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CHANGES IN VEGETATION COVER BY USING NDVI IN THE TERRITORY OF ŠUMADIJA ADMINISTRATIVE DISTRICT (CENTRAL SERBIA)

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Abstract: The study includes an analysis of the vegetation cover on the territory of the Šumadija Administrative District (Central Serbia) from 2002 to 2024. Vegetation analysis was performed using the Normalized Difference Vegetation Index (NDVI) in QGIS software. The method was used to identify grounds without vegetation and six distinct vegetation types were covered, with the goal of analyzing their changes in the study area. The research analyzed four Landsat 5 and Landsat 8 satellite scenes recorded in 2002, 2011, 2017, and 2024. Using the obtained NDVI values, vegetation types were mapped, and the area covered by each type was calculated. Vegetation cover underwent certain changes during the analyzed period in lower terrains and river valleys. An increase in areas without vegetation, areas overgrown with forest ecosystems, as well as areas of degraded forests, thickets, and thick shrub vegetation were registered. The reduction of agricultural land was recorded in all parts of the district, while the areas under vineyards and orchards decreased until 2017, after which their gradual increase was recorded. During the research period, the largest percentage increase was observed in areas overgrown with degraded forests, thickets, and dense bushy vegetation, whose share of the district's total area increased from 5.71% to 10.34%. Significant changes in the areas of all vegetation types have been largely influenced by the processes of depopulation, deagrarization, and urbanization. The results contribute to better understanding of long-term landscape transformation in the district and provide a strategic basis for spatial planning, environmental conservation, and sustainable development.

Keywords: NDVI; vegetation types; remote sensing; forests; Central Serbia

1. Introduction

Vegetation is a key component of terrestrial ecosystems, with an important role in the regulation of biogeographical and geochemical processes, as well as in the ecosystem's response to climate change and anthropogenic impacts (Dimson et al., 2024; Mehmood, Anees, Muhammad et al., 2024, Mehmood, Anees, Rehman et al., 2024; Munizaga et al.,

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2024; Sidi Almouctar et al., 2021). Vegetation changes reliably reflect ecological transformations, especially in conditions of climate change and accelerated urbanization (Sun et al., 2023; Verdugo et al., 2024). Due to the spatial and temporal heterogeneity of vegetation patterns, contemporary research increasingly uses high-resolution data obtained by remote sensing methods, whereby vegetation indices enable quantitative analysis of seasonal and perennial changes, including degradation and restoration effects (Che et al., 2023; Rahmi et al., 2024).

The combination of vegetation indices with time series from satellite databases such as Landsat and ERA5-Land enables the monitoring of vegetation dynamics at local, regional, and global levels (Banerjee et al., 2023; Liu et al., 2023; LP DAAC, 2025; Prasad et al., 2021). The correlation of these indicators with climatic parameters such as air temperature, precipitation, and air humidity confirms their value for ecological modeling and spatial planning (Ayhan et al., 2020; Zhang et al., 2021), while the pronounced negative association with drought indices is particularly evident in arid and semi-arid regions (Frutuoso et al., 2021; Khallef & Zennir, 2023).

Vegetation indices are increasingly used as tools for monitoring deforestation and forest degradation, as well as in the creation of sustainable land management strategies and policies adapted to climate change, confirming the importance of vegetation in climate regulation and the carbon cycle (Anees et al., 2022; Chaunhan et al., 2020; He et al., 2022). As one of the most commonly used vegetation indices, the Normalized Difference Vegetation Index (NDVI) is applied in agriculture and forestry to monitor seasonal changes, detect vegetation diseases, floods, pollution, and forest fires (Mehmood, Anees, Muhammad, et al. 2024). The greatest changes in forest cover today are recorded in tropical areas of Asia, Africa, and Latin America, mainly due to illegal logging and uncontrolled clearing, often fueled by weak institutional monitoring (Belhaj et al., 2025; Essaadia et al., 2022; Hartoyo et al., 2022; Huang et al., 2020; Khallef & Zennir, 2023).

In the last few decades, significant changes in vegetation cover have been recorded in Serbia, present in all parts of the country and in all types of vegetation, which are reflected in an increase or decrease in their areas, as well as in the expansion of degraded and urban areas (Durlević et al., 2022; Gatarić et al., 2022; Jakovljević & Đurđić, 2024; Marković et al., 2021; Miletić, 2024; Potić et al., 2022; Živanović et al., 2024). Remote sensing, especially in the hard-to-reach areas of southern and Central Serbia, enables precise mapping of changes in forest areas, while NDVI is used for detailed analysis of vegetation at the local level with high spatial resolution (Jovanović & Milanović, 2015; Jovanović et al., 2018). Considering that forests occupy about 30% of the territory of Serbia, NDVI is an effective tool for monitoring the impact of climatic and anthropogenic factors (Jovanović et al., 2018; Milanović et al., 2019).

This study analyzes changes in the vegetation cover on the territory of Šumadija Administrative District in Central Serbia using the NDVI in the period 2002–2024. The goal is to identify changes in vegetation types and examine the applicability of the NDVI method for the wider area of Serbia. The research is based on the hypothesis that the vegetation structure is continuously changing and that the reduction of agricultural and the increase of urban and degraded areas are mostly related to intensity of urbanization. The results can contribute to the development of sustainable land and forest management strategies, particularly those focused on vegetation restoration, prevention of forest degradation, and long-term ecosystem stability, as well as to making informed decisions in spatial planning at all levels of management, from local to national.

