Relationship between Landscape Pattern and Human Disturbance in Serbia from 2000 to 2018

LUÍS QUINTA-NOVA[1,2,a], JOSÉ MANUEL NARANJO GÓMEZ[2,4,b], ANA VULEVIC[5,c], RUI ALEXANDRE CASTANHO[2,6,d], LUÍS LOURES[2,7,e]

[1]Instituto Politécnico de Castelo Branco, Escola Superior Agrária,
PORTUGAL

[2]VALORIZA - Research Center for Endogenous Resource Valorization,
Instituto Politécnico de Portalegre (IPP),
PORTUGAL

[4]University of Extremadura,
SPAIN

[5]CIP, Belgrade,
SERBIA

[6]Advanced Research Centre, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin,
TURKEY

[7]Research Centre for Tourism, Sustainability and Well-being (CinTurs),
University of Algarve, 8005-139 Faro,
PORTUGAL

[a]ORCiD: https://orcid.org/0000-0002-8464-7527
[b]ORCiD: https://orcid.org/ 0000-0001-7998-9154
[c]ORCiD: https://orcid.org/0000-0001-5150-4477
[d]ORCiD: https://orcid.org/0000-0003-1882-4801
[e]ORCiD: https://orcid.org/0000-0002-6611-3417

Abstract: - This study intends to verify how the alteration of the landscape configuration, represented by different metrics of configuration and diversity, is related to the intensity of human disturbance. The objectives of the study are: (1) to quantify the change in land use/land cover (LULC) patterns and the degree of human disturbance in Serbia between 2000 and 2018, and (2) to study the relationship between LULC configuration and the impact resulting from human disturbance under different levels of intensity, to understand how changing trends in landscape pattern can serve as indicators to estimate landscape changes resulting from human actions. The Hemeroby Index (HI) was calculated to quantify the impacts on ecosystems resulting from disturbance caused by human actions. Based on the analysis of the variation in the value corresponding to the HI for the period between 2000 and 2018, the level of naturalness increased by only 5% of the territory of Serbia, with this change being verified mainly in SE Serbia. The landscape pattern was quantified using a set of LULC metrics. We used the Spearman method to identify the existing statistical correlations between the geometric parameters of the landscape and the HIs values. At the landscape level, the Mean Shape Index, Edge Density, Mean Patch Fractal Dimension, and Shannon Diversity Index show a strong negative correlation with HI. This correlation suggests that landscapes with greater structural complexity are good indicators of low levels of hemeroby. At the class level, Edge Density and Mean Patch Size correlate significantly with the HI for artificial surfaces, agricultural areas, forests, and semi-natural areas.

Key-Words: - Hemeroby level, Land-cover changes, Land-use, LULC metrics, Serbia, Sustainable development.

Received: June 15, 2023. Revised: March 6, 2024. Accepted: April 11, 2024. Published: May 16, 2024.

1 Introduction

Anthropogenic actions significantly impact the landscape's structure and functionality, which is a growing concern, and their monitoring has become one of the critical points and essential areas of research in landscape ecology, [1], [2]. Many researchers have focused on the spatial variability of disruption resulting from such actions and its relationship with the evolution of landscape patterns, [3], [4].

Contextually, environmental indices play a substantial role in delivering information about the environment's condition. For example, they assist in decision-making processes or monitoring and evaluating the efficiency of political and administrative measures, [5]. Moreover, considering the broad scope of landscape ecology, such indices are developed to quantify landscapes' state and changes.

The ecological pattern and process paradigm indicates that a landscape's configuration influences ecological processes, and landscape metrics provide a suitable means of quantifying these patterns. Thus, landscape metrics reflect the spatial configuration of the landscape mosaic, [6], [7], [8].

Landscape metrics also present an exhaustive view of landscape structure, measuring and describing the landscape's configuration and composition, [6]. Given the recent advances in remote sensing and computation, analyzing large datasets representing various aspects of landscape patterns has become even more feasible.

In this regard, the Hemeroby Index (HI) is essential for evaluating human interventions' repercussions on ecosystems - once it has been widely used in different studies, [3], [4], [9] to quantify the intensity of anthropic changes in landscape structure and function resulting from such activities in the ecological environment, [10].

Therefore, we can say that the degree of hemeroby, as indicated by the HI, serves as an integrative measure of the impacts of human activities on ecosystems, whether intended or not. It measures an area's human impact level/naturalness, indicating the deviation from potential natural vegetation, [11], [12]. As hemeroby levels rise, human influence becomes more detrimental, resulting in increased landscape disturbance and alteration, [3]. It can be classified into seven levels concerning the degree of naturalness, [5].

Multiple authors underscore that examining landscape patterns at the class level offers a more effective method for estimating human disturbance levels than landscape-level analyses based solely on the total number of patches, [3]. Therefore, it is essential to complement the study of the relationships between the alteration of the landscape mosaic and the degree of hemeroby at the landscape level with the changes at the level of the LULC classes to achieve a more detailed analysis of the LULC tendencies and to select the more suitable indicators. In this study, we used both approaches (landscape and class level) to understand the phenomena better.

In short, environmental indices are valuable tools for understanding the impact of human interventions on ecosystems and landscape patterns. They aid decision-making, monitoring environmental changes, and formulating effective landscape management policies promoting sustainable development.

Using land based on suitability involves using tools to regulate the implementation of land use planning measures in Serbia, [13]. The Law on soil protection, spatial planning, and utilizing natural resources and commodities in alignment with spatial, urban, and other planning documents are vital in preventing land degradation, [14].

Efforts were made twice in present-day Serbia to adopt a land planning approach - during the post-World War II socialist period in the former Yugoslavia and the transition period to free-market democracy after 2000, [15].

Decades of large-scale urbanization, combined with ineffective and unsustainable attempts at regional and urban planning, have led to ecosystem degradation on a global scale. The rural abandonment-urban concentration gap is anticipated to further widen during the XXI century, [16]. Land use is significant in addressing various sustainability issues, including conserving biodiversity, mitigating climate change, ensuring food security, alleviating poverty, and promoting sustainable energy. These issues are interconnected and require attention to achieve long-term sustainability. Land systems exhibit complex behaviors and often experience irreversible changes, making it crucial to adopt sustainable land management practices, [17]. Brundtland presented sustainability as "(…) development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs", [18].

To assess sustainability, suitable approaches must be employed that consider its diverse dimensions, including its environmental, economic, and social aspects, at various spatial and temporal scales, [19], [20], [21].

To achieve the desired sustainability, understanding how societies use, manage, and interact with land is crucial, [22], [23]. For this reason, a combined and comprehensive approach to land use implies many compromises between these three pillars, and consequently, it is necessary for a right European policy, [24], [25]. Thus, member State approaches to spatial and land-use planning are also vital factors in shaping the impact of EU policies on land, [26] and they can be resolved by employing integrated sectoral policies and targeted policy instruments, [27].

Institutional arrangements are pivotal in supervising the processes of information gathering, monitoring, and evaluation of land use policies, which are indispensable for attaining territorial cohesion, [25], [26], [27], [28]. The adoption of CORINE land cover classification (CLC) is intended to facilitate the advancement of complex spatial analyses covering a wide range of land-use categories, [29]. The geodatabase is structured hierarchically, with the first tier encompassing primary land use types and land cover categories such as artificial areas, agricultural areas, forest and semi-natural areas, wetlands, and water bodies. Subsequently, the second tier comprises 15 departments, and the third tier consists of 44 departments. Additionally, the CLC incorporates registered data from different years, namely 1990, 2000, 2006, 2012, and 2018, [29], [30], [31].

The CLC records changes are beneficial for new research at the regional level, which has conducted spatial analysis studies based on Geographic Information System (GIS) tools and CORINE data methodological approaches to landscape mosaic dynamics with different types of land cover countries, regions, islands, or cities, [29], [32], [33], [34], [35].

