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IPA ADRION

THEMATIC2GREEN



Territorial analysis of climate change impact on tourism and
cultural industries in the ADRION Region

City of Niš

Deliverable: D 2.1.1

July 2025



PARTNER CONSULTING

Working together

The project is co-funded by the European Union through the Interreg IPA ADRION programme

Project title: IPA-ADRION00228 THEMATIC2GREEN

Activity: Activity 2: Territorial analysis of the impacts of climate change on economic systems
Sub-activity 2.4. Preparation of the Report on the Territorial Analysis of Climate Change Impacts on Economic Systems in the Most Vulnerable Areas of the City of Niš

Document title: Territorial analysis of climate change impact on tourism and cultural industries in the ADRION Region – City of Niš

Contracting Authority: City Municipality of Medijana

Contract number: 181/2025-62-1 from 06.05.2025.

Contractor: Radoje Laušević pr. Agencija Partner Consulting, Kneza Danila 7, Beograd – Palilula

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Submission date: 30.08.2025.

Status: Draft

Version: 1

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Abbreviations

AR	Augmented reality
CHERISH	Cultural Heritage Resilience in South-East Europe) program
CHP	Combined heat and power
COVID-19	Coronavirus disease 2019
CRP	City Resilience Program
DG CLIMA	Directorate-General for Climate Action of the European Commission
E-OBS	ENSEMBLE observational dataset (European Observational Gridded Dataset)
EmBRACE	Building Resilience Amongst Communities in Europe
EMERALD	Ecological network of Areas of Special Conservation Interest
EPS	“Elektroprivreda Srbije” – the national electricity company of Serbia
EU	European Union
EUKI	European Climate Initiative
EUSAIR	EU Strategy for the Adriatic and Ionian Region
FERP	Flood Emergency Reconstruction Project in Serbia
GUP	“Generalni urbanistički plan” – General urban plan
HVAC	Heating, ventilation, and air conditioning
IBA	Important bird and biodiversity area
IPA	Instrument for Pre-Accession Assistance
MIN	“Mašinska industrija u Nišu” (Mechanical / Engineering Industry in Niš), traditional industrial sectors in the City of Niš
NAP	National adaptation plan
NbS	Nature-based solutions
NGO	Non-governmental organization
PBA	Protected Bird Area
PDR	“Plan detaljne regulacije” – Detailed Regulation Plan
PGR	“Plan generalne regulacije” – General Regulation Plan
PPP	Public-private partnership
PV	Photovoltaics
RCP4.5	Representative Concentration Pathway 4.5 climate scenario
RCP8.5	Representative Concentration Pathway 8.5 climate scenario
SDGs	Sustainable development goals
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
SMS	Short Message Service
SORS	Statistical Office of the Republic of Serbia



SPEI-06	Standardized Precipitation Evapotranspiration Index at a 6-month timescale
UHI	Urban Heat Island
UNESCO	United Nations Educational, Scientific and Cultural Organization
VLR	Voluntary local review
VR	Virtual reality
WB	World Bank

1 Introduction

In an era of accelerating climate change, the Adriatic-Ionian (ADRION) Region faces profound challenges that threaten its natural landscapes, economic vitality, and cultural heritage. As part of the THEMATIC project, this territorial analysis examines the vulnerabilities, impacts, and risks posed by climate change to tourism and cultural industries within selected territories across partner countries. By focusing on a mix of coastal and inland areas, the report provides a comprehensive overview of regional dynamics, highlighting the need for adaptive strategies to safeguard these vital sectors.

This draft (Deliverable D2.1.1) centers on the City of Niš, an inland territory in southeastern Serbia, as the primary case study. Situated in the Niš Basin at the confluence of the Nišava and Južna Morava rivers, Niš serves as a key administrative, economic, and cultural hub for the Nišava District. With its rich historical legacy—from Roman ruins like Mediana to Ottoman-era sites such as the Niš Fortress—and growing tourism appeal, including spa resorts in Niška Banja and eco-adventures in surrounding mountains, the city exemplifies the interplay between climate pressures and human systems. Recent trends, including rising temperatures, irregular precipitation, and extreme weather events, have already begun to reshape Niš's environment, economy, and society, underscoring the urgency of this assessment.

Drawing on data from sources like the E-OBS database, the Digital Climate Atlas of Serbia, and local planning documents, this analysis explores Niš's natural resources, urban and rural structures, demographic trends, and economic systems. It evaluates short- and long-term climate risks—such as heatwaves, droughts, floods, and wildfires—and their implications for tourism, cultural heritage, public infrastructure, and overall resilience. The report concludes with policy recommendations, infrastructure proposals, and opportunities for private innovation and international cooperation to foster sustainable adaptation.

By addressing these issues, this document aims to inform stakeholders in Niš and the broader ADRION Region, promoting integrated actions that mitigate risks while harnessing new opportunities for resilient growth in tourism and cultural industries.

1.1 Introduction to the climate change impact on the target territory

In recent years, the City of Niš has experienced notable changes in its local climate, reflecting broader regional trends associated with climate change. Average temperatures have been steadily rising, while precipitation patterns have become more irregular. Summers are increasingly warmer, with August emerging as the hottest month, averaging around 22.3 °C. Winters, though

still cold, show a slight warming trend, with January temperatures averaging approximately 0.6 °C. These developments suggest a gradual transition toward a warmer and more variable climate in the region.

The observed climate changes were analysed for the period of recent past 2001-2020, particularly for the second decade of this climate period 2011-2020 when the greater influences of climate changes were observed. Data for the analysis of observed climate changes and their effects were obtained from the E-OBS database (Cornes, et al, 2018) for the period 1961-2020, which includes interpolated daily data for temperatures and precipitation at a resolution of 0.11°. The period 1961-1990 is the reference climate period for analysing changes in the recent past and future until the end of the 21st century. This period is considered representative of climate conditions before significant changes occurred. The data used for the analysis of observed and future climate changes are available through the web portal Digital Climate Atlas of Serbia (Ministry of Environmental Protection, 2022). The observed climate changes were analysed for the period of recent past 2001-2020, with a special emphasis on the period between 2011 and 2020, when the greater influences of climate changes were observed. This was aimed at illustrating the significant acceleration of temperature rise and various other climate-related risks.

2 The target territory. Natural resources, urban and rural structures, society and economic systems

The City of Niš is situated in the Niš Basin, at 43°19' north latitude and 21°54' east longitude. It spans an area of 597 km², accounting for approximately 0.7% of Serbia's total territory and 21.8% of the Nišava District.

The territory of the City of Niš is located in the southeastern part of Serbia, at the confluence of the river Nišava with the river Južna Morava, between the branches of the mountains Svrljiške Planine, Suva Planina, and Jastrebac. The relief of this area is characterized by a combination of hilly-mountainous terrain in the north and south, and flatland terrain in the central part of the area.

The City of Niš is the administrative, economic, and cultural center of the Nišava District, which encompasses nine municipalities in total. While districts in Serbia serve as administrative units for state authority and coordination of certain public services, they are not units of local self-government and do not have independent governing bodies or elected assemblies. Niš, as the largest urban settlement in the district, occupies a central position both geographically and functionally, serving as the district seat.



Figure 1. Position of the City of Niš within the Republic of Serbia

Administratively, Niš functions as a city municipality (grad), which is a special status in the Serbian system of local self-government granted to major urban centers. Within its jurisdiction, the city is further divided into five urban municipalities:

- Medijana – the central and most densely populated municipality, serving as the commercial, administrative, and cultural core of Niš, where most institutions, services, and businesses are concentrated.
- Palilula – located to the east of the city center, combining urban neighborhoods with rural settlements, and encompassing important industrial and transport zones.
- Crveni Krst – situated in the western part of Niš, notable for its mixed urban-rural character and important historical sites, as well as areas of ongoing industrial and residential development.
- Pantelej – stretching towards the north, characterized by rapidly expanding residential zones, cultural heritage sites, and access to natural areas in the direction of Svrlijske Planine.

- Niška Banja – the smallest and most distinct municipality, known for its spa tourism, health resorts, and surrounding natural landscapes, forming a strong link between the city and nearby mountainous areas.

Together, these municipalities form an integrated administrative unit, but each maintains its own local government structures to manage services, development planning, and community needs in line with the overall strategy of the City of Niš.

2.1 The natural environment

The administrative territory of Niš is characterized by diverse terrain with numerous faults, the most prominent being the Morava–Vardar fault along the South Morava River. The landscape is dominated by the Niš–Aleksinac Basin, surrounded by mid-altitude mountains, along with notable morphological units such as the Zaplanje and Svrljig basins, and the Dobrič area in the lower part of the Toplica River basin. The city's highest elevation point is “Sokolov Kamen” on Suva Planina, reaching 1,523 meters above sea level, while the lowest point lies downstream from the confluence of the Nišava and Morava rivers near the village of Trupale, at 173 meters above sea level.



Figure 2. City of Niš 3D territory. Source: Perović et al, 2016.

Agricultural land is one of the most valuable natural resources in this area, characterized by remarkable diversity and high productive potential in certain zones. The highest quality soils are found in the flat areas of the Niš Basin and in the alluvial plains along the valleys of the South Morava, Nišava, and Toplica rivers, where fertile land supports intensive crop and vegetable production. These areas are particularly suitable for cultivating cereals, maize, industrial crops, vegetables, and forage plants.

While most arable land has moderate productive potential, certain basins within the composite river valleys stand out for their exceptionally fertile soils. Additionally, favorable microclimatic, pedological, and terrain conditions along the valleys of the Timok, Moravica, Nišava, and Toplica rivers provide excellent opportunities for viticulture, supported by a centuries-old tradition of quality wine production.

Within the total agricultural land of the urban territory of Niš, arable land represents the dominant type, particularly in cadastral municipalities situated at the lowest elevations of the Niš Basin, along the South Morava and Nišava rivers. In these zones, arable land and gardens account for more than 50% of the total area. In contrast, orchards and vineyards make up a relatively small portion—seldom exceeding 10% of the total agricultural land—indicating a high level of dispersion and parcel fragmentation. This suggests that such production is primarily intended for individual or household use rather than commercial purposes. Meadows also occupy a very small share of the agricultural landscape, with parcels scattered and fragmented across the entire planning area. Pastures, as a distinct land category, show a varied presence throughout the region. This variation reflects the diverse geological, morphological, climatic, and soil conditions that characterize the urban territory of Niš.

The most significant threats to the quality of agricultural land include the reduction of arable areas and the degradation of agro-ecological quality caused by water and wind erosion, salinization, loss of nutrients, disruption of soil structure, and mechanical compaction from heavy machinery during cultivation. Additional challenges are soil waterlogging, flooding, fertility loss, and changes in land use.

There is a noticeable trend of converting agricultural land for the construction and development of settlements, infrastructure, industrial zones, and similar uses. This leads to permanent loss of the land's productive capacity and ecosystem functions due to its coverage with impermeable layers. Soil chemical pollution is also evident, with frequent exceedances of threshold and remediation values, most commonly for nickel, copper, and zinc, as well as other elements. The territory of the City of Niš faces serious cases of soil contamination, primarily due to rising groundwater levels during exceptionally rainy years. A key contributing factor is the unresolved issue of waste disposal at a non-sanitary landfill. Around 300 hectares of land are directly impacted, extending from the area below the landfill between the villages of Bujanj and Belotinac.

Forests in Niš are primarily located in the hilly and mountainous areas of the north and southeast, covering 23.099 km² or about 39% of the territory. Northern forest zones are found near villages Paligrace, Kravlje, Cerje, Leskovik, Rujnik, and Kamenica, while southeastern ones are in the areas of Berbatovo, Vukmanovo, Gabrovac, Donje Vlase, and Lazarevo Selo. The largest forested areas are in City Municipality of Niška Banja

(8,394 ha) and City Municipality of Pantelej (6,761 ha), with smaller areas in City Municipality of Crveni Krst (5,315 ha) and City Municipality of Palilula (2,630 ha), while there are no forest areas in the City Municipality of Medijana. Based on their function, the forests are categorized as production-protection forests (42.59%) and primarily protection forests (46.48%). Regarding protection status, the forests comprise park forests (0.46%), nature parks (9.16%), areas of exceptional natural beauty (0.7%), and special nature reserves (0.61%).

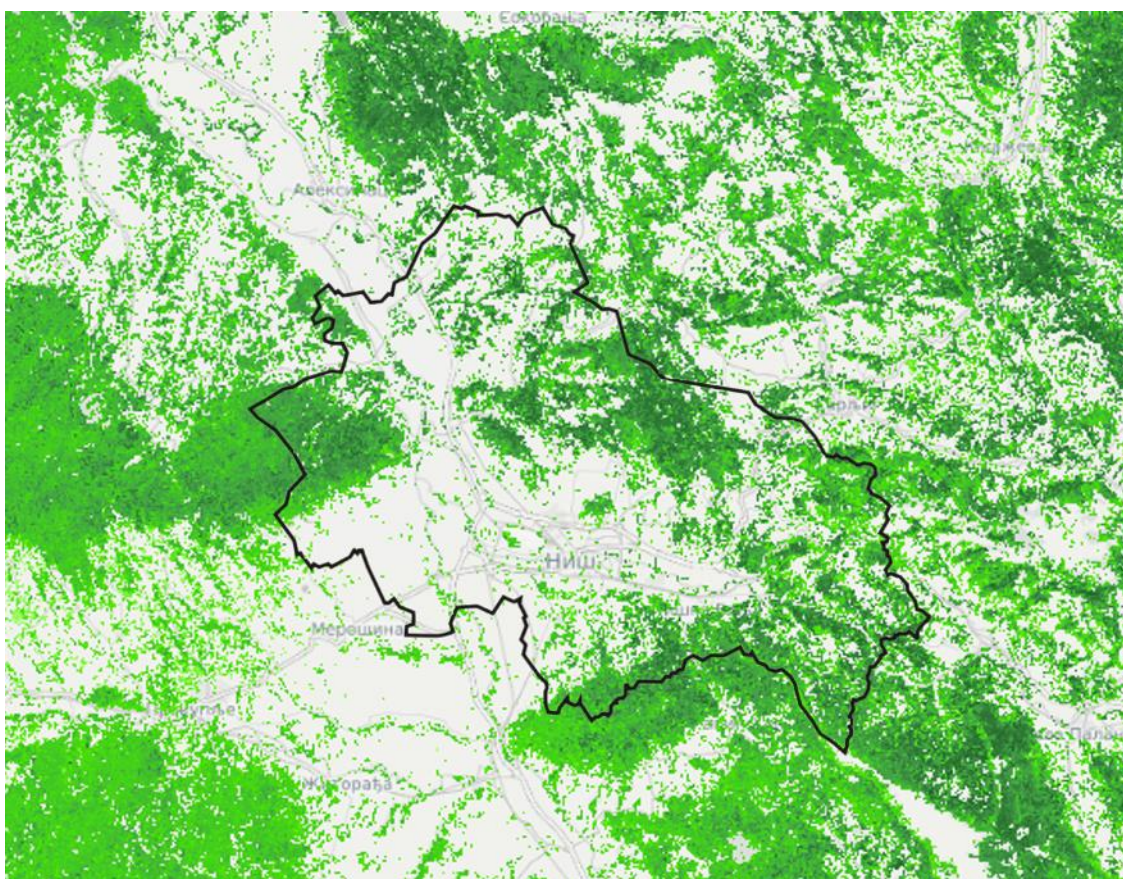


Figure 3. Forests and forest land at the urban territory of Niš. Source: Copernicus Land Monitoring Service <https://land.copernicus.eu>

Beech and mixed deciduous forest complexes are the most widespread, with some stands containing more than fifteen species. Along the edges of the mesophilic beech forests—primarily state-owned—at lower elevations and nearer to settlements, xeromesophilous hornbeam–field maple forests are found, and at even lower altitudes, xerothermophilous sweet chestnut–Turkey oak forests occur. The beech forest complexes are well-maintained and preserved, consisting mainly of productive, dense, and mature stands. In contrast, the hornbeam–field maple and sweet chestnut–Turkey oak complexes fulfill primarily ecological rather than production functions. Overall, the

forests and forest lands feature good density and coverage, with a significant presence of shrubs and undergrowth.

The territory of the City of Niš is characterized by an uneven distribution of forest areas, with a particularly low presence of forests within the urban core. This lack of green coverage in densely populated zones significantly limits the city's capacity to improve air quality and enhance overall environmental conditions. Moreover, the existing forest land faces increasing pressure and degradation, primarily due to uncontrolled logging, illegal construction activities, and the absence of consistent, planned afforestation measures.

Forests in the City of Niš are highly vulnerable to fire, particularly due to climate pressure, terrain, accumulated dry biomass, and human-induced ignitions. While recent response efforts have improved, systemic vulnerability remains high, especially under climate change scenarios.

