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Change of vegetation cover on the territory of the Nišava District

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Abstract

The study includes an analysis of the vegetation cover in the period from 2004 to 2023 in the territory of the Nišava District. Vegetation analysis was performed using the Normalized Difference Vegetation Index (NDVI). The method is most often applied in detecting degraded forest areas, detecting illegal deforestation, and determining changes in vegetation types. The aim of the work is to determine changes in the vegetation cover on the territory of the municipalities of the Nišava District. In the research, two satellite scenes Landsat 5 and Landsat 8 were analyzed in QGIS software. The first scene was recorded on July 8, 2004, and the second on July 22, 2023. Based on the obtained NDVI values, vegetation types cover on the territory of the district were identified. The maps show the value of the index in 2004 and 2023 in order to make it easier to interpret the results and visually observe the changes. A comparative analysis was performed for each municipality in order to observe spatial and temporal changes in vegetation types. In the same way, maps of vegetation types were made in order to show the changes during the research period as convincingly as possible. Vegetation cover underwent certain changes during the research period. The biggest changes were recorded in the Niš and Aleksinac basins, Južna Morava River valley and it is tributaries. An increase in the area under forest vegetation and a decrease in the area under agricultural crops were determined.

1. Introduction

Vegetation, as the most important component of terrestrial ecosystems, plays an important role in energy exchange, metabolic processes of organisms in the soil, and biological and chemical cycles on the Earth's surface (Ning et al., 2015; Liu et al., 2018; Sidi Almouctar et al., 2021). Vegetation connects the atmosphere, soil and moisture in it. It has an irreplaceable role in preserving the stability of the climate, controlling the carbon balance and the increase in greenhouse gases (Kumar and Kumar, 2022). Ding et al. (2007) believe that vegetation is prone to climate change. With the advancement of technology and remote sensing, it is possible to collect a large amount of data on vegetation characteristics and their seasonal and annual changes (Manfreda et al., 2018; Sojka et al., 2019).

Spatial and temporal changes in the vegetation structure are of great importance in researching the relationship between vegetation and climate change, the process of ecosystem evolution and predicting future changes (Zhang et al., 2018; Chauhan et al., 2020; Sidi Almouctar et al., 2021). The vegetation structure cover largely depends on the types of soil, its depth and the conditions prevailing in it. The growth and development of ecosystems is influenced by surface and underground water, which depend on climatic conditions. If the climatic conditions are unfavorable and there is a moisture deficit in the soil, the plants suffer great stress, which manifests itself through drying and falling leaves. On the other hand, a greater amount of moisture in the soil and a period in which there is a lot of precipitation positively affects the growth of vegetation (Calow et al., 2010; Cui and Shi, 2010; Chauhan et al., 2020).

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For the last 30 years, remote sensing has been used to continuously monitor the Earth's surface and all the changes that occur on it. It provided the possibility for the analysis of the vegetation cover in the regions of the world (Ladanyi et al., 2011; Milanović et al., 2019). Remote sensing is often used to obtain information about the Earth's surface without making contact with it. Therefore, it is used to detect, recognize and monitor the development of phenomena from a certain height (Jovanović and Milanović, 2015). Remote detection has found its application in agriculture and forestry by monitoring seasonal changes, the degree of crop development, monitoring the occurrence of diseases in plants, the state of vegetation, as well as the occurrence of plant stress due to changes in natural conditions. It is used to detect changes caused by anthropogenic activities such as pollution of soil, water, air and the occurrence of fires (Milanović et al., 2017; Milanović et al., 2019).

The richness of biodiversity on the territory of Serbia is a consequence of the morphology of the terrain, the specific geographical position, the composition of the soil, climatic conditions, the breakdown of the relief and the exposure of the terrain (Tzedakis et al., 2002; Marković et al., 2014). The territory of the Balkan Peninsula and Serbia is characterized by diverse plant communities, which is why they are one of the richest floristic regions in Europe. About 2,500 autochthonous plant species have been registered on the territory of Serbia (Rodić and Pavlović, 1994). Humans have greatly altered or destroyed natural ecosystems through his activities. Negative human activities are agriculture, deforestation, processes of urbanization and industrialization, water management and infrastructure works, mining, tourism, hunting and fishing. In order to prevent human activities that greatly degrade natural ecosystems, it is necessary to implement conservation and monitoring measures in endangered areas (Vasić and Stevanović, 1995; Jovanović et al., 2018; Milanović et al., 2019).

Research by scientists over the last few decades has shown that vegetation structure cover on the territory of Serbia has changed. A decrease in the area under forests was registered in a large number of municipalities, while the area of urban areas increased. During the conducted research, there was a discrepancy between the data on the areas under forests and other vegetation types with the estimated areas of the Statistical Office of Rebulic of Serbia (Sahebjalal and Dashtekian, 2013; Rašković, 2015; Jovanović et al., 2018; Milanović et al., 2019; Durlević et al., 2022). According to them, vegetation indices can be applied as the most effective methods for evaluating vegetation types. Based on all of the above, the subject and goal of the work were set. The subject of the work was the analysis of the vegetation cover on the territory of the Nišava District, as well as the comparative analysis of the vegetation cover on the territory of the municipalities belonging to the Nišava District. From the subject of the work comes the goal of the work, which was the registration of changes in vegetation types in the period from 2004 to 2023.

2. Study area

The study covers the territory of the Nišava District, which administratively belongs to the region of Južna Srbija. The district consists of 11 municipalities, and its total area is 2,728 km^2. There are 5 municipalities on the territory of the city of Niš, which is why all of them are presented in the paper as a single territory of the city (Figure 1). The smallest by area is the municipality of Medijana, followed by Palilula, Pantelej, Niška Banja and Crveni krst. The remaining 6 municipalities include agricultural and forest land in the greater part of the district. Those municipalities have in common the existence of an urban center of the same name, where local self-government bodies are located. The largest municipality in the district is Aleksinac and covers the northern parts of the district and the Aleksinac basin. The Južna Morava River flows through the bottom of the Aleksinac basin. The municipality belongs to the southern slopes of Bukovik, the western and southern slopes of Ozren and the northern slopes of Mali Jastrebac. The northernmost municipality in the district is Ražanj. The municipality of Svrljig is located in the north-east of the district. The most dominant morphological forms on the territory of the municipality are the Svrljiški Timok River valley and the Svrljiške planine mountains. The municipality of Gadžin Han is the southernmost municipality of the district and the highest terrains in the district belong to this municipality, namely the slopes of Suva planina mountain. The municipality of Merošina covers the western areas of the district in relation to the administrative center of the district (the city of Niš). It includes the left side Južna Morava River valley, the southern and south-eastern slopes of Mali Jastrebac mountain and the Krajkovačka River valley. The municipality of Doljevac covers the south-western area of the district in the Južna Morava River valley. On the territory of the municipality, the Toplica and Pusta Rivers flow into the Južna Morava River. The municipality also includes the western slopes of Seličevica mountain (Pavlović, 2019a; Republic Institute of Statistics, 2023).

Table 1. Surface areas of municipalities belonging to the Nišava District

Municipalities	Surface area (km²)
Ražanj	289
Aleksinac	707
Teritory of the city of Niš	596
Medijana	10
Niška Banja	146
Palilula	117
Pantelej	141
Crveni krst	182
Svrljig	497
Gadžin Han	325
Merošina	193
Doljevac	121

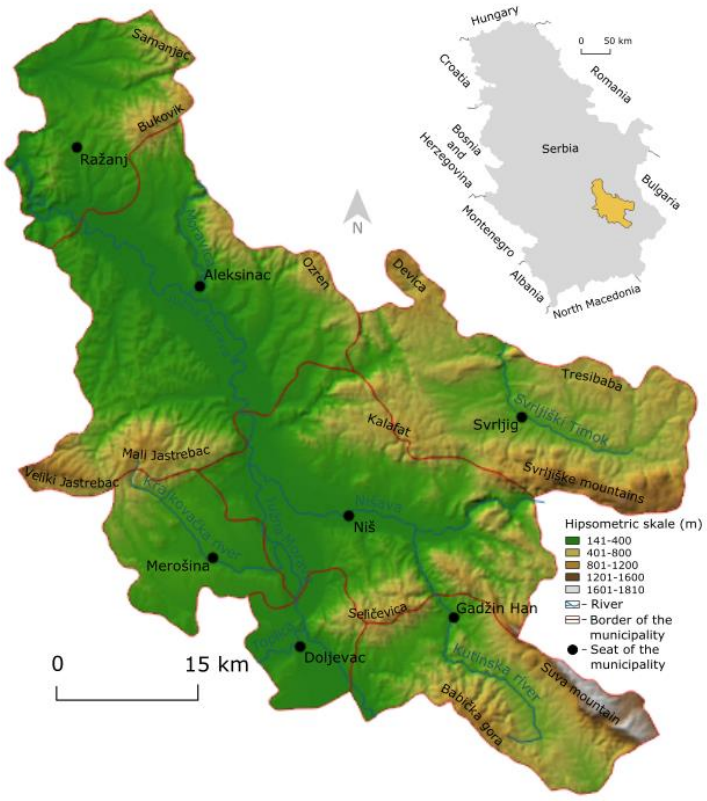

Figure 1. The position of the Nišava District.

According to Tomislav Rakićević (1980), on the territory of the district, it is possible to separate the Niško-Leskovački, Ponišavski, Sokobanjsko-Knjaževački and Vlasinski climatic regions. The Niško-Leskovački climatic region includes the Niš and Aleksinac basins as well as the Južna Morava River and Toplica River valleys on the territory of the municipalities of Doljevac and Merošina. According to the amount of precipitation, this is the area with the least amount of precipitation in Serbia. The amount of precipitation in Niš is about 555 mm and in Aleksinac about 580 mm. The areas belonging to this region are the warmest in Serbia. The vegetation period lasts longer than 260 days per year (Pavlović, 2019b). The Ponišavski climatic region includes the Nišava River valley. The climate is harsher compared to the Niško-Leskovački climate region, summers are fresher and winters colder. The annual amount of precipitation increases from west to east, while the average annual temperatures decrease, which is a consequence of the increase in altitude towards the east. The Sokobanjsko-Knjaževački climatic region includes the Svrljig basin. It represents the temperate-continental climate zone. Summers are warm, winters are milder and the amount of precipitation is less than 700 mm. The Vlasinski climate region includes the Rodopske Mountains on the territory of the municipality of Gadžin Han. The average annual rainfall in these areas is between 800-1000 mm. The warmest month is August and the coldest is January (Pavlović, 2019b).

3. Materials and methods

Two satellite scenes with a resolution of 30 m recorded by Landsat satellites were processed in the paper. The first scene was recorded on July 8, 2004, and the second on July 22, 2023. The first satellite scene was recorded by the Landsat 5 satellite, while the second was recorded by the Landsat 8 satellite. Both scenes in different wavelengths were processed in QGIS Desktop 3.28.2 software (Table 1). When choosing scenes, it was necessary to find scenes that were created in clear weather when the cloud cover was 0%. On that occasion, the correction of atmospheric effects was turned off. Atmospheric correlation was performed on the satellite scenes that are available and downloaded from the website of the United States Geological Survey (USGS) so that it was not necessary to additionally process the images (Milanović et al., 2019).

Table 2. Annual flow of air temperature, water vapor pressure and equivalent temperatures on Zlatibor (1991-2020).