Since the CLC2000 project and databases were developed in Serbia in 2005, a considerable interest in using the data has been experienced in different institutions. Back then, the production of the CLC2000 database followed standard CORINE procedure: computer-aided visual arrangement of Landsat 7 satellite imagery sustained with ancillary data produced under the CARDS Programme and field checking. The methodology created a polygon-based vector dataset that seamlessly integrates various spatial features. This method's essential mapping criteria consist of a map scale set at 1:100,000, a minimum mapping unit of 25 hectares, and a minimum width specification for linear elements (100 meters), [28], [29], [30].

The IMAGE2000 database was used as source data, consisting of orthorectified Landsat 7 ETM+ images in national projection. The images are from 2000 with a tolerated deviation of +/- one year. The CLC Changes database compares CLC2000 and the satellite images from 2000 (IMAGE2000), [36]. Also, the ESPON Project SUPER, [37], has created a database to perform analyses by merging data on land use with possible drivers of land-use change. Thus, all data were collected or converted to NUTS 3 (2016 limits) for the four dates of the CLC (2000, 2006, 2012, and 2018). The database is customized to enable user-generated queries and is publicly available.

As for former research in Serbia using land use changes related to CLC, it is noticeable as several works describe farmer lands being replaced by urban areas, [38], [39], [40] and as the forest cover in certain regions experiencing depopulation increased, [41], [42], [43]. Nonetheless, the number of studies related to hemeroby is still being determined, [44]. Finally, most of these studies establish that sustainable land use policies should be defined at the national and regional level, [14], [15], [38], [39], [40], [41], [45].

Contextually, the aim of this study is (1) to quantify the change in land use/land cover patterns and the degree of human disturbance in Serbia between 2000 and 2018 and (2) to study the relationship between landscape metrics and the impact resulting from human disturbance under different levels of intensity, to understand how changing trends in landscape pattern can serve as indicators to estimate landscape changes resulting from human actions.

2 Methodology

Situated in Southeast Europe on the Balkan Peninsula, Serbia is a continental country covering 88,361 km^2. Serbia experiences a warm-humid continental climate characterized by cold and relatively dry winters and humid summers. The northern region is predominantly flat, while the central parts comprise highlands. Moving south, the hills gradually transform into mountains, with the

Dinaric Alps and the Carpathian Mountains stretching to the south and southeast. The capital city of Serbia is Belgrade, situated at the confluence of the Sava and Danube rivers. In the north, the Autonomous Province of Vojvodina stands out for its highly developed agricultural production. Areas with agricultural, forest, and pasture activities are dominant. The ongoing transition to a market-oriented economy has increased demand for land use changes, particularly for constructing industrial, infrastructure, and recreational facilities.

The Corine Land Cover (CLC 2000; CLC 2006; CLC 2012 and CLC 2018) Land Use and Cover (LULC) databases were used to calculate the values of the different landscape indices. Class-level and landscape-level metrics were calculated for the 88 squares of 30 km^2 each, corresponding to a grid covering Serbia. The Patch Analyst extension included in the Arc GIS 10.8 software was used to calculate the landscape metrics.

The LULC classes were transformed into a scale representing different levels of hemeroby, ranging from ahemerobic (no anthropogenic influence) to metahemerobic (destroyed biocenosis). This seven-point scale enabled the classification of LULC based on their corresponding degrees of hemeroby, as indicated in Table 1. Subsequently, an average value was computed for each 10 km^2 grid using the following equation:

$$M = \sum_{h=1}^{n} \text{fn} * h \qquad (1)$$

n - Number of categories of hemeroby
(here: n = 6)
fn - Proportion of the area of the category n
h - Hemeroby-factor
M - HI

The landscape structure was quantified through a set of landscape metrics shown in Table 2. Those landscape metrics were selected based on some criteria, namely: (1) these should represent and define the dimensions of the characteristics of spatial patterns; (2) these should be easily calculated and not be redundant; and (3) they were previously adopted in similar studies considered relevant. In selecting the metrics to be used in the study, the results of their application in various research work with identical objectives to this study were also considered, [3], [46], [47], [48].

Metrics that describe the patch area distribution, such as the Mean Patch Size (MPS), allow for characterizing the area distribution between patches at the class or landscape level. The Mean Shape Index (MSI) describes the patch structure in the landscape as that of the average patch characteristic and indicates the level of landscape fragmentation. Edge Density (ED) standardizes the length of edges on a per-unit area basis. Mean Patch Fractal Dimension (MPFD) describes landscape complexity, [49].

The correlation between the values of landscape metrics and those associated with the HI at both the landscape and class levels was determined using IBM SPSS Statistics 22 software. The Shapiro-Wilk test was initially applied to assess the normal distribution of the variables. However, most of the variables did not follow the normal distribution. Hence, a non-parametric Spearman's correlation coefficient was utilized, [50]. Using LULC maps from 2000, 2006, and 2018, the study identified landscape metrics that showed a statistically significant relationship with the HI at a significance level of 0.01.

Table 1. Assignment of LULC types onto the Hemeroby scale, [14]

Degree of hemeroby	LULC types
Oligohemerobic weak human impacts	Potential natural vegetation (PNV) forest. Natural habitats and other seminatural areas, like dunes and inland marshes.
Mesohemerobic moderate human impacts	Forest stands (not PNV). Scrub and/or herbaceous vegetation associations. Sparsely vegetated areas.
β-euhemerobic Moderate to strong human impacts	Pastures. Green urban areas. Inland waters. Heterogeneous agricultural areas with natural vegetation.
α-euhemerobic strong human impacts	Arable land and permanent crops. Artificial, non-agricultural vegetated areas
Polyhemerobic very strong human impacts	Discontinuous urban areas. Mine, dump, and construction sites.
Metahemerobic Excessively strong human impacts. Biocoenosis destroyed	Continuous urban areas. Industrial, commercial, and transport units.

Table 2. Landscape metrics used in the study

Structural feature	Index	Name	Description
Edges	ED	Edge Density	Calculating the edge length within a landscape considers the distribution of patch types per square km, including the landscape boundary and background segments.
Area	MSI	Mean Shape Index	The measurement of average patch shape (complexity) refers to quantifying the spatial structure of patterns, typically land cover, within a specific class or for all patches present in the landscape.
	MPS	Mean Patch Size	The Mean Patch Size is calculated by dividing the cumulative area occupied by patches within the landscape (or a designated class) by the total number of patches within that area.
Shape complexity	MPFD	Mean Patch Fractal Dimension	MPFD characterizes the complexity of a patch based on its perimeter and area, describing the relationship between the patch's size and shape.
	MPAR	Mean Perimeter-Area Ratio	Indicator of polygon shape complexity. Unlike other shape parameters, the perimeter-area ratio is not standardized to a simple Euclidean shape.
Diversity	SDI	Shannon Diversity Index	It reflects landscape heterogeneity and represents the degree of landscape diversity.

3 Results

Figure 1 presents the LULC maps for the four years: 2000, 2006, 2012, and 2018.

Agriculture in Serbia is primarily concentrated in the northern region and near the major rivers. In recent years, there has been a decline in agricultural and pasture areas, impacting them the most. In 2018, agriculture was the dominant sector and covered a significant portion of Serbia's territory (Figures 2, Figure3 and Table 3).

From 2000 to 2018, the decrease in agricultural areas was evident (3.53%), and forest area has been increasing since 2000 with a variation of 1.34%, representing about 29.82% of Serbia's territory in 2018. Also, the artificial areas increased in spatial coverage from 3.29 % to 3.74 %.