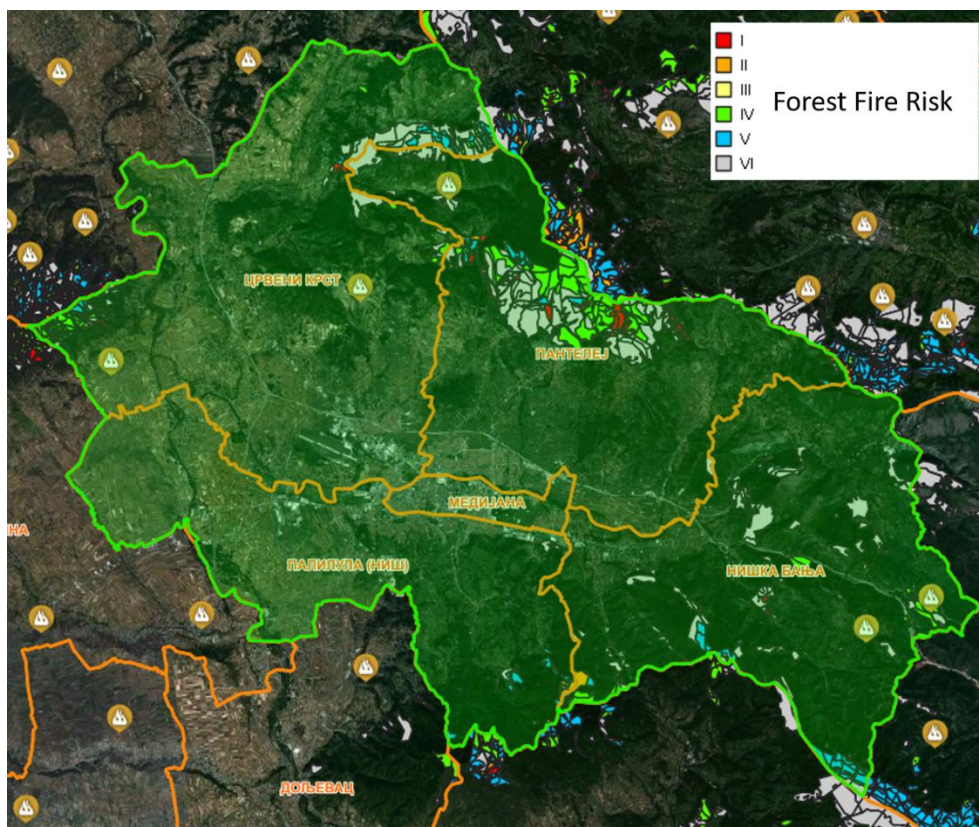


Figure 4. Vulnerability of forest in the City of Niš to fire. Source: Register of Disaster Risks of the Republic of Serbia, <https://drr.geosrbija.rs/>

The most vulnerable areas include the lower slopes of Suva Planina, the forested surroundings of Niška Banja, and the hill zones near Gabrovac and Donja Studena. These locations exhibit a high concentration of risk factors, including steep topography,

dense vegetation, and difficult accessibility, which collectively hinder fire detection and suppression efforts. In these zones, dry leaf litter and unmanaged undergrowth act as fuel beds, while summer heatwaves and wind patterns create favorable conditions for fire ignition and rapid spread.

Niška Banja, although a popular recreational and residential area, is especially at risk due to the interface between forest and urban development. The presence of tourists, weekend houses, and informal burning of waste adds human-related ignition risks, while local vegetation remains largely unmanaged. Similarly, the Bujanj forest, located closer to the urban core, shows a moderate level of vulnerability. While better accessible, this area is impacted by proximity to roads and urban sprawl, and lacks proactive firebreak infrastructure. It faces rising pressure from urban expansion and informal activities, making it a growing concern despite its location. In the southern rural belt — particularly in Donja Studena and surrounding villages — vulnerability is high due to the combined effect of abandoned agricultural fields, frequent burning practices, and limited institutional presence. These areas often serve as ignition points for wildfires that can later spread into adjacent forest zones. In contrast, northern and western parts of Niš, characterized by lower forest density and flatter terrain, are generally less vulnerable, though not immune to the risk during prolonged drought periods.

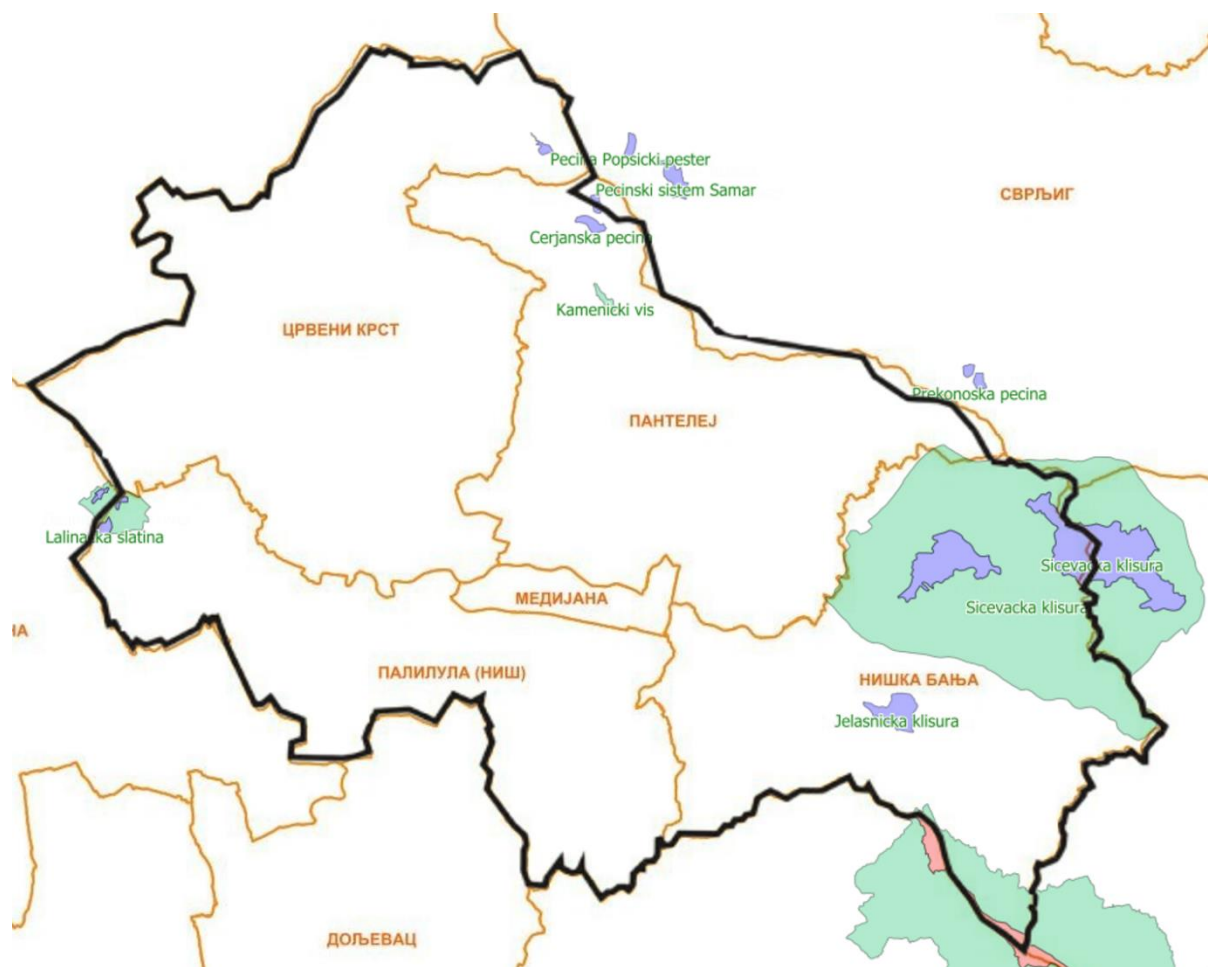


Figure 5. City of Niš protected areas. Source: geosrbija.rs

The most important **protected natural areas** include the Sicevo Gorge Nature Park and the special nature reserves of Suva Planina and Jelašnica Gorge. Sicevo Gorge Nature Park spans 7,746 hectares, covering parts of the City of Niš and Bela Palanka municipality. Within the City of Niš, it includes 5,559 hectares, making up 72% of the park's total protected area. Most of the park is designated under a Level III protection regime. The Suva Planina Special Nature Reserve, encompassing 18,116 hectares, stretches across the territories of Niš, Gadžin Han, and Bela Palanka. This vast natural area is managed under a comprehensive protection regime that includes all three levels of conservation. The most strictly protected zone, classified as Level I, covers 848 hectares, while Level II protection is in place over 2,194 hectares. The largest portion of the reserve, 15,073 hectares, falls under Level III protection, allowing for sustainable use while preserving the region's unique ecological value. In addition, 12 natural monuments have been protected, including the hydrological heritage site of Lalinačka Slatina. Areas proposed for future protection include Seličevica area, Svrljiške Planine, and Jastrebac.

Sićevo Gorge Nature Park, along with the Jelašnica Gorge and Suva Planina Special Nature Reserves, has been recognized as an area of international importance for birdlife (IBA), plant diversity (IPA), and butterfly habitats (PBA). Both Sićevo Gorge and Suva Planina are also part of the EMERALD Network, contributing to the broader European ecological network for the preservation of wild species and their habitats. Furthermore, the Južna Morava River and its riparian zone have been designated as an internationally significant ecological corridor.

Public green space within the urban area of Niš covers a total of 292.37 hectares. The city's park network includes 15 parks, 3 small squares, the old river quay, a new quay currently under construction, and a park in Niška Banja. Excluding the quay under development, designated park greenery accounts for 49.01 hectares.

The city is also home to two urban forest parks: Bubanj, covering 50.54 hectares, and Koritnik in Niška Banja, with an area of around 40 hectares. Protective green zones are primarily located along waterways but are often overgrown with unmanaged vegetation, limiting their ecological and recreational function.

The share of green areas, amounting to only 1.2 m² per capita, indicates not only that green spaces are insufficiently represented within the territory of the City, but also that their proportion within public open areas is very limited. A particularly pressing issue is the lack of neighborhood (block) greenery, much of which has been lost to the expansion of car parking areas.

2.2 Historical and cultural of the target territory.

Niš's strategic location in the Morava–Vardar valley, a key transit route between Central Europe and the Middle East, has significantly shaped its **history**. The wider area was inhabited since the Early Bronze Age by the Dardanians and later by Celts, who likely gave the city its early name Naissus. By the 2nd century, it was known as Niz or Nissa, and in the 3rd century became a Roman castrum with fortifications defending a bridge over the Nišava River, marking the city's early urban development.

In the late 18th century, Niš thrived again, developing on both riverbanks into a major town divided into Serbian and Turkish quarters. By the mid-19th century, following liberation from Ottoman rule, Niš had over 30 neighborhoods, numerous mosques, shops, military barracks, churches, and a synagogue.

The city's industrial development began with the construction of the railway in 1884. Today, the Niš basin is characterized by a dispersed spatial structure with integrated residential, work, public service, transport, infrastructure, and utility functions.

Niš offers a rich tapestry of cultural and historical monuments that testify to its significance from prehistory to the modern era. Niš is home to a rich collection of immovable **cultural heritage**, with 111 registered sites across its territory. Among them, six have been designated as cultural properties of exceptional importance. Archaeological findings confirm continuous settlement since prehistoric times, with major developments during Roman, Byzantine, Ottoman, and modern Serbian periods. The National Museum's Archaeological Hall houses artifacts from prehistoric sites like Bubanj and Malča, Roman coins and statues, early Christian relics, and medieval Christian items. Highlights include a portrait of Emperor Constantine, a sculpture of Jupiter, and a depiction of Byzantine Empress Theodora. Early Christian heritage includes mosaicked tombs and churches from the 4th–6th centuries, such as the Jagodin Mala martyrion and painted tombs bearing Christ's monogram—important symbols of the city's spiritual identity. Mediana, a luxurious Roman estate on the ancient Via Militaris (now E-80), spreads over 40 hectares. It features remains of villas, baths, workshops, and granaries. The villa with a peristyle is adorned with impressive mosaics, including depictions of Medusa and a river god—possibly Neptune. Artefacts from the site, such as pottery, coins, sculptures, and lead pipes that supplied thermal water from Niška Banja, are displayed on-site and in the Archaeological Hall of the National Museum of Niš.

Ćele Kula (Skull Tower) is a unique monument built by the Ottomans using the skulls of Serbian rebels after the Battle of Čegar (1809). Originally containing 952 skulls, only 58 remain today. A chapel was added in 1938 to preserve the tower, accompanied by a bust of hero Stevan Sinđelić and a plaque with a message from French poet Lamartine, highlighting the value of freedom.

The Concentration Camp “Crveni Krst”, one of the few preserved WWII Nazi camps in Europe, is notable for a mass prisoner escape in 1942. It was turned into the Memorial Museum “12th February” in 1967.

Niš Fortress, a well-preserved example of Ottoman military architecture, spans 22 hectares with 2.1 km of walls. Inside are remains from Roman, Byzantine, and Ottoman times, including a Roman lapidarium, ancient streets and baths, and the 15th-century Hammam (Turkish bath). The Octagonal Building, discovered in 1988 outside the fortress, dates to the 4th century. With underfloor heating and mosaicked interiors, it reflects luxury Roman architecture.

Čegar Hill commemorates the site of the 1809 battle where Serbian forces led by Stevan Sinđelić made a heroic last stand. The first monument was erected in 1878, while the current tower-shaped monument was unveiled in 1927.

Bubanj Memorial Park, southwest of the city, marks one of the largest WWII execution sites in Yugoslavia. The park features symbolic sculptures that honor the victims and preserve the memory of the atrocities.

Immovable cultural properties of great importance in Niš include seven sites: the Latin Church in Gornji Matejevac, Sićevo Monastery, Niš Fortress, the Officer's Club building, the Pasteur Institute building, the Old Prefecture (Banovina) building, and the archaeological site Humska Čuka. In addition to these, Niš is home to numerous other cultural heritage sites spread across its territory. The City's territory also includes officially recorded 15 properties currently under preliminary protection. These protected cultural assets comprise 745 monument-style buildings, 27 architectural and environmental complexes, and 60 archaeological sites, all presumed to hold significant cultural value.

The key challenges facing cultural heritage in Niš are primarily financial. Over recent decades, limited funding has resulted in minimal investment in the preservation of valuable heritage sites. Efforts to showcase and promote these cultural assets have also been insufficient. Consequently, the full potential of cultural heritage for boosting tourism remains largely untapped. Stakeholders have highlighted the urgent need to enhance the preservation of the city's cultural heritage and to undertake comprehensive research in the field of architectural heritage.

2.3 The demography, social and economic systems

The population of the City of Niš is characterized by a gradual but long-term decline, primarily due to negative natural growth and emigration, especially of young people to larger cities or abroad. According to the latest estimates (2024), the City of Niš has 248,418 inhabitants, making it the third-largest city in Serbia. The demographic structure shows an aging population, with an increasing share of people over the age of 65, while the number of young people and children continues to decrease.

Niš has an average of 416 people per square kilometer, as reported in 2022. The population density in the urban core of Niš is significantly higher than the city average. Urban center — including the city's main neighborhoods and downtown area — can have densities ranging from approximately 1,500 to 3,000 people per square kilometer or more. This higher density reflects concentrated residential, commercial, and administrative activities typical of a city center, with apartment buildings, mixed-use developments, and limited open space compared to suburban or rural parts of the municipality. Moreover, City municipality of Medijana as a central urban municipality within Niš, exhibits a significantly higher population density compared to rural areas. The population density in the urban core of Medijana is estimated to be approximately 3,000 to 4,000 people per square kilometer.

Population growth in Niš was negative in 2024, with a decline of 887 people. The negative natural population growth rate per 1,000 inhabitants was 3.6 in 2024. This long-standing trend has been especially pronounced over the past two decades and mirrors broader demographic shifts occurring across Serbia. The low birth rate is a result of delayed childbirth, a reduced number of women of reproductive age, economic insecurity, and shifting life priorities. At the same time, a growing proportion of elderly residents contributes to a higher mortality rate. Negative population growth further worsens the city’s demographic situation, especially in suburban and rural areas, where declining birth rates and an aging population are even more pronounced.

