Racic M., Borota D., Martac N., Golubovic A., Lazarevic N., Racic I., Petrovic N. (2025). The NDVI values differences in relation to canopy density using sentinel-2 level-2A remote sensing data. Agriculture and Forestry, 71 (3): 189 - 198. https://doi:10.17707/AgricultForest.71.3.11

DOI: 10.17707/AgricultForest.71.3.11

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THE NDVI VALUES DIFFERENCES IN RELATION TO CANOPY DENSITY USING SENTINEL-2 LEVEL-2A REMOTE SENSING DATA

SUMMARY

This paper presents the results of a research on the relationship between the NDVI and stand canopy density. The study was conducted within the Forest Management Unit "Bruske šume", located in Central Serbia. The aim of this study is to determine whether there is a significant difference between the NDVI values depending on stand canopy density in high forests, coppice forests and artificially established stands. The stand canopy density data were collected from the Forest Management Plan and validated in the field, while the NDVI data were obtained using the Google Earth Engine platform based on Sentinel-2 Level 2A imagery. A one-way ANOVA was performed to assess the statistical significance of differences in the NDVI values between stand canopy density classes, followed by an LSD test for post-hoc group comparisons. The results of the research indicate that the arithmetic means of the NDVI values by stand canopy density across the three forest origin categories reveal a clear and consistent trend of decrease of the NDVI values with decreasing stand canopy density. The ANOVA revealed that the NDVI values differed significantly between stands with different levels of canopy density within each of the three forest origin groups. In all analyzed categories, stands with a dense canopy had the highest NDVI values. The highest NDVI values were recorded in high forest stands, while the lowest values were observed in artificially established stands.

Keywords: NDVI, remote sensing, stand canopy density, forest origin,

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.

Recieved:28/04/2025 *Accepted:01/09/2025*

INTRODUCTION

Thirty percent of the Earth's surface is covered by forests, and a wide range of services is provided by them (Jenkins and Schaap, 2018). Providing these services in sustainable way has the potential to provide answers to major societal challenges, such as reducing greenhouse gas concentrations, mitigating global warming, biodiversity loss or enhancing rural development (Hernández-Morcillo *et al.,* 2022; Thien *et al.,* 2023; Li *et al.,* 2022). In forestry research, the monitoring of forest ecosystems and vegetation change has always been recognized as essential (Wu *et al.,* 2025). Monitoring changes in forest cover and identifying their drivers are essential for developing sustainable forest management strategies to restore forest resources and ecosystem services (Debebe *et al.,* 2023). Monitoring forests at both local and regional scales can be effectively achieved through the use of remote sensing techniques (Le *et al.,* 2023).

Spectral indices based on vegetation reflectance in different spectral regions are widely used for vegetation monitoring (Nijland *et al.,* 2014). Among the earliest remote sensing analytical products, the Normalized Difference Vegetation Index (NDVI) remains extensively used for assessing vegetation (Huang *et al.,* 2021; Zhao and Qu, 2024). It represents the normalized ratio of the difference between near-infrared and red reflectance (Rouse *et al.,* 1973). The NDVI has found wide application in the field of forestry. The NDVI serves as an effective tool for monitoring land use change (Nath and Acharjee, 2013; Gandhi *et al.,* 2015; Othman *et al.,* 2018) and forest health (Meneses -Tovar, 2012; Tuominen *et al.,* 2009; Ya`acob *et al.,* 2014). A significant number of studies emphasise the potential of using the NDVI for estimating various stand characteristics, such as vegetation productivity and forest density (D'Arrigo *et al.,* 2000; Kumar *et al.,*2007; Kinyanjui, 2011). The NDVI exhibits correlation with primary climate factors, especially precipitation and temperature (Ghebrezgabher *et al.,* 2020, Luo *et al.,* 2016, Hao *et al.,* 2012). Understanding the relationship between the NDVI and key climate variables enables the prediction of productivity changes under different climate scenarios (Wang *et al.,* 2003).

Although NDVI has been widely applied in monitoring forest health and productivity, comparatively limited research has focused on its variability across different forest structures and management types. Canopy density—defined as the proportion of ground area covered by the projection of tree crowns—directly influences the amount of intercepted light and, consequently, the NDVI values. Understanding how NDVI responds to variations in canopy density within high forests, coppice forests, and artificially established stands can yield deeper insights into forest condition assessment. In this context, the aim of this study is to determine whether there is a significant difference in the NDVI values depending on canopy density in high forests, coppice forests and artificially established stands.

