas altered by human activities but still retaining some natural features. The anthropogenic landscape refers to fully human-modified land uses.

The analysis focuses on evaluating the area changes for each landscape category, utilizing data from relevant land fund statistics. The analysis was based on data from the Land Fund of the Republic of Lithuania for the period 2004–2024. Additionally, the percentage and hectare distribution of the Capital Region landscape types in 2024 were assessed.

The study also analyzed the ratio of relatively natural to cultivated land in the Capital Region.

Furthermore, the relative deviation (Dr) of the landscape structure in the Capital Region from the optimal ratio was calculated, and the optimality class was determined based on a reference table outlining the classification criteria for natural and artificial land use.

In addition to these methods, the study employed analytical and logical analysis approaches. Graphical representation techniques were used, with seven figures and one table included in the article.

Results and Discussion

The transformation of landscape areas in the Capital Region

This work analyzes the change in the areas of three types of landscapes in the Capital Region and the optimality of their structure.

The Capital Region of the Republic of Lithuania covers the entire territory of the Vilnius County, which spans an area of 972,981.51 hectares. This region consists of eight municipalities, six of which are district municipalities.

The transformation of the natural landscape

Changes in the natural landscape involve key elements such as forests, water bodies, and wetlands. Trends in forest cover provide a useful indicator of shifts in landscape naturalness. In the Capital Region, forests span 413,843.23 hectares, representing 42.53% of the total area. Between 2004 and 2024, forest cover increased by 22,096.80 hectares, reflecting a growth of 5.64%.

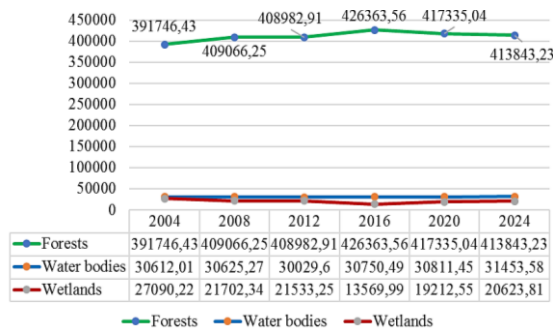
In 2024, water bodies accounted for 31,453.58 hectares or 3.23% of the region. From 2004 to 2024, their area grew by 841.57 hectares, an increase of 2.75%.

Conversely, wetlands, which are among the most vital and natural components of the landscape, experienced a significant decline over the same period. In 2004, wetlands covered an area of 27,090.22 hectares, providing critical habitats for diverse species, regulating water flow, and serving as natural buffers against floods. However, by 2024, this area had shrunk to 20,623.81 hectares, representing a loss of 6,466.41 hectares, equivalent to a staggering 23.87% reduction. This sharp decline could be attributed to factors such as urbanization, agricultural expansion, drainage for

land development, and possibly the impacts of climate change. The loss of wetlands not only diminishes biodiversity but also undermines their essential ecological services, such as carbon sequestration, water purification, and flood mitigation, highlighting an urgent need for conservation and restoration initiatives to address this critical issue.

So this analysis highlights that while forests and water bodies expanded between 2004 and 2024, wetlands experienced a notable reduction 'Figure 1'.

Figure 1
The change in the area of natural landscape components from 2004 to 2024

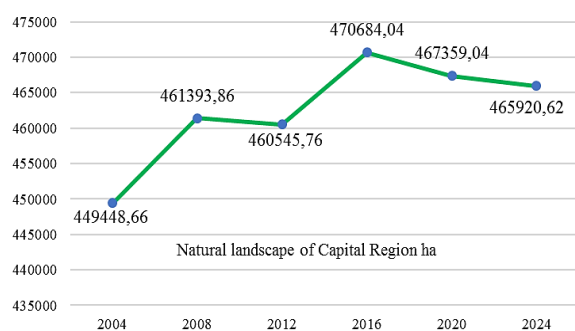


(Nacionaline..., 2004–2024).

Overall, the natural landscape in the Capital Region increased by 16,471.96 hectares, marking a 3.66% rise during this period 'Figure 2'.