Population Pyramid for the City of Niš (2024 estimation)

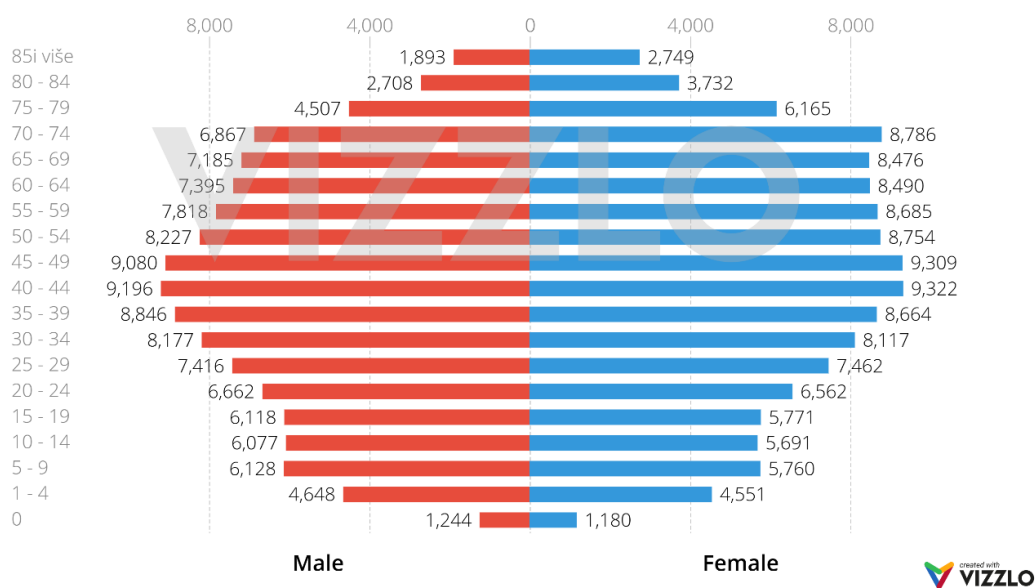


Figure 6. Population pyramid for the City of Niš, 2024 estimation. Source: Statistical Office of the Republic of Serbia (<https://stat.gov.rs/en-US/>)

Migration trends in Niš over the last two decades have been dominated by internal migration dynamics, which at times offset the negative natural population growth. From 2002 to 2011, the city’s population growth was sustained largely due to positive migratory balance, which exceeded the natural decline by a factor of about 1.8. However, since around 2011, Niš—like many medium-sized urban centers outside Belgrade and Novi Sad—has seen slower or stagnating migration-driven recovery, with underperformance particularly evident after 2011, when urban shrinkage became more common. In 2024, the Nišava District, which

includes the City of Niš, recorded a positive internal migration balance of approximately 6,500 people, indicating that significantly more individuals moved into the area than left it. The City of Niš itself also had a positive internal migration balance, with 506 more people moving in than moving out. Additionally, there was a recorded immigration of 873 foreign nationals.

Emigration from Niš is primarily characterized by the departure of young and working-age individuals, driven by economic and social factors, which significantly impact the city's demographic and economic structure. The majority of those leaving Niš are young people, especially those between the ages of 20 and 40 who are in their most productive and active working years. The main reasons for emigration include economic insecurity, unemployment or a lack of attractive job opportunities, as well as the desire for a higher standard of living, better living conditions, and improved access to education and healthcare. Additionally, many seek better educational and employment prospects abroad or in larger cities within Serbia.

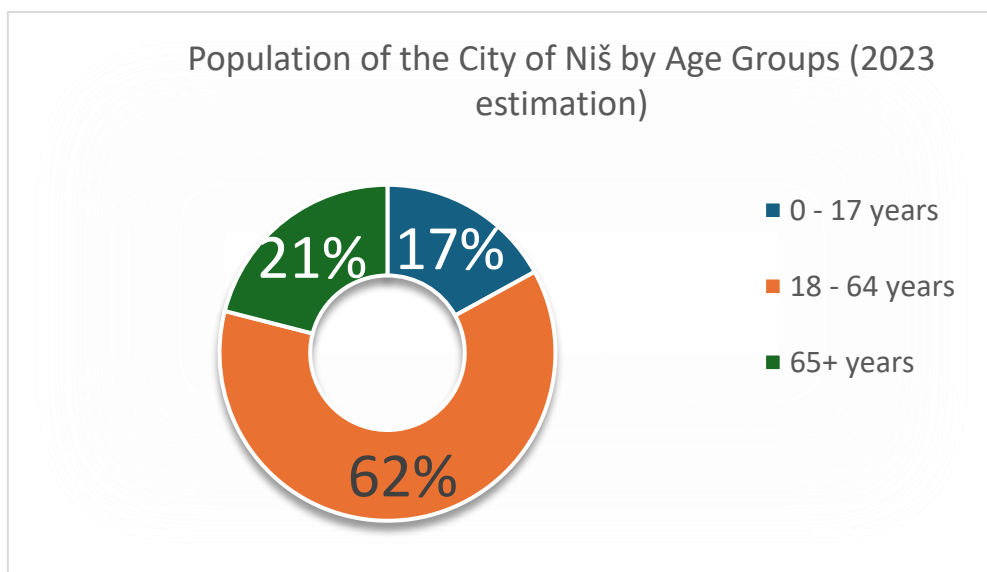


Figure 7. Population of the City of Niš by age groups (2023 estimation). Source: Statistical Office of the Republic of Serbia (<https://stat.gov.rs/en-US/>)

According to the Draft Spatial Plan of the Republic of Serbia until 2035 (2023), the urban territory of Niš is classified as an agglomeration – a morphologically and functionally connected urban center with developed infrastructure and significant functional capacities. While it has good transport connectivity, the region faces demographic challenges, particularly population decline and aging. The Niš agglomeration represents a key point within the primary development corridors along the South Morava and Nišava rivers and includes

direct zones of influence with over 500,000 inhabitants. The urban area includes the City of Niš, ten urban-type settlements, eight rural settlements, as well as agricultural and other land areas. In terms of land use, the urban area is predominantly composed of construction land. The main functional structure of the construction land comprises residential zones, work zones, supporting functions, primary infrastructure, primary traffic network, special-purpose areas, and more. Out of the total area of the City of Niš, which is 596.78 km², the urban area occupies 148.33 km². The rural surroundings of the City of Niš encompass 52 cadastral municipalities, with a total area of 448.45 km².

Within the local self-government unit of Niš, the settlement network consists of the urban core of Niš, the secondary center of Niška Banja, four community center settlements, 13 villages with central functions, and 51 primarily rural settlements. The urban core of Niš is surrounded by 17 gravitational settlements, while Niška Banja includes eight more. The community center settlements organize space through a network of suburban and rural areas that differ in their level of functional connection and economic activity.

The urban settlement of Niš is structured into three main zones according to functional and morphological characteristics:

1. The Central Zone is the historical and administrative heart of the city, where residential functions are interwoven with numerous public and commercial services – administration, culture, education, and various services.
2. The Middle Zone has a pronounced working and industrial character, dominated by industrial, manufacturing, warehouse, and trade complexes. It also includes low- to medium-density family housing (up to ground floor + 2 floors + attic), often mixed with small-scale economic activities, and a limited presence of multi-family housing and public facilities.
3. The Peripheral Zone is predominantly residential, with lower housing density (mostly family houses up to ground floor + 1 floor + attic), supplemented by public services, social, cultural, and recreational institutions, as well as small commercial and craft activities that are compatible with housing functions.

Within the territory of the City of Niš, four geothermal springs have been identified, with the most significant source located in Niška Banja. Research carried out at this site has confirmed the presence of exceptionally large reserves of high-temperature geothermal water. These resources hold considerable potential for multiple applications, including spa and wellness tourism, district heating, greenhouse cultivation, and possibly renewable energy production, thereby representing one of the most valuable natural assets of the city. In addition to Niška Banja, which has a long-

standing tradition as a spa tourism center, a number of surrounding rural and suburban settlements have specific tourist functions and potential for further development. These include Banja Topilo, Koritnik, Sićevo, Gornja and Donja Studena, Prosek, Cerje, Vele Polje, Miljkovac, and Sečanica. These places could play an important role in developing a sustainable tourism model in the region, especially in the domains of eco-tourism, cultural, and spa tourism.

Overall, the spatial structure and settlement network in the Niš area reflect a clear functional hierarchy and indicate potential for polycentric development. At the same time, they highlight the need for demographic stabilization, support for rural areas, and improvement of integrated urban governance.

The **economic structure** of Niš encompasses various sectors that contribute to the city’s and region’s development. The main branches include industry, services, trade, agriculture, and transportation. The industrial sector has traditionally been significant, with well-established textile, food processing, machinery, and chemical industries. In recent years, there has been notable growth in information technology and service activities. Trade and services play a vital role in the city’s economy, especially in retail, hospitality, and tourism. Agriculture is present mainly in the suburban and rural areas around Niš, focusing on the production of fruits, vegetables, and cereals. The transportation sector is important due to Niš’s strategic location as a hub for road and rail networks.

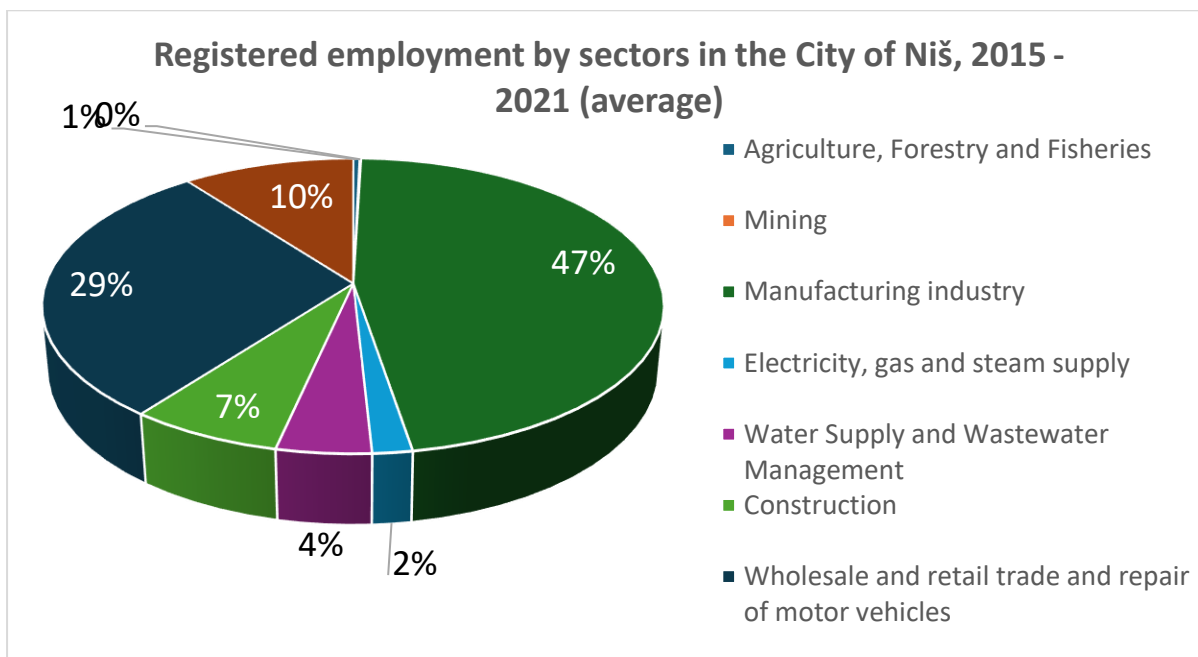


Figure 8. Registered employment by sectors in the City of Niš, 2015 - 2021 (average). Source: Statistical Office of the Republic of Serbia (<https://stat.gov.rs/en-US/>)

Tourism plays an increasingly important role in the economy of Niš. The city’s rich cultural heritage, historical landmarks, and natural attractions draw both domestic and international visitors, contributing to local economic growth. Tourism supports various sectors including hospitality, retail, transportation, and services, creating jobs and stimulating investment.

Tourist arrivals in the Nišava District from 2010 to 2024 show clear phases of decline, growth, disruption, and recovery. After a drop in domestic tourists between 2010 and 2013, numbers steadily increased from 2014, especially among foreign visitors, who more than doubled by 2019, when arrivals peaked at around 140,000. The COVID-19 pandemic caused a sharp decline in 2020, hitting foreign tourists hardest. Recovery began in 2021, led by international visitors, with total arrivals surpassing pre-pandemic levels in 2023 at over 160,000. Domestic tourism recovered more slowly, peaking in 2023 before slightly declining in 2024. Despite this slight drop, the district’s tourism growth over the decade highlights its rising importance, particularly as an international destination.

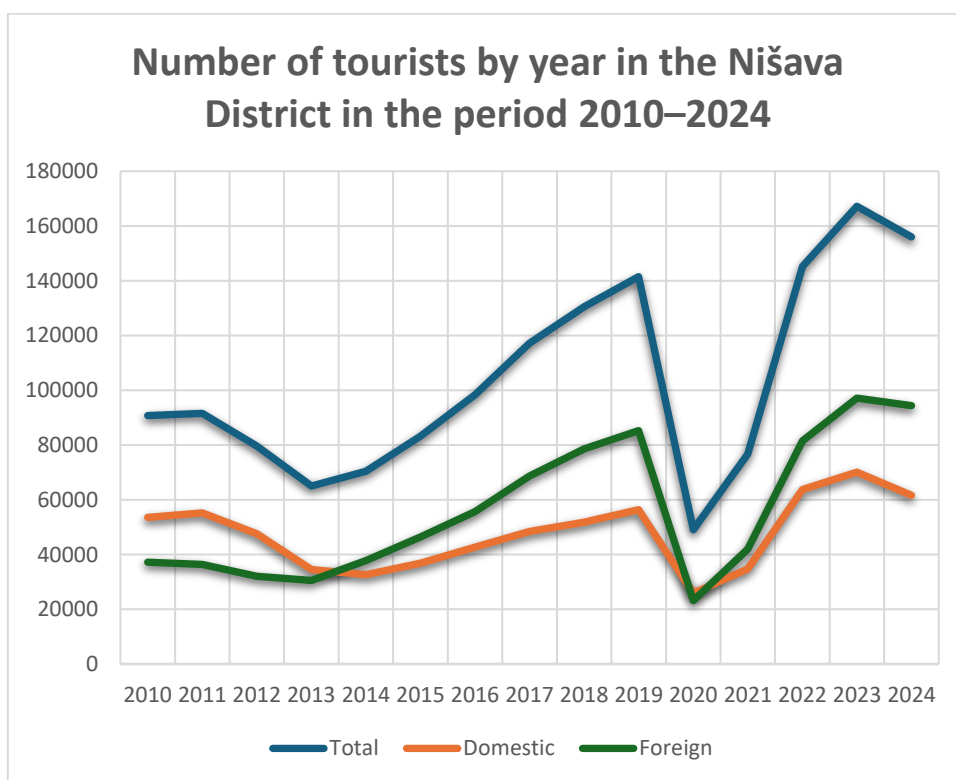


Figure 9. Number of tourists by year in the Nišava District in the period 2010–2024.

The pattern of overnight stays in the Nišava District from 2010 to 2024 reveals a cycle of decline, gradual improvement, and strong growth following the pandemic. From 2010 to 2013, there was a significant drop in overnight stays, especially among domestic tourists, whose numbers fell from over

260,000 to less than 90,000, bringing the total stays below 140,000 in 2013. Starting in 2014, both domestic and international overnight stays began to rise steadily, with foreign stays nearly doubling by 2019. The onset of the COVID-19 pandemic in 2020 caused a sharp decrease in all categories, with foreign stays being the most affected. Recovery started in 2021, accelerating to a record high of more than 360,000 overnight stays in 2023. Domestic stays exceeded 180,000 in 2023 and remained consistent in 2024. Although there was a slight decline in total and foreign stays in 2024, the figures still significantly exceed those from before the pandemic, highlighting the district's strengthened position in the tourism sector.

Tourist accommodation facilities in the City of Niš have experienced steady growth in recent years, reflecting the city's rising profile as a travel destination and an increase in tourism-related investments. While the absence of fully accurate and regularly updated data limits a comprehensive assessment, existing records suggest a notable expansion in capacity. According to the Tourist Organization of Niš, the city currently offers more than 4,000 beds distributed across various types of accommodations, including hotels, apartments, guesthouses, and hostels. Notably, 26 hotels located in the broader city center account for over 2,000 of these beds, highlighting the central area's role as the primary hub for overnight stays.

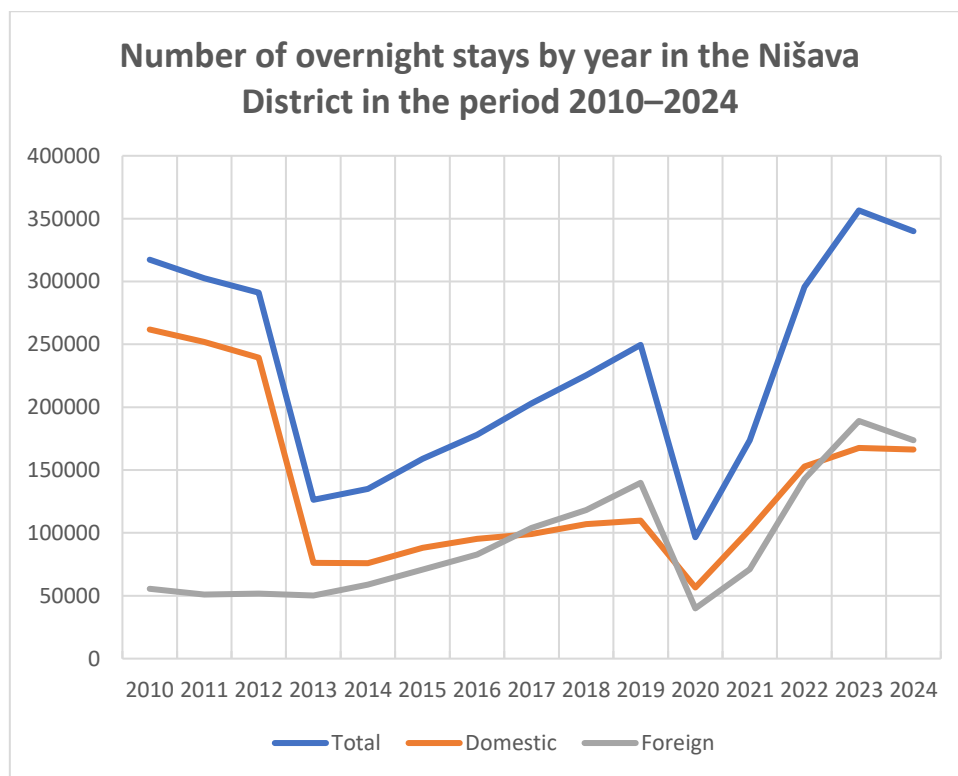


Figure 10. Number of overnight stays by year in the Nišava District in the period 2010–2024.