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

Analysis of the vegetation cover was performed using the Normalized Difference Vegetation Index - NDVI. According to Jensen (2007), Ladanyi et al. (2011), Jovanović et al. (2018) and Milanović et al. (2019) NDVI is one of the most commonly used vegetation indices. It is used to evaluate the dynamics of vegetation, it shows the change in the amount of biomass, the amount of chlorophyll and the water stress on the leaf surface (Ladanyi et al., 2011; Milanović et al., 2019).

The index is derived from measurements of the optical reflection of sunlight in different wavelengths (Ollinger, 2011; Novkovic et al., 2021; Durlević et al., 2022). It refers to the spectral absorption of chlorophyll in the red color (RED) with reflection in the near-infrared spectrum (NIR) under the influence of different types of leaves. The chlorophyll pigments of plant leaves absorb radiation in the visible part of the spectrum from 0.4 μm to 0.7 μm. Scientific research has established that these wavelengths are responsible for the process of photosynthesis. On the other hand, plant leaves reflect radiation in the near-infrared part of the spectrum from 0.7 μm to 1.1 μm (Ladanyi et al., 2011, Jovanović and Milanović, 2015; Milanović et al., 2019). The index can have values between -1 and 1. Negative values represent water surfaces and terrain without vegetation. Positive values represent the presence of vegetation (Milanović et al., 2019; Tang et al., 2020; Durlević et al., 2022). The index is calculated using the following formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where NIR value is close to the infrared part of the spectrum and RED is the value of the red (visible) part of the spectrum (Ladanyi et al., 2011; Jovanović and Milanović, 2015; Milanović et al., 2019). The procedure for obtaining the index was applied using the calculator for processing raster images in the QGIS software. The value of the index is calculated for the district and separately for each municipality in the district. Each raster image was made up of a large number of pixels, while each pixel had a specific value. The size of each pixel was 30 m and the area of each pixel was 900 m^2 (unit area). The next step after counting the pixels was to multiply by the unit area. This resulted is a value in m^2, and further calculation converted the area into hectares (ha).

The next step after obtaining the NDVI value was the classification of the terrain into 9 categories according to vegetation types. The classification was carried out in the same way as applied by Milanović et al. (2019) in their research. Terrains without vegetation represented one category whose value was between -1 and 0. Meadows as a separate category had values between 0 and 0.122. The value of the index was between 0.123 and 0.174 for terrains with agricultural land and sparse vegetation. Terrains covered with shrubs had a value between 0.175 and 0.230. Vineyards represented a special category whose values were between 0.231 and 0.262. Orchards as a separate category had values between 0.263 and 0.291. Forest areas that were represented by three distinct vegetation types have the highest values of the index. Deciduous (broad-leaved) forests had values between 0.292 and 0.438, mixed forests between 0.439 and 0.525, while coniferous forests had values higher than 0.526.

The process of calculating the areas of all vegetation types was the addition of all pixels that had equal values. In the event that the existence of pixels that had NDVI values for the forest type was registered on an agricultural or other area, those areas were added and influenced the increase of the total area of forest types. The same procedure

was followed when registering other vegetation types, so that areas with the same NDVI values were added together, thereby excluding the possibility of the existence of transitional vegetation types.

After obtaining the results, it was necessary to check their accuracy, that is, to carry out data validation. During validation, QGIS Desktop 3.28.2 software was used to obtain 100 random sampling points on the territory of each municipality. Then, the locations of those points were used in Google Earth Pro software to make a visual assessment of vegetation types. During the visual assessment, terrain recordings from both analyzed periods (2004 and 2023) and values recorded in the attribute tables of the QGIS Desktop 3.28.2 software were set. The validation process was also applied to the Nišava District as a unique territory. In case the validation results had more than 80% match with the NDVI results, the results could be considered credible (Milanović et al., 2019).

4. Results and discussion

4.1. Changes in the vegetation cover

4.1.1. Changes in the vegetation cover on the territory of the municipality of Ražanj

Major changes in the vegetation cover also occurred in the territory of the municipality of Ražanj. Low index values in 2004 were registered in the south-east and north of the municipality. By 2023, the area where low NDVI values were registered decreased, which coincides with the decrease in agricultural production (Živanović et al., 2022). The most significant changes in the index were registered on the edge of the Paraćinsko-Jagodinski basin, which includes the northernmost parts of the municipality. Negative index values in the south-west were recorded in the Južna Morava River valley. In some locations, the river bed was not overgrown with woody plants and therefore it was easy to see the water surface that had negative index values. The smallest changes occurred on the slopes of the Poslonske mountains in the west, Bukovik and Rožanj mountains in the east, and Samanjac mountain in the north-east (Figure 2).

In the territory of the municipality of Ražanj, there was an increase in the area of land without vegetation, areas under shrubs and deciduous forests. Lands without vegetation covered 0.48% of the municipality's surface in 2004, while their surface in 2023 was 0.6%. In 2004, areas with scarce vegetation and agricultural areas occupied 32.49% of the municipality's area, while their area decreased by 4.23% by 2023 (Figure 3). The biggest changes in the structure were recorded in the terrain under forest vegetation. In 2004, the area under deciduous forests was 5 138.4 ha (17.78%). By 2023, their area increased by 87.2% and amounted to 9 619.7 ha. A decrease in areas under mixed

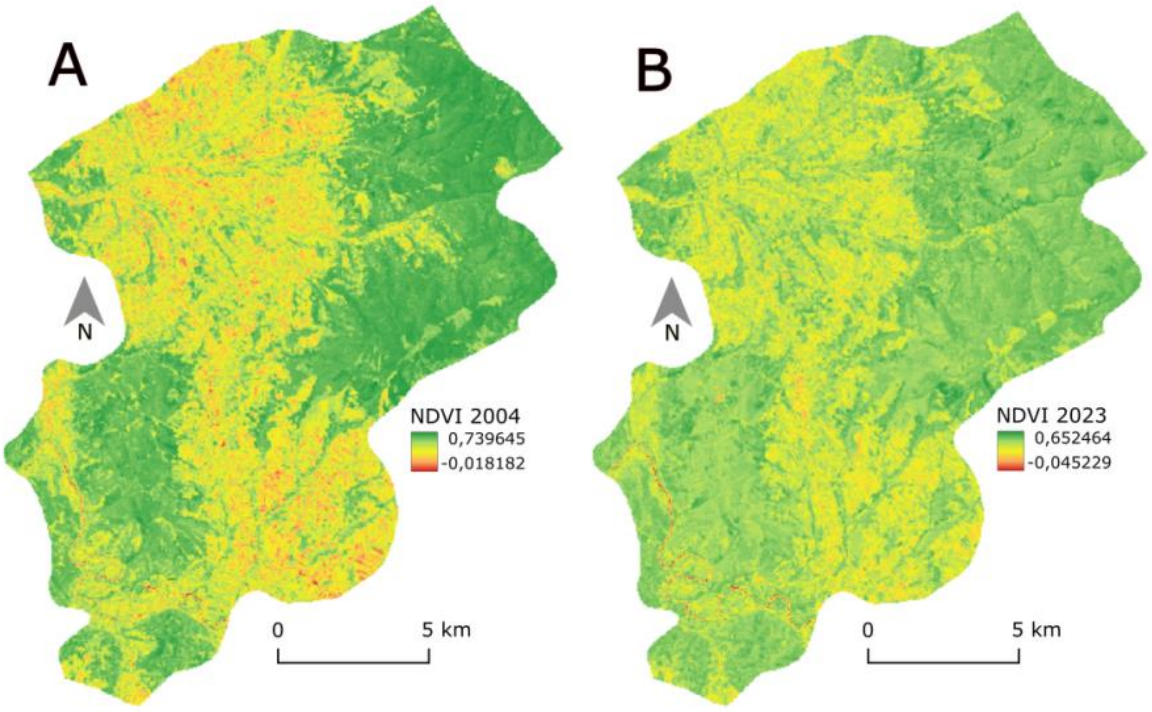

Figure 2. NDVI values on the territory of the municipality of Ražanj (A - 2004, B - 2023)

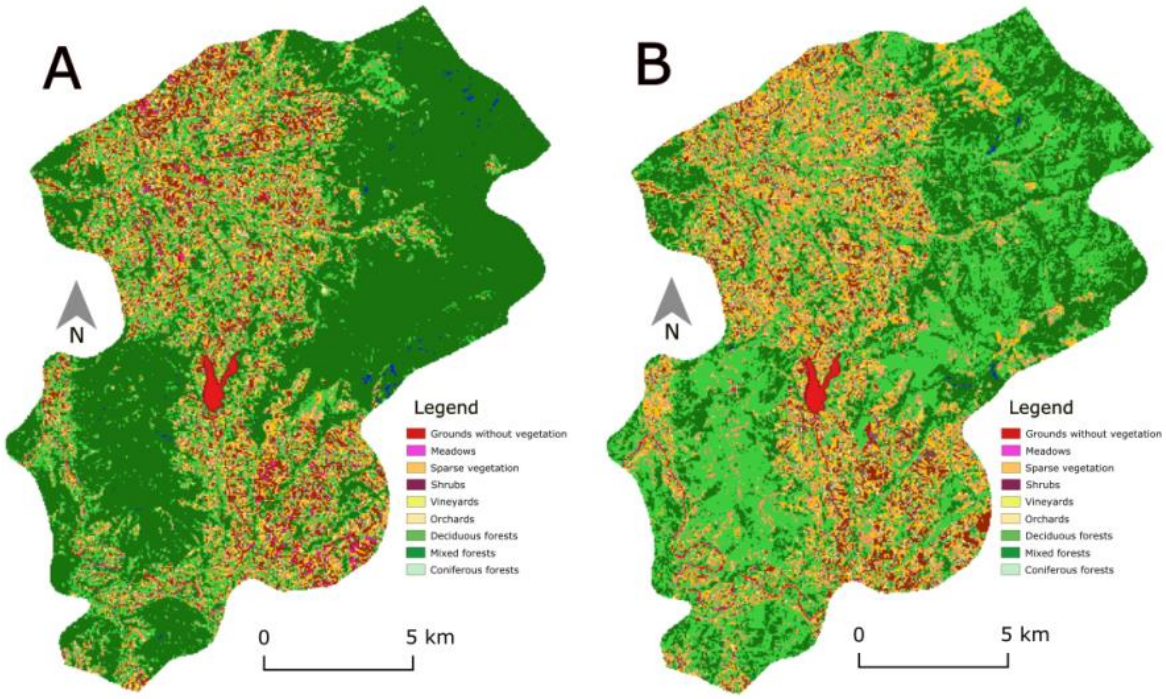

Figure 3. Vegetation types on the territory of the municipality of Ražanj classified according to NDVI values (A - 2004, B - 2023)

forests was recorded. In mid-2004, they covered 36.6% of the municipality's area, while in 2023, they covered 22.6%. During the research period, no changes of increase or decrease in the area under coniferous forests were registered. Areas under arable land, orchards, vineyards and shrubby vegetation recorded a slight decrease. Data validation showed that the accuracy of the results for 2004 was 83%, while for 2023 it was 86%.

4.1.2. Changes in the vegetation cover in the territory of the municipality of Aleksinac

On the territory of the municipality of Aleksinac, significant changes were recorded in the structure of the vegetation cover in the Južna Morava River valley. A significant reduction of low NDVI values was also registered on the edge of the Aleksinac basin. The volume of agricultural production as well as the decrease in the number of inhabitants influenced the increase in the area of forest ecosystems. There were minimal changes on the slopes of Bukovik mountain in the north of the municipality, the slopes of Ozren mountain in the east and the slopes of Mali and Veliki Jastrebac mointains in the south and south-west (Figure 4).