2. Study area

The study covers the territory of Šumadija Administrative District, which administratively belongs to the region of Šumadija and Western Serbia. The district includes the territory of the City of Kragujevac and the municipalities of Aranđelovac, Topola, Rača, Lapovo, Batočina, and Knić, with a total area of 2,388 km² (Statistical Office of the Republic of Serbia, 2024a). The administrative center of the district is the City of Kragujevac, which territorially covers the largest area of the district. The highest terrains in the district are on Mount Rudnik (1,132 m a.s.l), while the lowest (93 m a.s.l) are in the valleys of the Velika Morava River and its tributaries. The largest tributaries of the Velika Morava River that flow through the district are Lepenica, Rača, Jasenica, and Kubršnica, while the Gruža, as the largest river in the south of the district, flows into the Zapadna Morava River (Figure 1).

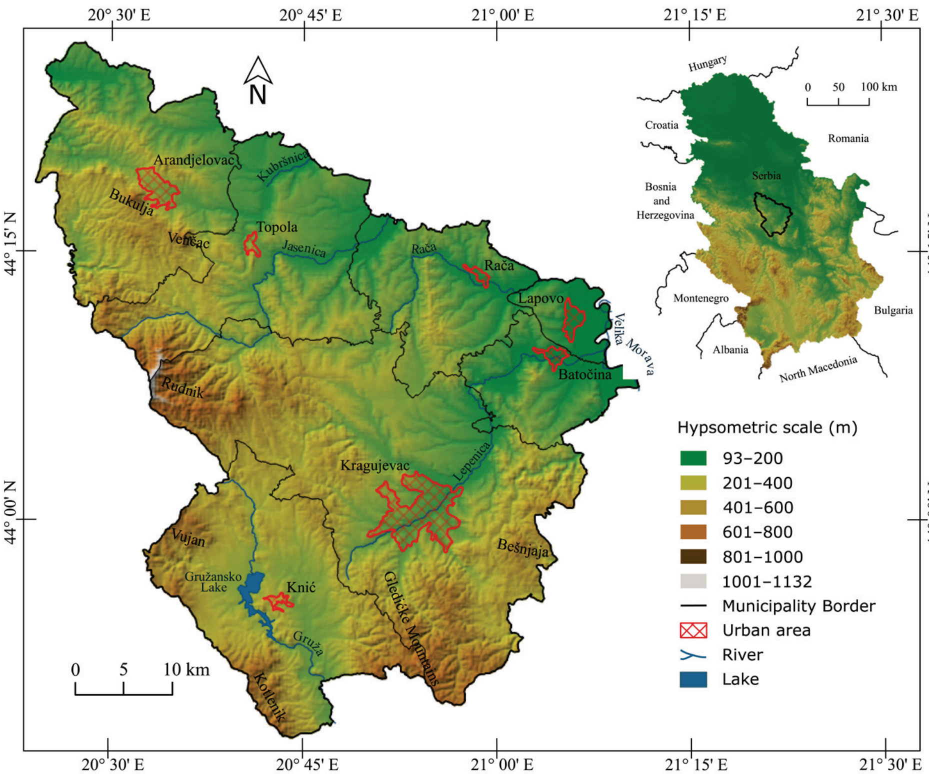

Figure 1. Geographical position of the Šumadija Administrative District.

The district has a complex geological structure composed of sedimentary, metamorphic, and igneous rocks. Quaternary eolian, terrestrial, and fluvial sediments dominate valleys, Pliocene–Quaternary gravel, sand, and clay occur in basins. Lower Miocene sediments prevail northward, Cretaceous limestones, marls, dolomite, and flysch form mountains, and Precambrian schists occur southeastward (Blagojević, 2019). River valleys are predominantly covered by recent alluvial soils, which provide favorable conditions for growing agricultural crops. In the eastern, northern, and north-western parts of the district, as well as in the area extending from north of Gružansko Lake to Mount Rudnik, Rendzina-type soils prevail. In the basins of the Jasenica and Kubršnica rivers, as well as in the upper reaches of the Rača and Lepenica rivers, Vertisols and metamorphic Vertisols are dominant. At higher altitudes in mountainous terrain, acidic, brown, and podzolic soils prevail (Pavlović, 2019)

According to the European Environment Agency (EEA, 2020), the higher mountain terrains are covered by broad-leaved forests, while the lower areas of the river valleys are dominated by complex cultivation patterns, non-irrigated arable land and land principally occupied by agriculture, with significant areas of natural vegetation. In the hilly and mountainous areas south of Topola, fruit trees and berry plantations prevail. Areas without vegetation are present in all parts of the district, contributed by both urban and rural settlements.