Tourist demand in the City of Niš has shown a consistent upward trend, marked by growth in the number of visitors, overnight stays, and average length of stay. A significant portion of this demand comes from foreign tourists, whose numbers have increased due to improved international accessibility, including direct flights and enhanced infrastructure. While most international visitors come from neighboring countries and across Europe, the city has also experienced a stable rise in domestic tourism, particularly driven by interest in weekend travel and cultural experiences. Demand is highest during the spring and summer months, yet the growing number of year-round visits suggests an expanding and diversified tourism offer. This includes cultural and historical attractions, health and spa tourism, business and conference events, as well as rural and adventure tourism in the surrounding areas.

The tourism sector in the City of Niš faces several current challenges that need to be addressed to sustain and accelerate growth. Among these challenges are insufficient promotion in certain international markets, which limits the city's visibility and appeal to a broader range of potential visitors. Additionally, tourism in Niš remains heavily seasonal, with demand concentrated mainly in spring and summer months, creating fluctuations that affect local businesses and service providers. There is also a pressing need to enhance the quality of services offered to tourists, ensuring a consistently high standard that meets international expectations. Finally, further development and modernization of tourism infrastructure are essential to support increased visitor numbers and diversify the range of tourism products available.

3 Vulnerability assessment of the target territory

The City of Niš faces escalating climate change impacts that threaten its tourism, cultural heritage, and infrastructure. Rising temperatures, shifting precipitation patterns, and increasing extreme weather events—such as heatwaves, droughts, floods, and wildfires—pose significant risks to the region's natural and human systems. This chapter assesses these vulnerabilities across Niš's urban, suburban, and rural zones, with a focus on tourism and cultural sectors. Drawing on climate data and local studies, it evaluates how these changes affect visitor experiences, heritage preservation, and critical infrastructure, while identifying adaptation measures to enhance resilience.

3.1 The tourism systems

Tourism in Niš is highly sensitive to climate conditions, with climate variability playing a critical role in shaping both the duration and overall quality of the tourist season. Since the majority of tourist demand is concentrated in the spring and summer months,

shifts in temperature and weather patterns have a direct impact on visitor flows and experiences. Warmer temperatures and more frequent heatwaves may initially seem beneficial by potentially extending the peak tourist season. However, these conditions also pose significant health risks, such as heat exhaustion and dehydration, which can diminish visitor comfort and limit outdoor recreational activities that are central to the region's tourism offerings.

From a territorial perspective, the impact of climate variability on tourism differs across the various zones within the Niš region. In the urban core and wider city center, where cultural, historical, and business tourism predominates, heatwaves can reduce visitor comfort during outdoor sightseeing and events, potentially decreasing daytime activity but possibly increasing indoor tourism options such as museums and galleries. Meanwhile, in the suburban and rural areas, including Niška Banja and surrounding spa resorts, the effects of heat and drought are more pronounced. These areas rely heavily on natural amenities like thermal springs and outdoor recreational spaces, where extreme heat can deter visitors and strain water resources critical for wellness tourism. Furthermore, the surrounding mountainous and forested zones, popular for adventure, hiking, and eco-tourism, face added vulnerability; sudden weather changes or prolonged dry spells increase wildfire risks and reduce accessibility, which can restrict tourist movement and raise safety concerns. Additionally, the mountainous and forested zones surrounding Niš, popular for adventure, hiking, and eco-tourism, face heightened vulnerability during heatwaves. Elevated temperatures combined with dry conditions increase the risk of wildfires, which not only threaten the safety of tourists but can also restrict access to these natural areas. Such events can result in temporary closures and long-term damage to the natural environment that forms a core part of Niš's tourism appeal.

Conversely, increasing climate unpredictability—manifested through sudden storms, heavy rainfall, or extended drought periods—can disrupt planned events, damage infrastructure, and reduce the overall attractiveness of key tourist sites. Such erratic weather can discourage tourists from visiting or shorten their stays, affecting local businesses and the economy. Moreover, water scarcity, exacerbated by changing climatic conditions, poses a serious threat to wellness and spa tourism in Niš, which heavily depends on the availability and quality of thermal springs and natural water bodies. Reduced water availability not only limits these health-focused attractions but may also impact general visitor satisfaction.

In the long term, climate change is expected to alter the natural landscapes and biodiversity that contribute significantly to Niš's unique tourism appeal. Changes in vegetation patterns, loss of native species, and increased vulnerability of natural habitats can reduce the attractiveness of outdoor

and nature-based tourism activities. This growing environmental stress highlights the urgent need for comprehensive adaptation strategies, including sustainable resource management, diversification of tourism products, and investment in resilient infrastructure to safeguard Niš's tourism sector against the adverse effects of climate variability and climate change.

3.2 Public infrastructure

The City of Niš has a generally developed basic communal infrastructure; however, despite the presence of systems for water supply, wastewater disposal, electricity, heating, gas distribution, waste collection, and transport, challenges remain in terms of modernization, maintenance, and coverage in certain peripheral or underserved areas. Many of these systems operate with outdated technology and insufficient investment, which can impact service quality, efficiency, and environmental sustainability.

3.2.1 Water supply

Average water daily consumption across the City of Niš hovers around 1,280 L/s, rising to 1,500 L/s in summer months when demand spikes. The City of Niš relies on four territorially distinct but functionally interconnected water supply systems—"Medijana," "Studena," "Ljuberađa-Niš," and "Morava Waterworks". These systems are operated by the public utility company "Naissus," responsible for water supply and wastewater services. The "Medijana" system (operational capacity of approximately 400–550 liters per second (L/s); nearly half of Niš's total water demand during dry-season conditions) sources groundwater that is supplemented by pre-treated surface water from the Nišava River. "Medijana" supplies about 30% of Niš's total water needs. Its role is particularly critical when output from karst sources decreases during dry periods—then "Medijana" helps stabilize the entire system. In contrast, the "Studena" (220–400 L/s), "Ljuberađa-Niš" (150–300 L/s), and "Morava" (800 L/s) systems draw from natural karst springs and include intake structures and transmission pipelines. Currently, around 90% of the city's population has access to safe drinking water (Dinić Branković, 2024). The remaining residents have improved access, meaning they can collect drinking water from public sources such as fountains or wells within a 30-minute round trip. The water supply system in Niš currently meets the basic needs of most of the population. Despite multiple sources (groundwater and karst springs) provide a diversified and relatively resilient water supply, and the existing infrastructure generally meets current demand under normal conditions, demand during peak summer periods may strain capacity, especially in areas with growing populations or tourism. Furthermore, climate variability (e.g., droughts or reduced spring flow) could impact karst sources like "Studena" and "Morava". According to available analyses, the issue

is not the overall capacity of water sources, but rather the uneven distribution, the condition of infrastructure, and inadequate coverage of certain settlements.

However, while the Mediana system is effective in replenishing and extracting groundwater, it does not include a real-time monitoring component. Moreover, There is no indication from available sources that new monitoring wells equipped with automated sensors have been implemented specifically in the recharge zones of Niška Banja or Pantelejš. As a result, the status of the aquifer—particularly trends in water levels and quality—cannot be continuously tracked, leaving a gap in the city’s ability to detect early signs of depletion or stress.

3.2.2 Wastewater collection and discharge.

Wastewater collection and discharge in Niš are managed through an extensive sewer system that stretches approximately 532 kilometers, serving the majority of the city’s population. Most of the urban area is covered by a combined sewer system, which simultaneously carries both sewage and stormwater runoff. This integrated approach, while common in many older cities, presents challenges such as increased risk of system overload during heavy rainfall, potentially leading to untreated discharges into the environment. Recognizing these issues, efforts to develop a separate sewer system—where stormwater and wastewater are conveyed independently—are underway but remain in the early stages of implementation.

The Public Utility Company “Naissus” is responsible for operating and maintaining the sewer infrastructure as well as managing wastewater disposal services. The company ensures that most households within Niš are connected to the public sewer network, providing a centralized system for sanitation. However, a segment of the population, particularly in more remote or less densely populated areas, continues to rely on septic tanks and other on-site sanitation solutions.

Current estimates suggest that approximately 92% of Niš’s residents have access to sanitation services through these systems. Despite this relatively high coverage, the sanitation services cannot be considered safely managed because Niš lacks adequate wastewater treatment facilities. Household wastewater is discharged without any form of treatment. Industrial wastewater is treated only to a limited degree, as existing pre-treatment measures prior to discharge into the sewage network are applied solely in certain sectors, such as the meat industry, fuel stations, and similar activities. Moreover, the majority of the urban area lacks a separate system for the collection of stormwater. As a result, stormwater is released directly into receiving waters without treatment, together with other wastewater streams. Untreated or partially treated wastewater discharged into local waterways poses environmental and public health risks, including contamination of surface and

groundwater sources, eutrophication, and the spread of waterborne diseases. Reduced river flow, increasingly driven by climate change, directly worsens water quality. With less water, rivers lose their natural capacity to dilute and self-purify, so untreated municipal, industrial, and agricultural wastewater has a much stronger impact. Higher water temperatures further reduce oxygen levels, slowing decomposition and harming aquatic life. In the City of Niš, this problem is especially visible because most wastewater is still discharged untreated into the Nišava River. During dry periods, when flows are low, downstream villages regularly face foul odors and degraded water quality. Until the planned wastewater treatment plant is completed, expected around 2026, climate-driven reductions in river flow will continue to amplify both ecological and public health risks in Niš and its surroundings.

Urban flooding in Niš has become a significant and recurring problem, especially during periods of intense and prolonged rainfall. These floods occur when the city's drainage and sewer infrastructure lack the capacity to quickly absorb and redirect large volumes of surface and wastewater. As a result, water accumulates on streets, in low-lying urban zones, and even within buildings, causing damage and disrupting daily life.

Certain areas in Niš are particularly vulnerable during extreme rainfall events, and this vulnerability is linked to several underlying issues:

- Outdated and undersized sewer infrastructure – in older parts of the city, the sewer system was not designed to accommodate heavy rainfall, leading to frequent overflows and water retention.
- Low-lying areas and natural depressions – neighborhoods located in valleys or terrain depressions are more prone to flooding, as surface water naturally accumulates there, overwhelming the local sewer capacity.
- Blocked storm drains and street grates – when drainage openings are clogged with debris or poorly maintained, they become critical points of water buildup, significantly increasing the risk of flooding.
- Sewer overflows near rivers and streams – during heavy rains, rising water levels in nearby rivers can put pressure on the sewer system, making it harder to discharge wastewater and exacerbating flood risks.

The risk of urban flooding is particularly high in the city center due to high population density, a large percentage of impermeable surfaces, and outdated infrastructure. Water frequently accumulates at intersections such as Bulevar Nemanjića and King Milan Square (Trg Kralja Milana). Part of the Delijski Vis neighbourhood, located in a depression, often experiences difficulties in draining stormwater during heavy rains. The Trošarina neighbourhood also faces drainage problems due to an outdated sewer

network and uneven terrain that hinders the natural flow of water. Donja Vrežina is prone to flooding as well, primarily due to insufficient wastewater drainage capacity. Finally, the stormwater drainage system in the industrial zones in the southeastern part of the city is often overloaded, due to the large surface area and high intensity of industrial activity.

3.2.3 District heating

District heating is a key component of Niš's urban energy infrastructure, providing reliable and centralized heating services to a significant portion of the city's population and businesses. Managed by the Public Utility Company "Gradska toplana", the system produces thermal energy primarily through combined heat and power (CHP) plants and boilers fueled by natural gas and other energy sources. The distribution network consists of approximately 72 kilometers of insulated heat pipelines, delivering hot water or steam from production facilities to end-users. The network is supported by 1,055 heat substations, which regulate and distribute heat to individual buildings, ensuring efficient and controlled delivery tailored to consumption needs. Currently, district heating serves around 30,000 residential units and over 2,100 commercial and public sector customers, including schools, hospitals, and government buildings. The system is concentrated mainly in the central urban areas, particularly on the left bank of the Nišava River, where population density and demand for heating are highest.

The district heating system in Niš is moderately vulnerable to climate change impacts, primarily through shifts in heating demand, water resource availability, and infrastructure risks. Climate change is expected to bring milder winters and hotter summers to the Niš region. This shift may reduce overall heating demand during winter months, potentially decreasing the utilization rates of the district heating system. While this could lower fuel consumption and emissions, it might also affect the economic viability of the system by reducing revenues and creating challenges in maintaining efficient operation at lower loads. Conversely, increased temperature extremes could lead to more frequent rapid shifts between heating and cooling demands, stressing system flexibility.

District heating relies on water as a medium to transfer thermal energy. Climate change-induced droughts and reduced precipitation could limit water availability, impacting the operation of heat generation plants and the cooling processes required in combined heat and power (CHP) facilities. Scarcity of water resources may force the utility to seek alternative cooling technologies or sources, potentially increasing operational costs.

Rising temperatures, increased frequency of heatwaves, and extreme weather events (storms, floods) can physically stress district

heating infrastructure. Pipelines, substations, and related equipment may face higher risks of damage or failure due to thermal expansion, flooding, or erosion. Moreover, extreme weather could disrupt supply chains for fuel or maintenance, leading to service interruptions.

Niš's district heating system currently depends heavily on natural gas and possibly other fossil fuels. Climate change-related geopolitical tensions or supply disruptions could affect fuel availability and prices. Additionally, transitioning to low-carbon energy sources may require significant investments and adaptation, posing both a challenge and an opportunity.

3.2.4 Power generation and distribution

The City of Niš does not rely on large power plants within its own territory but instead functions as an important distribution hub in southern Serbia. Electricity consumed in Niš primarily comes from the national grid, supplied by EPS through thermal plants in Kolubara and Kostolac, hydroelectric plants on major rivers, and an increasing share of renewables. Within the city, electricity is distributed through a network of substations, the most significant being the 110/35 kV transmission substation "Niš 2," which connects Niš to the wider Serbian grid. From there, medium- and low-voltage substations ensure supply to residential neighborhoods, commercial zones, and industrial areas across Medijana, Palilula, Crveni Krst, Panteleji, and Niška Banja.

Local power generation remains limited. Rooftop solar installations are slowly expanding, with households, businesses, and public institutions beginning to install small systems supported by government incentives. Peri-urban areas around Niš have been identified as promising for larger solar farms, though most projects are still in planning or early development. Biomass and natural gas are primarily used in the district heating system (Toplana Niš), which covers much of the urban core but currently produces only heat, not electricity.

The city faces persistent challenges. Parts of the distribution network are outdated, leading to occasional outages during peak consumption in both winter and summer. Technical and non-technical losses in distribution remain higher than in many European cities, highlighting the need for modernization. Climate change further increases vulnerability: rising summer temperatures drive higher electricity consumption for cooling, placing heavy strain on the city's substations and distribution network. At the same time, extreme weather events such as storms, strong winds, and heatwaves increase the risk of outages by damaging lines and overloading transformers. Seasonal droughts, while less directly tied to electricity supply, have indirect effects as they reduce water availability for hydropower across Serbia, thereby increasing reliance on thermal generation and

imports — all of which can raise vulnerability for cities like Niš. Niš's energy system remains dependent on distant thermal and hydroelectric plants, meaning that local resilience depends less on large-scale generation and more on the flexibility and stability of its distribution grid. However, parts of the medium- and low-voltage network are outdated, which reduces the system's ability to respond to climate-driven stresses.

3.2.5 Traffic

The road network in Niš is comprised of approximately 9% main highways (state first-class roads), 23% regional roads (state second-class), and 68% local municipal roads. In the urban core, major city streets are directly linked to highways and first-class roads, facilitating efficient connectivity. To alleviate congestion, a traffic ring road encircles the city center, helping to divert heavy and transit traffic away from the busiest urban areas.

In suburban and rural parts of Niš, the municipal road network connects all settlements internally and links them with regional routes and the city center, supporting both local mobility and access to broader transport corridors. However, some local roads may face maintenance challenges and varying traffic loads depending on the area.

Public transportation in Niš relies solely on a comprehensive bus system that serves urban, suburban, and rural zones. Urban bus lines primarily follow main city streets, while suburban routes connect outlying settlements via local and state roads to the central urban area. The system achieves high coverage, with approximately 91.8% of the population living within walking distance of a public transport stop, ensuring broad accessibility even in less densely populated areas.

Despite this extensive network, Niš experiences typical urban traffic issues such as congestion during peak hours in the city center and on major connecting roads, limited road capacity in some neighbourhoods, and challenges in integrating different transport modes.

The traffic system and road network in Niš face growing challenges as climate change intensifies, making the city increasingly vulnerable to a range of environmental stresses. Prolonged periods of extreme heat can weaken road surfaces, causing asphalt to soften and crack, which shortens the lifespan of the pavement and increases maintenance costs. These high temperatures also affect vehicle reliability, potentially leading to more breakdowns and traffic disruptions.