Areas without vegetation increased by 9.8% during the research period. Since 2004, when they occupied 1.02% of the territory of the municipality, an increase to 1.12% was recorded. The increase in the area under shrubs was 2.44 times. At the beginning of the research period, they covered 8.77%, while in 2023 they covered 21.4% of the total area of the municipality. Deciduous forests are the only type of forest vegetation that increased its area during the research period. At the beginning of the period, they covered 14.4% of the territory of the municipality, while in 2023 they covered 25.55% (Table 3). In relation to the total area of the municipality, mixed forests are vegetation type that dominated at the beginning of the research period. By 2023, drastic changes in the types of forest vegetation were registered on the territory of the municipality, so that deciduous forests dominated. In 2004, the area covered by forests comprised 32.24% of the territory of the municipality. In the middle of 2023, an increase of 23.95% was registered. The areas under conifers decreased by 0.05% of the territory of the municipality (Figure 5). The validation of the data established a greater accuracy of the results obtained in relation to the municipality of Ražanj. The accuracy of the results on the percentage share of vegetation types for the year 2004 was 88%, while for the year 2023 it was 90%.

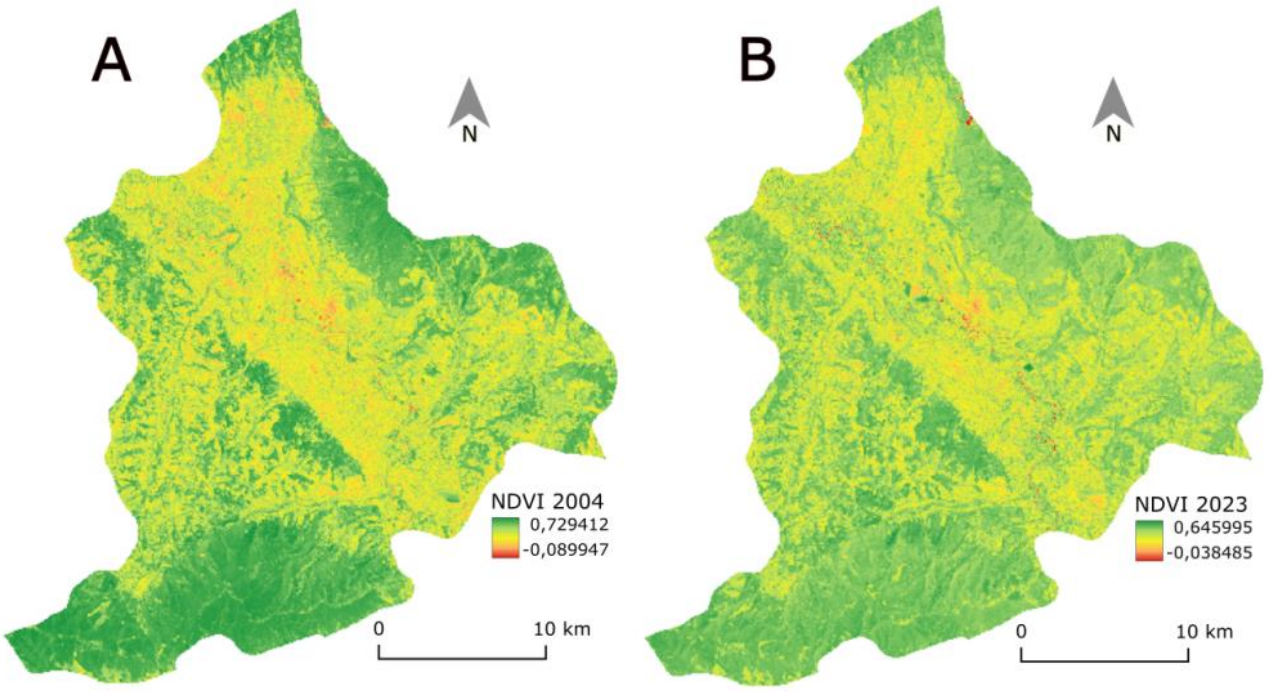

Figure 4. NDVI values on the territory of the municipality of Aleksinac (A - 2004, B - 2023)

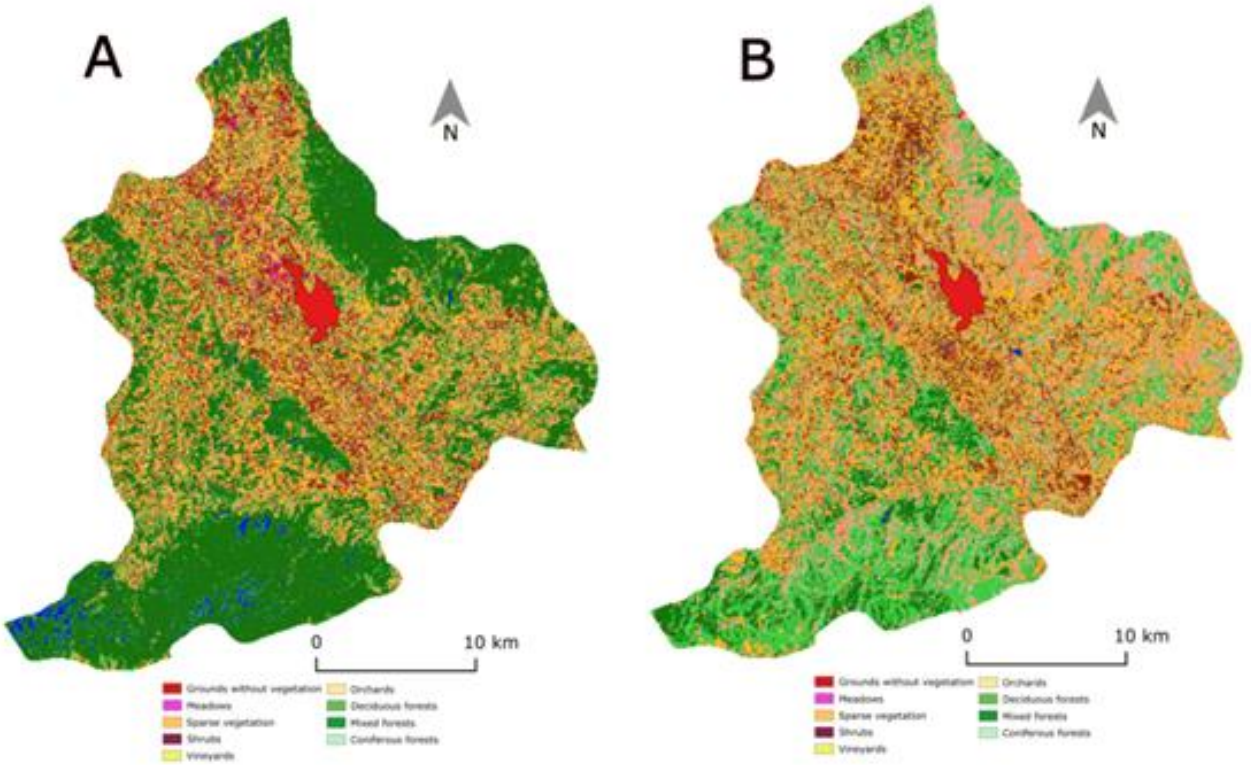

Figure 5. Vegetation types on the territory of the municipality of Aleksinac classified according to NDVI values (A - 2004,

4.1.3. Changes in the vegetation cover in the territory of Svrljig municipality

Significant changes in all vegetation types were registered on the territory of Svrljig municipality. A decrease in areas with low NDVI values was registered in all parts of the municipality. The biggest changes were recorded in the

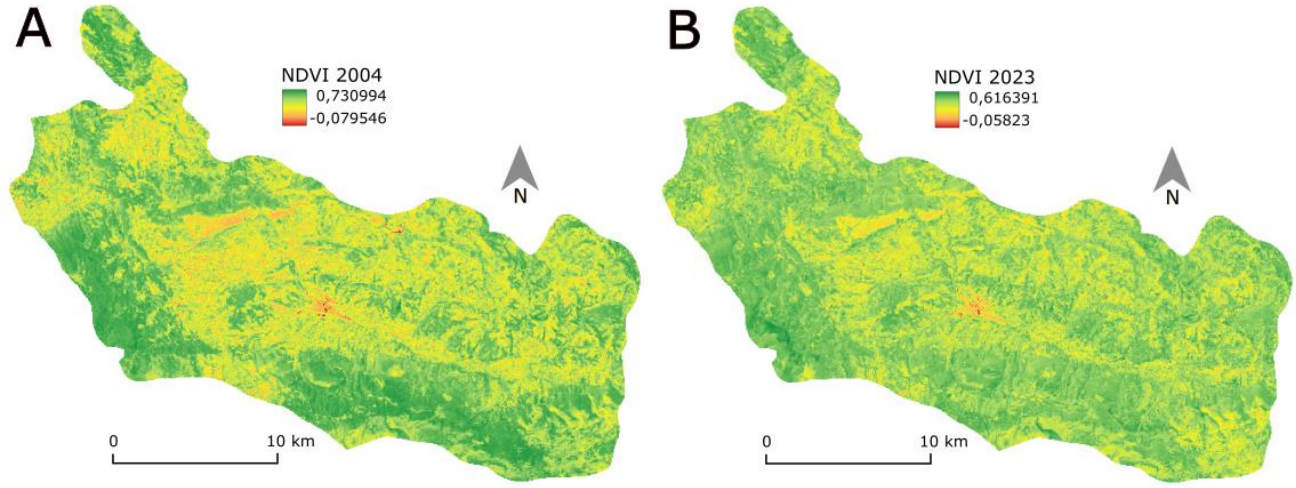

Figure 6. NDVI values on the territory of Svrljig municipality (A - 2004, B - 2023)

Svrljig basin and the Svrljiški Timok River valley. The smallest changes were registered on the slopes of Tresibaba mountain and Svrljiške planine mountains (Figure 6).

During the research period, an increase in areas without vegetation was registered by 28.79%. In 2023, they covered 0.85% of the total area of the municipality. In 2023, meadows and pastures occupied a 39.34% smaller area compared to the beginning of the analyzed period. A decrease in the area under vineyards by 0.01% was registered. In the territory of the Svrljig municipality, a decrease in arable land was registered. In 2004, areas with scarce vegetation and agricultural areas occupied 24.63% of the total area of the municipality. By 2023, their area has decreased to 18.02% of the municipality's territory. The areas under orchards and vineyards have drastically reduced their area. The total decrease in the area under vineyards was 22.73%, while the decrease in the area under orchards was 28.5%. The territory under shrubs increased by 55.1% during the research period.