According to the Köppen Climate Classification (KCC), the district belongs to climate type Cfb, characterized as a moderately warm and humid climate with a dry winter and hot summer. Based on these characteristics, the area falls within the continental pluviometric regime, and its specific climate formula is Cf'w'bx (Mihajlović, 2018). The average annual precipitation in Kragujevac, which best reflects the climatic characteristics of the Šumadija Administrative District, was 651.8 mm. The highest mean monthly precipitation was recorded in June (77.2 mm), while the lowest mean monthly precipitation was recorded in February (40.1 mm). The mean annual air temperature in Kragujevac during the period 1991–2020 was 12.1 °C, with the highest mean monthly temperature in July (22.6 °C) and the lowest in January (1.3 °C) (Republic Hydrometeorological Service of Serbia, 2025).

3. Data and methods

Four satellite scenes with a resolution of 30 m recorded by Landsat satellites were processed in the paper. The satellite scenes covered the study area as well as parts of the neighboring districts. The delimitation of the research area was carried out in QGIS Desktop 3.34.13 software (QGIS Development Team, 2023) using a vector data layer containing the administrative boundaries of the district, downloaded from the digital platform GeoSrbija of the Republic Geodetic Office of Serbia (2025). After cropping the satellite scenes to the corresponding wavelength bands, the datasets were prepared for further analysis. The first and second scenes were captured by Landsat 5 satellites on June 24, 2002 (United States Geological Survey [USGS], 2025a), and July 19, 2011 (USGS, 2025b), while the third and fourth scenes were captured by Landsat 8 satellites on August 4, 2017 (USGS, 2025c), and July 14, 2024 (USGS, 2025d; Table 1). When selecting the scenes, it was necessary to find scenes that were created in clear weather when the cloud cover was 0% to eliminate the correction of atmospheric effects. Atmospheric correlation was performed over satellite scenes downloaded from USGS (2025a, 2025b, 2025c, 2025d) website, thus avoiding the need for additional scene processing (Milanović et al., 2019).

The analysis of the vegetation cover on the territory of the district was carried out using NDVI. The index is one of the most commonly used vegetation indices in Serbia and the world for evaluating vegetation dynamics, changes in the amount of biomass, the amount of chlorophyll, and water stress on the leaf surface (Bannari & Abuelgasim, 2021; Durlević et al., 2022; Gong et al., 2019; Hartoyo et al., 2022; Jovanović et al., 2018; Khallef & Zennir, 2023; Liu et al., 2023; Mansourmoghaddam et al., 2022). The index is obtained based on the measurement of the optical reflection of sunlight in different wavelengths (Durlević et al., 2022; Novković et al., 2021). NDVI is based on the fact that chlorophyll in plant leaves absorbs light in the red portion of the spectrum (RED), while the internal structure of leaves strongly reflects radiation in the near-infrared region (NIR). These spectral characteristics of vegetation are documented in the USGS Spectral Library Version 7, which provides standardized laboratory and field reflectance spectra across the visible and near-infrared wavelength ranges (USGS, 2017).

Table 1. Wavelengths and spatial resolution of spectral bands of the Landsat 5 and Landsat 8 satellites

C	Landsat 5		Landsat 8	
	Wavelength (μm)	Resolution (m)	Wavelength (μm)	Resolution (m)
Band 1	0.45–0.52	30	0.43–0.45	30
Band 2	0.52–0.60	30	0.45–0.51	30
Band 3*	0.63–0.69	30	0.53–0.59	30
Band 4*	0.76–0.90	30	0.64–0.67	30
Band 5*	1.55–1.75	30	0.85–0.88	30
Band 6	10.40–12.50	120	1.57–1.65	30
Band 7	2.08–2.35	30	2.11–2.29	30
Band 8	/	/	0.50–0.68	15
Band 9	/	/	1.36–1.38	30
Band 10	/	/	10.60–11.19	100
Band 11	/	/	11.50–12.51	100

Note. *Bands used in analysis. According to the technical specifications for Landsat 5 (USGS, 2025a, 2025b) and Landsat 8 (USGS, 2025c, 2025d).

The index can have values between –1 and 1. Negative values represent water surfaces, terrains without vegetation and artificial surfaces, while positive values represent terrains with vegetation (Hartoyo et al., 2022; Jovanović & Milanović, 2015; Khallef & Zennir, 2023; Milanović et al., 2019). The index is calculated using the following Equation (1):

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

where NIR represents the near-infrared part of the spectrum and RED represents the value from the red visible part of the spectrum (Essaadia et al., 2022; Hartoyo et al., 2022; Jovanović et al., 2018; Liu et al., 2023).

After calculating the NDVI value, the terrain was classified into seven categories. The classification was carried out in a manner similar to the approach applied by Milanović et al. (2019) in their research of vegetation types in Central Serbia. Threshold values between the categories were determined based on the terrain characteristics and the variations in the obtained NDVI values. In that process, the NDVI values of randomly selected surfaces on each of the analyzed satellite scenes were used as the basis for determining the boundaries. Therefore, areas without vegetation, water bodies, territories of cities, and larger settlements, as well as artificial surfaces represented the first category whose index value was between –1 and 0. Agricultural lands, including arable land and gardens, had index values ranging between 0 and 0.4. Meadows and pastures as a separate category had index values between 0.41 and 0.44. Areas under vineyards had index values between 0.441 and 0.45, while orchards had values between 0.451 and 0.46. As a separate, specific category, areas with degraded forest ecosystems, thickets, and dense shrub vegetation, which had index values between 0.461 and 0.5, were singled out. Index values higher than 0.51 represented the category of terrain covered with healthy forest ecosystems. The class boundary values are not common for NDVI classification in the territory of Serbia because they are the result of the specificity of the terrain and the recorded satellite scenes, which is why higher NDVI values were observed in all classes compared to reference study by Milanović et al. (2019). High NDVI class values may be a consequence of high biomass productivity during the period when the satellite images were acquired, in combination with favorable meteorological and hydrological conditions (Zheng et al., 2018).