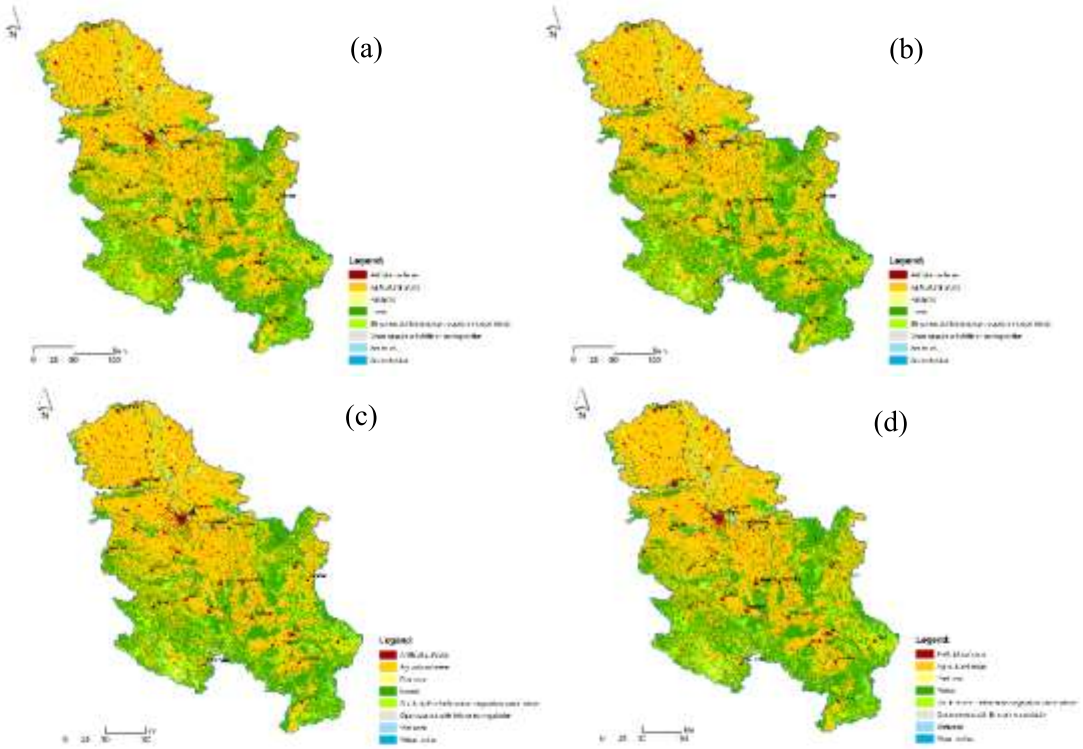

Fig. 1: Distribution of the land use and land cover major categories: (a) 2000; (b) 2006; (c) 2012; (d) 2018 (Corine Land Cover)

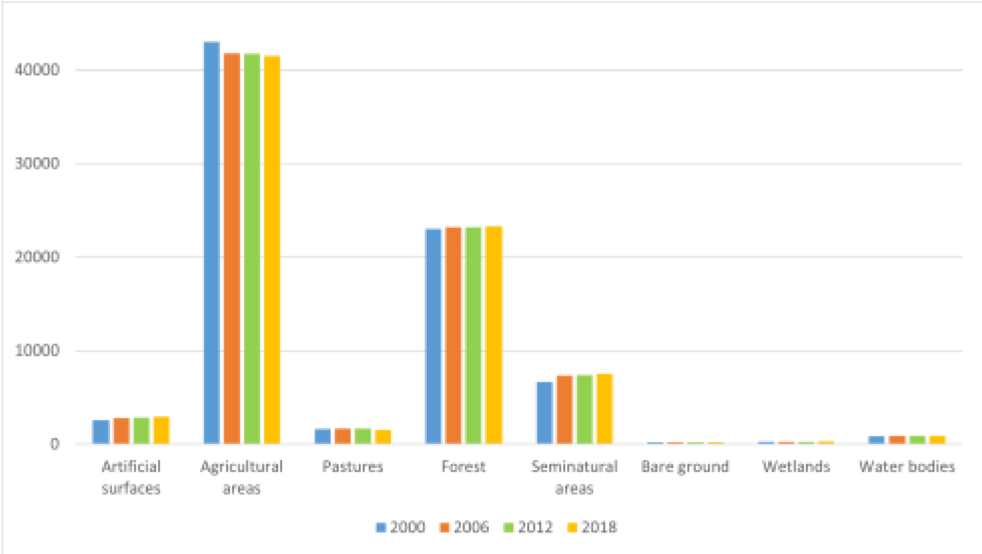

Fig. 2: Land use changes between 2000 and 2018 (km^2).

Table 3. Distribution of land uses (CLC - level 1) in Serbia from 2000-2018

	2000	2006	2012	2018
Artificial surfaces	3.29%	3.61%	3.65%	3.74%
Agricultural areas	54.97%	53.38%	53.33%	53.03%
Pastures	2.08%	2.15%	2.15%	1.97%
Forest	29.43%	29.71%	29.68%	29.82%
Seminatural areas	8.54%	9.40%	9.45%	9.63%
Bareground	0.28%	0.27%	0.27%	0.27%
Wetlands	0.32%	0.35%	0.34%	0.40%
Water bodies	1.09%	1.14%	1.14%	1.14%

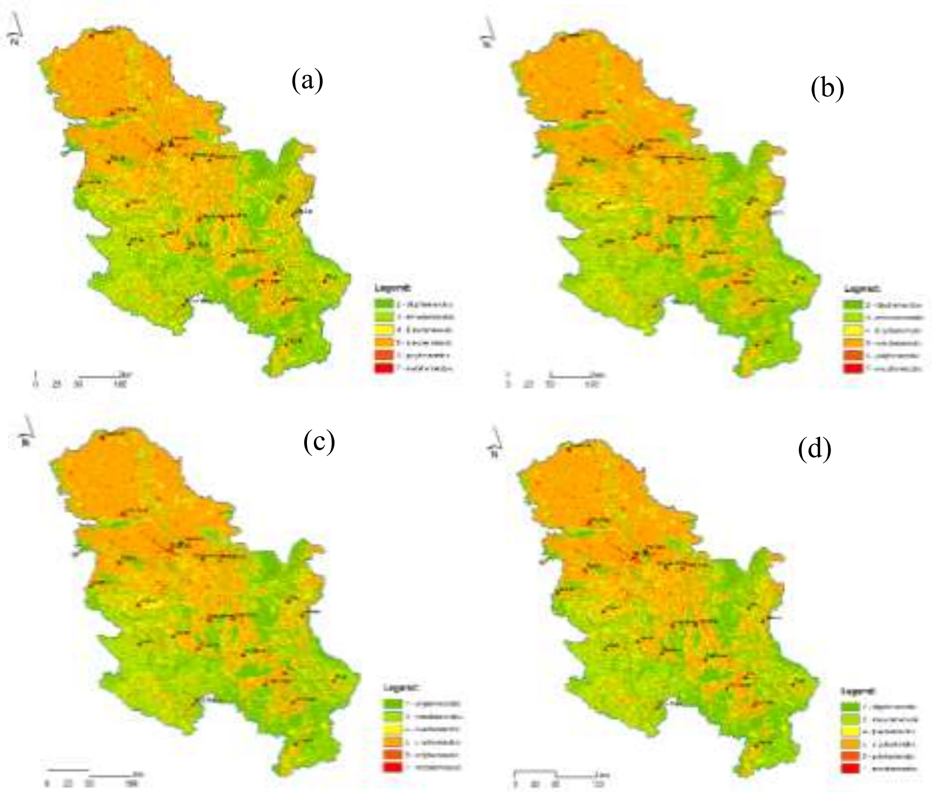

Fig. 3: Hemeroby level maps for the four years: (a) 2000; (b) 2006; (c) 2012; (d) 2018.

During the study period, the average HI value for Serbia decreased. In 2000, the index value was 3,847 ± 0.747, which decreased to 3,834 ± 0.758 in 2006, 3,835 ± 0.759 in 2012, and further decreased to 3,829 ± 0.758 in 2018. These values correspond to a β-euhemerobic level, indicating moderate to strong human impacts.

Figure 4 presents the change in the average values for the spatial metrics obtained at a landscape level. MSI and MPFD values have decreased since 2006, which indicates a decrease in landscape complexity. On the other hand, the SDI value has steadily increased since 2000, corresponding to a higher diversity of land uses. The MPS value has decreased since 2006, corresponding to a reduction in the average patch dimension.