MATERIAL AND METHODS

The investigation was conducted within the Forest Management Unit (FMU) "Bruske šume", which is managed by the Public Enterprise " Srbijašume" (Figure 1). The FMU is located in Central Serbia and covers mainly the territory of Brus municipality and partly of the municipality of Aleksandrovac (between 18°34' and 18°44' E and 43°20' and 43°27' N) with a total area of 4935.44 ha. The altitude ranges from 340 to 1431 m above sea level. The average annual temperature is 10.6°C, while the total annual precipitation amounts to 675.4 mm (Osnova gazdovanja šumama za GJ „Bruske šume" 2024-2033).

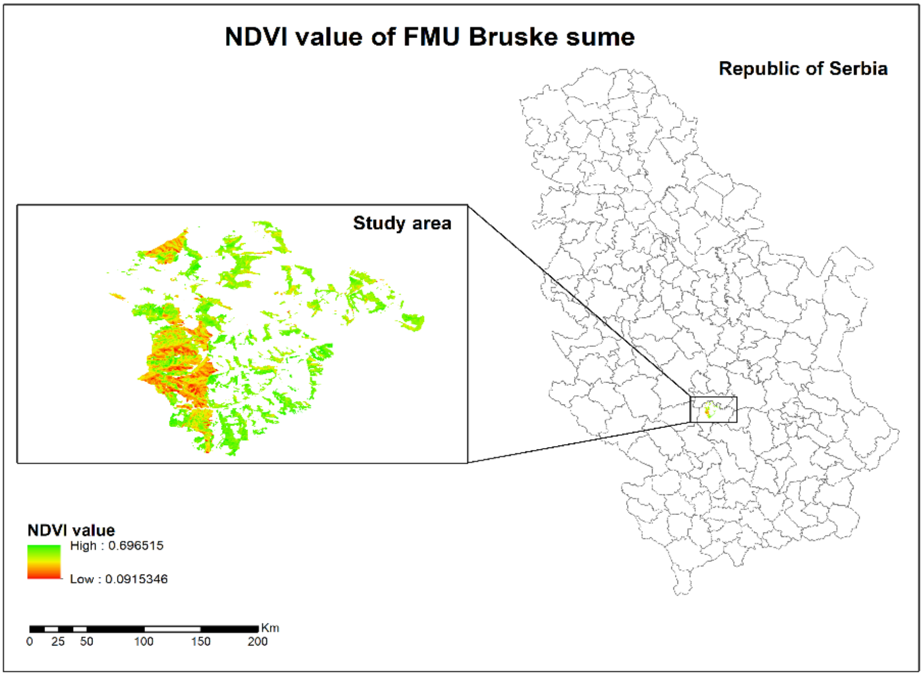


Figure 1. Study Area

The three identified forest origin categories cover an area of 3924.53ha (Table 1) which corresponds to 79.5% of the total area of the FMU. Coppice forests are the most represented (1445.93 ha or 36.8%), followed by high forests (1389.06 ha or 35.4%), and artificially established stands (1089.54 ha or 27.8%) (Osnova gazdovanja šumama za GJ „Bruske šume" 2024-2033).

Table 1. Forest cover by stand origin

Stands origin	Area	
	ha	**%**
High forests	1389.06	35.4
Coppice forests	1445.93	36.8
Artificially established stands	1089.54	27.8
Total	**3924.53**	**100**

The data on stand canopy density were obtained from the Forest Management Plan (FMP) for the respective FMU, whereby the data collected was subsequently verified on site. Stands were classified into canopy density classes based on the estimated crown closure percentage, and classification scheme is the following: dense: >80% canopy closure, complete: 60–80% canopy closure, partial: 40–60% canopy closure and sparse (only for artificial stands): <40% canopy closure.