The procedure for obtaining the vegetation index was applied using a calculator for processing raster images. All processed satellite scenes were in raster format, so they were composed of a large number of pixels. All pixels had the same unit values of 30 m, i.e. an area of 900 m^2. After adding pixels with the same values of vegetation types, multiplication by a unit value followed. The obtained areas, originally expressed in square meters, were converted into hectares (ha) for easier interpretation.

The obtained results were subjected to verification and accuracy assessment, i.e. data validation was performed. The validation process was implemented using two software tools. A total of 100 random sampling points were automatically determined across the research area for the analysis of satellite scenes. This method made it possible to eliminate subjectivity and bias in the selection of locations. The locations of randomly selected points were saved as a vector dataset, with the aim of enabling their overlap with the results of the vegetation type classification and satellite images from different time periods. The set of points was then loaded into the Google Earth Pro software (Google LLC, 2025), where a visual assessment of the vegetation type was performed for each point. Points where the visual assessment confirmed a match with the results obtained from the analysis in QGIS software were assigned a value of 1, while points where no match was determined were assigned a value of 0. In the last step of the analysis, correct and incorrect values were counted, based on which percentage accuracy values for all vegetation types were calculated.

Some researchers, including Gong et al. (2019), Jovanović and Milanović (2015), Mansourmoghaddam et al. (2022), and Milanović et al. (2019), consider that the agreement between visual assessment and NDVI classification can be regarded as reliable if the accuracy of the results exceeds 80%, despite the subjective nature inherent to visual assessment. Therefore, in this study, visual interpretation was employed as a method for evaluating the NDVI classification results.

4. Results

The lowest NDVI values on the territory of the district during the research period were recorded in urbanization zones, lowland areas, and valleys of larger watercourses, as well as in the water area of Gružansko Lake, which is located in the southwestern part of the district. These areas are characterized by a lower degree of vegetation coverage, which is a consequence of anthropogenic activities and the presence of water bodies that reflect low NDVI values. The river valleys of Jasenica, Rača, Gruža, Lepenica, and Velika Morava stand out in particular. On the contrary, the highest NDVI values were registered in mountainous and hilly areas, where forest complexes and natural vegetation dominate, such as the slopes of Bukulja, Venčac, Rudnik, Vujan, Kotlenik, Gledićke Mountains, and Bešnjaja (Figure 2).