The results of the analysis shown in Table 4 demonstrate that the HI has a significant negative correlation ($p < 0.01$) with landscape pattern indexes, specifically Mean Shape Index (MSI), Total Edge (ED), Shannon Diversity Index (SDI), and Mean Patch Fractal Dimension (MPFD) and, at a Landscape Level during the study period from 2000 to 2018. This suggests that complex landscapes serve as reliable indicators of low levels of hemeroby. The change of the average values for the landscape metrics obtained at a class level is presented in Figure 5.

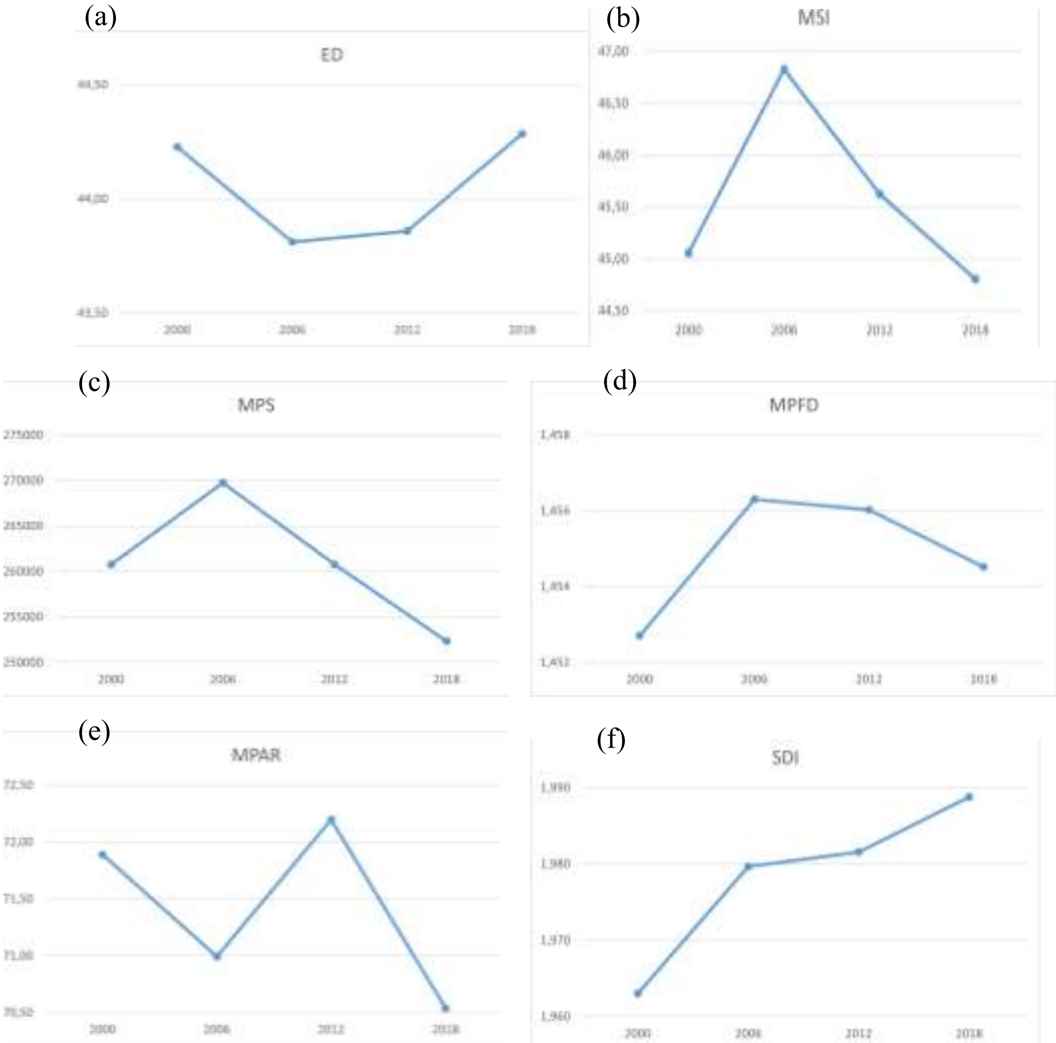

Fig. 4: Landscape pattern indexes and HI values change between 2000 and 2018 at a Landscape Scale: (a) Edge Density (ED); (b) Mean Shape Index (MSI); (c) Mean Patch Size (MPS); (d) Mean Patch Fractal Dimension (MPFD); (e) Mean Perimeter-Area Ratio (MPAR); (f) Shannon Diversity Index (SDI)

Table 4. Spearman's correlations between the HI and the landscape metrics - Landscape Level (2000 - 2018).

	2000	2006	2012	2018
Edge Density (ED)	**-0.417***	**-0.425***	**-0.424***	**-0.433***
Mean Shape Index (MSI)	**-0.493***	**-0.654***	**-0.639***	**-0.645***
Mean Patch Size (MPS)	**-0.280***	-0.203	-0.194	-0.149
Mean Patch Fractal Dimension (MPFD)	**-0.438***	**-0.586***	**-0.589***	**-0.616***
Mean Perimeter-Area Ratio (MPAR)	0.084	0.094	0.097	-0.037
Shannon Diversity Index (SDI)	**-0.323***	**-0.375***	**-0.377***	**-0.383***