Normalised Difference Vegetation Index (NDVI), a commonly used indicator in satellite-based vegetation remote sensing, was calculated using the following equation (Rouse *et al.,* 1973):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

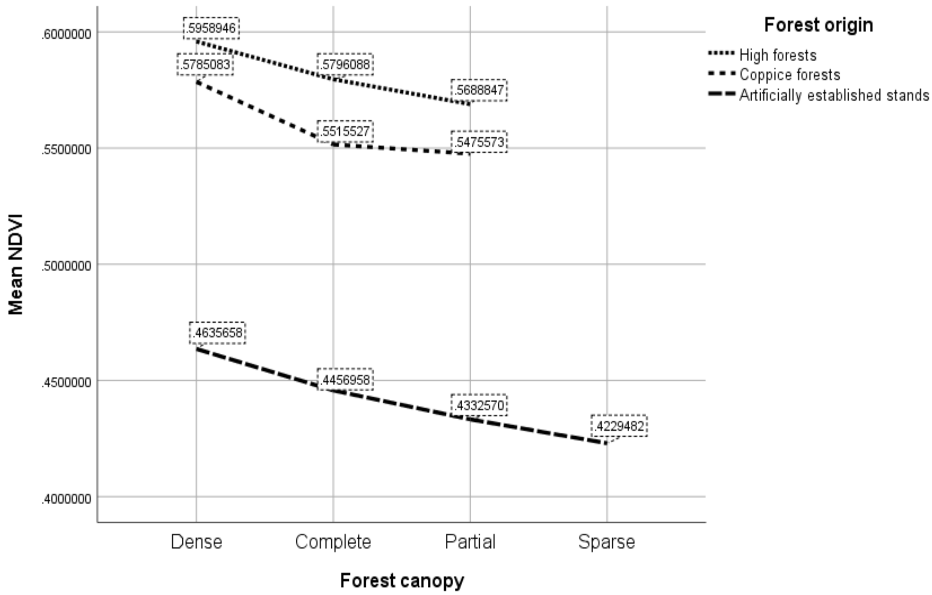
where, NIR represent the light reflectance in the near-infrared wavelength from 720 to 1300nm, while Red is the light reflectance in red wavelength from 600 to 720 nm reflectance (Naser *et al.,* 2020).

Since the data collection was conducted during 2023, the NDVI values were also acquired for the same year. The NDVI values were derived from Sentinel-2 Level-2A using the Google Earth Engine (GEE) platform. The imagery from the vegetation peak period (June – August 2023) was used to minimize phenological differences of observed species and stands. Average NDVI values for each stand within the FMU were calculated and extracted using the Zonal Statistics in ArcMap. The NDVI data were extracted exclusively for the year 2023 to ensure methodological consistency with the ground-based forest inventory conducted in the same period. This approach was chosen in order to minimize the influence of anthropogenic forestry operations (thinning, harvesting, or afforestation) that are typically carried out as part of regular forest management activities. Since no such interventions occurred within the FMU in 2023, the year represented a neutral baseline, allowing the NDVI values to reflect undisturbed canopy conditions. As such, the 2023 dataset provides an ecologically representative and methodologically aligned snapshot of canopy structure at the time of ground verification.

A one-way analysis of variance (ONE-WAY ANOVA) was performed to examine significant differences in the NDVI values among stands with different canopy closure within high forests, coppice forests, and artificially established stands. The Least Significant Difference (LSD) post hoc test was performed to identify differences between specific groups. All statistical analyses were conducted at a significance level $\alpha < 0.05$, with prior verification of the main assumptions for ANOVA, including normality of distribution (Shapiro-Wilk test) and homogeneity of variances (Levene`s test). Statistical processing was carried out usiang IBM SPSS Statistics.

RESULTS AND DISCUSSION

The line graph (Graph 1) which shows the arithmetic means of the NDVI values by stand canopy density across the three forest origin categories reveals a clear and consistent trend of decrease of the NDVI values with decreasing stand canopy density. By researching the possibility of improving and changing significant vegetation indices (Xue and Su, 2017), it has been indicated that NDVI is related to canopy structure.



Graph 1. Arithmetic means of the NDVI values by canopy density across forest origin categories

The results of the one-way analysis of variance (ONE-WAY ANOVA) (Table 2) demonstrated that there are statistically significant differences in the NDVI values depending on canopy density across all three forest origin categories.In the category of high forests, the ANOVA revealed a statistically significant difference in the NDVI values among stands with different canopy densities ($F(2, 90) = 6.913$, $p = 0.002$). The mean NDVI values indicated that the stands with dense canopy had the highest NDVI (Mean = 0.596), while those with partial canopy exhibited the lowest values (Mean= 0.569). Post hoc LSD testing confirmed that the differences between dense and complete canopy ($p = 0.008$), as well as between dense and partial canopy ($p = 0.001$), were statistically significant. The difference between complete and partial canopy was not statistically significant.