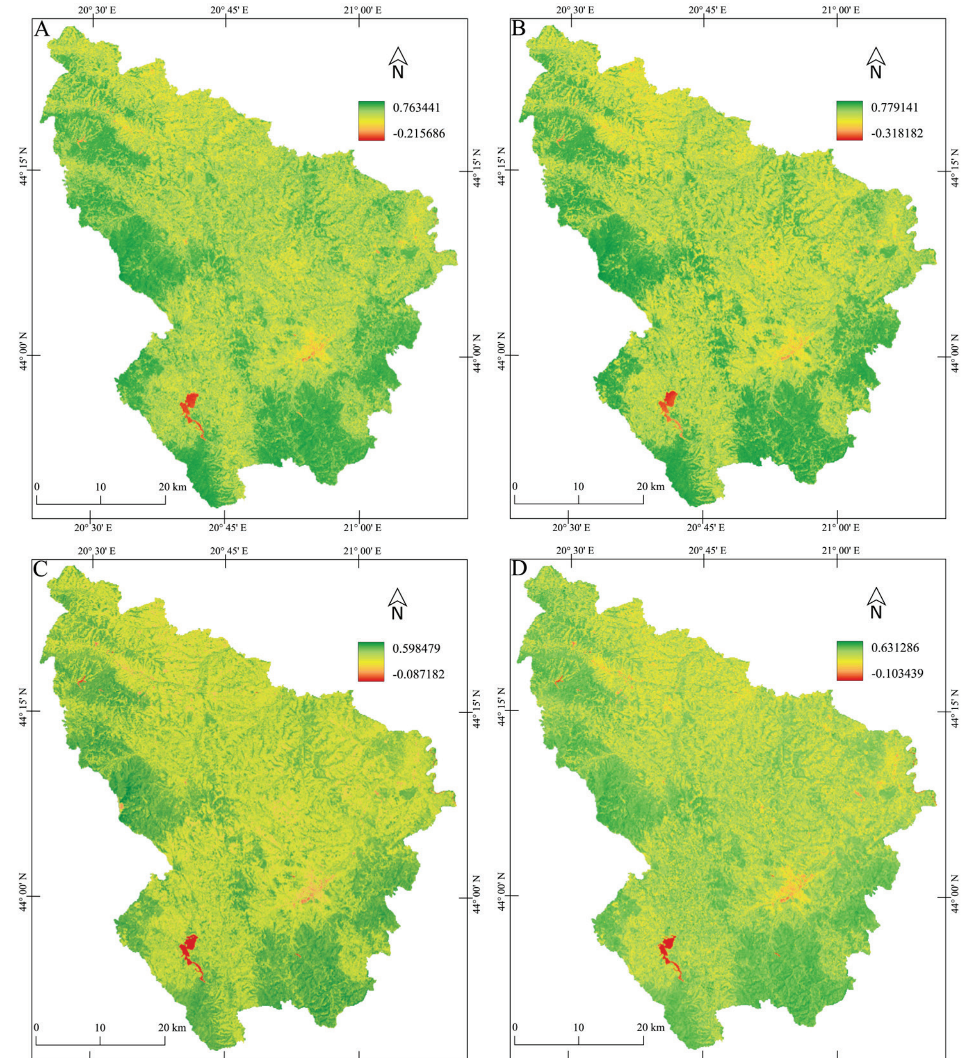

Figure 2. NDVI values for the years 2002 (A), 2011 (B), 2017 (C), and 2024 (D) in the Šumadija Administrative District.

In the satellite scene from 2017, an increase in areas without vegetation was observed compared to the scenes from 2002 and 2011. At the same time, an increase in forest areas was registered, as well as an expansion of the area of degraded forests, thickets, and dense shrubby vegetation. The biggest changes were recorded at lower altitudes, where there was a significant decrease in the area under crops, which directly affected the increase in natural vegetation, primarily shrubs, and thickets (Figure 2).

During the research period, the share of urban areas in the district showed only minor changes. In 2002, areas without vegetation accounted for 3.13% of the total area. By 2011, this proportion was 3.17%, and by 2017, it reached 3.21%. Between 2017 and 2024, areas without vegetation covered 3.42% of the district's territory (Table 2).

At the beginning of the research period, meadows and pastures comprised 10.7% of the territory. By 2011, they covered 11.87% of the study area. The area decreased after 2011, and in 2017 it covered 11.45% of the study area. By 2024, meadows and pastures amounted to 11.27% of the territory (Table 2). Changes were mainly recorded in the hilly and mountainous areas of the district, where abandoned land was gradually overgrown by natural vegetation. Similar trends were also observed in the lowland areas, particularly on agricultural land that had been left fallow, leading to a slight increase in meadow and pasture coverage.

In 2002, the areas under vineyards covered 1.83% of the district's territory. Between 2002 and 2017, the area remained relatively stable. In 2011, vineyards covered 1.76% of the district's territory, and by 2017 it was 0.85%. In 2024, the area accounted for 1.15% of the district's territory (Table 2). Unlike vineyards, the area under orchards exhibited only minor changes. At the beginning of the analyzed period, in 2002, orchards comprised 3.02% of the total territory. In 2011, orchards covered 2.73%, followed by 2.86% in 2017. By 2024, orchards accounted for 3.01% of the territory.

Table 2. Area of vegetation types (in ha and % share of the total area) on the territory of the Šumadija Administrative District in 2002, 2011, 2017, and 2024

Vegetation type	2002	2011	2017	2024
Areas without vegetation	7,473.66 (3.13%)	7,569.1 (3.17%)	7,671.1 (3.21%)	8,172.45 (3.42%)
Agricultural land	114,652.08 (48.03%)	110,373.3 (46.24%)	102,140.72 (42.79%)	92,904.93 (38.92%)
Meadows and pastures	25,540.93 (10.7%)	28,339.47 (11.87%)	27,329.1 (11.45%)	26,899.41 (11.27%)
Vineyards	4,375.89 (1.83%)	4,211.3 (1.76%)	2,019 (0.85%)	2,733.7 (1.15%)
Orchards	7,215.7 (3.02%)	6,514.1 (2.73%)	6,826.5 (2.86%)	7,175.9 (3.01%)
Degraded forests, thickets, shrubs	13,618.9 (5.71%)	16,370.46 (6.86%)	22,145.5 (9.28%)	24,684.1 (10.34%)
Forests	65,815.84 (27.58%)	65,314.82 (27.37%)	70,561.08 (29.56%)	76,122.9 (31.89%)

Note. Values differ by ± 0.05% of the district's territory.

Degraded forest ecosystems, thickets, and terrains overgrown with dense shrub ecosystems recorded an increase over the entire research period. In 2002, the mentioned areas comprised 5.71% of the district's territory. In 2011, these areas covered 6.86% of the district's territory, while in 2017 they covered 9.28%. In the period that followed until 2024, the mentioned areas further increased their area to 10.34% of the territory. The observed increase was primarily recorded in the hilly and mountainous areas of the district, where the greatest transformations of vegetation types occurred. In these regions, degraded forest ecosystems, thickets, and terrains overgrown with dense shrub ecosystems expanded at the expense of other vegetation types (Figure 3).