* *Correlation is significant at the 0.01 level.*

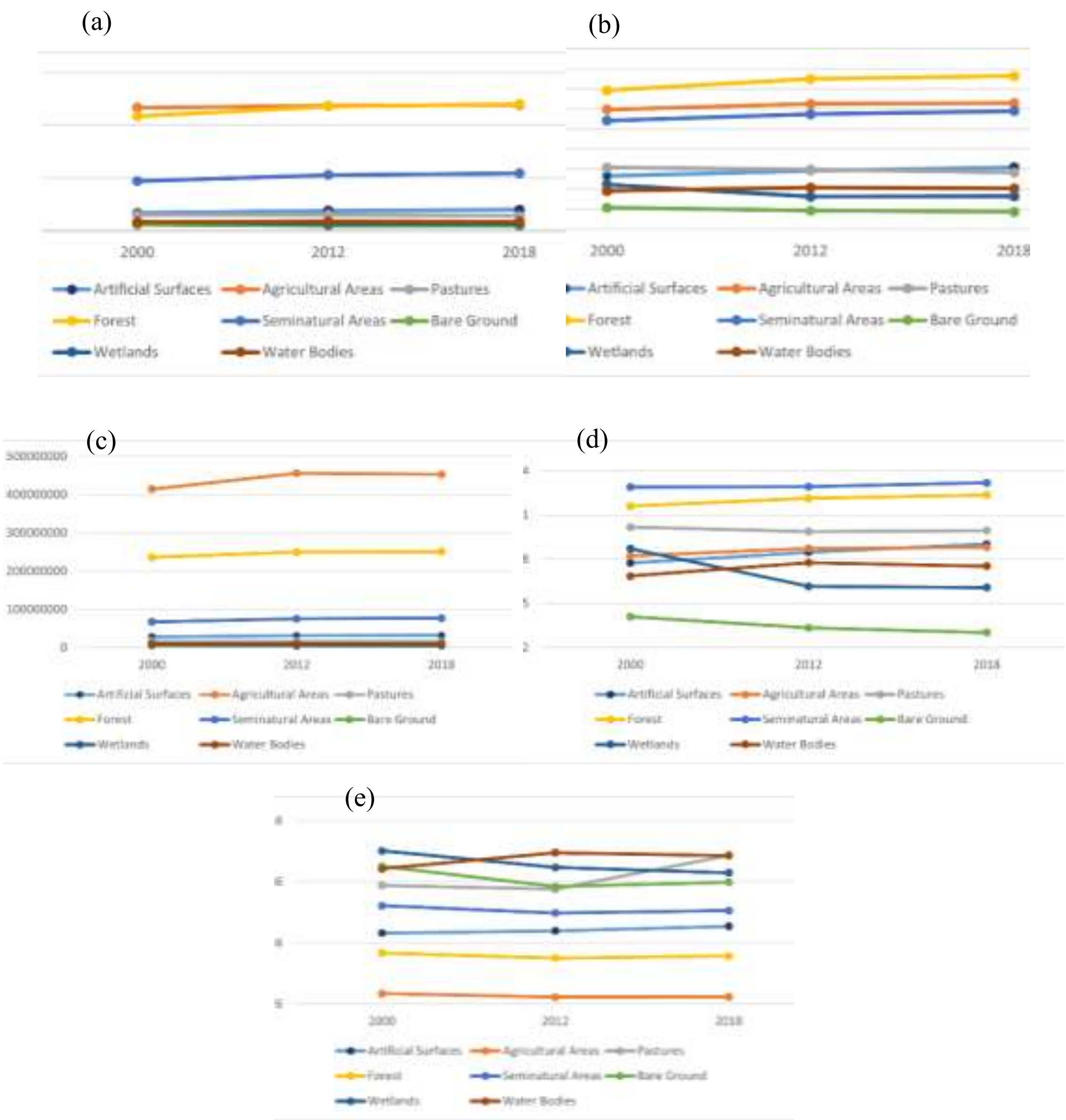

Fig. 5: Landscape pattern indexes average values change between 2000 and 2018 at a Class Scale: (a) Edge Density (ED); (b) Mean Shape Index (MSI); (c) Mean Patch Size (MPS); (d) Mean Patch Fractal Dimension (MPFD); (e) Mean Perimeter-Area Ratio (MPAR)

At a class level, we notice a gradual increase in edge density, particularly in forest, agricultural, and seminatural areas. Also, a slight increase in other spatial metrics, like Mean Shape Index, Mean Patch Size, and Mean Patch Fractal Dimension values, were verified for the same land uses. Those results indicate increased LULC fragmentation and complexity for those land use categories.

The results presented in Table 5 demonstrate the correlation between hemeroby and landscape pattern indexes at a Landscape Level for various land types, including artificial surfaces, agricultural areas, forests, and seminatural areas, during the study period from 2000 to 2018. The analysis reveals that Edge Density (ED) and Mean Patch Size (MPS) significantly correlate with the HI in these land categories over the mentioned time frame.

Based on the analysis of the variation in HI value verified between 2000 and 2018 (Figure 5), we verified that the hemeroby degree decreased by 5% for the 1 km^2 quadrats and increased by 3.5% for the quadrats. In the remaining territory, the hemeroby level remained stable.

The increase in naturalness, mainly in the SE part of Serbia, could be related to forestation. Contextually, the rise in hemeroby level is consistent with the urban growth rates seen in and around settlements.

Table 5. Spearman's correlations between the HI and the landscape metrics - Class Level (2000 - 2018)

	ED				**MSI**				**MPS**			
	2000	**2006**	**2012**	**2018**	**2000**	**2006**	**2012**	**2018**	**2000**	**2006**	**2012**	**2018**
Artificial surfaces	**0.763***	**0.734***	**0.547***	**0.509***	**0.648***	0.085	**0.721***	**0.706***	**0.830***	**0.777***	**0.806***	**0.799***
Agricultural areas	**-0.421***	**-0.365***	**-0.346***	**-0.331***	**-0.792***	-0.122	**-0.742***	**-0.726***	**0.673***	**0.731***	**0.889***	**0.887***
Pastures	-0.116	-0.226	-0.225	-0.146	-0.192	-0.197	**-0.280***	-0.217	-0.049	-0.232	-0.167	-0.093
Forest	**-0.866***	**-0.846***	**-0.835***	**-0.831***	**-0.596***	-0.204	**-0.500***	**-0.520***	**-0.935***	**-0.904***	**-0.923***	**-0.924***
Seminatural areas	**-0.693***	**-0.726***	**-0.718***	**-0.737***	**-0.694***	-0.045	**-0.742***	**-0.746***	**-0.634***	**-0.714***	**-0.656***	**-0.678***
Bare ground	-0.209	-0.223	-0.278	-0.207	-0.298	-0.307	-0.232	-0.117	-0.154	-0.085	-0.274	-0.197
Wetlands	0.230	0.381	0.377	**0.420***	0.277	0.201	**0.458***	**0.471***	0.130	0.276	0.267	0.299
Water bodies	**0.415***	**0.386***	**0.387***	**0.371***	**0.399***	0.280	**0.389***	**0.345***	**0.379***	**0.342***	**0.365***	**0.362***

**Correlation is significant at the 0.01 level.*

	MPFD				**MPAR**			
	2000	**2006**	**2012**	**2018**	**2000**	**2006**	**2012**	**2018**
Artificial surfaces	**0.430***	-0.035	**0.286***	0.158	**-0.554***	-0.019	**-0.585***	**-0.587***
Agricultural areas	**-0.894***	-0.189	**-0.875***	**-0.861***	**-0.651***	-0.076	**-0.933***	**-0.934***
Pastures	**-0.319***	0.000	**-0.355***	**-0.322***	-0.047	0.123	-0.039	-0.118
Forest	-0.285	-0.152	-0.212	-0.222	**0.686***	0.209	**0.651***	**0.659***
Seminatural areas	**-0.416***	0.077	**-0.578***	**-0.568***	0.181	0.006	**0.299***	**0.319***
Bare ground	-0.276	-0.341	-0.207	-0.104	0.057	-0.240	0.233	0.242
Wetlands	**0.348***	0.074	**0.506***	**0.519***	**0.538***	0.091	**0.448***	0.356
Water bodies	**0.325***	0.137	**0.302***	0.290	-0.156	0.094	-0.141	-0.145

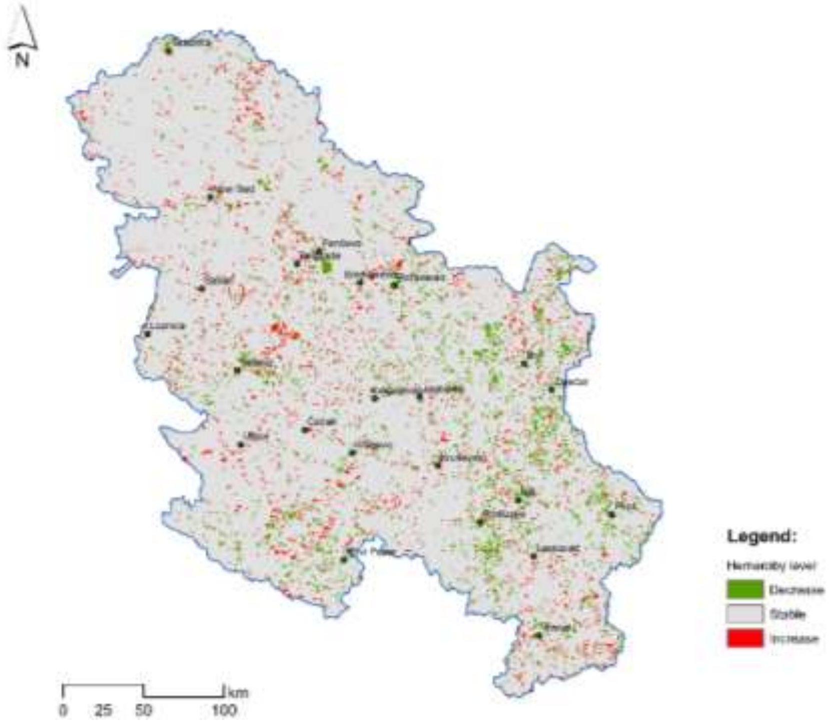

Fig. 5: The estimated change in the HI values between 2000 and 2018

4 Discussion

Based on the results, the landscape pattern response to human disturbance differs depending on the scale. At a landscape level, the HI has a significant negative correlation ($p < 0.01$) with landscape pattern indexes that are good indicators of land-scape complexity (ED, MSI, MPFD, SDI). This suggests that decreased human disturbance would lead to more complex landscapes. A tendency to increase LULC fragmentation and complexity was also verified at a class level, especially for forest, agricultural, and seminatural areas. Other studies showed the exact relation between hemeroby level and landscape complexity, [9], [46].