As mentioned, urban flooding remains a significant issue in Niš, where drainage systems can be overwhelmed during intense storms. This often results in water accumulation on roads, particularly in low-lying areas, hindering accessibility and emergency response. Such events highlight the need for improved stormwater management to protect the road network and ensure continuous mobility. From a

territorial perspective, the impacts of climate change on traffic and road infrastructure vary across Niš's urban, suburban, and rural zones. In the urban core, where traffic density is highest, flooding and storm damage can cause significant congestion and disrupt daily commutes, affecting a large number of residents and businesses. Narrow streets and older infrastructure in some neighborhoods exacerbate vulnerability to extreme weather, making traffic management more complex during emergencies. In the suburban areas, especially those connected by municipal and regional roads, flood-prone zones and inadequate drainage can isolate communities during heavy rains, restricting access to the city center and essential services. Roads in these areas may also be less resilient to heat-related damage due to lower maintenance levels, increasing the risk of degradation. The rural outskirts of Niš face particular challenges with road accessibility during extreme weather events. Limited alternative routes and less frequent maintenance can mean that flooding or road damage effectively cuts off some villages, impacting mobility for residents and emergency services alike. Additionally, these areas may lack sufficient public transport options, making reliable road access even more critical.

Many of the city's roads, especially local and regional ones, were not originally designed to cope with these new climate pressures. Aging infrastructure combined with increased traffic volumes leaves the network vulnerable to faster deterioration and failure if proactive adaptation is not undertaken. Public transport, which relies entirely on the road system, is also affected by these disruptions, potentially reducing service reliability and limiting access for residents, especially those without private vehicles.

Beyond the physical impacts, these challenges carry broader socioeconomic consequences. Traffic delays and road closures caused by climate-related events can lead to lost productivity, higher transport costs, and diminished appeal for business and tourism. Residents' dependent on consistent road access may find it harder to reach jobs, schools, and healthcare, amplifying social inequalities.

These climate-related disruptions have wider implications for Niš tourism sector. Traffic delays, road closures, and poor transport reliability can diminish the visitor experience, reduce repeat visits, and impact the economic benefits derived from tourism. Vulnerable transportation infrastructure in key tourist areas may also limit the city's ability to host events or expand tourism offerings.

3.2.6 Protection against the harmful effects of surface water

The most prominent water-related hazard in Niš is flooding, primarily caused by intense rainfall events, rapid snowmelt, and rising river levels, especially along the Nišava River and its tributaries. Urban expansion and changes in land use have increased surface runoff and reduced natural water absorption,

exacerbating flood risks. Floods can inundate residential areas, disrupt transport and utilities, damage public and private property, and pose health hazards.

Catastrophic floods in the territory of the City of Niš were recorded in 1897, 1926, and 1948, with the latter being the most severe. Although Niš was also affected by the major floods that struck Serbia in 2014, the scale of the event in Niš was not as extensive as in other parts of the country.

Areas at risk of flooding have been identified in the Master Plan of Niš 2010-2025 (Urban Planning Institute of Niš, 2011). Flood-prone areas are situated along first-order watercourses (Nišava, Južna Morava, and Toponička reka), as well as along small urban watercourses (second-order watercourses), which, due to their torrential nature and sudden surges in water volume, significantly contribute to flooding events. Nišava, the main watercourse passing through the central urban area, is particularly vulnerable near Duvanište, Trošarina, Pantelej, Donji Komren, and Crveni Krst due to urbanization, insufficient channel capacity, and stormwater inflow. It is subject to frequent flood management and riverbank protection projects. Južna Morava borders the northern and western outskirts of the Niš territory (villages Hum, Donji Komren, and Pasi Poljana). Broad floodplains are especially vulnerable during snowmelt or heavy rains, and risk increased by overflow from tributaries and backwater effects during high flows. Toponička reka, a right tributary of the Nišava, near the western part of the city, flows through rural and peri-urban zones, and is characterised by increased flash flood risk during intense rainfall. Moreover, there is lack of retention and insufficient drainage infrastructure in surrounding areas.

Flood defense measures for second-order watercourses in the territory of the City of Niš are planned for the following streams and rivers: Gabrovačka Reka (upstream from the railway line), Suvodolski Potok, Kovanlučki Potok, Jelašnička Reka (also known as Studena), Kunovička Reka, Malčanska Reka, Matejevačka Reka with the Brenička Reka, Rujnička Reka (after the confluence of Rujnički and Hum Potoks), Hum Potok, Rujnički Potok, and Mramorski Potok.

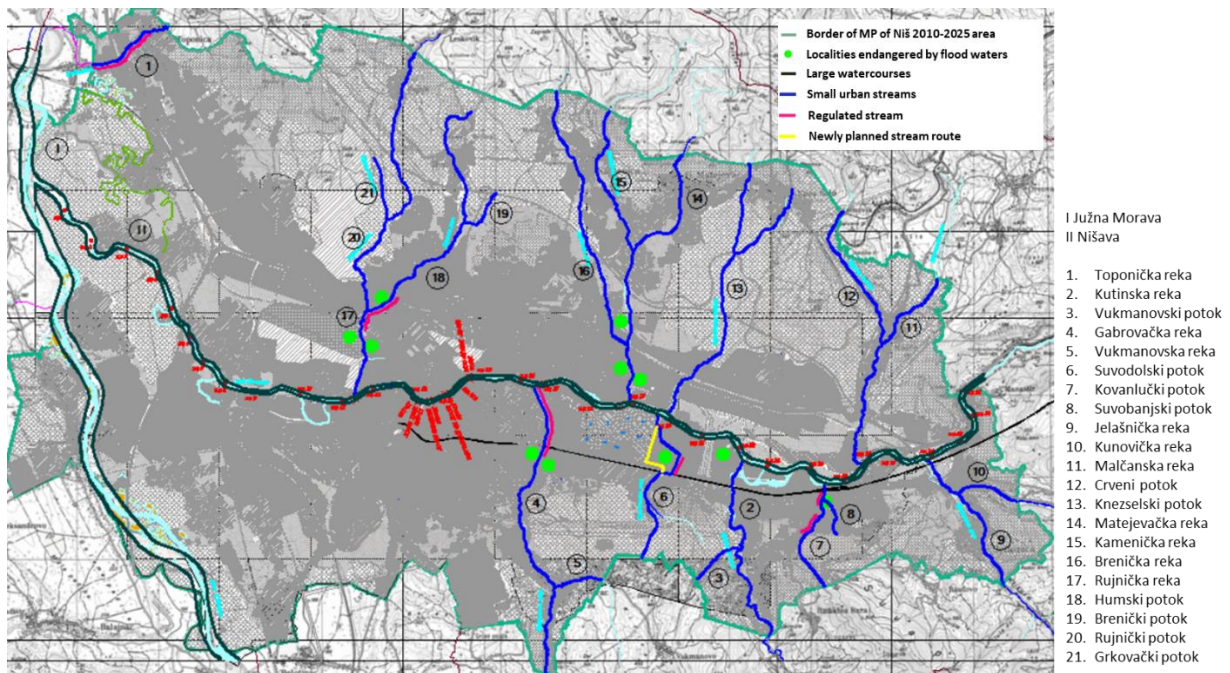


Figure 11. Watercourses in the City of Niš territory. Source: Dinić Branković, 2020.

In order to mitigate the harmful impacts of high-water levels and protect riverbanks from flooding, a significant portion of watercourses within the territory of the City of Niš has been regulated through hydraulic and structural interventions. Nevertheless, certain stretches remain unregulated, affecting both primary (first-order) and secondary (second-order) water bodies. These unregulated sections continue to pose a risk to nearby settlements, infrastructure, and agricultural land, especially during periods of intense rainfall or rapid snowmelt. Gabrovačka reka, a torrential stream running through central part of Niš, has historically posed a flood risk, especially when high flows coincide with the Nišava River. Although the riverbed was regulated in 2010 along a 1,660-meter section up to the railway, the upstream part remains unregulated. Limited channel capacity leads to frequent flooding, particularly between the railway and the village of Gabrovac. Suvodolski potok, especially in its lower course through Brzi Brod neighborhood, lacks a clearly defined channel, leading to frequent flooding of nearby homes after rainfall or snowmelt. Urban expansion increases the need for stream regulation. A key issue is the culvert on Bulevar Cara Konstantina Street, which obstructs flow even during moderate water levels, causing upstream sediment buildup and reducing channel capacity.

There is no data available for pluvial floods in the City of Niš, generated from extreme rainfall events, independent of an overflowing water body. However, according the City Scans from the World Bank's City Resilience Program (CRP), 60 percent of police stations, 37 percent of schools, 64 percent of hospitals and 24 percent of major roads

are located in a river flood risk zone with a minimum depth of 15cm. Niš faces growing exposure to pluvial floods as intense short-duration rainfall increasingly exceeds the capacity of its urban drainage infrastructure. The predominance of impermeable surfaces such as asphalt and concrete limits natural infiltration and accelerates surface runoff. This challenge is compounded by the lack of a dedicated stormwater collection system across most of the city, where stormwater is directed into the combined sewer network along with household and industrial wastewater. During heavy precipitation, the system frequently becomes overloaded, resulting in localized flooding, particularly in low-lying urban areas.

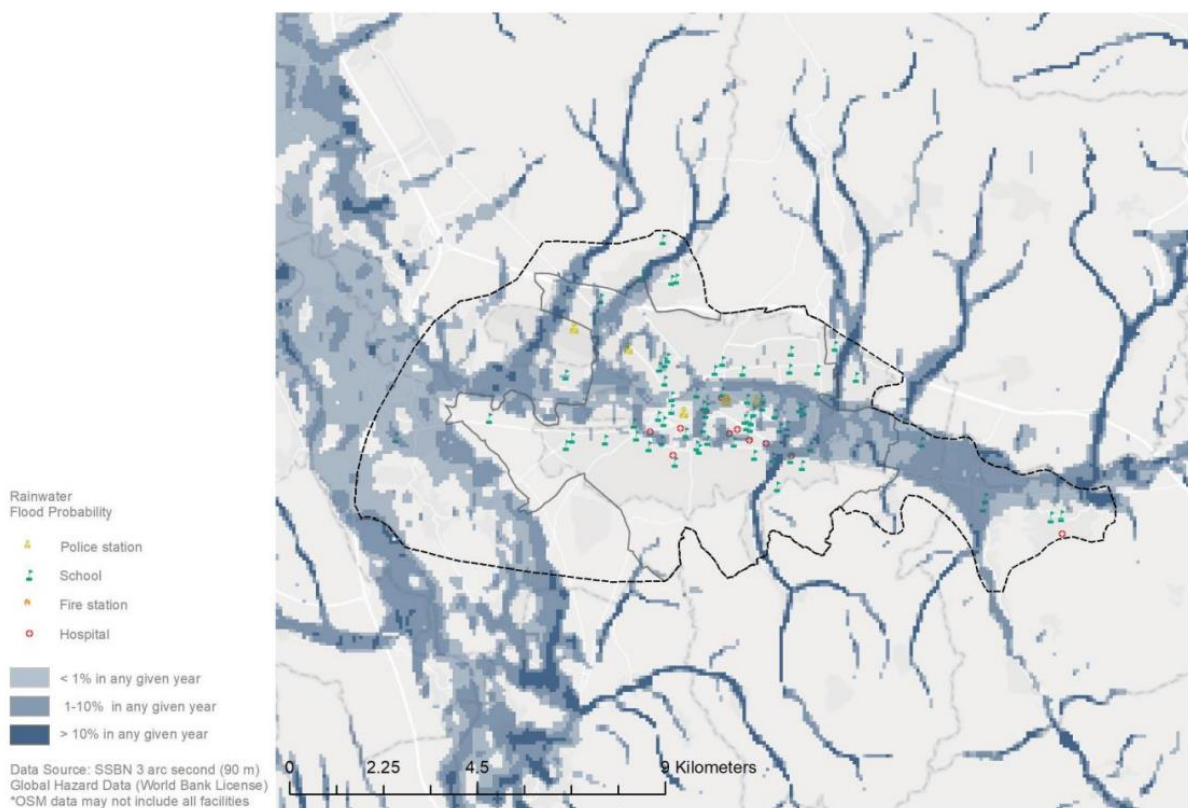


Figure 12. Assets potentially exposed to pluvial flood risk in Niš. Source: World Bank, 2023.

3.2.7 Erosion

The City of Niš is generally classified as an area with a low risk of soil erosion. The estimated average annual soil loss across its territory is approximately 8.48 tons per hectare per year, indicating relatively limited degradation under current land use and climatic conditions. A significant portion of the municipality—around 78.20%—is affected by very weak to weak erosion (Perović, et al, 2016), which typically results in minimal soil displacement and poses little threat to land productivity or ecosystem stability. These areas are often characterized by favorable topography, sufficient

vegetation cover, or sustainable land management practices that help minimize erosion. In contrast, zones experiencing moderate to very high erosion intensity occupy an estimated 130.08 square kilometers (Perović, et al, 2016), which corresponds to roughly 21.80% of the city's total area. The highest erosion intensity is recorded in the Niška Banja area, where the average annual soil loss reaches 12.30 t/ha/year. This elevated rate corresponds to the steep terrain that characterizes the region, making it particularly vulnerable to surface runoff and soil displacement. In contrast, the lowest erosion levels are found in Medijana, the municipality's most urbanized and densely populated area, where the average annual soil loss is estimated at just 1.12 t/ha/year. These findings align with the land use patterns and topographical features of each area (Perović et al., 2016). These more severely affected territories may include sloped agricultural lands, deforested zones, or areas with sparse vegetation cover where erosive forces such as rainfall and surface runoff have a more pronounced impact. Erosion is seasonally intensified during periods of heavy rainfall, particularly in spring and autumn.

Based on the Decision on Erosive Areas and Anti-Erosion Measures adopted by the Assembly of the City of Niš, all types of erosion in the territory of the City of Niš are classified into eight categories, as follows (City of Niš, 2021a):

- CATEGORY I – Sediment accumulation in alluvial plains: Includes land on flat terrain with slopes from 0° to 2°, in the valley of the South Morava River, around Gornje and Donje Međurovo, Popovac, Lalinec, Trupale, Vrelo, Mezgraja, Donja Toponica, and Donja Trnava; also in the valley of the Nišava River from Niš to Brzi Brod, that is, Niška Banja, and from Niš along both the left and right banks of the Nišava River to its confluence with the South Morava.
- CATEGORY II – Very slight surface erosion: Covers land with slopes from 2° to 5°, between Kravlje and Paligrace, upstream from Kravlje from Gornja Toponica to Čamurlija, from Donja Vrežina to Malča and around Malča, above Ravni Do, and between Donji Vlas and Gabrovac.
- CATEGORY III – Slight surface erosion: Includes areas with slopes from 5° to 7°, in Jasenovik, larger areas between Gornji Matejevac and Gornja Vrežina, around Pasi Poljana, from Čamurlija to Gornja Toponica, and from Gornja Trnava and Vele Polje to Paligrace.
- CATEGORY IV – Moderate erosion: Covers land with slopes from 7° to 10°, between Paligrace and Vele Polje, Vele Polje and Miljkovac, around Cerje, above Leskovik, around Rujnik, Čamurlija, Hum, Kamenica, Donji Matejevac, between Sićevo, Malča, Gornja Vrežina, and around Gabrovac.
- CATEGORY V – Moderately severe erosion: Covers hilly terrain with slopes from 10° to 15°, around Sečanica, Supovac, Vele Polje, Cerje, Leskovik, Kravlje,

Kamenica, Pasi Poljana, between Gabrovac and Donji Vlas, near Jelašnica and Sićevo, Mramor, Mramorski Potok, and Krušac.

- CATEGORY VI – Severe erosion: Covers areas with slopes from 15° to 20°, between Gabrovac, Vukmanovo, and Prva Kutina, near Jelašnica, Prosek, Sićevo, Ostrovica, Ravni Do, Vrelo, Brenica, Leskovik, Cerje, and Paljina.
- CATEGORY VII – Very severe erosion: Covers areas with slopes greater than 20°, occurring on the slopes of steeper streams near Ravni Do, Ostrovica, Pasjača, Vrelo, Brenica, and Hum.
- CATEGORY VIII – Excessive erosion: Covers a small area with slopes greater than 30°, between Pasjača and Jasenovik.

One of the most critical zones is found along the southern slopes of Suva Planina, where steep gradients, shallow soils, and sparse vegetation create ideal conditions for intense surface runoff. Villages such as Donja and Gornja Studena, Jelašnica, and Vrežina are particularly exposed. In these areas, historical deforestation and overexploitation of natural resources have led to the weakening of natural barriers that would otherwise prevent soil erosion. During periods of intense rainfall—especially in spring and autumn—these slopes become highly active in terms of erosive processes, often resulting in the formation of gullies and landslides.