The natural landscape area has grown as a result of the expansion and development of forests and water bodies. This increase is driven by factors such as afforestation and reforestation projects, stricter conservation efforts, and natural processes. The water

Figure 2
Changes in the natural landscape area (in hectares) in the Capital Region from 2004 to 2024



(Nacionaline..., 2004–2024).

bodies area growth reflects the impact of natural processes, conservation efforts, and possibly human interventions aimed at restoring or creating aquatic ecosystems. Such an increase underscores the significance of water bodies in enhancing biodiversity,

improving water resource availability, and supporting a balanced ecosystem in the region.

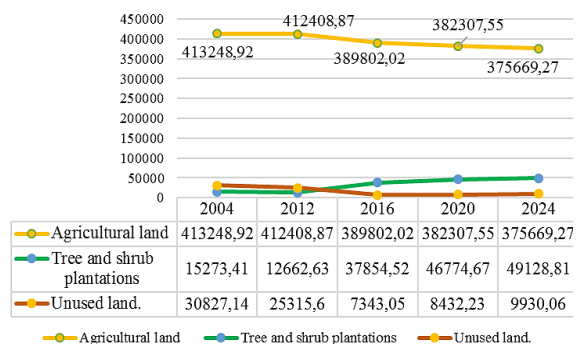
As forests regenerate and new water bodies form, the overall area of natural landscapes has expanded, contributing to improved biodiversity, climate regulation, and ecosystem stability.

Change in the area of anthropogenized landscape. Changes in the area of anthropogenized landscape refer to the modifications in the environment brought about by human activities.

The anthropogenized landscape can include various components, such as agricultural land (arable land, orchards, meadows and natural pastures), tree and shrub plantations, and unused land.

Between 2004 and 2024, the area of agricultural land in the Capital Region decreased by 37,579.65 hectares, representing a 9.09% decline 'Figure 3'. This significant reduction reflects broader trends in land-use changes, largely driven by human economic activities and shifting priorities in land management. As urbanization accelerates and the demand for residential, commercial, and industrial development grows, agricultural land is increasingly being repurposed for other uses, such as housing, infrastructure, and industrial zones.

Figure 3
The change in the area of anthropogenized landscape components from 2004 to 2024



(Nacionaline..., 2004–2024).

The decline in agricultural land is a clear indication of the ongoing transformation of the region's landscape, where natural and rural areas are gradually giving way to urban expansion and economic development. The conversion of farmland into built-up areas not only reduces the land available for food production but also affects local ecosystems, biodiversity, and the region's capacity to provide ecosystem services such as carbon sequestration, water filtration, and soil fertility maintenance.

During the same period, the area covered by trees and shrubs increased significantly by 33,855.40 hectares, or 221.66%, primarily due to the expansion of green spaces and the implementation of afforestation programs.

Meanwhile, the area of unused land in the Capital Region shrank by 20,897.08 hectares, or 67.79%.

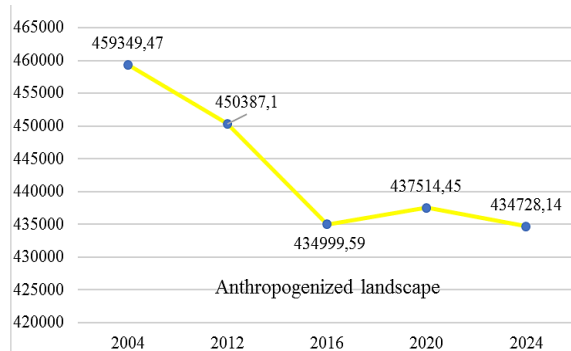
An analysis of these changes in the components of the anthropogenized landscape reveals that, between 2004 and 2024, agricultural land and unused land in the Capital Region declined, while areas covered by trees and shrubs grew substantially.

From 2004 to 2024, the anthropogenized landscape experienced a total area reduction of 24,621.33 hectares, equating to a 5.36% decrease (Figure 4).

The decrease in the area of anthropogenic landscape was caused by the reduction of agricultural land abandonment and unused land areas.

Figure 4

Changes in the anthropogenized landscape area (in hectares) in the Capital Region from 2004 to 2024



(Nacionalinė..., 2004–2024).