By analyzing the correlation between hemeroby and landscape metrics in different LULC classes, it was also found that the effect of human disturbance on landscape pattern was more intense in low-level hemeroby areas (i.e., forest, agricultural areas, semi-natural areas) but less severe in artificial areas. Therefore, it is better to focus on monitoring the change in the existing agroforest ecosystems, as their ecological quality is more sensitive to human disturbances.

The results obtained through applying both qualitative and quantitative landscape pattern indicators helped identify and interpret the main trends of land transformation in Serbia. However, some limitations still need to be further improved, namely the reduction of the scale effect in the interaction of multiple land-scape functions, which may have affected the results to a certain extent.

Although agriculture is nominally one of the most important land uses in Serbia, every year, a significant proportion of the agricultural land in Serbia changes to another use. In the fifties, Serbia lost approximately 222,000 ha of agricultural land irrecoverably to constructing industrial, mining, energy, and traffic infrastructure, [50]. It should be noted that in the period immediately before 2000, there was a planned trend of reducing land use with agriculture in the long term, which was demonstrated by the quantitative analysis of planning and management processes of the territory at the local level, [51].

It is essential to understand the circumstances under which land use transitions occur since planning instruments give a territorial expression to societies for sustainable development. Land use changes may have negative feedback resulting from the depletion of critical resources and/or a decline in the supply of essential ecosystem goods and services. Conversely, modifications in LULC can be driven by socioeconomic transformations and innovations that operate independently of the ecological system, following their dynamics, [52]. In reality, land use change phenomena exhibit a remarkable diversity of geographical and historical contexts, presenting several aspects of high complexity in ecological and social systems, [53]. Consequently, a more integrated, broad, and contemporary land use planning and management policy is needed, [28].

Furthermore, data on land use in Serbia are encountering multiple obstacles - i.e., political and economic transition or the pursuit of sustainable development of energy production itself. 2005-2006, CORINE Land Cover (CLC) databases were assembled for Serbia. Since then, they have allowed us to acquire data on land cover for the whole territory of the Republic of Serbia, [28].

The ubiquitous emphasis on an integrative approach to using and preserving agricultural and forest land as the most critical resource is nevertheless in conflict with a practice that shows the conversion of agricultural and forest land into building land, the expansion of settlements, and illegal construction at the cost of agricultural land, which is subsequently "legalized", [54], [55].

Alongside the enactment of laws, regulations, and strategies for safeguarding and conserving land resources, it's apparent that organizations and institutions in the Republic of Serbia face challenges in effectively implementing these legal measures [56]; consequently, it is expected that systems of spatial planning and territorial governance should intervene at different levels from national to local. As a strategic document for spatial planning, the new RS Spatial Plan 2021-2035 [57] aims at more rational use of previously occupied agricultural land, increasing the area of Serbia's territory under forest use to 41.4% by 2050 and restructuring other regions. There is about 923,000 ha of agricultural land in state ownership, and the problems faced by the competent Ministry of Agriculture are numerous: a threat to agrobiodiversity, threat to land quality, undeveloped land market, restitution process that is still ongoing, are just a few examples.

The reduction of the area under agricultural land is caused by the changes in the agricultural sector since 2000, which continues even after the restitution, and is also economically conditioned for the conversion of land "(…) if we take into account that in the Republic of Serbia in 2004, the value of construction land was approx. 1,000 times higher than the initial value of the original (agricultural or forest) land that is converted into construction land (World Bank document, 2004; Strategy for Sustainable Urban Development of the RS until 2030, 2019)", [58]. Also, in demographically depleted, peripheral, remote, and mountainous areas, we have a case of converting agricultural land into forest land due to the absence of the possibility for someone to cultivate that land.

The primary shifts in purpose occurred during the expansion of urban settlements. In the post-socialist era, there is a need to harmonize the legal framework of spatial and urban planning systems and practices, [59], [60]. Due to significant changes in the purpose of agricultural land for construction and the needs of public purposes, two by the concepts of neutral degradation and land safety, as well as for residential construction, planning solutions are submitted during the preparation of planning and urban planning documents in Serbia for the opinion of the competent Ministry for the environmental protection.

Given what was mentioned in the previous paragraphs, it is crucial to characterize the changes in Serbia's territorial planning policy and the implications for land occupation and its associated impacts, emphasizing the transition to a free-market democracy after 2000.

5 Conclusions

Based on the results obtained, we can conclude that the landscape metrics work as good indicators of the quality of the landscape mosaic, being appropriate to describe its degree of hemeroby and allowing us to anticipate possible changes in naturalness/artificialization based on LULC at a regional scale. This confirms the results of previous studies developed in different countries.

No index is interpretable by itself, as there is a wide range of elements of uncertainty regarding ecological interpretation. Only an approach using various spatial metrics and indicators, including the HI, allows a comprehensive analysis of changing use trends and consequences.

The results obtained through the application of different indicators of the state of the environment and LULC can be integrated into a nationwide system for monitoring the implementation of spatial planning measures and their impact on land systems. Therefore, consistently computing the mentioned metrics over time could significantly enhance the qualitative and quantitative understanding of Serbia's land use and land cover (LULC) changes. This data would give decision-makers and the public comprehensive insights into territorial transformations across various levels. Adapting planning models based on these indicators and the relations between them can effectively prevent and mitigate anthropic impacts on the ecosystem.

In sum, and broadly, the theoretical explanation of the relationship between landscape patterns and human disturbance lies in landscape metrics, disturbance theory, and human-environment interactions. Through these theoretical frameworks, we can understand how human activities shape landscape patterns and, in turn, how landscape patterns influence the distribution and impacts of human disturbance on ecological systems. This knowledge is essential for guiding landscape management, conservation efforts, and sustainable development strategies that balance human needs with environmental protection.

Future research should pay more attention to other determining factors influencing changes in use, namely population growth, economic development, and technological progress. It is also suggested that a territorial observatory be implemented to enable the systematic collection of data and, consequently, the monitoring and subsequent analysis of Territorial Dynamics. This observatory may have the configuration of a spatial data infrastructure.

Acknowledgments:
The authors would like to acknowledge the financial support of the National Funds provided by FCT-Foundation for Science and Technology to VALORIZA-Research Center for Endogenous Resource Valorization (project UIDB/05064/2020).

References:

[1] F. Geri, V. Amici and D. Rocchini, “Human activity impact on the heterogeneity of Mediterranean landscape”, *Appl. Geogr.* 30, 370-379, 2010.

[2] H. L. Li, J. Peng, Y. X., Liu and Y.N. Hu, “Urbanization impact on landscape patterns in Beijing City, China: A spatial heterogeneity perspective”, *Ecol. Indic.* 82, 50-60, 2017.

[3] P. Szilassi, T. Bata, S. Szabó, B. Czúcz, Z. Molnár and G. Mezősi, “The link between landscape pattern and vegetation naturalness on a regional scale”, *Ecol. Indic.* 81, 252-259, 2017. https://doi.org/10.1016/j.ecolind.2017.06.003

[4] T. Wu, P. Zha, M. Yu, G. Jiang, J. Zhang, Q. You and X. Xie, “Landscape Pattern Evolution and Its Response to Human Disturbance in a Newly Metropolitan Area: A Case Study in Jin-Yi Metropolitan Area”, *Land* 10(8), 767, 2021, https://doi.org/10.3390/land10080767.

[5] U. Steinhardt, F. Herzog F., A. Lausch, E. Müller, S. Lehmann , Hemeroby index for landscape monitoring and evaluation. In: Pykh, Y.A., Hyatt, D.E., Lenz, R.J. (eds): Environmental Indices – System Analysis Approach. *Oxford, EOLSS Publ.,* pp. 237-254, 1999.