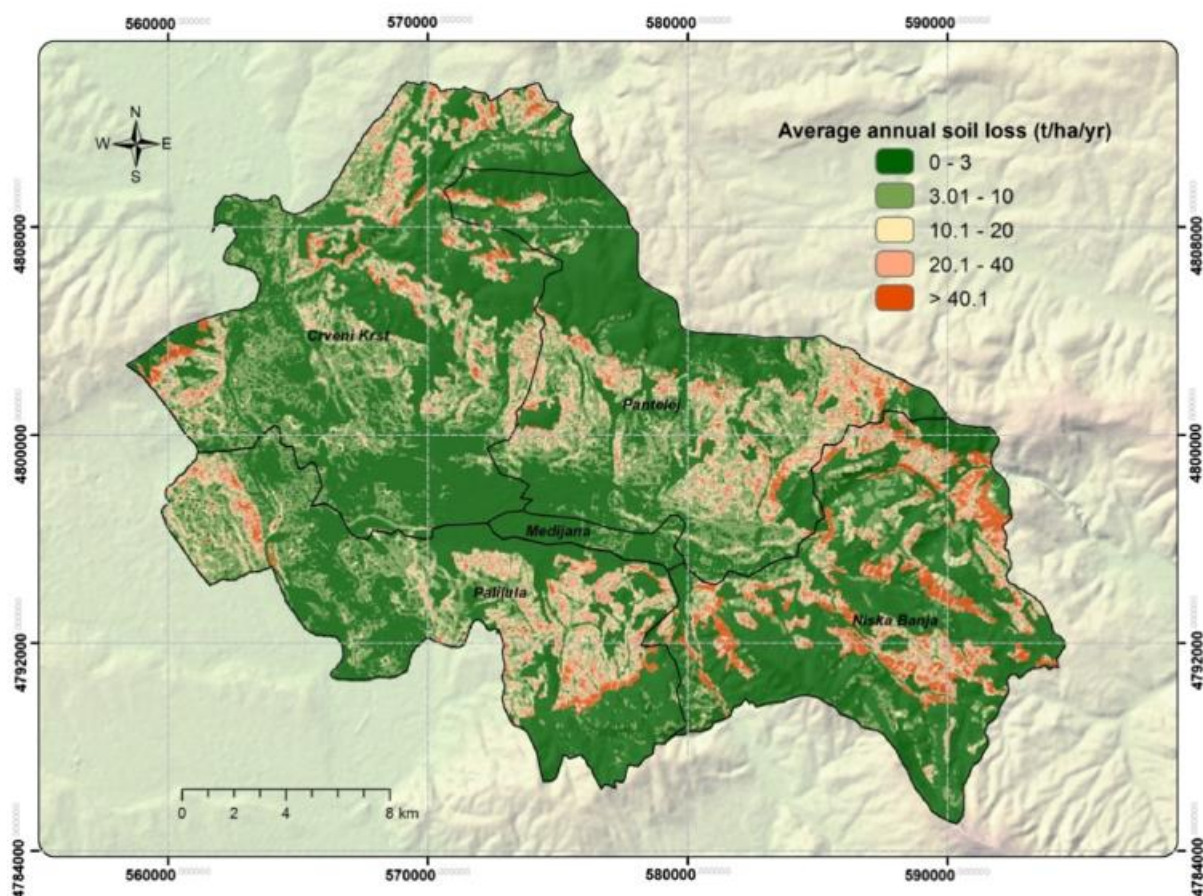


Figure 13. The spatial distribution of the potential average annual soil loss by water erosion (t/ha/year) in the City of Niš. Source: Perović, et al., 2016.

Another area with notable erosion issues is Niška Banja and its surroundings. Although this area is best known for its spa tourism, it also faces considerable environmental challenges. The combination of rugged terrain and increased construction activity, often without proper land stabilization, has led to localized but severe erosion. Heavy rains frequently result in flash runoff, damaging infrastructure and contributing to sedimentation in downstream watercourses.

In the eastern and southeastern rural parts of the municipality—such as Bubanj, Kamenica, Hum, and the Matejevac villages—erosion is driven largely by unsustainable agricultural practices. Cropland is often cultivated on sloped terrain without the use of terraces, buffer strips, or vegetation cover. This leaves the soil exposed to direct impact from rainfall, leading to both sheet and gully erosion. In these zones, erosion not only reduces soil fertility but also poses risks to rural roads and water supply systems. Additionally, the peri-urban zones around neighbourhoods like Brzi Brod, Pasi Poljana, Duvanište, and Čalije are facing increasing erosion risks due to unregulated urban sprawl. In many of these areas, construction has outpaced the development of

stormwater infrastructure. As a result, intense rainfall events lead to uncontrolled runoff, which quickly erodes exposed soil and damages roads, sidewalks, and foundations of newly built homes.

3.2.8 Landslides

Landslides and slope instability remain a significant geological hazard for the City of Niš, particularly in hilly and peri-urban zones where steep gradients, unstable soil structures, and human activity converge. While the central Nišava River valley is relatively flat, large sections of the city's administrative territory extend into geologically sensitive slopes prone to movement during periods of intense rainfall, rapid snowmelt, or seismic activity. Climate change is expected to exacerbate these triggers, making the prevention and mitigation of slope hazards a growing priority. Landslides have been identified in several areas within the City of Niš. Significant landslide activity has been recorded along the corridor between the rural settlements of Mramor and Krušće, within parts of the Palilula City Municipality, in Niška Banja, as well as in the suburban and rural settlements of Gabrovac, Prva Kutina, Matejevac, and Prosek. The landslide between Mramor and Krušće was first documented in 1987 and has since reactivated multiple times, with major events occurring in 2005, 2008, 2010, and 2016. These landslides have caused damage to approximately 90 residential and commercial buildings. Furthermore, the landslide has repeatedly caused disruptions, including obstructing traffic along the important Niš–Merošina highway. In Niška Banja, landslides tend to be small to medium in size but are widespread, appearing in various locations throughout the area. Their activation often coincides with periods of heavy rainfall or rapid snowmelt, contributing to their recurring nature.

3.3 The agricultural systems, rural and agritourism

Agriculture in the City of Niš plays a significant role in the local economy, particularly in its suburban and rural settlements, which make up the majority of the city's territory outside the urban core. Although Niš is an urban and administrative center of southeastern Serbia, it still has a substantial agricultural base due to its fertile soils, favorable climate, and position in the Nišava and Južna Morava valleys.

The central part of the territory, stretching along the Nišava and Južna Morava River valleys, is characterized by flat and highly fertile alluvial plains. These lowland zones are the heart of agricultural production, hosting the majority of arable fields used for cereals, vegetables, and industrial crops. Settlements in these areas often have fields extending right up to the village boundaries, with a patchwork of small, privately owned plots that have been cultivated for generations. Moving north and south from the river valleys, the terrain transitions into hilly and mountainous landscapes, including the slopes of Suva Planina, Svrljig Mountains, and Jastrebac. These upland areas are less

suitable for intensive crop farming but are valuable for pastures, orchards, vineyards, and forestry. Many of the hillside plots are planted with plums, apples, or grapes, while the higher elevations remain covered in mixed forests that contribute to local biodiversity and serve as a buffer against soil erosion.

The urban and industrial zones of Niš, while compact relative to the total municipal area, exert growing pressure on surrounding farmland. In recent decades, parts of the fertile valley floor have been converted for residential neighborhoods, road corridors, and economic zones, leading to the gradual loss of productive soil. This trend is most visible along major transport routes and in the immediate periphery of the city.

Scattered throughout the rural zones are small watercourses and irrigation channels, some of which are in need of maintenance. These hydrological features, combined with the mix of fertile plains and surrounding uplands, give Niš a diversified land-use pattern that integrates intensive agriculture, traditional smallholder farming, forestry, and expanding urban infrastructure within a relatively compact geographic area.

Agricultural activity in the City of Niš is concentrated across an available agricultural land area of approximately 37,841 hectares (Dinić Branković, 2024). Of this, utilized agricultural land—meaning land actively farmed—is around 13,815 ha, representing 51.85 % of the available agricultural land. The remaining 12.37 % is unutilized farmland, reflecting challenges such as fragmentation and insufficient productivity (Dinić Branković, 2024). Within agricultural land ownership, private holdings dominate—about 31,710 ha are privately owned, while 4,055 ha belong to public or state entities (of which 1,151 ha are arable, gardens, orchards, vineyards, or meadows; and 2,904 ha fall under other land categories like pastures or non-cultivated areas). Farms tend to be small—there are 7,113 agricultural holdings, most of which are family-run and focused on subsistence or small-scale production. The average farm size is just 3.2 ha, well below the regional average of 4.3 ha and Serbia's national average of 6.1 ha, and only 44 farms (0.5 %) have more than 10 ha.

Although crop production dominates the agricultural profile of Niš, livestock farming remains an important complementary activity, particularly in rural and hilly areas where soil and terrain conditions are less suitable for intensive cultivation. Most livestock production is carried out by small family farms, often for mixed purposes — part for household consumption and part for sale in local markets. Livestock farming in Niš is still largely extensive or semi-intensive, relying on traditional feeding practices and open grazing where possible. Pastures in upland areas, especially in the north and south of the city, provide seasonal forage, while lowland farms often grow fodder crops (such as maize silage) alongside their cereals. Livestock farming in Niš is constrained by small herd sizes, an aging farmer population, and low interest from younger

generations. Market volatility in feed and meat prices reduces profitability, while animal disease risks are heightened by uneven veterinary services in remote areas, keeping the sector largely traditional and small-scale. Despite these constraints, livestock production is closely tied to the cultural identity of Niš's rural communities. Traditional products such as "svinjska pršuta" (pork prosciutto), "lamb roasted on the spit", and various cheeses remain strong symbols of local gastronomy and are often key attractions for rural tourism.

Rural tourism in the City of Niš is a growing but still underdeveloped sector that builds on the area's rich natural landscapes, cultural heritage, and strong traditions in food and hospitality. While the city itself serves as a transport and cultural hub of southeastern Serbia, its surrounding rural settlements offer visitors a slower pace, authentic experiences, and direct contact with the local way of life.

The hilly and mountainous zones to the south and north — including the slopes of Suva Planina, Svrlijske Planine, and Jastrebac — provide scenic settings for hiking, cycling, and nature observation. Villages in these areas often combine agriculture with tourism, offering farm stays, home-cooked meals, and participation in seasonal activities such as fruit picking or traditional food preparation.

A key draw for rural tourism is Niška Banja, a spa town within the city's administrative boundaries. Known for its thermal mineral springs and therapeutic climate, it attracts visitors for both health tourism and as a base for exploring nearby mountain trails. Smaller villages like Jelašnica and Sićevo have also developed modest tourism offerings, benefiting from their proximity to the Jelašnica Gorge and Sićevo Gorge, both natural monuments known for climbing, rafting, and biodiversity.

Gastronomy is a central component of the rural tourism experience. Guests are often served local specialties such as lamb roasted on the spit, homemade cheeses, plum rakija, and ajvar, much of it prepared from ingredients grown on-site. Culinary tourism is increasingly linked to cultural events and village fairs, where visitors can experience folk music, dance, and traditional crafts.

Despite these assets, the sector faces limitations. Accommodation capacity in villages is still low, marketing is fragmented, and there is a lack of structured tourist routes that connect rural attractions into cohesive experiences. Infrastructure, particularly road access to more remote hamlets, remains uneven. However, there is clear potential for growth through eco-tourism, agro-tourism, and adventure tourism, especially if supported by investment in infrastructure, promotion, and training for local hosts.

Agritourism is still a small but growing segment in Niš's overall tourism landscape. Currently, there are approximately 15 to 20 registered rural households and farms

offering some form of agritourism accommodation and experiences within the city's administrative area, mostly concentrated in Niška Banja, Gadžin Han, and Doljevac municipalities (Tourist Organization of Niš, 2023).

Most agritourism providers operate small guesthouses or family-run farms with 5 to 15 beds available, reflecting a limited but intimate hospitality capacity. These accommodations often include traditional rural architecture, with local meals prepared from farm-grown products such as plums, apples, vegetables, and homemade cheeses.

Agritourism farms frequently integrate seasonal activities that engage visitors directly in agricultural work (fruit picking: in spring and summer, farms host tourists for plum, apple, and cherry harvesting, with about 30-40% of agritourism visitors participating in these experiences; vineyard tours and grape harvesting: small vineyards in the southern outskirts welcome visitors during the September harvest season; livestock care and shepherding: some farms with sheep and cattle invite guests to assist with feeding and herding, enhancing the authenticity of the stay).

Economic data indicate that agritourism contributes modestly but importantly to rural incomes. On average, participating households report that agritourism accounts for 15-25% of their annual revenue, supplementing farming activities (Regional Rural Development Report, 2022). Surveys show that visitor numbers to agritourism farms in Niš increased by approximately 10% annually over the last 3 years, reflecting rising demand for authentic rural experiences and eco-friendly tourism. The potential for expansion is high, especially with coordinated support from local authorities and tourism organizations.

The impacts of climate change on rural tourism and agritourism in the City of Niš are becoming increasingly significant, affecting both the natural environment that attracts visitors and the agricultural activities that form the core of agritourism experiences. Rising average temperatures and more frequent heatwaves can reduce the comfort of visitors, especially during summer months when rural tourism typically peaks. This may lead to shorter stays or avoidance of outdoor activities like hiking in mountainous areas such as Suva Planina and Jastrebac. More frequent heavy rains, floods, and storms can damage infrastructure such as rural roads, hiking trails, and visitor facilities. Flooding in valleys like Nišava and South Morava can disrupt access to natural attractions and rural settlements, reducing tourism accessibility. Climate change may alter the local flora and fauna, impacting the natural beauty and biodiversity that attract nature-based tourists. For example, some native plant species could decline, and invasive species might increase, changing the character of protected areas like Jelašnica and Sićevo Gorges.

Changes in precipitation patterns and temperature extremes can reduce crop yields (fruits, vegetables, cereals) and affect livestock health. Droughts or irregular rainfall threaten orchard productivity and grape harvests, directly impacting the seasonal activities central to agritourism. Altered growing seasons may disrupt traditional agricultural calendars, affecting the timing of harvest festivals and agritourism events that depend on predictable crop cycles. Reduced water availability during dry periods can challenge irrigation and animal watering, forcing farms to adapt or reduce production, which in turn limits the quality and authenticity of agritourism experiences. Warmer temperatures may increase the prevalence of crop pests and animal diseases, raising production costs and complicating farm management for agritourism hosts.

4 Imminent and long-term risks of climate change impact

Niš is increasingly vulnerable to imminent impacts such as flash floods, heatwaves, and seasonal droughts that affect health, water supply, and urban safety. In the long term, rising temperatures, more extreme rainfall, and prolonged dry periods are expected to intensify these hazards, strain natural resources, and disrupt economic and social life across the city.

4.1 Imminent risks

In recent decades, the City of Niš and its surrounding district have experienced a marked increase in extreme heat events, signaling urgent climate change impacts. Climate in Niš that is growing hotter and more extreme, with longer and more intense heatwaves affecting daily life. Over the past two decades, the Nišava district, including the city of Niš, has experienced a significant rise in ground-level temperatures. Between 2001 and 2020, the average daily temperature increased by approximately 1.42°C compared to the mid-20th century baseline (1961–1990), with an even steeper rise of 1.72°C recorded in the more recent decade from 2011 to 2020 (Milutinović, 2024, based on Ministry of Environmental Protection, 2022). This warming trend is particularly pronounced in the urban core of Niš, specifically the City Municipality of Medijana, where temperatures climbed by as much as 1.80°C during the last decade (Milutinović, 2024, based on Ministry of Environmental Protection, 2022).