In coppice forests, the differences were even more pronounced $F(2, 191) = 17.945$, $p < 0.001$. The highest NDVI was again recorded in the stands with dense canopy (Mean = 0.579), while the lowest was found in those with partial canopy (M = 0.548). Post hoc analysis showed statistically significant differences between dense and complete canopy ($p < 0.001$), as well as between dense and partial canopy ($p = 0.004$). However, the difference between complete and partial canopy was not significant.

Table 2. The NDVI values depending on stand canopy density

Forest Origin	Canopy density	Mean NDVI ± SD	ANOVA F(df1, df2)	p – value	Significant Differences (LSD, p <0.05
High Forests	Dense	0.596 ±0.019	6.91 (2.90)	0.002	Dense>Complete (p=0.008), Dense>Partial (p=0.001)
	Complete	0.580±0.025			/
	Partial	0.569±0.028			/
Coppice Forests	Dense	0.579±0.027	17.95 (2.191)	0.000	Dense>Complete (p=0.000), Dense>Partial (p=0.004)
	Complete	0.552±0.030			/
	Partial	0.548±0.024			/
Artificially established stands	Dense	0.464±0.043	4.19 (3.249)	0.006	Dense > Complete (p=0.033), Partial (p=0.011), Sparse (p=0.002)
	Complete	0.446±0.057			/
	Partial	0.433±0.053			/
	Sparse	0.423±0.054			/

The most complex canopy structure was observed in artificially established stands, which included four canopy density levels (dense, complete, partial and sparse). The ANOVA confirmed statistically significant differences in the NDVI values among these groups $F(3, 249) = 4.189$, $p = 0.006$. The stands with dense canopy had the highest mean NDVI value ($M = 0.464$), whereas the sparse canopy category recorded the lowest ($M = 0.423$). The LSD test revealed that all differences between dense canopy and other canopy types were statistically significant: dense–complete ($p = 0.033$), dense–partial ($p = 0.011$), and dense–sparse ($p = 0.002$). Other pairwise differences (between complete, partial, and sparse canopy types) were not statistically significant.

Research on the relationship between forest biophysical factors and NDVI in the key coniferous layers of the temperate Himalayas shows that NDVI values rise with increasing crown and tree density (Wani *et al.*, 2021). The findings from the Yatir research station on the northern edge of the Negev desert in Israel, in an Aleppo pine forest, further support a correlation between the NDVI values and stand canopy density, with higher NDVI values also being recorded in denser stands (Wang *et al.*, 2022). Similar to our finding on the relationship between canopy density and NDVI, other studies have demonstrated that canopy gaps can also serve as reliable indicators of forest dynamics, with UAV-derived high-resolution imagery proving to be an efficient tool for their detection and monitoring (Felix *et al*., 2021).

CONCLUSION

The results of this study indicate the existence of statistically significant differences in the NDVI values depending on the degree of canopy density within the three forest origin categories: high forests, coppice forests, and artificially established stands. In all examined categories, the stands with dense canopy exhibited the highest NDVI values, which suggests a higher level of photosynthetic activity and better overall vegetation health.

As canopy closure decreases, there is a continuous decline in the NDVI values, with this trend being the most pronounced in artificially established stands. These findings confirm that canopy structure is one of the key factors influencing the NDVI, and consequently, the vegetative potential of forests. These findings may be of great importance for future forest condition monitoring, forest management planning, and the implementation of remote sensing in forestry practice. The NDVI has proven to be a reliable indicator for assessing canopy condition and density, thereby contributing to modern and efficient forest ecosystem monitoring.

This study was specifically designed to evaluate the statistical significance of variations in the NDVI values corresponding to different levels of canopy density, with the aim of isolating the influence of this structural attribute on vegetation reflectance. In order to maintain a focused and controlled analytical framework, other potentially relevant stand and site variables were intentionally excluded.

For future research, however, it is recommended to incorporate additional factors such as elevation, aspect, species composition, and stand age. The inclusion of these variables within a multivariate analytical approach would enable a more nuanced understanding of the ecological complexity underlying the NDVI variation, thereby enhancing the interpretability and applicability of remote sensing data in forest assessment and management.

ACKNOWLEDGEMENTS

This study was carried out under the Agreement on realization and funding of scientific research activity of scientific research organizations in 2025, funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, no. 451-03-136/2025-03/ 200027 of February 4, 2025 and 451-03-137/2025-03/ 200027 of February 4, 2025.

I am deeply grateful to my colleagues at the public enterprise "Srbijašume" for their valuable support and collaboration throughout the course of this research.

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