Drastic changes in forest vegetation types were registered on the territory of Svrljig municipality. The total area under forests in 2004 was 45.55% of the area of the municipality. Mixed forests dominated, covering 26.81% of the territory of the municipality. In the middle of 2023, forest vegetation covered 59% of the territory of the municipality. During the research period, the area under forests increased by 2.2 times (Figure 7). There is a significant increase in the area under deciduous forests by 69.61% and an

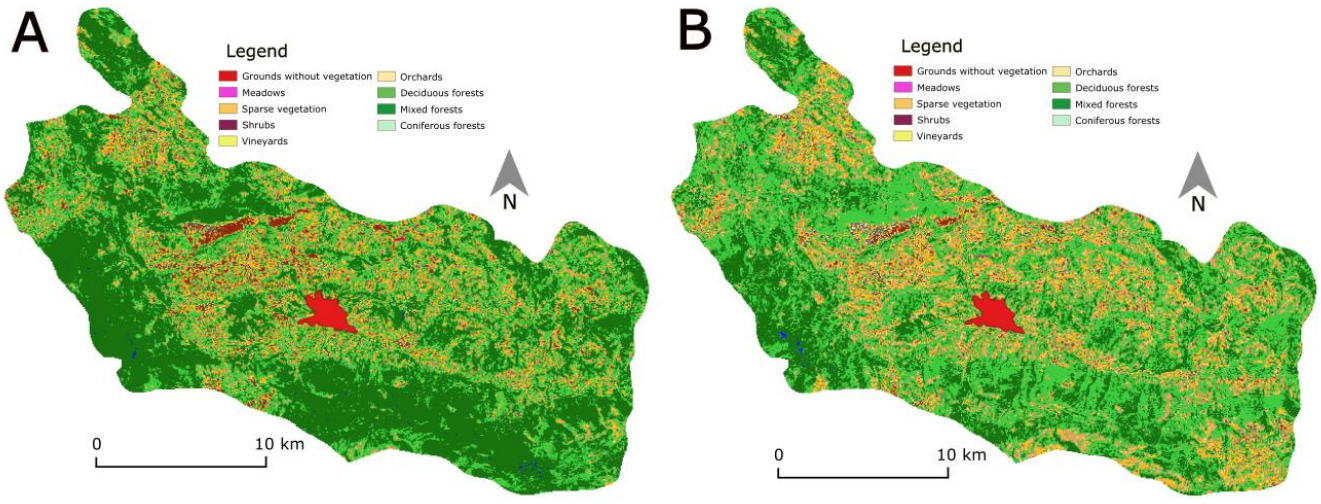

Figure 7. Vegetation types on the territory of Svrljig municipality classified according to NDVI values (A - 2004, B - 2023)

increase in the area under mixed forests by 1.69%. Data validation determined that the accuracy of the results for 2004 was 81%. The registered changes for the year 2023 show a higher degree of accuracy, which is 84%.

4.1.4. Changes in the vegetation cover in the territory of the city of Niš

On the territory of the city of Niš, a significant reduction of areas with negative and low NDVI values was registered in the west, south-west and north-west. The reduction of areas with low index values also occurred on the edge of the Niš basin, in suburban and rural settlements. A significant decrease in agricultural production in the past two decades has influenced changes in the structure of the vegetation composition (Pavlović, 2019a; Živanović et al., 2022). In Figure 8, it is possible to visually observe the changes that occurred in the territory of the urban part of the city of Niš. Index values on the slopes of Seličevica mountain in the south and Suva planina mountain in the south-east had the highest values in both observed periods.

In the territory of the city of Nis, an increase in areas

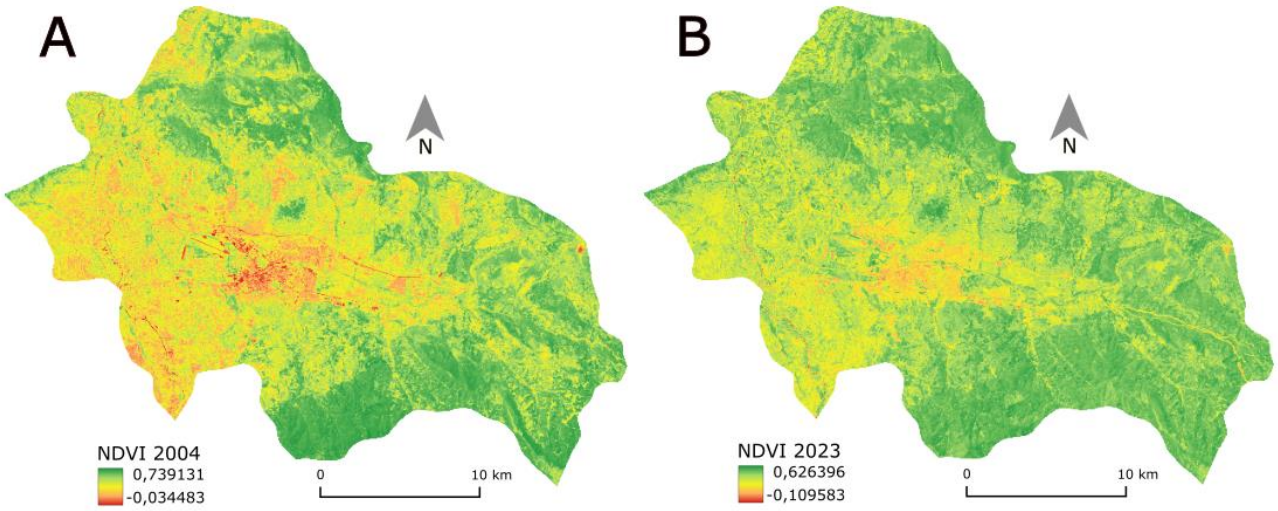

Figure 8. NDVI values on the territory of the city of Niš (A - 2004, B - 2023)

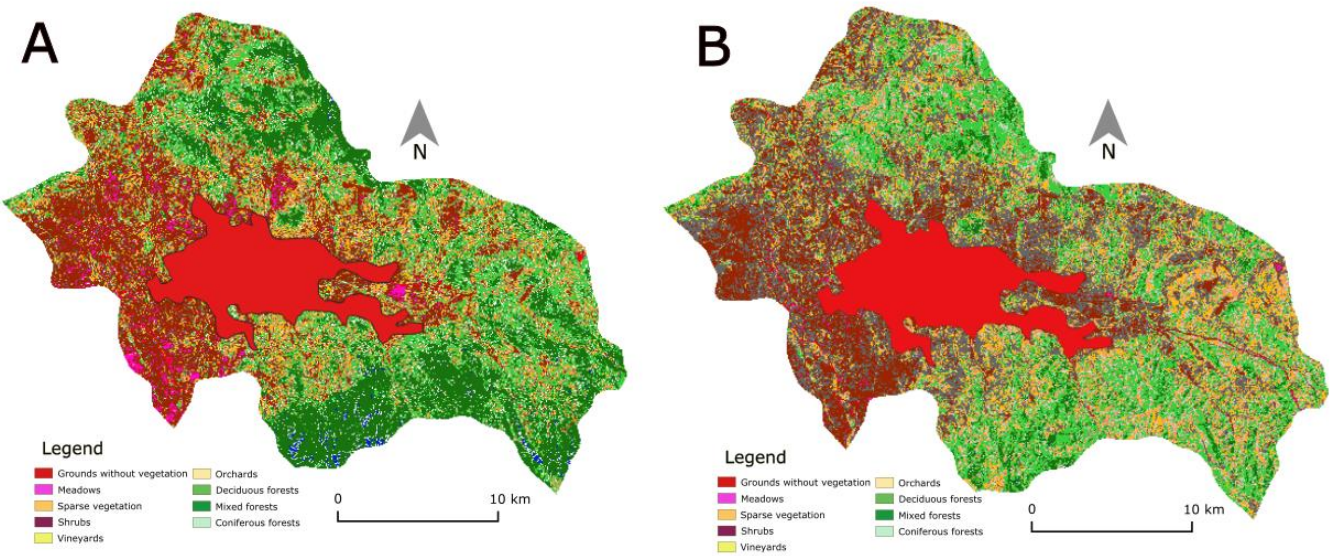

Figure 9. Vegetation types on the territory of the city of Niš classified according to NDVI values (A - 2004, B - 2023)

without vegetation was registered. In the territory of the city of Niš, as one of the largest cities in Serbia and the largest city in Southern Serbia, an increase in artificial surfaces, concrete, asphalt and industrial complexes was registered during the research period. The total area of land without vegetation in 2023 was 7 354 ha, i.e. 12.3% of the city's territory. In 2004, the same areas comprised 12.05% of the city's territory (Figure 9). Of all vegetation types, only the areas under shrubs and deciduous forests increased. In 2004, the areas covered by shrubs comprised only 7.55% of the city's area, while in 2023, they comprised 16.03%. The increase in the area under deciduous forests was 37.63%. Areas under forest vegetation increased by 14.15% during the research period. The area under coniferous forests decreased by a third (Table 3).

The territory of the city of Niš also includes suburban settlements whose population is actively engaged in agriculture. Such settlements are most numerous in the territory of Crveni Krst, Palilula and Pantelej municipalities. The territory under arable land, vineyards and orchards has decreased as a result of deagrarianization and industrialization (Živanović et al., 2022). The results showed that in 2004, the area under arable land covered 23.28% of the total area of the city's territory, while in 2023 it covered 17.6%. The reduction of areas under vineyards and orchards amounted to about 50%. Data validation determined that the accuracy of the processed results from 2004 was 82%, while the accuracy from 2023 was 84%.

4.1.5. Changes in the vegetation cover in the territory of the municipality of Gadžin Han

Significant changes in the vegetation cover on the territory of the municipality of Gadžin Han were registered in the valley of the Kutinska River, primarily in its upper course, as well as in the valley of the Južna Morava and Barbeška Rivers in the west. The biggest changes took place in the west of the municipality, which can be seen visually in Figure 10. The highest NDVI values were registered on the slopes of Seličevica mountain in the north-west, Babička gora mountain in the west and south-west, and Suva planina mountain in the east.

A significant change in the vegetation types on the territory of the municipality of Gadzin Han was registered with the forest communities. The total area under forests was 61.78% in 2023, which is 83.98% more than at the beginning of the research period. The area under deciduous forests increased 2.34 times during the research period, while the area under mixed forests increased 1.46 times. At the beginning of the research period, mixed forests dominated, unlike in 2023, when deciduous forests covered the largest area. It is important to mention that the area under shrubs increased from 5.52% of the total area of the municipality to 13.13%. The large proportion of forests on the territory of the municipality is a consequence of the terrain's morphology dominated by mountains.

The process of deagrarianization has been present in recent decades in the territory of Gadžin Han municipality (Pavlović, 2019a). As a consequence of the process, there is a decrease in the volume of agricultural production, farming and viticulture. During the research period, a drastic reduction of agricultural areas was registered. In 2004, agricultural areas occupied 31.38% of the total area of the municipality. By 2023, their reduction by 68.67% was registered.