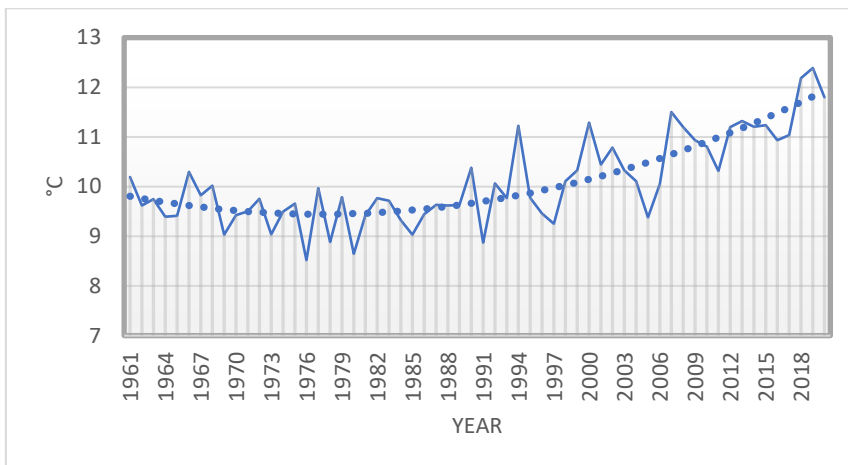


Figure 14. Observed average daily temperatures for the territory of the Nišava District (t_{as}) in the period 1961-2020. Source: Milutinović, 2024

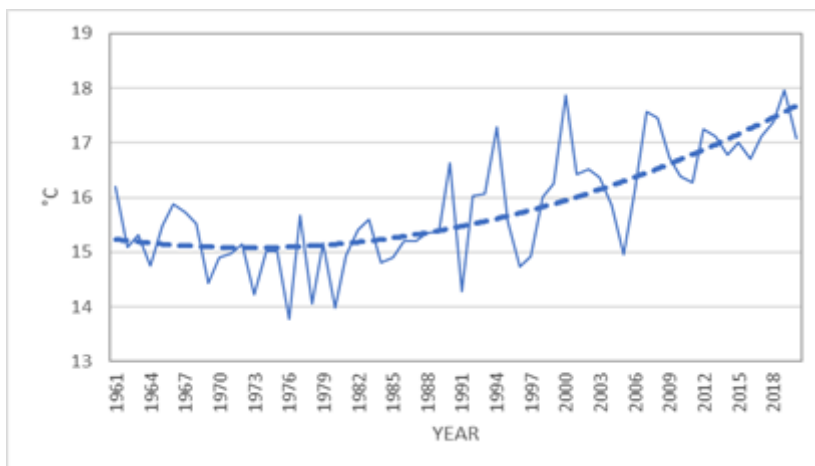


Figure 15. Observed average maximum daily temperatures for the territory of the Nišava District ($t_{as\ max}$) in the period 1961-2020. Source: Milutinović, 2024

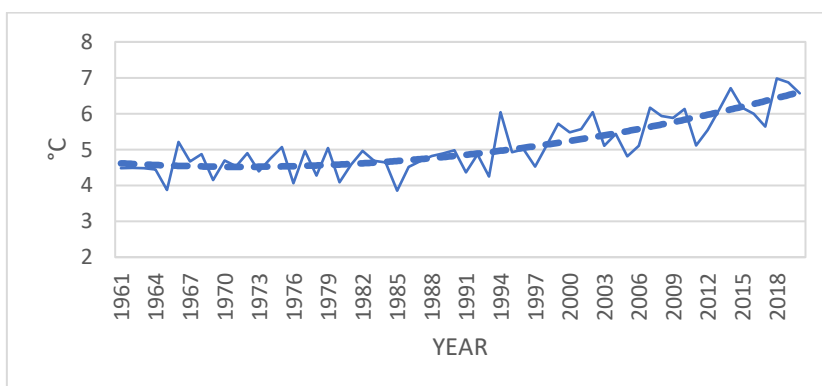


Figure 16. Observed average minimum daily temperatures for the territory of the Nišava District ($t_{as\ min}$) in the period 1961-2020. Source: Milutinović, 2024

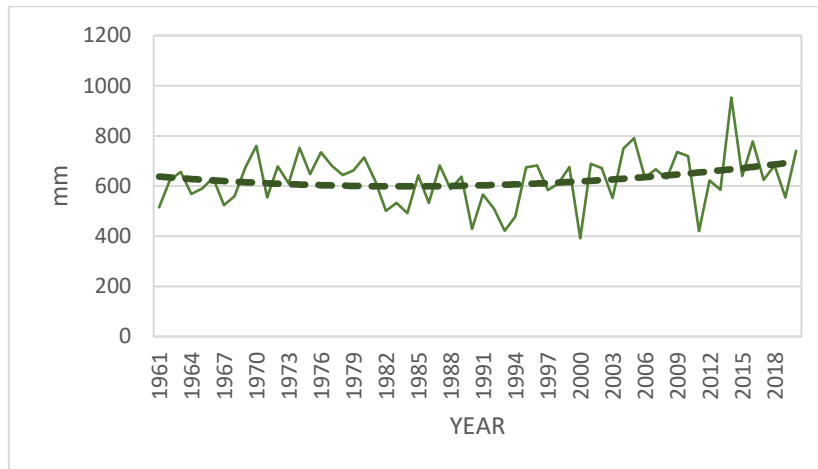


Figure 17. Observed precipitation averages in the Nišava District (pr) from 1961 to 2020.
Source: Milutinović, 2024

The summer months—June, July, and August—have seen the greatest temperature increases, intensifying the frequency and severity of heatwaves. Notably, the maximum daily temperatures have risen faster than the minimum temperatures, signaling hotter days and warmer nights. Such temperature extremes can exacerbate heat-related health problems, strain energy systems, and place pressure on natural ecosystems.

While the total amount of annual precipitation in the Nišava district has not dramatically changed, showing a modest increase of 7 to 9% over recent decades (Milutinović, 2024, based on Ministry of Environmental Protection, 2022), there is a notable shift in the timing of peak rainfall. The highest accumulation of precipitation now occurs earlier in the year, moving from late spring and early summer toward mid-spring. This shift has important implications for water management, agriculture, and flood risk, as the altered seasonal distribution of rainfall could lead to changes in river flow patterns and increase the likelihood of flash floods during different periods than previously observed.

Between 2001 and 2020, the number of summer days—defined as days when temperatures exceed 25°C—increased by an average of 23 days annually compared to the mid-20th century baseline (1961–1990). This trend intensified during the most recent decade (2011–2020), with an average of 30 additional summer days each year. The city municipalities of Niška Banja and Palilula have seen especially pronounced increases in hot days, reflecting localized heat intensification.

Even more striking is the rise in tropical days, where temperatures surpass 30°C. The Nišava district recorded an increase of 18 such days annually, effectively more than doubling the frequency of these hot days since the reference period. Days with

extreme heat above 35°C surged dramatically, nearly quadrupling over the last two decades and increasing by nearly 400% during the past decade alone.

Nighttime temperatures have followed a similar alarming trajectory. Tropical nights—when temperatures remain above 20°C—have increased by nearly 400% since the 1960s and 1970s, and by an astonishing 475% in the last decade. These warmer nights reduce relief from daytime heat, exacerbating health risks and energy demands. Simultaneously, between 2001 and 2020, the annual number of frost days—when minimum temperatures drop below zero degrees Celsius—decreased by 18 days compared to the 1961–1990 baseline, representing a 7% decline. Similarly, ice days, defined as days when the maximum temperature remains below freezing, fell by 7 days annually, a 24% decrease. This warming trend signals milder winters and disruptions to traditional seasonal cycles.

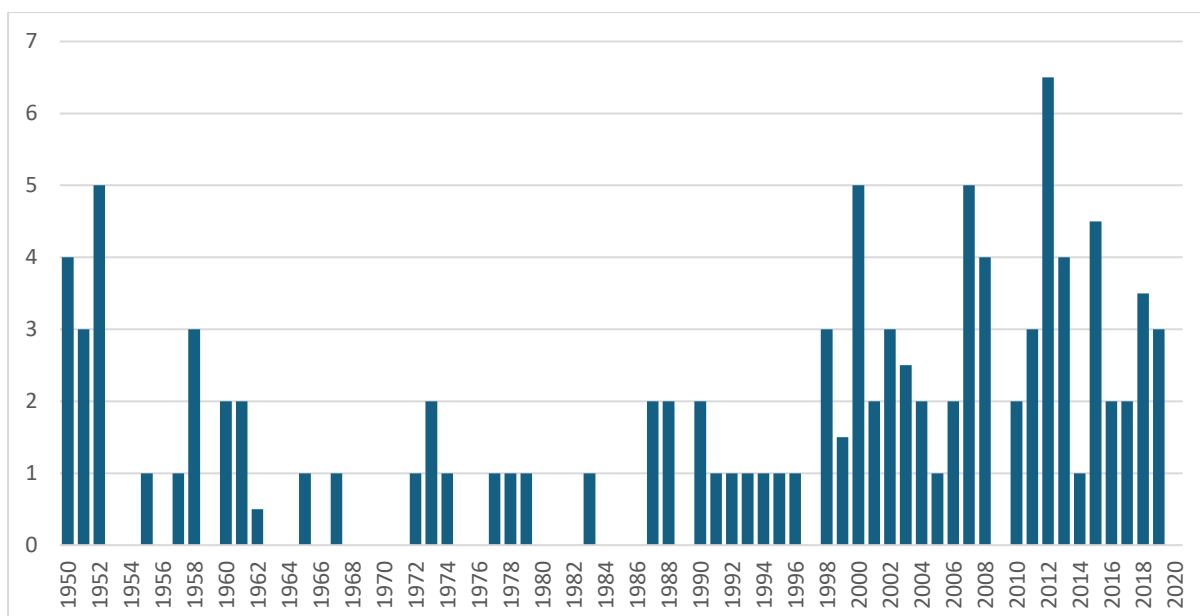


Figure 18. Observed values of climate indices in the territory of the Medijana city municipality: number of heatwaves per year in the period 1950–2020. Source: Milutinović, 2025

At the same time, the frequency and severity of heatwaves have surged dramatically. Where the Nišava district experienced fewer than one heatwave per year during the 1960s to 1990s, recent decades have seen a nearly fourfold increase, with an average of 2.79 heatwaves per year between 2001 and 2020, climbing to 3.11 heatwaves annually in the last decade. Some years in the 2010s recorded as many as four separate heatwaves. Not only are heatwaves more frequent, but their duration has expanded significantly—from an average of just under five days annually to over 26 days in the most recent decade. These prolonged hot spells have increased the number of consecutive hot days, with the longest

hot periods extending from two weeks in the late 20th century to six weeks in recent years. Such changes heighten health risks, strain energy systems, and challenge local ecosystems. Urban effects such as the “urban heat island” phenomenon, particularly in densely built-up Medijana, have further intensified warming, particularly in comparison to surrounding municipalities. This indicates that built environment characteristics significantly modulate local climate dynamics, with implications for heat stress, energy consumption, and urban health outcomes. The most vulnerable parts of Niš’s urban area include the central city zone—especially sections south of the Nišava River and Nikole Pašića Street; older multi-family residential neighborhoods from the socialist era (such as Bulevar Nemanjića, the city’s largest residential complex), which face ongoing densification and a steady loss of green space; and newly developed multi-family housing areas (for example, the “Somborska” neighborhood), where green space is scarce. Urban heat island effects are also pronounced in the “Sever” and “Sever-2” industrial zones, the railway hub, and the utility and warehouse district to the east, toward Niška Banja (City of Niš, 2025).

Table 1. Most heatwaves and UHI vulnerable locations in the City of Niš

City core and marketplace zone	Highest UHI due to dense buildings, asphalt, and low vegetation
High-density housing blocks in Medijana & Pantelej	Limited shade, large impervious courtyards
Industrial areas in Palilula	Vast heat-retaining surfaces, few cooling elements
Transit corridors	Pedestrian-heavy, asphalt-dominated boulevards
Schools and playgrounds	Vulnerable children, long sun exposure

The growing frequency of scorching days and nights poses significant challenges for public health, energy infrastructure, local agriculture, and tourism. Vulnerable populations, including the elderly and those with health conditions, are at heightened risk, and the city must prepare to adapt to these intensifying heat stresses.

The increasing frequency and duration of heatwaves have directly contributed to greater dryness in soil and vegetation, significantly raising the risk and vulnerability to forest fires. Since 2000, Serbia has seen a rise in both the number of forest fires and the length of the fire season, with the Nišava, Pirot, and Jablanica Districts among the most affected areas. In the Nišava District specifically, the past 20 years have shown a slight upward trend in the frequency and intensity of fires, particularly during periods of above-average summer temperatures and below-average rainfall that create extreme drought conditions—key triggers for fire outbreaks. These areas are characterized by a combination of dense vegetation, proximity to human settlements, and climatic conditions conducive to fire risk. The most forest fire-vulnerable areas

within the administrative territory of Niš are predominantly located in its peri-urban and forest-adjacent zones (Niška Banja City Municipality, surrounded by forested areas, particularly the hills and slopes, are prone to wildfires due to their vegetation and topography. The proximity to the town also increases the risk to human settlements; Bubanj Hill, located to the north of the city center, is a forested area that has experienced wildfires in the past. The combination of dry vegetation, steep slopes, and human activities contributes to its vulnerability; Suvi Do, situated to the northwest of Niš, is characterized by forested terrains that are susceptible to wildfires. The presence of dry grasslands and shrubs, along with climatic conditions, heightens the fire risk; their peri-urban forest zones on the outskirts of Niš, including those near the settlements of Durlan and Pantelejš, are also at risk. These zones often have dense vegetation and are in close proximity to urban areas, making them susceptible to wildfires).

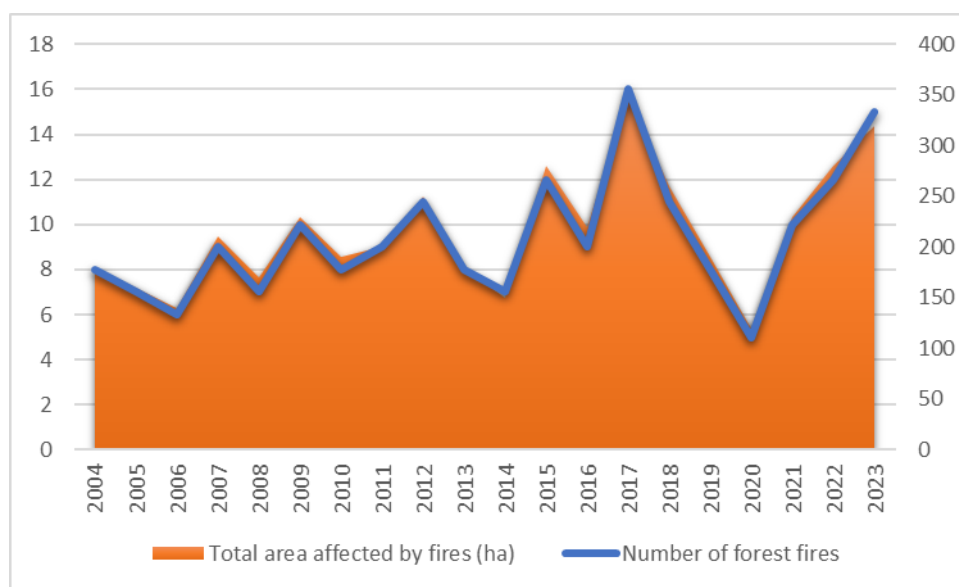


Figure 19. Number of forest fires and total area affected by fire in the Nišava district in the period 2004 – 2023. Source: author

The Nišava District, with its unique climate and terrain, experiences most forest fires during the summer months, especially July and August, which account for 70-80% of incidents. Between 150 and 200 major fires have been reported over two decades, averaging 7 to 12 per year, with peaks during dry years such as 2017 and 2023, and fewer fires during wetter years like 2020. This increasing fire activity poses serious threats to tourism by damaging natural resources, threatening public safety, and causing economic losses. Restrictions on access to tourist sites due to fires and their aftermath, combined with ecological impacts and negative perceptions, undermine the

region's tourism viability, underscoring the urgent need for effective fire prevention and management strategies.

However, although numerous studies worldwide conclude that high-temperature weather reduces tourist flows, influencing both urban and rural tourist flows, data for the City of Niš show that in the recent past, despite the presence of intense heat waves in July and August of 2023 and 2024, tourist traffic did not significantly decline. Hotels and tourist destinations record peak visitation in August and July, indicating that tourists generally come and stay despite the high temperatures.

Analysis of available data on tourist traffic in Serbia shows that July and August are traditionally the most active months in terms of tourism—precisely when the most intense heat waves occur. For example, in Niš, June 2024 recorded over 14,000 arrivals and more than 32,000 overnight stays, while July and August are the months with the highest rate of domestic tourist overnight stays.

A similar trend is present throughout Serbia, where there was an increase in tourist arrivals and overnight stays in 2024 compared to 2023, despite higher temperatures. This data indicates the resilience of the tourism sector in Niš, as well as tourists' ability to adapt to unfavorable weather conditions.

Increased use of air-conditioned spaces in hotels, restaurants, and museums, as well as organizing events in the evening or early morning hours when temperatures are lower, enables tourists to have a comfortable experience even during the hottest days. Besides the urban tourism offer, a significant portion of tourists take the opportunity to visit spa and mountain destinations that provide a more pleasant climate and ease the stay during heatwaves. Such destinations are becoming increasingly attractive as “escape points” from extreme weather conditions in the cities.

However, heatwaves also bring a number of challenges to the tourism industry. Prolonged exposure to high temperatures can increase the risk of heat stroke and dehydration, especially among the elderly and children. Increased electricity consumption due to cooling needs can jeopardize supply stability, which can negatively impact hotel comfort and other tourist services. Despite the resilience, some types of tourism, especially those related to nature and active outdoor stays, may suffer due to unfavorable weather conditions.

Rainfall patterns are also shifting in ways that compound climate risks. Although total annual precipitation has increased only slightly, the intensity and distribution have changed noticeably. In the last decade, Niš has faced increased variability and intensity of precipitation, especially in the form of extreme downpours. Days with very intense rainfall (e.g., over 30 mm in 24 hours) have shown a slight increase in frequency over

the past 5–7 years. The maximum one-day rainfall amounts have grown by 30 millimeters since the period 1961 - 1990, with an additional 20% increase in recent years. Similarly, maximum rainfall over five-day periods has risen by 13 to 20 percent. This intensification of short-term rainfall events raises the threat of flash floods, placing pressure on urban drainage and flood management systems. Conversely, the longest dry spells—periods without significant rainfall—have decreased by 10% overall but show concerning increases in frequency during more recent years, indicating a higher risk of drought and water scarcity.