Change in the area of anthropogenic landscape

The anthropogenic landscape comprises built-up areas, roads, and damaged land. Between 2004 and 2024, built-up areas in the Capital Region expanded by 11,354.31 hectares, a growth of 29.50%, reaching a total of 49,837.87 hectares in 2024.

Built-up areas are increasing due to urbanization, population growth, economic development, and rising demand for housing and infrastructure.

According to the Land Fund of the Republic of Lithuania (Nacionalinė..., 2004–2024), it was found that between 2004 and 2024, the road area in the Capital Region decreased by 3,757.11 hectares, or 16.65%. By 2024, the road area covered 18,811.17 hectares.

The observed decrease in road area can be attributed primarily to inaccuracies in the theoretical calculations conducted before 2015. These earlier estimates likely lacked precision and did not fully reflect the actual situation on the ground. However, a significant methodological improvement occurred in 2015 with the introduction of cadastral measurements, which provided a more accurate and detailed assessment of land use.

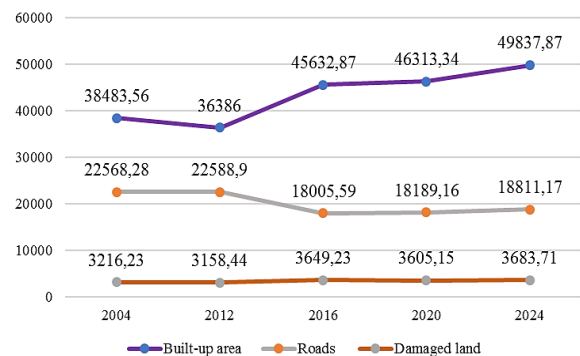
Since the adoption of cadastral measurements, the data on areas occupied by roads have been updated annually, ensuring a more reliable and up-to-date representation of road infrastructure. As a result, the apparent reduction in road area should not be

interpreted as a physical decline in road infrastructure but rather as a correction stemming from improved measurement techniques. Therefore, the decrease in road area is considered conditional and reflects adjustments in data accuracy rather than actual changes in land use.

Between 2004 and 2024, the area of damaged land in the analyzed region increased by 467.48 hectares, or 14.54% (Figure 5).

Figure 5

The change in the area of anthropogenic landscape components from 2004 to 2024



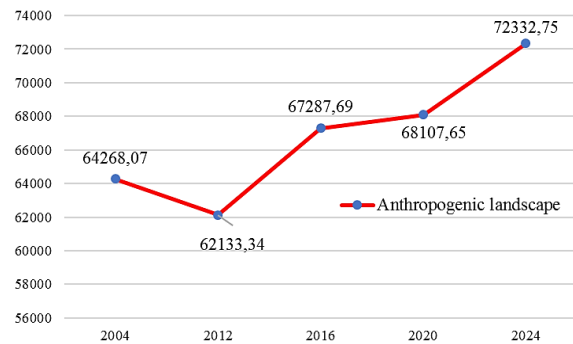
(Nacionalinė..., 2004–2024).

Before Lithuania joined the European Union, numerous legal and illegal landfills operated across the country, including the Capital Region. With the introduction of a waste collection and disposal system, the Kazokiškės landfill in the Capital Region was opened in 2007. In 2013, the second section of the Kazokiškės landfill was launched.

The increase in damaged land areas was also influenced by the establishment of mineral extraction quarries. During the analyzed period in the Capital Region, mineral extraction began in the following quarries: Miškiniai gravel and sand, Papiškiai, Daniliškiai sand and gravel, Margis gravel, Bijūnai gravel, Gudakiemis gravel and sand, Šventininkai gravel and sand, Pagiriai-Kaišialakiai gravel and sand, Zujūnai gravel, Serapiniškės sand and gravel, Račkūnai deposit sand and gravel, Gojaus sand resources, Pašiliai sand and gravel deposit, Būda II sand and gravel, Vaidegiai sand and gravel, Dobrovolė II sand and gravel, Mačiuliškiai sand and gravel, Merešlėnai deposit sand and gravel, and other quarries. After analyzing the changes in the Capital Region's anthropogenic landscape between 2004 and 2024, it was found that the area increased by 8,064.68 hectares, or 12.55% (Figure 6).