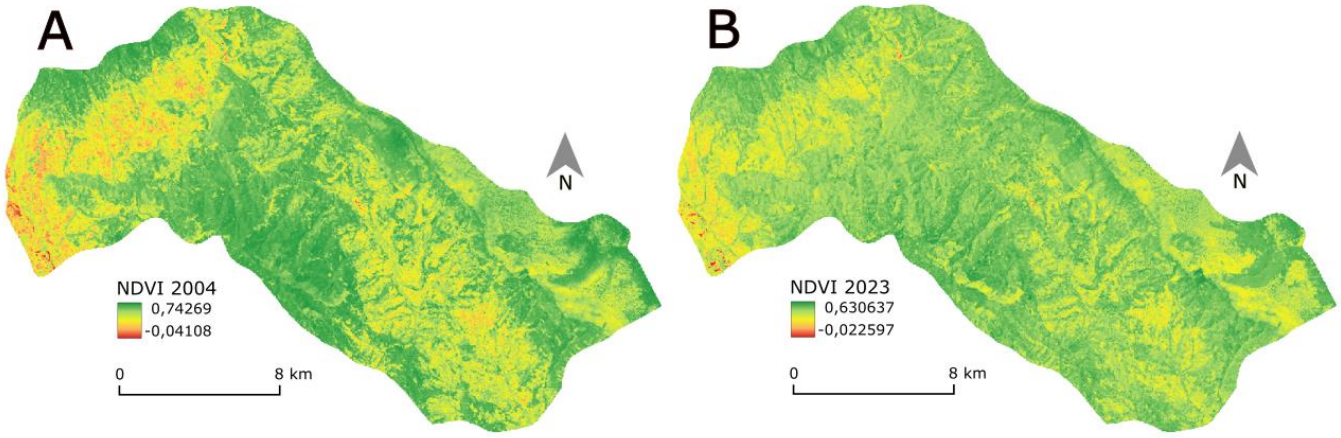

Figure 10. NDVI values on the territory of the municipality of Gadžin Han (A - 2004, B - 2023)

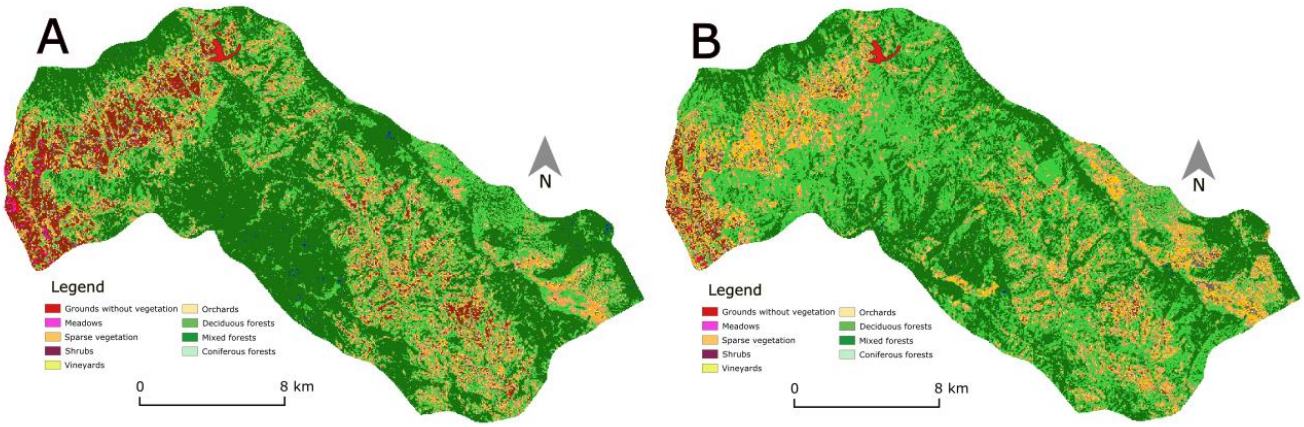

Figure 11. Vegetation types on the territory of Gadžin Han municipality classified according to NDVI values (A - 2004, B - 2023)

The areas under vineyards decreased 7.1 times. In 2023, vineyards covered 76.3 ha, which represented only 0.24% of the territory of the municipality. In 2004, the area under orchards covered 1 813.8 ha, which was 5.58% of the territory of the municipality. By 2023, their area decreased by 46.59%, i.e. a total of 969.7 ha were under fruit plantations (Figure 11). Validation of the results revealed a match of 88% with the data from 2004 and 91% with the data from 2023.

4.1.6. Changes in the vegetation cover in the territory of the municipality of Merošina

Negative NDVI values on the territory of Merošina municipality represented rural settlements, areas without vegetation, as well as two reservoirs - Krajkovačko and Oblačinsko lake. It is possible to observe a significant decrease in the low values of the index in the Južna Morava River valley and the Dobrič agricultural area. The highest values of the index on satellite scenes from both periods were recorded on the slopes of Mali Jastrebac mountain in the north of the municipality (Figure 12). High values of the index were registered in the Krajkovačka, Devčanska and Bresnička Rivers valleys, which are spread in the form of strips in the north-west - south-east direction.

In the territory of the municipality of Merošina, an increase in areas under shrubs, orchards and deciduous forests was registered. Areas covered with shrubs increased 1.7 times. There is a probability that natural ecosystems could have developed undisturbed on neglected agricultural areas and thereby contributed to the rapid development of bushy vegetation on the territory of the municipality. Areas under forest ecosystems increased their area by 1.86% during the research period. The total area under forests in 2023 comprised 24.62% of the territory of the municipality. The percentage of areas under coniferous forests did not change during the research period. Deciduous forests as the dominant type of forest vegetation in 2004 covered 15.15% of the territory of the municipality, while in 2023 they covered 16.31%. The increase in the area under forests is a consequence of the decrease in the area under vineyards, arable land and fields overgrown with grass

During the research period, the areas without vegetation were reduced by 44.54%. In 2004, the total area without vegetation included 212.3 ha, while in 2023, the area included 95.6 ha (Figure 13). The processes of deagrarianization and depopulation caused the arable land to decrease 1.19 times. In 2004, agricultural areas comprised 36.07% of the total area of the municipality. By 2023, the share of agricultural land has decreased to 30.34% of the total area of the municipality. A significant reduction of the area under meadows by 3.95 times was registered. During the research period, the area under fruit plantations increased by 89.21%. The validation of the results established an accuracy of 93% for data from 2004, and an accuracy of 95% for data from 2023.

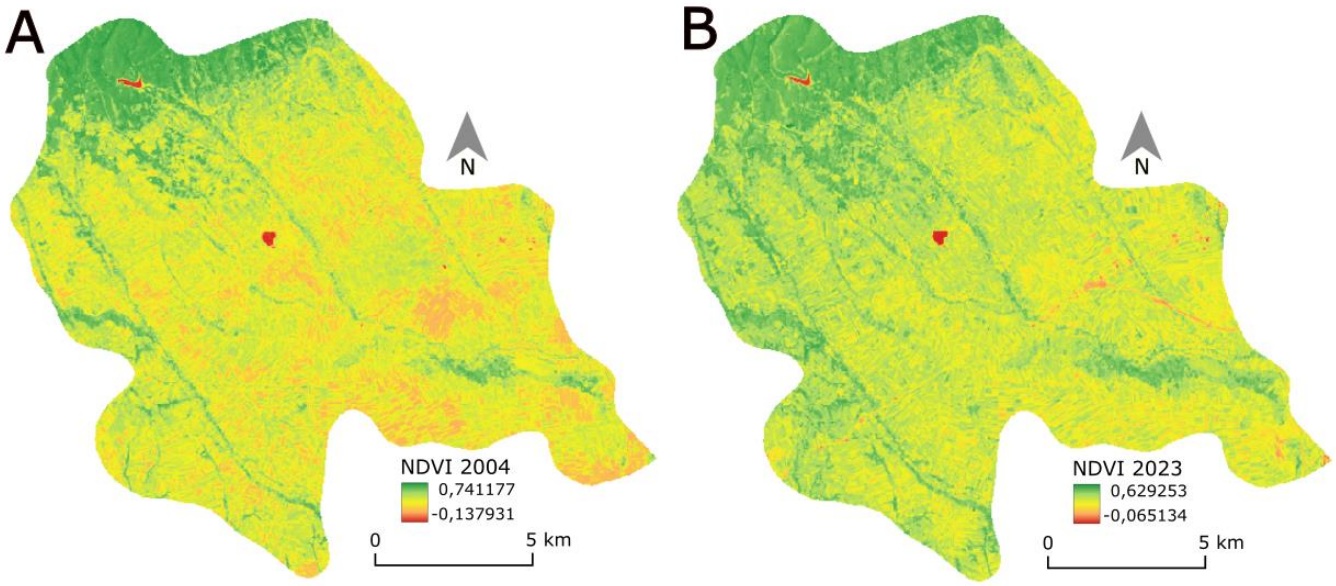

Figure 12. NDVI values on the territory of the municipality of Merošina (A - 2004, B - 2023)

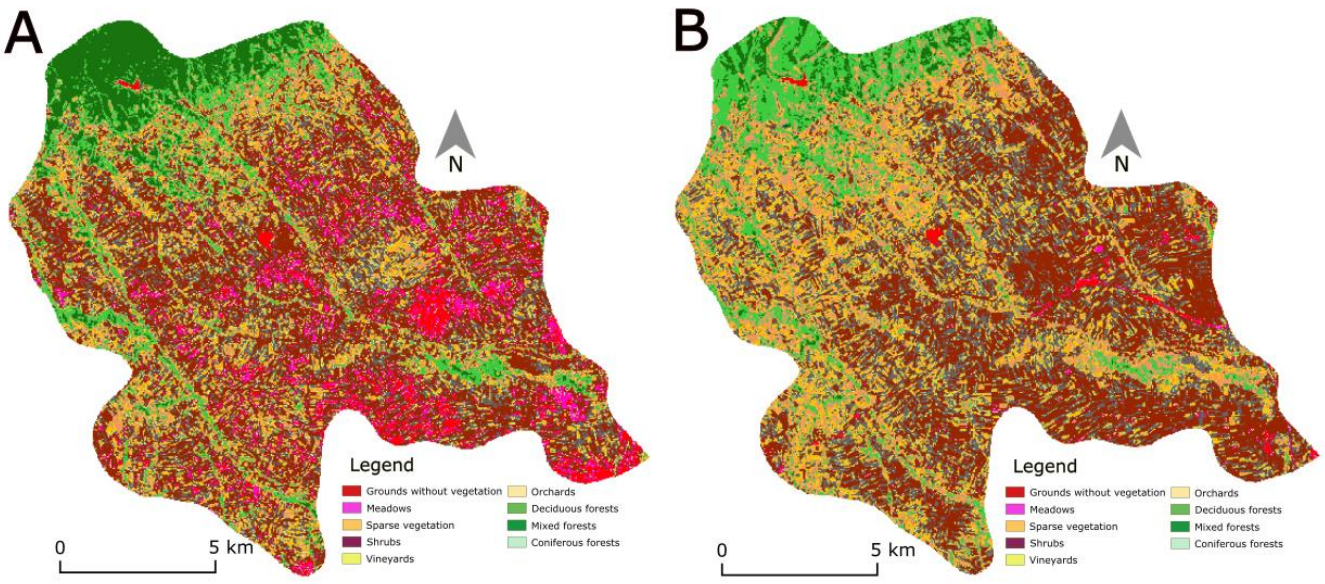

Figure 13. Vegetation types on the territory of the municipality of Merošina classified according to NDVI values (A - 2004, B -

4.1.7. Changes in the vegetation cover in the territory of the municipality of Doljevac

Minimal changes in the territory of the municipality of Doljevac were registered in the east, on the western slopes of Selicevica mountain. Two significant areas that on the satellite scenes from both periods had high NDVI values, which indicates the presence of woody plants, were the valley of Toplica River in the form of a strip that stretches in the west-east direction and the elevation of Delnica, slightly more regular in shape (trapezoidal shape) to the south. Negative and very low index values were recorded in most of the municipality (Figure 14). The consequence of such a structure of the vegetation cover is the morphology of the terrain because the Južna Morava River flows through the middle of the municipality, the northern part of the municipality belongs to the Niš basin and the southern part of the municipality to the edge of the Leskovac basin. The flat terrain and very fertile soil influenced the development of agricultural production, which has contin-

ued to this day (Pavlović, 2019a). This can explain the low values of the index in most of the municipality.