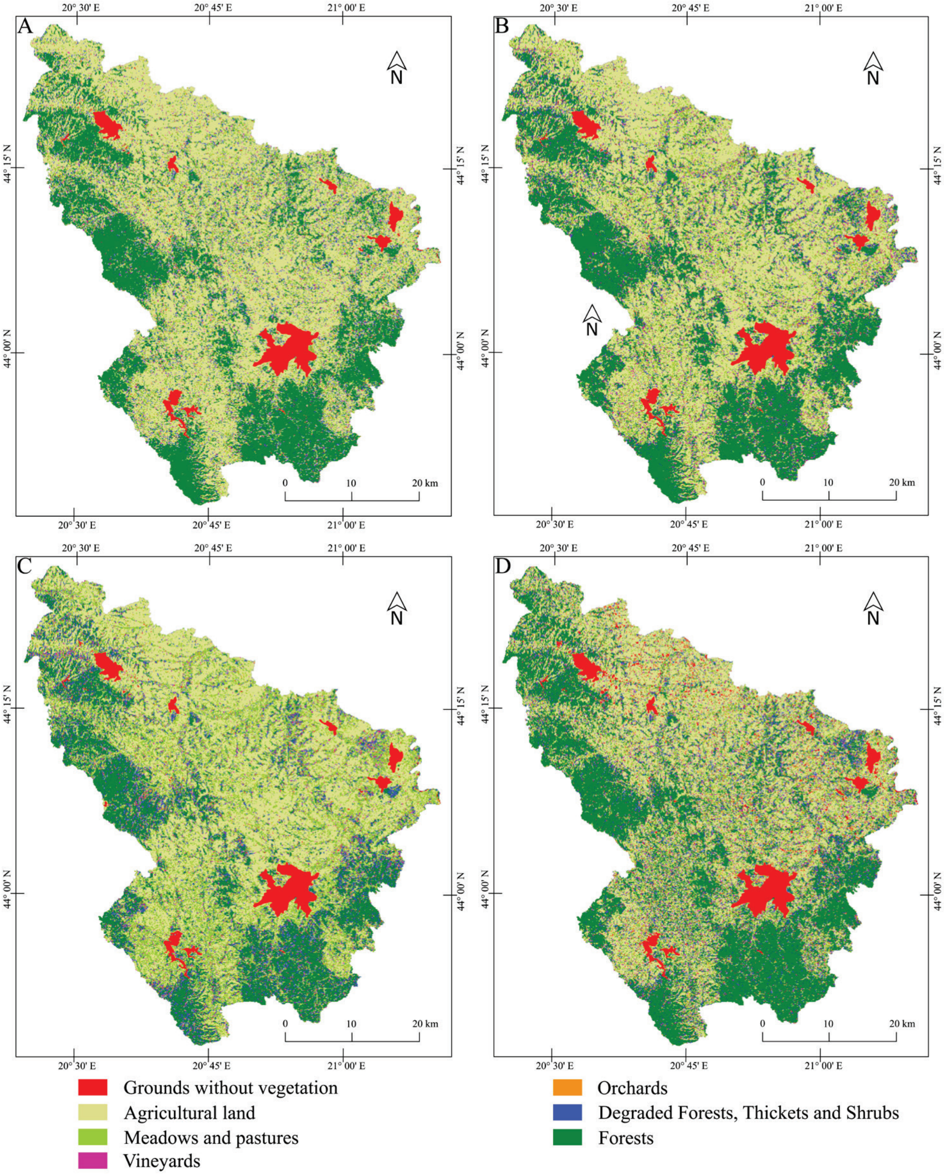

Figure 3. Vegetation types for the years 2002 (A), 2011 (B), 2017 (C), and 2024 (D) in the Šumadija Administrative District.

At the beginning of the analyzed period, the areas covered by forests comprised 27.58% of the territory. A decrease in area was recorded only in the period from 2002 to 2011, when they covered 27.37% of the studied area. After 2011, the area under forests recorded constant growth. In 2017, it accounted for 29.56% of the territory, while in 2024 it reached 31.89%. The largest increase in forests areas was recorded in the mountainous and hilly regions of the district (Figure 3).

The areas under crops, arable land, and gardens comprised 48.03% of the district's territory in 2002. In the period that followed until 2024, a continuous decrease in their areas was recorded. In 2011, agricultural areas comprised 46.24% of the district's territory, and this share continued to decline until 2017, when agricultural land covered 42.79% of the territory. The most significant decline occurred during the 2017–2024 period, with agricultural areas covering only 38.92% of the district's territory in 2024 (Figure 3).

The results of the validation of the NDVI analysis for the period from 2002 to 2024 show a clear trend of increasing the accuracy of the classification of different types of vegetation. The average classification accuracy value increased from 82% in 2002 to 89% in 2024. Looking at individual categories, it can be seen that areas without vegetation recorded a constant increased from 84% in 2002 to 91% in 2024. The agricultural land category shows an increase in accuracy from 80% in 2002 to 86% in 2011, after which the values remain stable until 2024 (88%). For the meadows and pastures category, slightly larger oscillations were recorded, with an increase up to 88% in 2011, a slight decrease in 2017 (85%), and an increase again to 90% in 2024. Values for vineyards and orchards indicate steady growth across all observed years, with vineyards reaching 87% and orchards reaching 89% accuracy in 2024. The categories that include degraded forests, thicket, shrubs, and forests maintain high accuracy values throughout the period, ranging from 82% to 90% (Table 3).

Table 3. Validation accuracy (in %) of vegetation types by year and average values (2002–2024)

Vegetation type	2002	2011	2017	2024
Areas without vegetation	84	85	87	91
Agricultural land	80	86	88	88
Meadows and pastures	83	88	85	90
Vineyards	81	84	87	87
Orchards	78	83	85	89
Degraded forests, Thicket, Shrubs	85	87	88	90
Forests	82	83	83	87
Average value	82	85	86	89

Note. Values differ by ± 0.15% accuracy.