The increase in the anthropogenic landscape area is primarily due to the development of built-up areas (29.50%) and damaged land (14.54%). Together, these two factors have driven the overall increase in the anthropogenic landscape, highlighting the ongoing transformation of natural and rural areas into spaces dominated by human activity.

Figure 6
Changes in the anthropogenic landscape area (in hectares) in the Capital Region from 2004 to 2024

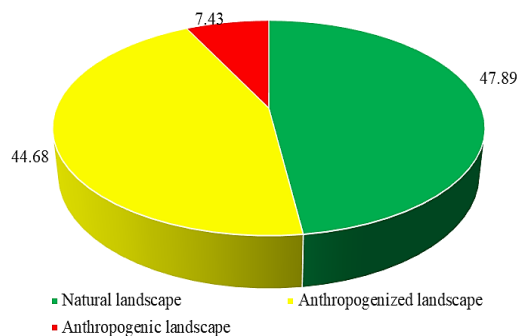


(Nacionalinė..., 2004–2024).

This trend underscores the need for sustainable development strategies to balance human needs with environmental conservation.

After analyzing the landscape of the Capital Region, it was found that in 2024, the natural landscape covered the largest portion of the region (47.89% or 465,920.62 hectares), while the smallest portion was occupied by the anthropogenic landscape (7.43% or 72,332.75 hectares). The anthropogenic landscape in 2024 accounted for 44.68% of the region's total area 'Figure 7'.

Figure 7
The distribution of landscape types in the Capital Region by percentage in 2024



While the dominance of natural landscapes is indicative of the area's ecological richness, the presence of anthropogenic landscapes reflects the region's economic and societal development. Striking a balance between these contrasting land uses remains crucial for ensuring sustainable development and environmental conservation in the region.

Examination of the proportion of relatively natural versus cultivated land in the Capital Region

The analysis of the ratio of relatively natural and cultivated land in Capital Region involves examining the proportion of land that remains in its natural state versus the land that has been modified for agricultural or human use. Relatively natural land refers to areas with minimal human intervention, such as forests, wetlands, and other natural ecosystems. Cultivated

land includes agricultural areas like arable land, orchards, and pastures, as well as areas developed for infrastructure.

The methodology for landscape formation, as described by Kavaliauskas et al. (2013), defines the optimal landscape structure of a country based on the geoecological compensation index. According to this approach, 38% of the land should consist of active anthropogenic (human-modified) areas, while 62% should remain passive or relatively natural (Skorupskas & Kavaliauskas, 2007).

A landscape is not considered optimal if the minimum required percentage of natural areas necessary to balance anthropogenic impacts is not achieved.

From the analysis and 'Figure 7', it is evident that in 2024, natural areas in Capital Region constituted 47.89% of the landscape, while anthropogenic and anthropogenized areas together accounted for 52.11%. Given the variety of land uses, the ratio of relatively natural to cultivated land (Rns) can be calculated for any sufficiently large region with defined boundaries using a specific formula:

$$R_{ns} = \frac{P+M+0.5A+0.8V}{U+T+0.5A+0.2V} \tag{1}$$

where Rns represents the ratio of relatively natural land (numerator fraction) to relatively cultivated land (denominator fraction) within the territory: P denotes wetlands, M represents forests, A stands for agricultural land, U and T refer to urban and technological components, and V signifies water bodies.

After calculating using the given 1 formula, the ratio of relatively natural land to cultivated land (Rns) in Capital Region was determined to be 1.99.

A landscape is considered natural when Rns equals Ro, the optimal ratio value, which is 1.63.

The optimality of a territory's landscape structure can be evaluated using these formulas:

$$Dr = \frac{Rns}{Ro}, \text{ when } Rns > Ro \tag{2}$$

or

$$Dr = -\frac{Ro}{RoRns}, \text{ when } Rns < Ro \tag{3}$$

where: Dr is the relative deviation from the optimal ratio value (Ro), Rns is the ratio of relatively natural land to relatively cultivated land within the territory, Ro is the optimal ratio value.