The municipality of Doljevac was known for its agricultural production, but in recent years the volume of agricultural production has been decreasing (Pavlović, 2019a). Such a claim is confirmed by the results obtained from the

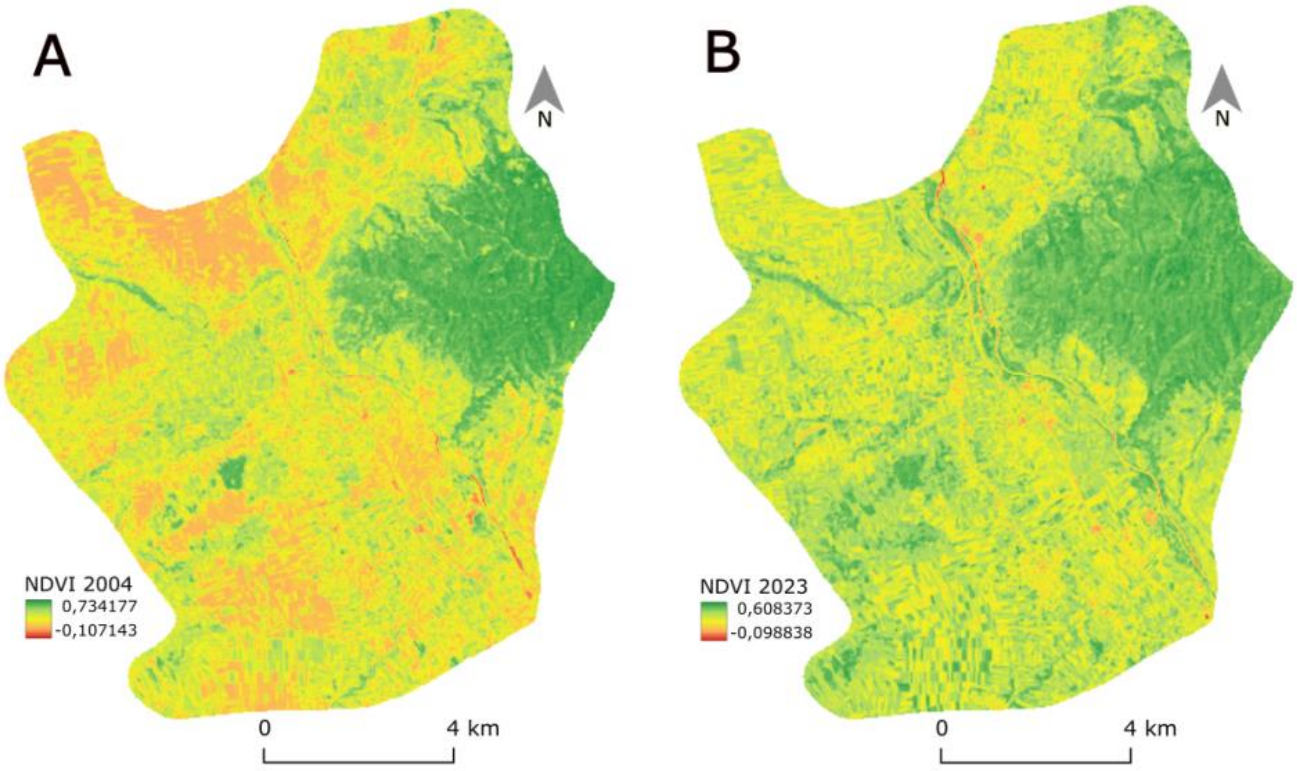

Figure 14. NDVI values on the territory of the municipality of Doljevac (A - 2004, B - 2023)

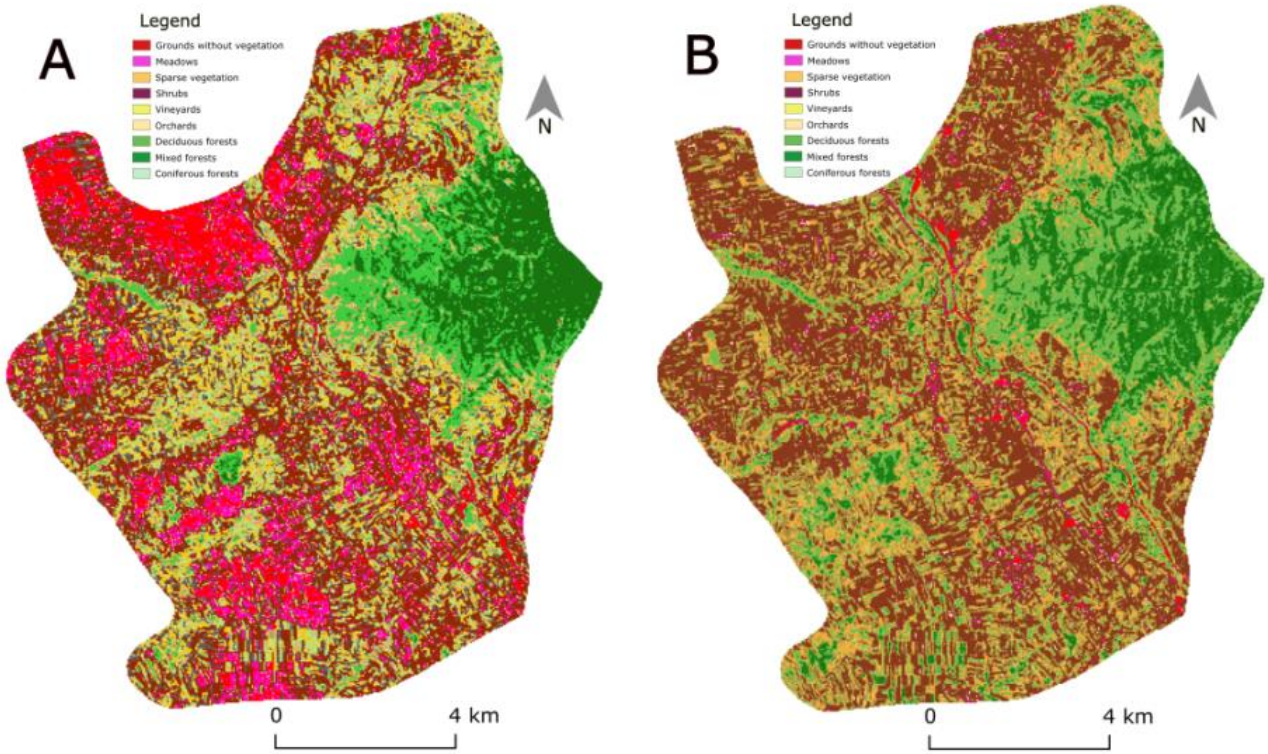

Figure 15. Vegetation types on the territory of the municipality of Doljevac classified according to NDVI values (A - 2004, B -

analysis of satellite scenes. The registered changes in the territory of the municipality of Doljevac differ from the changes in the territory of other municipalities in the district. Minimal changes were recorded during the analysis of the terrain without vegetation, the area of which increased by 0.04% of the area of the municipality. There have been major changes in forest vegetation types. The total area under forests in 2004 comprised 22.91% of the territory of the municipality. Deciduous forests dominated with a total of 16.09% of the territory of the municipality. By the middle of 2023, the area under forests increased to 31.09% of the territory of the municipality (Figure 15). The increase in deciduous forests, which covered 23.01% of the territory of the municipality, was a significant registered change. The area of mixed forests increased by 18.33% during the research period (Table 3).

Areas without vegetation, areas under meadows, arable fields, vineyards and orchards have reduced their areas. In the territory of the municipality of Doljevac, a reduction of the area under fruit plantations by 65.07% was registered. In 2023, the areas under orchards comprised 2.09% of the territory of the municipality. The areas under vine plantings decreased by 86.79% (Figure 15). Unlike vineyards and orchards, the area under arable land has decreased significantly. A decrease of 1.22 times was registered in the research period, which is a consequence of deagrarianization and depopulation. The validation determined the accuracy of the results for the year 2004 to be 82%, while the accuracy of the results for the year 2023 is 85%.

4.1.8. Changes in the vegetation cover on the territory of the district

Analysis of satellite scenes from 2004 and 2023 revealed major changes in the vegetation cover on the territory of the district. The lowest values of the index on the satellite scenes were recorded in the Niš and Aleksinac basins and the Južna Morava and Nišava Rivers valleys. Significant changes were registered in the reduction of negative index values in the north-east of the district in the Svrljig basin and its periphery. In the south-west of the district in the Južna Morava River valley and the area of Dobrič, a significant reduction of agricultural land was registered. The low NDVI values show that in 2004 agricultural crops, areas with sparse vegetation and meadows dominated, and that their area decreased by 2023 (Figure 16). In low mountain areas (500-1000 m above sea level) in 2023, a drastic increase in dense vegetation represented by young forest communities and shrubs was observed.

Negative NDVI values in 2004 covered 3.20% of the district's territory. The area under forests included 37.62% of the total area of the district, while the area of other vegetation types included 59.18%. The largest area was occupied by agricultural areas with a total of 90 335.75ha (33.10%).

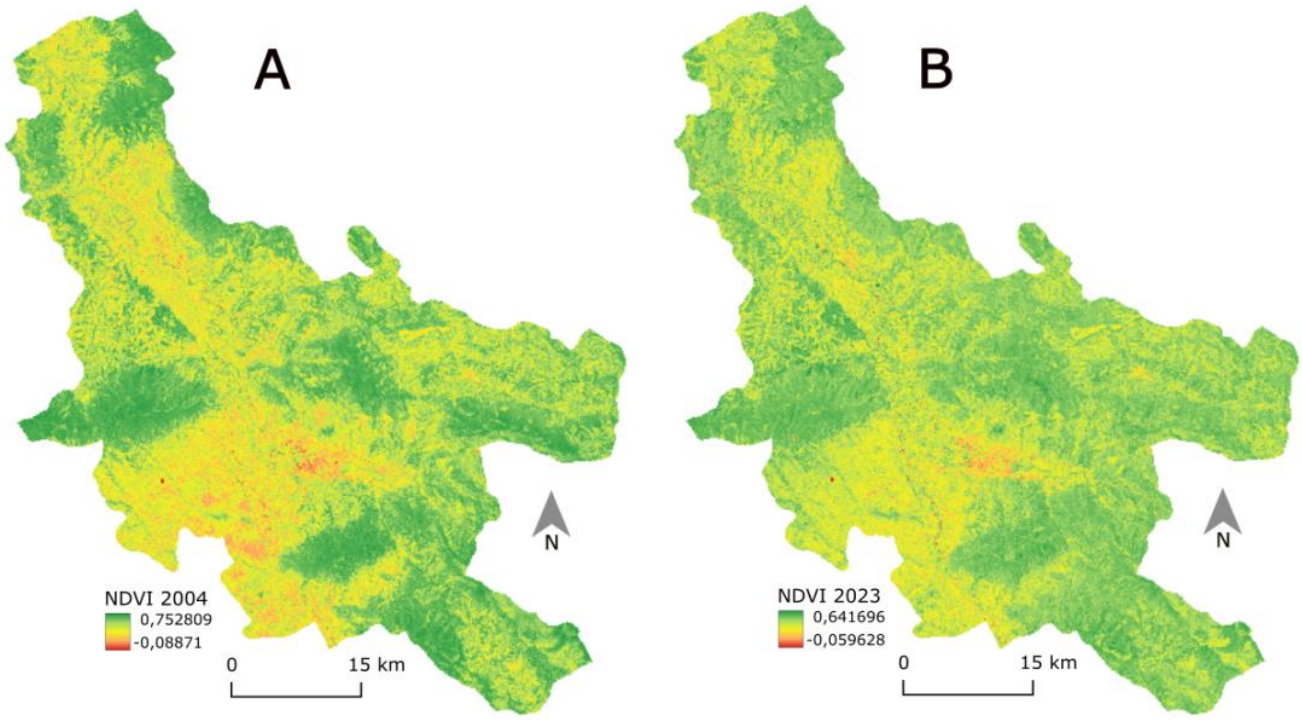

Figure 16. NDVI values on the territory of the Nišava District (A - 2004, B - 2023)