5. Discussion

The spatial and temporal analysis of NDVI values in the Šumadija Administrative District indicates significant changes in vegetation cover during the period from 2002 to 2024. The results show that the structure and distribution of vegetation have changed under the influence of natural factors and anthropogenic processes. Changes in NDVI values reflect trends of agricultural land reduction and forest area expansion, indicating a dynamic transformation of land use over the past two decades. The results for the Šumadija Administrative District are comparable to regional trends observed in Topola municipality, where abandoned agricultural plots have undergone natural succession, resulting in the gradual restoration of forest complexes (Jovanović & Milanović, 2015).

The lowest NDVI values were recorded in urban areas, water bodies such as Gružansko Lake, and river valleys including Jasenica, Rača, Gruža, Lepenica, and Velika Morava. These zones exhibit low vegetation cover due to intensive land use, urban expansion, and water surface reflectance. In contrast, the highest NDVI values in the Šumadija Administrative District occur in mountainous and hilly areas dominated by forest complexes and natural vegetation. The slopes of Bukulja, Venčac, Rudnik, Vujan, Kotlenik, Gledićke Mountains, and Bešnjaja show stable vegetation activity. This pattern confirms the relationship between relief, altitude, and anthropogenic pressure, in line with trends observed in the Zlatibor Administrative District, located in the western part of Serbia (Marković et al., 2021).

During the analyzed period, a continuous decline in the area of agricultural land, including arable land and gardens, was observed. In 2002, agricultural land covered 48.03% of the total district territory, but by 2024, it decreased to 38.92%. This trend indicates a long-term reduction in agricultural activity and land abandonment, especially in lowland and peri-urban areas. At the same time, a continuous increase was recorded in degraded forest ecosystems, thickets, and dense shrub formations, which expanded from 5.71% of the district's area in 2002 to 10.34% in 2024. These changes point to the natural succession of abandoned agricultural lands and the gradual transformation of anthropogenic landscapes into semi-natural vegetation forms.

The continuous decrease in agricultural land area can be partly explained by depopulation and urbanization processes (Gatarić et al., 2022). According to the censuses of 2002, 2011, and 2022, the number of inhabitants in the territory of the Šumadija Administrative District has been steadily decreasing. The population decreased from 298,778 in 2002 to 269,728 in 2022, representing a total decline of 9.73% (Statistical Office of the Republic of Serbia, 2024b). The decline was more pronounced in rural settlements, while urban areas recorded a slight population increase between 2002 and 2011, reflecting migration from villages to cities. These demographic changes directly contributed to reduced agricultural activity and arable land.

After 2011, forested areas recorded continuous growth, becoming one of the most dynamic land cover categories in the study region. Forest ecosystems expanded from 27.58% to 31.89% of the district's total area between 2002 and 2024. However, during 2002–2011, forest cover slightly declined from 27.58% to 27.37%, likely reflecting logging and other anthropogenic disturbances. These trends contrast with other parts of Serbia, where forest cover declined due to mining, urban expansion, illegal logging, and soil degradation, such as in the Kolubara Coal Basin in the Kolubara River basin, Kopaonik National Park, and the municipalities of Topola, Jagodina, and Kuršumlija in Central Serbia (Durlević et al., 2022; Jovanović et al., 2018; Milanović et al., 2019; Živanović et al., 2024). The sustained increase after 2011 reflects natural regeneration, possible reforestation, and agricultural land abandonment. Forest expansion is pronounced on the slopes of Bukulja, Venčac, Rudnik, Vujan, Kotlenik, and the Gledićke Mountains, where vegetation improves stability and locally reduces erosion areas.

Simultaneous expansion of degraded forests, thickets, and shrub vegetation indicates spatially nonuniform regeneration. Transitional formations occur mainly in hilly and mountainous areas where succession is ongoing, producing heterogeneous structures. Thus, increasing forest cover partly reflects early successional and fragmented habitats. This ecological transition, shaped by natural and anthropogenic factors, is consistent with results based on NDVI analysis in the Kuršumlija municipality in Central Serbia (Jakovljević & Đurđić, 2024).

Variability was observed in perennial crops such as vineyards and orchards. Vineyards declined until 2017, reaching 0.85% of the district's territory, followed by partial recovery to 1.15% by 2024. Orchards decreased until 2011 (2.73%) and then gradually increased to 3.01% in 2024. These trends reflect changes in agricultural practices and adaptation to favorable conditions. However, these changes affect relatively small areas, so despite notable percentage variation, their impact on overall vegetation dynamics remains limited.

Areas without vegetation increased gradually until 2017, followed by more pronounced growth, reaching a 6.54% increase between 2017 and 2024. This trend reflects urbanization, infrastructure development, and conversion of natural or agricultural land into built-up surfaces, especially near urban centers, transport corridors, and peri-urban zones. Similar trends were observed in the Nišava Administrative District in Central Serbia, where urban and industrial expansion reduced vegetation cover while peripheral forests remained stable (Miletić, 2024). The spread of roads and concentrated human activity has increased non-vegetated surfaces, reducing vegetation regeneration, altering microclimate and soil permeability, fragmenting landscapes, and affecting ecological connectivity, highlighting the ongoing spatial restructuring between built and natural environments.