After calculating the Dr value, it was determined that the relative deviation from the optimal ratio value in the Capital Region is 1.22. Once Dr is calculated, the landscape structure's optimality class can be identified using the criteria outlined in 'Table 1'.

The Capital Region has been assigned the A2 landscape structure optimality class because, based on the calculations, the landscape structure of this region meets the optimality criteria, but with some deviation from the ideal ratio (A1).

The A2 class indicates that the region has a sufficient amount of natural areas (47.89%), but certain measures may be needed for the protection or further restoration of the natural environment.

The study shows that urbanization is occurring in the Capital Region – during the 2004-2024 period, the area of built-up land increased by 29.50%, and the total area of anthropogenic landscape increased by 12.55%. If urbanization in this region continues at such a rapid pace, it may pose a threat to the landscape structure.

Table 1

Determining the optimality class of a site based on the deviation of its natural and artificial land use ratio from the ideal value

Ratio of natural and cultivated land (R_{ns})	R_{ns} deviation from optimal value (D_r)	Optimality classes
>78.25	>48.00	A6
13.37...78.24	8.01...48.00	A5
3.27...13.36	2.01...8.00	A4
2.46...3.26	1.51...2.00	A3
1.97...2.45	1.21...1.50	A2
1.631...1.96	1.00...1.20	A1
1.629...1.36	-1.00...-1.20	B1
1.35...1.09	-1.21...-1.50	B2
1.08...0.82	-1.51...-2.00	B3
0.81...0.20	-2.01...-8.00	B4
0.19...0.03	-8.01...-48.00	B5
<0.03	<-48.00	B6

(Lietuvos Respublikos aplinkos..., 2015).

To maintain the landscape structure of Capital Region and ensure its optimality, the following measures should be taken:

- Protect natural areas: to maintain the portion of natural land, it is essential to ensure the protection of existing forests, wetlands, water bodies, and other natural ecosystems.
- Management of agricultural activities: sustainable agricultural practices need to be implemented to reduce the negative impact of agriculture on the landscape and nature. This includes promoting organic farming and managing the intensity of agricultural land use.
- Encourage a mosaic landscape by avoiding monocultural landscapes: the preservation of mixed lands (forests, meadows, agricultural areas) should be encouraged, as they can ensure biodiversity and ecosystem services.

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- Control of urbanization: the development of intensive urbanization and infrastructure in natural areas should be limited to maintain landscape integrity and balance the ratio of natural and anthropogenic lands.

- Landscape planning and management: it is essential to consider the condition of the region's ecosystems, their conservation, and sustainable use.

- Education and public involvement: raising public awareness about the importance of landscapes and encouraging local residents and businesses to contribute to environmental conservation, particularly in environmental protection initiatives and sustainable land use.

Conclusions

1. Between 2004 and 2024, the natural landscape in the Capital Region grew by 16,471.96 hectares, reflecting a 3.66% increase. This expansion was primarily driven by the growth of forests (5.64%) and water bodies (2.75%). During the same period, the anthropogenized landscape decreased by 24,621.33 hectares, a 5.36% reduction. This decline was largely due to the decrease in abandoned agricultural land (9.09%) and unused land areas (67.79%). However, the analysis of changes in the anthropogenic landscape revealed an increase of 8,064.68 hectares, or 12.55%, largely attributed to the growth of built-up areas (29.50%) and damaged land (14.54%).

2. After analyzing the landscape of the Capital Region, it was determined that in 2024, the natural landscape comprised the largest portion of the region (47.89% or 465,920.62 hectares), while the smallest portion was taken up by the anthropogenic landscape (7.43% or 72,332.75 hectares).

3. After calculating the ratio of relatively natural land to cultivated land (R_{ns}) in the Capital Region, it was determined that the R_{ns} is 1.99. Upon calculating the D_r value, it was found that the relative deviation from the optimal ratio value in the Capital Region is 1.22.

4. The Capital Region has been classified under the A2 landscape structure optimality class because, according to the calculations, its landscape structure meets the optimality criteria, albeit with some deviation from the ideal ratio (A1). The A2 class signifies that the region possesses a sufficient proportion of natural areas (47.89%), but some actions may be necessary to safeguard or further restore the natural environment.

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