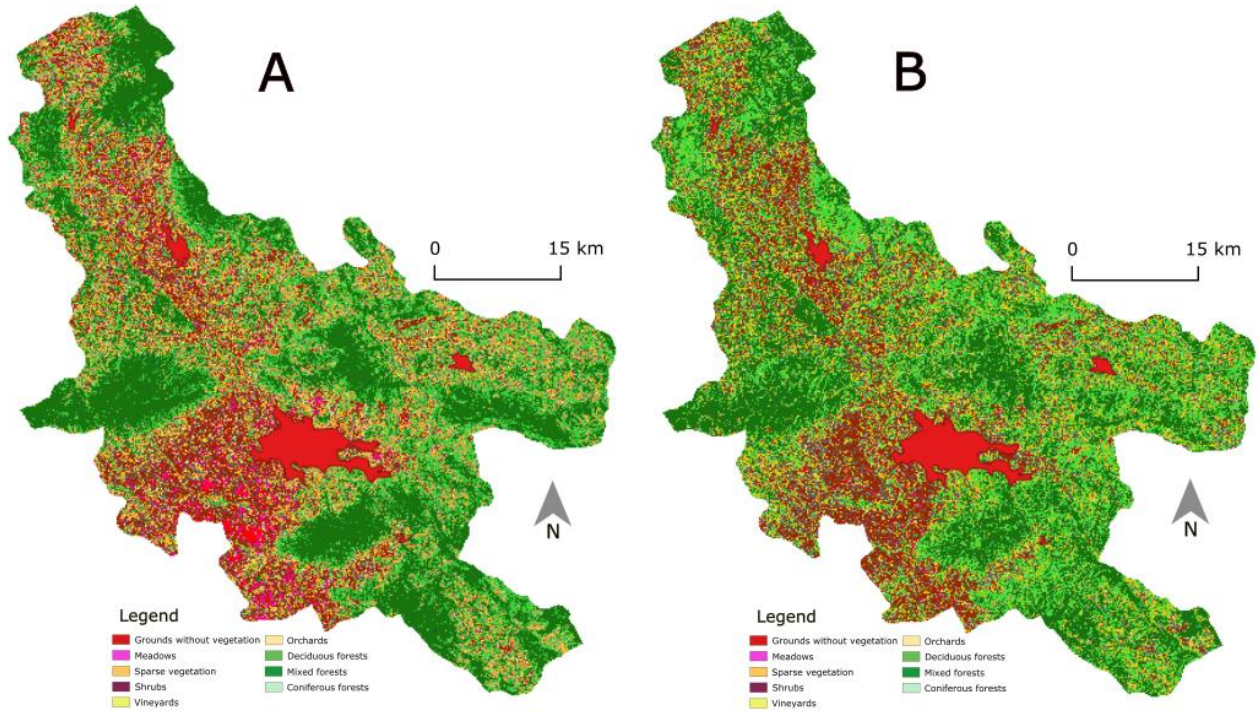

Figure 17. Vegetation types on the territory of the Nišava District classified according to NDVI values (A - 2004, B - 2023)

In 2023, areas without vegetation included 3.30% of the district's area. An increase in the area under forests by 26.18% was recorded. Areas under mixed forests during the research period decreased by 6.87% (Figure 17). A decrease in the area under coniferous forests by a third was recorded. Areas under deciduous forests increased their area from 16.46% (in 2004) to 27.78% (in 2023). Areas with sparse vegetation, vineyards, orchards and agricultural land with arable land were subject to changes during the research period, whereby the areas decreased (Table 3).

4.2. The decrease in the number of inhabitants as a cause of the change in the structure of the vegetation cover

During the research period, there were drastic changes in the structure of the vegetation cover on the territory of the Nišava District. In order to determine the causes of the changes, the results of the last three population censuses were analyzed. The last two censuses were conducted in 2011 and 2022 and they coincide with the research period. In order to better understand changes in the number of inhabitants before 2011, the results of the 2002 census were analyzed, even though it was conducted two years before the first processed satellite scene.

In the period 2002-2022, the number of inhabitants on the territory of the Nišava District was constantly decreasing. The decrease in the number of inhabitants amounted to 9.9%. The average decrease in the number of inhabitants of all urban settlements on the territory of the district was 0.4%, while the average decrease in the number of inhabitants of rural settlements was 21%. The city of Niš with its 5 municipalities had an increase in the number of inhabitants in the urban part of the territory by 1.5% during the research period. The number of inhabitants increased by 4.2% between the 2002 and 2011 censuses, while it decreased by 2.5% between the 2011 and 2022 censuses. In the period 2002-2011, rural areas in the territory of the city of Niš had an increase in the number of inhabitants by 3.2%. In the later period of 2011-2022, the reduction amounted to 8.2% (Republic Institute of Statistics, 2023; Republic Institute of Statistics, 2024).

In the territory of the municipality of Aleksinac, the number of inhabitants decreased between all three censuses. In the period 2002-2011, a decrease of 10.2% was recorded, while the decrease in the period 2011-2022 was 16.9%. The decrease in the number of inhabitants between the three censuses was 25.4%. The number of inhabitants in the territory of the city of Aleksinac fell drastically between the 2011 and 2022 censuses by 13.2%. A pronounced decrease in the number of inhabitants in the territory of rural settlements was recorded and amounted to 29.7% (2002-2022). The number of inhabitants of the municipality of Doljevac decreased by 19% in the period 2002-2022. In the territory of the municipality of Merošina, a decrease in the number of inhabitants by 5.7% was recorded in the period 2002-2011. The decrease was more pronounced in the period 2011-2022 and amounted to 15%. The largest recorded decrease in the number of inhabitants was recorded in the territory of the municipality of Gadžin Han. The number of inhabitants decreased by 44.1% between the 2002 and 2022 censuses. The second largest decrease in the number of inhabitants between the three censuses was recorded in the territory of the municipality of Ražanj in the amount of 38.3%. The largest decrease in the number of inhabitants in rural areas was recorded in the territory of the municipality of Svrljig. The number of inhabitants decreased between the three censuses by 59.5%. The decrease in the number of inhabitants in the period 2002-2011 amounted to 32.5%, while in the period 2011-2022 the decrease was more pronounced and amounted to 40%. The number of inhabitants in the territory of Svrljig municipality in the period from

Table 3. Area of vegetation types on the territory of the Nišava District and its municipalities in 2004 and 2023 (values are expressed in ha)

Vegetation type	Period	Ražanj	Aleksinac	Svrljig	City of Niš	Gadžin Han	Merošina	Doljevac	District
Grounds without veg.	2004.	138.1 (0.48%)	719.2 (1.02%)	329.1 (0.66)	7179 (12.05%)	84.5 (0.26%)	212.3 (1.10%)	76.1 (0.63%)	8738.3 (3.20%)
	2023.	170.6 (0.60%)	792.8 (1.12%)	423.8 (0.85%)	7354 (12.30%)	79.8 (0.25%)	95.6 (0.50%)	71.3 (0.59%)	8987.9 (3.30%)
Meadows	2004.	1543.6 (5.34%)	6353.1 (8.99%)	9348.6 (18.81%)	1706.58 (2.86%)	7153.1 (22.01%)	2238.7 (11.6%)	992.3 (8.20%)	29335.75 (10.70%)
	2023.	872.1 (3.20)	2134 (3.02%)	3673 (7.40%)	941.67 (1.58)	3831.9 (11.79%)	567.3 (2.94%)	231.3 (1.92)	12251.3 (4.49)
Agricultural land*	2004.	9388.7 (32.49%)	31102.2 (43.99%)	12239.5 (24.63%)	14246.64 (23.28%)	10197.8 (31.38%)	6960.9 (36.07%)	5878.9 (48.57%)	90014.64 (33.10%)
	2023.	8991.2 (31.23%)	22113 (31.28%)	8957.1 (18.02%)	10507.23 (17.60%)	3194.6 (9.83%)	5854.9 (30.34%)	4800.3 (39.67)	64518.33 (23.61%)
Shrubs	2004.	837.4 (2.90%)	6202 (8.77%)	3459.3 (6.95%)	4439 (7.55%)	1793.6 (5.52%)	2780.3 (14.41%)	1239.2 (10.22%)	20750.8 (7.61)
	2023.	1969.7 (6.82)	15129.4 (21.40%)	6270.4 (12.62%)	9554 (16.03%)	4266.9 (13.13%)	4724.4 (24.50%)	2886.1 (23.85%)	44800.9 (16.42%)
Vineyards	2004.	435.1 (1.51%)	1175.3 (1.66%)	327.4 (0.66%)	4283.3 (7.29%)	541.7 (1.67%)	832.6 (4.31%)	723.1 (5.98%)	8318.5 (3.05%)
	2023.	107.6 (0.37%)	1057 (1.50%)	75.9 (0.15%)	2390 (4.02%)	76.3 (0.24%)	254.3 (1.32%)	95.7 (0.79%)	4056.8 (1.49%)
Orchards	2004.	819,2 (2.84%)	2351.5 (3.33%)	1358.7 (2.74%)	4516.7 (7.68%)	1813.8 (5.58%)	1610.3 (8.34%)	417.4 (3.45%)	12887.6 (4.72%)
	2023.	315.8 (1.10%)	1216.2 (1.72)	975.8 (1.96%)	2004 (3.35)	969.7 (2.98%)	3045.8 (15.78%)	253.2 (2.09%)	8780.5 (3.22%)
Deciduous forests	2004.	5138.4 (17.78)	10178.6 (14.40%)	9286.8 (18.69%)	10780.29 (18.39%)	4761.5 (14.65%)	2924.7 (15.15%)	1946.8 (16.09%)	45017.09 (16.46%)
	2023.	9619.7 (33.30%)	18066.8 (25.55%)	15749.3 (31.70%)	15144 (25.31%)	11123 (34.23%)	3153.7 (16.31)	2783.9 (23.01)	75740.87 (27.78%)
Mixed forests	2004.	10581 (36.60%)	12539.1 (17.74)	13326 (26.81%)	12436.02 (20.87%)	6124.9 (18.84)	1738.5 (9.01%)	825.7 (6.82%)	57571.22 (21.10%)
	2023.	6537.1 (22.6)	10153.6 (14.36%)	13554.8 (27.26%)	11693.52 (19.52%)	8941 (27.50%)	1601.5 (8.30%)	977 (8.07%)	53558.52 (19.65%)
Coniferous forests	2004.	18.5 (0.06%)	79 (0.10%)	24.6 (0.05%)	12.7 (0.03%)	29.1 (0.09%)	1.7 (0.01%)	0.5 (0.004%)	166.1 (0.06%)
	2023.	16.3 (0.06%)	37.2 (0.05%)	19.9 (0.04%)	10.98 (0.02%)	16.8 (0.05%)	2.5 (0.01%)	1.2 (0.01%)	104.88 (0.04%)

2002-2022 decreased by 37.6%. In the territory of the urban part of Svrljig, the number of residents decreased by 8.1% in the analyzed period (Republic Institute of Statistics, 2023; Republic Institute of Statistics, 2024).