During the research period, small changes in meadows and pastures were registered, increasing from 10.7% in 2002 to 11.87% in 2011, then decreasing to 11.27% in 2024. These variations reflect land abandonment, overgrowth, and seasonal grazing, especially in hilly areas. In lowlands, abandoned parcels are colonized by natural vegetation, showing ongoing succession (Potić et al., 2022).

The classification results, with accuracy values ranging from 82% in 2002 to 89% in 2024, demonstrate a consistent improvement throughout the analyzed period. The average accuracy increased by 7%, indicating enhanced precision in distinguishing vegetation types across time. Among individual categories, areas without vegetation achieved the highest accuracy, rising from 84% to 91%, while agricultural land improved from 80% to 88% and remained stable thereafter. Meadows and pastures showed moderate fluctuation, with values ranging from 85% to 90%, reflecting the natural variability of grassland vegetation. Vineyards and orchards recorded gradual improvement, from 81% to 87% and from 78% to 89%, respectively, indicating better detection of perennial crops. Degraded forests, thickets, and shrubs maintained high accuracy (85–90%), while forests showed a steady increase from 82% to 87%.

The validation results in this study align with regional and global research. Milanović et al. (2019) obtained an overall accuracy of 80–85% for vegetation derived from NDVI in Central Serbia, and Jovanović and Milanović (2015) achieved 80–83% for forest classes. Internationally, NDVI-based classifications reached 80–90% accuracy, highlighting the importance of validation and spatial autocorrelation (Gong et al., 2019; Mansurmoghadam et al., 2022).

Compared to previous studies, the present NDVI-based classification demonstrates slightly higher accuracy for forests, areas without vegetation, and perennial crops, while meadows and pastures show moderate fluctuations, reflecting natural heterogeneity. The differences likely result from landscape composition, spatial resolution, and reference data quality. Despite its reliability, NDVI is sensitive to soil reflectance, atmospheric conditions, and vegetation phenology, which may reduce separability between grasslands, sparse shrubs, and heterogeneous agricultural mosaics (Bannari & Abuelgasim, 2021). The use of a single spectral index and reference data limitations may also affect accuracy, while spatial autocorrelation can overestimate performance (Gong et al., 2019). Overall, the analysis reveals complex interactions between topography, land-use dynamics, and ecological processes, highlighting the gradual reduction of agricultural land, forest expansion, and vegetation recovery. These changes indicate a shift toward a more diverse ecological mosaic, shaped by natural succession, relief, and anthropogenic pressure.

6. Conclusion

The analysis of NDVI values and land cover changes in the Šumadija Administrative District between 2002 and 2024 indicates significant spatiotemporal transformations in vegetation structure and land use. The lowest NDVI values were consistently associated with urbanized zones, lowland areas, and major river valleys, while the highest values corresponded to mountainous regions dominated by forest vegetation. Agricultural areas, particularly arable land and crops, declined continuously, accompanied by the expansion of degraded vegetation, thickets, and natural succession on abandoned land. Forest areas showed a marked increase after 2011, highlighting ongoing processes of reforestation and vegetation recovery. The expansion of urban areas and the reduction of agricultural land reflect the growing anthropogenic impact on the landscape. Overall, the results emphasize the progressive transformation of land cover driven by natural vegetation dynamics and human-induced land use changes.

Between 2002 and 2024, the share of agricultural areas in the district decreased markedly from 48.03% to 38.92%, representing a total reduction of 9.11%, with the most pronounced decline occurring after 2017. In contrast, forested areas expanded from 27.58% to 31.89%, indicating a 4.31% increase over the same period. Degraded forest ecosystems, thickets, and dense shrub vegetation also showed a steady upward trend, increasing from 5.71% in 2002 to 10.34% in 2024. The area without vegetation nearly doubled in the final period, rising from 3.21% in 2017 to 9.75% in 2024, highlighting intensified urbanization processes. These quantitative shifts clearly demonstrate a dual trajectory of landscape transformation, on one hand, urban expansion, and agricultural decline, and on the other, natural reforestation and vegetation regeneration in previously cultivated or abandoned areas. The observed faster expansion of degraded forest areas, compared to that of healthy forests, underscores a critical ecological concern and emphasizes the necessity for systematic, long-term monitoring to prevent further environmental deterioration.

Demographic processes, especially the depopulation of rural settlements and urbanization, significantly influenced the change in land use. The decrease in the number of inhabitants in rural areas contributed to the abandonment of arable land, which led to an increase in secondary vegetation and the succession of pastures and thickets. At the same time, urbanization contributed to the increase of areas without vegetation. These changes have direct consequences on local ecosystem functions, potential for vegetation restoration, and sustainable use of land resources.

The results of this study provide an important basis for sustainable land management and the conservation of forest and agricultural ecosystems. However, the study is limited by the exclusive use of NDVI for vegetation analysis, the spatial and temporal resolution of the available satellite imagery, and possible errors in land cover classification. Future research could incorporate other vegetation indices, higher-resolution satellite data, and more detailed analyses of ecological processes to improve understanding of land cover dynamics and contribute to sustainable environmental management.

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