[6] R.T.T.Forman, *Land Mosaics - The Ecology of Landscape and Regions*. Cambridge University Press, Cambridge, pp. 632, 1995.

[7] P. Liu, C. Wu, M. Chen, X. Ye, Y. Peng and S. Li, “A Spatiotemporal Analysis of the Effects of Urbanization’s Socio-Economic Factors on Landscape Patterns Considering Operational Scales”, *Sustainability,* 12, 2543, 2020, https://doi.org/10.3390/su12062543.

[8] T. Wrbka, K. H. Erb, N. B. Schulz, J. Peterseil, C. Hahn and H. Haberl, “Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators”, *Land Use Policy*, 21, 289-306, 2004, https://doi.org/10.1016/j.landusepol.2003.10.012.

[9] Y. Tian, B. Liu, Y. Hu, Q. Xu, M. Qu and D. Xu, “Spatio-Temporal Land-Use Changes and the Response in Landscape Pattern to Hemeroby in a Resource-Based City”, *Int. Journal of Geo-Information*, 9, 1-26, 2020, https://doi.org/10.3390/ijgi9010020.

[10] J. Jalas, *“Hemerobe und hemechore Pflanzenarten Ein terminologischer Reformversuch”*. Acta Fauna Flora Fenn. 72, 1-15, 1955.

[11] A. Machado, “An index of naturalness”, *J. Nat. Conserv*., 12, 95–110, 2004.

[12] H. Sukopp. “Human-caused Impact on Preserved Vegetation”, *Landscape and Urban Planning*, 68(4), 347-345, 2004.

[13] Copernicus Program, *“CORINE Land Cover”*, Available from: https://land.copernicus.eu/paneuropean/corine-land-cover (Accessed Date: January 25, 2023).

[14] K. McGarigal and B. J. Marks, *Fragstats: Spatial pattern analysis program for quantifying landscape structure.* General Technical Report PNW-GTR-351, US Forest Service Pacific Northwest Research Station, Portland, USA, 1995.

[15] T. Dabovic, et al.. "Compliance with social requirements for integrated local land use

planning in Serbia." *European Planning Studies*, 28(6): 1219-1241, 2020.

[16] C. García Fernández, D. Peek. Connecting the Smart Village: A Switch towards Smart and Sustainable Rural-Urban Linkages in Spain. *Land,* 12(4), 822, 2023, https://doi.org/10.3390/land12040822.

[17] P. Meyfroidt, A. de Bremond, C. M. Ryan, E. Archer, R. Aspinall, A. Chhabra, G. Camara, E. Corbera, R. DeFries, S. Díaz, et al. Ten facts about land systems for sustainability. *Proceedings of the National Academy of Sciences* 2022, 119, e2109217118, http://doi.org/10.1073/pnasszila.2109217118.

[18] G. H. Brundtland, M. Khalid, S. Agnelli, S. A. Al-Athel, P. G. Casanova, B. T. G. Chidzero, L. M. Padika, V. Hauff, I. Lang, M. Shijun. *Our Common Future; World Commission on Environment and Development*: Geneva, Switzerland, 1987; p. 300.

[19] B. Ness, E. Urbel-Piirsalu, S. Anderberg, L. Olsson. Categorising tools for sustainability assessment. *Ecol. Econ.*, 60, 498–508, 2007, https://doi.org/10.1016/j.ecolecon.2006.07.023.

[20] A. Zenya, A., Ø. Nystad, "Assessing Corporate Sustainability with the Enterprise Sustainability Evaluation Tool (E-SET)". *Sustainability,* 10, 4661, 2018, https://doi.org/10.3390/su10124661.

[21] U. Walz and C. Stein, "Indicators of hemeroby for the monitoring of landscapes in Germany", *J. Nat. Conserv.*, 22, 279-289, 2014, http://dx.doi.org/10.1016/j.jnc.2014.01.007.

[22] P. Newman, J. Kenworthy, *Sustainability and cities: overcoming automobile dependence;* Island Press, Washington, D.C., United States, 1999.

[23] C. Renetzeder, M. van Eupen, S. Mücher, T. Wrbka. "A spatial regional reference framework for sustainability assessment in Europe". In: Helming, K., Pérez-Soba, M., Tabbush, P. (eds.) *Sustainability Impact Assessment of Land Use Changes*, pp. 249-268, 2008, https://doi.org/10.1007/978-3-540-78648-1_13.

[24] F. van Stappen, I. Brose, Y. Schenkel. "Direct and indirect land use changes issues in European sustainability initiatives: State-of-the-art, open issues and future developments". *Biomass and Bioenergy*, 35, 4824-4834, 2011, https://doi.org/10.1016/j.biombioe.2011.07.015.

[25] J. Banski, M. Bednarek, M. Danes, E. Feliu, J. Fons Esteve, G. Garcia, G. Hazeu, S. Mucher, S.; R. Ole Rasmussen, M. Perez Soba. *EU-LUPA: European Land Use Patterns.* EU Commission, Luxembourg, 2013.

[26] European Environment Agency. *The direct and indirect impacts of EU policies on land; 8/2016*, Publications Office of the European Union: Luxembourg, 2016; p. 122, [Online]. https://www.eea.europa.eu/publications/impacts-of-eu-policies-on-land (Accessed Date: May 4, 2024).

[27] European Environment Agency. The European Environment. State and outlook 2010. Land use; Publications Office of the European Union: Luxembourg, 2010; p. 52, [Online]. https://www.eea.europa.eu/soer/2010 (Accessed Date: May 4, 2024).

[28] A. Vulevic, R. A. Castanho, J. M. Naranjo Gómez, L. Quinta-Nova. "Tendencies in land use and land cover in Serbia towards sustainable development in 1990–2018". *Acadlore Transactions on Geosciences*, 1, 43-52, 2022, https://doi.org/10.56578/atg010106.

[29] R. A. Castanho, J. M. Naranjo Gomez, A. Vulevic, G. Couto. "The Land-Use Change Dynamics Based on the CORINE Data in the Period 1990–2018 in the European Archipelagos of the Macaronesia Region: Azores, Canary Islands, and Madeira". *ISPRS International Journal of Geo-Information*, 10, 342, 2021, https://doi.org/10.3390/ijgi10050342.

[30] CORINE Land Cover - CLC, [Online]. http://clc.gios.gov.pl/index.php/o-clc/program-clc (Accessed Date: May 30, 2023).

[31] J. Martínez-Fernández, P. Ruiz-Benito, A. Bonet, C. Gómez. "Methodological variations in the production of CORINE land cover and consequences for long-term land cover change studies. The case of Spain". *Int. J. Remote Sens.*, 40, 1–19, 2019, https://doi.org/10.1080/01431161.2019.1624864.

[32] A. Pasca, D. Nasui. "The use of Corine Land Cover 2012 and Urban Atlas 2012 databases in agricultural spatial analysis.

Case study: Cluj County, Romania". *Res. J. Agric. Sci.*, 48, 314-322, 2016.

[33] Q. Weng. *Remote Sensing for Sustainability. In The Efects of Land Use and Land Cover Geoinformation Raster 23*. In: B. Meneses, E. Reis, R. Reis, M. J. Vale, M.J. (Eds.), Routledge: London, UK, p. 357, 2016.

[34] B. Meneses, E. Reis, R. Reis, R., M. J. Vale. "The Efects of Land Use and Land Cover Geoinformation Raster Generalization in the Analysis of LUCC in Portugal". *ISPRS Int. J. Geo-Inf.*, 7, 390, 2018, https://doi.org/10.3390/ijgi7100390.

[35] M. Hartvigsen. "Land reform and land fragmentation in Central and Eastern Europe". *Land Use Policy*, 36, 330–341, 2014, http://doi.org/10.5278/vbn.phd.engsci.00019

[36] D. Protic, I. Nestorov. "Development of digital cartographic database for managing the environment and natural resources in the Republic of Serbia". *In Proceedings of the International Cartographic Conference*. La Coruna, Spain, 2005.