On the territory of the city of Niš and the municipalities of Razanj, Aleksinac and Svrljig an increase in areas without vegetation was registered as a result of economic and social activities. The assumption is that areas without vegetation were registered in areas that became industrial zones by 2023, landslide zones on higher slopes, in mountainous areas due to deforestation and degradation of riverbanks which resulted in a negative NDVI value of the water surface. One of the causes may be the increase of urban areas in the territory of the district, primarily in the cities of Niš, Aleksinac and Svrljig. Cities have expanded territorially, but only in the territory of the city of Niš, an increase in the number of inhabitants by 1.5% was recorded in the period between 2002 and 2022, which can be explained by migrations between the village and the city. On the territory of the district there are several artificial lakes, the largest of which are Krajkovačko, Oblačinsko and Bovansko, whose surfaces are represented by negative NDVI values.

The processes of depopulation and deagrarianization have influenced the reduction of agricultural areas, meadows, vineyards and orchards. The decline of the mentioned areas was greatly influenced by the already mentioned phenomenon of migration between the village and the city. Through this process, the able-bodied and young population left rural areas and settled in urban areas in search of better living conditions and economic stability. The population in rural areas has become older, which has had the effect of reducing the volume of agricultural production. On the other hand, natural ecosystems could develop undisturbed on neglected areas, which contributed to the increase of areas under shrubs and forest vegetation.

5. Conclusion

The analysis of the vegetation cover on the territory of the Nišava District and its municipalities revealed great possibilities for the application of remote sensing and NDVI as one of the most important indices for the analysis of the state of vegetation. The application is reflected in the monitoring and evaluation of temporal changes in land cover, whereby a comparative analysis of a certain territory from two different periods of observation can be performed. Through the processing and analysis of Landsat 5 and Landsat 8 satellite scenes, drastic changes in the vegetation composition were observed over a period of 19 years (2004-2023).

On the territory of the district, a decrease in the area under meadows, arable fields, vineyards, orchards, mixed and coniferous forests was registered. In the territory of the Svrljig municipality, an increase in the area without vegetation, as well as the area under shrubs and forest vegetation, was registered. In the territory of the municipality of Doljevac, there was an increase in the area under shrubs and forest vegetation compared to the beginning of the analyzed period. An increase in the area under deciduous forests was registered in the territory of all municipalities, while the area under mixed forests decreased in the territory of the municipalities of Razanj, Aleksinc, Merošina and the territory of the city of Niš, and increased in the territory of the municipality of Svrljig, Gadžin Han and Doljevac. A decrease in the area under coniferous forests was recorded in the territory of the city of Niš, the municipality of Aleksinac, Svrljig and Gadžin Han. At the beginning and at the end of the research period, the territories of the municipalities of Merošina and Doljevac were dominated by deciduous forests.

The validation of the results established a high precision in determining the types of vegetation in municipalities with a lower percentage of forest areas. The municipalities with the highest accuracy are Merošina and Doljevac. A lower precision of the results was registered in other municipalities that had a higher percentage share of shrubs and forest vegetation. The assumption is that the precision of the results was influenced by the areas where dense shrubs and woody ecosystems were registered. Accordingly, future cabinet and field research can help us in further monitoring of vegetation types on the territory of the Nišava District and the municipalities that belong to it, as well as territories in other parts of Serbia. By applying remote sensing and calculating the NDVI, it is possible to spot areas that are threatened by illegal logging, the occurrence of landslides or some other negative human activities. Calculation of NDVI can help us in discovering areas where afforestation measures need to be implemented and indirectly reduce the degree of erosion in those areas.

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References

Calow, R. C., MacDonald, A. M., Nicol, A. L., Robins, N. S. (2010). Ground water security and drought in Africa: linking availability, access, and demand. Groundwater, 48 (2), 246-256.

Chauhan, M., Kumar, M., Kumar, A. (2020). Impact of carbon stocks of Anogeissus latifolia on climate change and socioeconomic development: A case study of Garhwal Himalaya, India. Water, Air, & Soil Pollution, 231 (8), 436.

Cui, L., Shi, J. (2010). Temporal and spatial response of vegetation NDVI to temperature and precipitation in eastern China. Journal of Geographical Sciences, 20 (2), 163-176.

Ding, M., Zhang, Y., Liu, L., Zhang, W., Wang, Z., Bai, W. (2007). The relationship between NDVI and precipitation on the Tibetan Plateau. Journal of Geographical Sciences, 17, 259-268.

Durlević, U., Milinčić, U., Petrović, D. (2022). Application of remote sensing in the monitoring of vegetation cover in the territory of the Kopaonik National Park. Proceedings of young researchers of the Ninth scientific-professional meeting with international participation "Local self-government in planning and arrangement of space and settlements", Veliko Gradište, 63-69.

Jensen, J. R. (2007). Remote Sensing of the Environment: An Earth Resource Perspective. Upper Saddle River, NJ, Prentice - Hall.

Jovanović, M. M., Milanović, M. M. (2015). Normalized Difference Vegetation Index (NDVI) as the Basis for Local Forest Management. Example of the Municipality of Topola, Serbia. Polish Journal of Environmental Studies, 24 (2).

Jovanović, M., Milanović, M., Zorn, M. (2018). The use of NDVI and CORINE Land Cover databases for forest management in Serbia. Acta Geographica Slovenica-Geografski Zbornik, 58 (1), 109-123.

Kumar, A., Kumar, M. (2022). Estimation of biomass and soil carbon stock in the hydroelectric catchment of India and its implementation to climate change. Journal of Sustainable Forestry, 41 (7), 642-657.

Ladanyi, Z., Rakonczai, J., Van Leeuwen, B. (2011). Evaluation of precipitation-vegetation interaction on a climate-sensitive landscape using vegetation indices. Journal of Applied Remote Sensing, 5 (1), 053519-053519.

Liu, H., Zheng, L., Yin, S. (2018). Multi-perspective analysis of vegetation cover changes and driving factors of long time series based on climate and terrain data in Hanjiang River Basin, China. Arabian Journal of Geosciences, 11, 1-16.

Manfreda, S., McCabe, M. F., Miller, P. E., Lucas, R., Pajuelo Madrigal, V., Mallinis, G., Ben Dor, E., Helman, D., Estes, L., Ciraolo, G., Mullerova, J., Tauro, F., De Lima, M. I., De Lima, J. L. M. P., Maltese, A., Frances, F., Caylor, K., Kohv, M., Perks, M., Ruiz-Perez, G., Su, Z., Vico, G., Toth, B. (2018). On the use of unmanned aerial systems for environmental monitoring. Remote sensing, 10 (4), 641.

Marković, S. B., Korać, M., Mrđić, N., Buylaert, j. P., Thiel, C., McLaren, S. J., Stevens, T., Tomić, N., Petić, N., Jovanović, M., Vasiljević, D. A., Sumegi, P., Gavrilov, M. B., Obreht, I. (2014). Palaeoenvironment and geoconservation of mammoths from the Nosak loess-palaeosol sequence (Drmno, northeastern serbia): initial results and perspectives. Quaternary International, 334, 30-39.

Milanović, M., Micić, T., Lukić, T., Nenadović, S. S., Basarin, B., Filipović, D., Tomić, M., Samardžić, I., Srdić, Z., Nikolić, G., Ninković, M. M., Sakulski, D., Ristanović, B. (2019). Application of Landsat-derived NDVI in monitoring and assessment of vegetation cover changes in Central Serbia. Carpathian Journal of Earth and Environmental Sciences, 14 (1), 119-129.

Milanović, M., Tomić, M., Perović, V., Radovanović, M., Mukherjee, S., Jakšić, D., Petrović, M., Radovanović, A. (2017). Land degradation analysis of mine-impacted zone of Kolubara in Serbia. Environmental Earth Sciences, 76, 1-10.

Ning, T., Liu, W., Lin, W., Song, X. (2015). NDVI variation and its responses to climate change on the northern Loess Plateau of China from 1998 to 2012. Advances in Meteorology, 2015 (1), 725427.

Novkovic, I., Markovic, G. B., Lukic, Dj., Dragicevic, S., Milosevic, M., Djurdjic, S., Samardzic, I., Lezaic, T., Tadic, M. (2021). GIS-based forest fire susceptibility zonation with IoT sensor network support, case study—Nature Park Golija, Serbia. Sensors, 21 (19), 6520.

Ollinger, S. V. (2011). Sources of variabillity in canopy re-

flectance and the convergent properties of plants. New Phytologist, 189 (2), 375-394.

Pavlović, M. (2019a). Geographical regions of Serbia 2 - Mountain-basin-valley macroregion. University of Belgrade, Faculty of Geography, Belgrade.

Pavlović, M. (2019b). Geography of Serbia 1. University of Belgrade, Faculty of Geography, Belgrade.

Rakićević, T. (1980). Climate regionalization of SR Serbia. Collection of papers of the Geographical Institute, 27, 29-42.

Rašković, D. (2015). Anthropogenic impacts on the stability of the forest ecosystems in Belgrade-comparative analysis of Košutnjak Forest and Zvezdarska Forest. Glasnik Srpskog geografskog društva, 95 (4), 195-214.

Republic Institute of Statistics (2023). Municipalities and regions in the Republic of Serbia. Belgrade.

Republic Institute of Statistics (2024). Comparative overview of the population of the Republic of Serbia 1948-2022. Belgrade.

Rodić, D., Pavlović, M. (1994). Geography of Yugoslavia 1. Modern administration. Belgrade.

Sahebjalal, E., Dashtekian, K. (2013). Analysis of land use-land covers changes using normalized difference vegetation index (NDVI) differencing and classification methods. African Journal of Agricultural Research, 8 (37), 4614-4622.

Sidi Almouctar, M. A., Wu, Y., Kumar, A., Zhao, F., Mambu, K. J., Sadek, M. (2021). Spatiotemporal analysis of vegetation cover changes around surface water based on NDVI: a case study in Korama basin, Southern Zinder, Niger. Applied Water Science, 11, 1-14.

Sojka, M., Jaskula, J., Wrozynski, R., Waligorski, B. (2019). Application of Sentinel-2 satellite imagery to assessment of spatio-temporal changes in the reservoir overgrowth process-a case study: Przebedowo, West Poland. Carpathian Journal of Earth and Environmental Sciences, 14 (1), 39-50.

Tang, J., Zeng, J., Zhang, Q., Zhang, R., Leng, S., Zeng, Y., Shui, W., Xu, Z., Wang, Q. (2020). Self-adapting extraction of cropland phenological transitions of rotation agroecosystems using dynamically fused NDVI images. International journal of biometeorology, 64, 1273-1283.

Tzedakis, P. C., Lawson, I. T., Frogley, M. R., Hewitt, G. M., Preece, R. C. (2002).Buffered tree population changes in a Quaternary refugium: evolutionary implications. Science, 297 (5589), 2044-2047.

United states Geological Survey (USGS), EarthExplorer. Partially available at: https://earthexplorer.usgs.gov/ (Accessed February 21 and June 21, 2024).

Vasić, V., Stevanović, V. (1995). Overview of anthropogenic factors that threaten the biodiversity of Yugoslavia. Biodiversity of Yugoslavia with an overview of species of international importance. Faculty of Biology and Ecolibri, Belgrade, 18-35.

Zhang, H., Chang, J., Zhang, L., Wang, Y., Li, Y., Wang, X. (2018). NDVI dynamic changes and their relationship with meteorological factors and soil moisture. Environmental earth sciences, 77, 1-11.

Živanović, V., Joksimović, M., Golić, R., Malinić, V., Krstić, F., Sedlak, M., Kovjanić, A. (2022). Depopulated and Abandoned Areas in Serbia in the 21st Century—From a Local to a National Problem. Sustainability, 14 (17), 10765.