[37] D. Evers, M. van Schie, L. van den Broek, T. Claus. *"SUPER - Sustainable Urbanization and Land-Use Practices in European Regions Report"*. Luxembourg, 2020, [Online]. https://www.espon.eu/sites/default/files/attachments/2020_ESPON_SUPER_Guide_final_A4_screenview.pdf (Accessed Date: May 4, 2024).

[38] T. Srejić, S. Manojlović, M. Sibinović, B. Bajat, I. Novković, M. V. Milošević, I. Carević, M. Todosijević, M. G. Sedlak. "Agricultural Land Use Changes as a Driving Force of Soil Erosion in the Velika Morava River Basin, Serbia". *Agriculture*, 13, 778, 2023, https://doi.org/10.3390/agriculture13040778

[39] D. Cvijanovic, O. Gavrilovic, M. Novkovic, D. Milosevic, M. Stojkovic Piperac, A. A. Andelkovic, B. Damnjanovic, L. Denic, N. Dreskovic, S. Radulovic. "Predicting retention effects of a riparian zone in an agricultural landscape: implication for eutrophication control of the Tisza river, Serbia". *Carpathian Journal of Earth and Environmental Sciences*, 18, 27-36, 2023, http://doi.org/10.26471/cjees/2023/018/238.

[40] J. Živanović Miljković, O. Dželebdžić, N. Čolić. "Land-Use Change Dynamics of Agricultural Land within Belgrade–Novi Sad Highway Corridor: A Spatial Planning Perspective". *Land*, 11, 1691, 2022, https://doi.org/10.3390/land11101691.

[41] D. Gataric, B. Dercan, M. B. Zivkovic, M. Ostojic, S. Manojlovic, M. Sibinovic, T. Lukic, M. Jeftic, M. Lutovac, M. Lutovac. "Can Depopulation Stop Deforestation? The Impact of Demographic Movement on Forest Cover Changes in the Settlements of the South Banat District (Serbia)". *Frontiers in Environmental Science*, 10, 897201, 2022, https://doi.org/10.3389/fenvs.2022.897201.

[42] N. Milentijević, M. Ostojić, R. Fekete, K. Kalkan, D. Ristić, N. R. Bačević, V. Stevanović, M. Pantelić. "Assessment of Soil Erosion Rates Using Revised Universal Soil Loss Equation (RUSLE) and GIS in Bačka (Serbia)". *Polish Journal of Environmental Studies*, 2021, 30(6), 5175-5184, 2021, http://doi.org/10.15244/pjoes/135617.

[43] M. Petković, I. Garvanov, D. Knežević, S. Aleksić. "Optimization of geographic information systems for forest fire risk assessment". In: *Proceedings of the 2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA)*, pp. 1-4, Bourgas, Bulgaria, 2020.

[44] D. Vukov, M. Ilić, M. Ćuk, R. Igić. "Environmental Drivers of Functional Structure and Diversity of Vascular Macrophyte Assemblages in Altered Waterbodies in Serbia". *Diversity*, 15, 231, 2023, https://doi.org/10.3390/d15020231.

[45] S. Zeković, K. Petovar, B. M. S. Nor-Hisham. "The credibility of illegal and informal construction: Assessing legalization policies in Serbia". *Cities*, 97, 102548, 2020, https://doi.org/10.1016/j.cities.2019.102548.

[46] L. Quinta-Nova. "Linking Landscape Pattern and Human Disturbance on a Regional Level: A Case Study in Beira Interior Region, Portugal", In: *CEUR Workshop Proceedings*, 3293, pp. 377-381, Athens, Greece, 2022.

[47] W. Wang, X. Li, H. Lv, Y. Tian. "What Are the Correlations between Human Disturbance, the Spatial Pattern of the Urban Landscape, and Eco-Environmental Quality?", *Sustainability*, 15, 1171, 2023, https://doi.org/10.3390/su15021171.

[48] Y. Fu, Y. Zhang. "Research on temporal and spatial evolution of land use and landscape pattern in Anshan City based on

GEE". Front. Environ. Sci., 10, 988346, 2022, https://doi.org/10.3389/fenvs.2022.988346.

[49] K. McGarigal. *"Landscape Pattern Metrics"*. In: A. H. El-Shaarawi and W. W. Piegorsch (Eds.) Encyclopedia of Environmetrics, 3. Ecological Statistics, Wiley, Hoboken, Nova Jersey, United States 2013, https://doi.org/10.1002/9780470057339.val006.

[50] P. Pavlović, , N. Kostić, B. Karadžić, M. Mitrović. *"The Soils of Serbia"*, Springer Netherlands, Dordrecht, 2017.

[51] Vulevic, A., Castanho, R.A., and Naranjo Gómez, J. M., (2023). Tourism as anthropogenic impact on the Land Cover change in the Park of nature "Sargan – Mokra Gora" in Serbia. *Desarrollo Compatible: Compatible Development: Experiences in Europe and Iberoamerica (Experiencias en Europa e Iberoamerica).* Ed. Thomson Reuters Aranzadi, Spain. ISBN 978-84-1163-6179 pp.17-38

[52] E. F. Lambin, P. Meyfroidt. "Land use transitions: Socio-ecological feedback versus socio-economic change". *Land Use Policy*, 27, 108-118, 2010, https://doi.org/10.1016/j.landusepol.2009.09.003.

[53] S. G. Perz. "Grand Theory and Context-Specificity in the Study of Forest Dynamics: Forest Transition Theory and Other Directions". *The Professional Geographer* 2007, 59, 105-114, 2007, https://doi.org/10.1111/j.1467-9272.2007.00594.x.

[54] J. Z. Miljkovic, V. Popovic, A. Gajić. "Land Take Processes and Challenges for Urban Agriculture: A Spatial Analysis for Novi Sad, Serbia". *Land*, 11(6), 769, 2022, https://doi.org/10.3390/land11060769.

[55] V. I. Ćirić, N. Drešković D. T. Mihailović, G. Mimić, I. Arsenić, V. Đurđević. "Which is the response of soils in the Vojvodina Region (Serbia) to climate change using regional climate simulations under the SRES-A1B". *Catena*, 158, 171-183, 2017, https://doi.org/10.1016/j.catena.2017.06.024

[56] N. Bogdanov, V. Rodić, M. Vittuari. "Structural change and transition in the agricultural sector: Experience of Serbia", *Communist and Post-Communist Studies*. 50(4), 319-330, 2017, https://doi.org/10.1016/j.postcomstud.2017.10.002.

[57] Vulevic, A., Castanho, R.A., and Couto, G., (2023). The impact of the COVID-19 on the tourism in Serbia. *Desarrollo Compatible: Compatible Development: Experiences in Europe and Iberoamerica (Experiencias en Europa e Iberoamerica).* Ed. Thomson Reuters Aranzadi, Spain. ISBN: 978-84-1163-6179, pp. 225-236.

[58] Spatial Plan of the Republic of Serbia 2021-2035, 04-00-1315, 2022, Serbia: SEA, [Online]. https://www.moew.government.bg/en/spatial-plan-of-the-republic-of-serbia-for-the-period-2021-2035/ (Accessed Date: May 4, 2024).

[59] Vulevic, A., Castanho, R.A., Obradovic, V., Zivak, N. (2018). Facing Urban Audit – Highlighting on Indicators and Perspectives for Public Urban Rail Transportation Services Access for Achieving Sustainable Urban Development. Briefly Literature Review. *25th APDR CONGRESS. FCHS,* Lisbon-Portugal. July 5-6. ISBN: 978-989-8780-06-5. pp. 263-267.

[60] Z. Nedovic-Budic, S. Zekovic, M. Vujosevic. "Land privatization and management in Serbia-Policy in limbo". *J. Archit. Plan. Res.*, 2012, 306-317, 2012.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

Funded by national funds through FCT - Portuguese Science and Technology Foundation, within the project reference UIDB/05064/2020.

Conflict of Interest

The authors have no conflicts of interest to declare.