Beside the fact that trend in mean annual precipitation is positive, changes in precipitation annual cycle reveals that there is decrease in summer precipitation. In half of the Serbian territory, deficit in summer precipitation is greater than 10% (Vukovic et al., 2018). This decrease in summer precipitation, since the beginning of 21st century, coincides with the more frequent occurrence of drought conditions in Serbia, especially during summer months. Serbia already faced several extreme drought episodes since 2000, mainly during summer months (dry summer in 2000, 2003, 2007, 2012, 2017, 2021, 2022, 2024, and 2025). Droughts have caused enormous damage to agriculture, and in 2022 alone, the estimated losses due to drought amounted to over 700 million euros. Since decrease in summer precipitation can trigger changes in hydrological cycles, but also affect agricultural production especially for crops that depends on summer precipitation such as maize, it is expected that this signal should be imminently seen in changes of river discharges and maize production in Serbia.

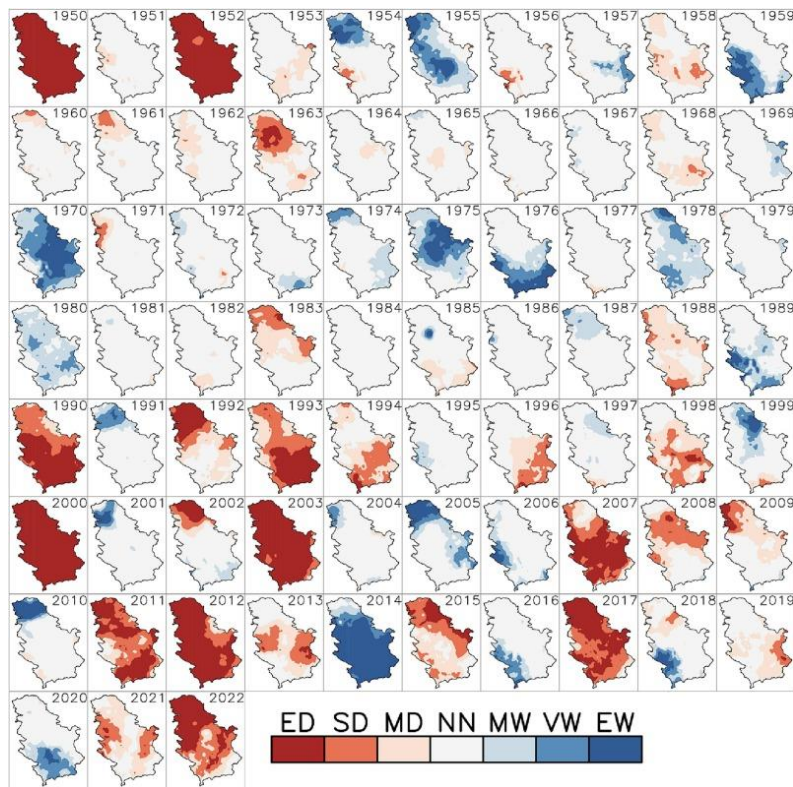


Figure 20. Spatial distribution of SPEI-06 for August in Serbia along the observation period 1950–2022. Source: Djurdjević, et al., 2024

4.2 Long term risks

Overall, Niš will face a higher frequency and longer duration of extremely hot periods, signaling a continuing trend toward more intense and prolonged heatwaves, combined with seasonal reductions in precipitation. These changes will have wide-ranging impacts on health, water resources, agriculture, and urban life.

Niš is projected to experience significant warming over the 21st century. According to the greenhouse gas mitigation scenario for the Nišava District, by 2041 the temperature is expected to increase by 1.07°C compared to the reference period 1971–2000, or by 0.95°C compared to the reference period 1986–2005. From 2041 to 2070, the increase would be 1.73°C, and by the end of the century (2100) it would reach 2.07°C. However, if greenhouse gas concentrations follow the no-mitigation scenario, the temperature rise would be much more significant. From 2011 to 2040, an increase of 1.18°C is projected relative to the period 1971–2000, while between 2071 and 2100 it could reach as high as 4.11°C.

It is also expected that the rise in average maximum temperature will be somewhat greater than the rise in average daily temperature.

In the long term, from 2071 to 2100, the increase in average maximum temperature is projected to exceed 5°C compared to the reference period 1971–2000. The most significant rise, both in average maximum and average daily temperatures, is expected during the summer months.

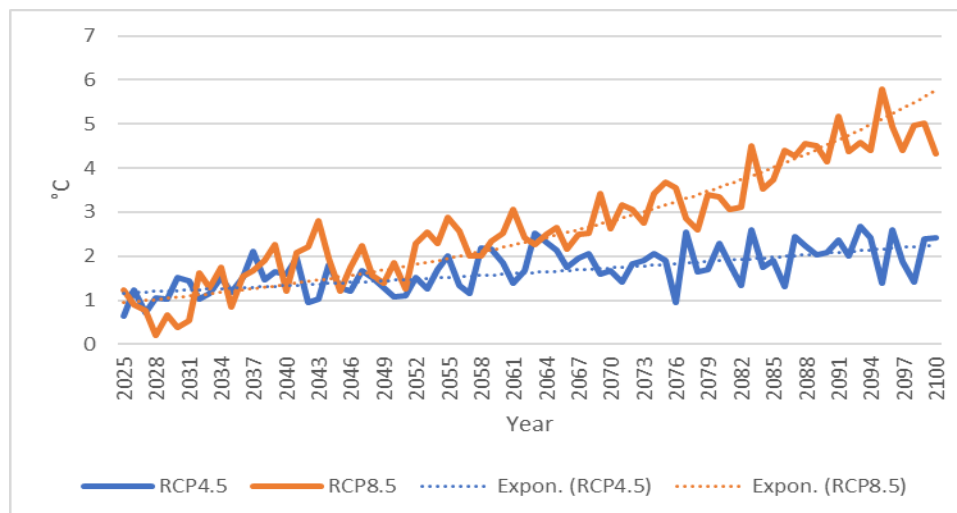


Figure 21. Median projected change in mean daily temperature for the Nišava Administrative District (2025–2100) relative to 1971–2000 under the RCP4.5 and RCP8.5 scenario. Source: Autor's calculation, based on Ministry of Environmental Protection (2022)

As for precipitation, a slight decrease on average precipitation is expected in the future. The reduction will be more pronounced during the summer and winter seasons, while the impact on spring and autumn will be negligible. However, the future decrease of extreme precipitation ranges from 10–100%. Changes are expected in the spatial distribution of extreme precipitation indices R20, R30, R40, and R50, which measure the number of days per year with daily rainfall exceeding 20 mm, 30 mm, 40 mm, and 50 mm, respectively. Increases are likely where these indices were at their minimum during the reference period, and decreases where they were highest. The most significant increases are projected in southern Central Serbia, particularly around Kopaonik, Niš, and Vranje, as well as in Loznica (west) and Zaječar (east). Overall, increases are more pronounced than decreases, with R50 showing the largest rise, up to ninefold. Moreover, greater total precipitation amplifies these changes, leading to more frequent and intense extreme rainfall events. Extreme precipitation in Central Serbia shifts spatially towards the south of the territory, and its time of occurrence is gradually shifting towards the second part of a year. In the period 1961–1990, the most frequent occurrences of extreme precipitation were during June. In the middle of the 21st century, they will mostly occur in August and October, and at the end of the 21st century, October is expected to be the month with the largest number of extreme precipitation events.

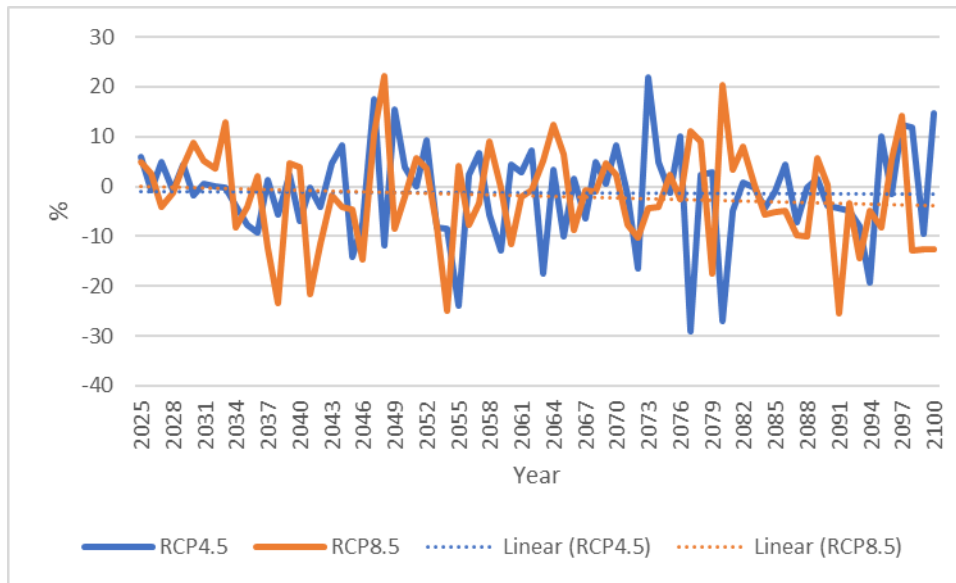


Figure 22. Median projected change in precipitation for the Nišava Administrative District (2025–2100) relative to 1971–2000 under RCP4.5 and RCP8.5 scenarios. Source: Autor’s calculation, based on Ministry of Environmental Protection (2022)

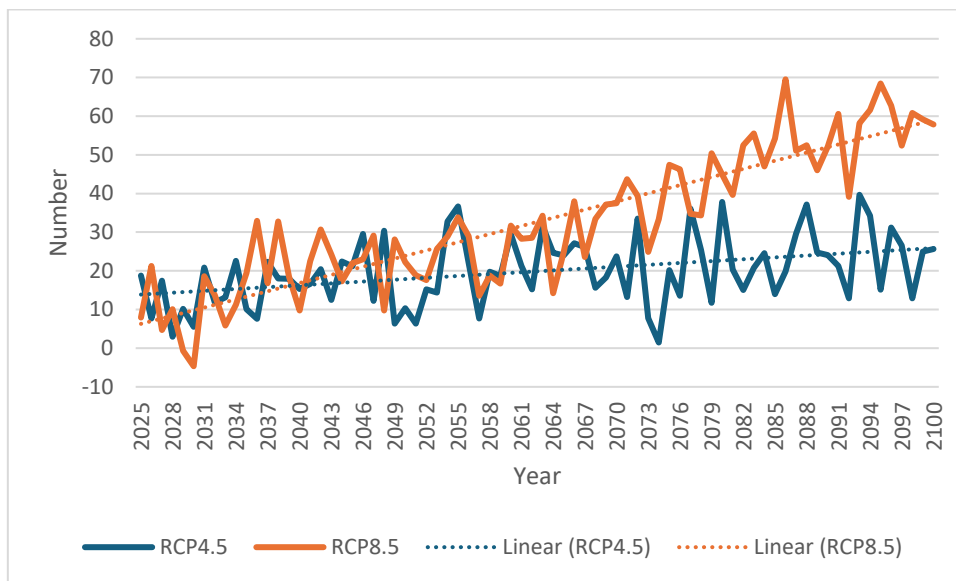


Figure 23. Median projected change in the number of tropical days (with maximum daily temperatures above 30°C) for the Nišava Administrative District (2025–2100) relative to 1971–2000 under RCP4.5 and RCP8.5 scenarios. Source: Autor’s calculation, based on Ministry of Environmental Protection (2022)

Climate models indicate that the number of summer days and tropical days (with maximum daily temperatures above 25°C and 30°C, respectively) will rise significantly in the future. The total average number of summer days could increase by up to +55 days by 2100 under the no-mitigation scenario. Similarly, the number of days with

extreme temperatures above 35°C is expected to rise, reaching up to 27 such days per year between 2071 and 2100 without mitigation measures.

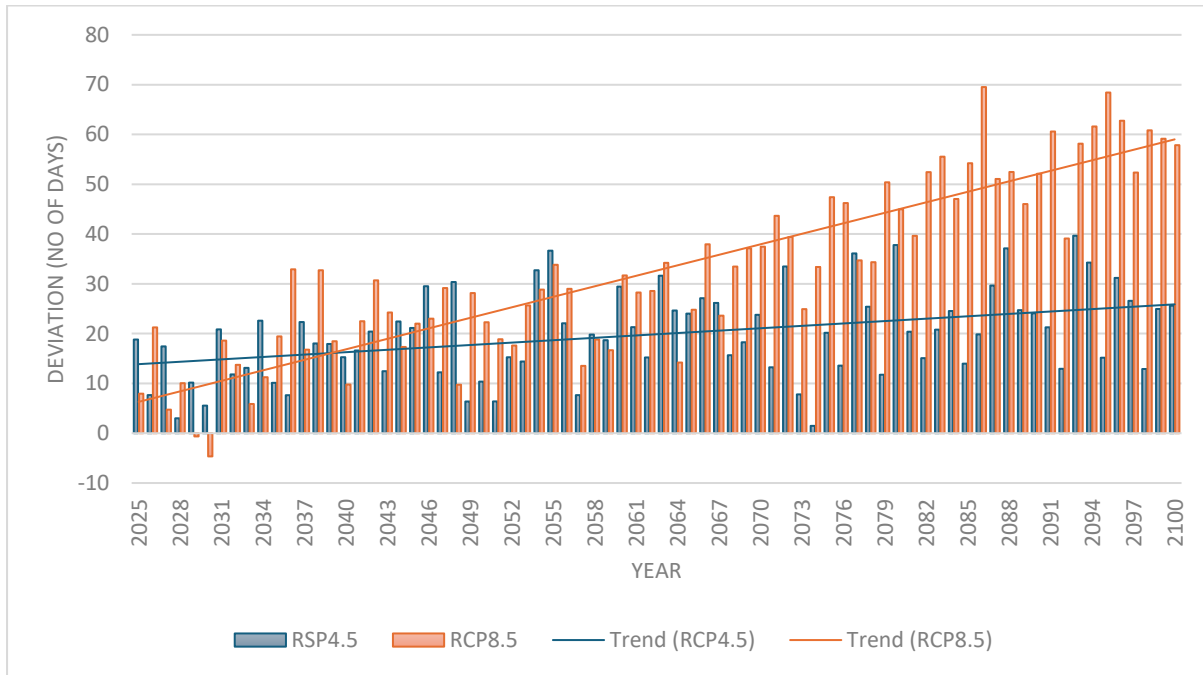


Figure 24. Median projected change in number of tropical days [deviation] for the Nišava Administrative District (2025–2100) relative to 1971–2000 under the RCP4.5 and RCP8.5 scenario. Source: Autor’s calculation, based on Ministry of Environmental Protection (2022)

An increase in the number of tropical nights (with minimum daily temperatures above 20°C) is also expected. Without climate change mitigation, the average number of tropical nights could reach 20 in the distant future. These projections indicate a rapid increase in the frequency of extremely hot periods, along with a continuing trend of longer and more intense heatwaves.

The number of drought years is also projected to increase drastically, especially toward the end of the century. Under RCP8.5, drought conditions may become the norm, occurring in virtually every year in the final decades of the century.

4.2.1 Cross-cutting climate hazards

In general, Niš will face a markedly different climate regime, defined by a combination of intensifying hazards. Rising temperatures will bring longer and more frequent heatwaves, with a surge in both tropical days and tropical nights, most pronounced in the dense neighborhoods of Medijana, Palilula, and Pantelej where the urban heat-island effect is strongest. Rainfall extremes are projected to increase: although annual

precipitation totals may remain similar to today, rain will fall in shorter, more intense events. This will heighten flash flood risks along the Nišava and its tributaries (Gablovačka, Toponička) and strain the city's drainage systems.

In contrast, extended summer droughts will deepen water scarcity, stressing both surface flows and the Mediana artificial recharge system, while also amplifying irrigation needs in the surrounding district. Hotter and drier summers will contribute to an elevated wildfire risk in peri-urban slopes and the Suva Planina foothills. Meanwhile, more frequent severe convective storms, often with hail and damaging winds, threaten crops, infrastructure, and housing.

These hazards interact and compound: drought followed by flash flooding, or heatwaves coinciding with wildfire smoke, will place mounting stress on public health, ecosystems, infrastructure, and economic stability.

4.2.2 Sectoral risks

4.2.2.1 Public health and social protection

Public health in Niš will be strongly challenged by hotter summers. Extended heatwaves will cause direct stress and increased mortality, particularly as tropical nights prevent the population from recovering between days. Poor air quality — from ozone build-up, dust during droughts, and wildfire smoke — will further burden vulnerable groups. Changing climate conditions may extend the season for vector-borne diseases such as ticks and mosquitoes, while floods and heat will periodically trigger outbreaks of water- and food-borne illnesses. These risks will not be felt equally: elderly residents, children, outdoor workers, and low-income households living in top-floor apartments without cooling will bear the greatest burden. Toward the end of the century, unmanaged heat will emerge as the dominant climate-driven mortality risk.

4.2.2.2 Water resources

Water security will become increasingly fragile. During long summer droughts, river baseflows will decline, putting pressure on drinking water supplies, agricultural irrigation, and ecosystems. The Mediana artificial recharge system — crucial to stabilizing Niš's water supply — will face greater variability and water quality challenges, especially as low-flow conditions allow pollutants and sediments to accumulate. At the same time, intense storms will bring sudden floods of water, carrying pollutants into the system and overwhelming wastewater infrastructure. By late-century, multi-season deficits are likely to become common, forcing stronger demand management, diversification of sources, and protection of water quality.

4.2.2.3 Flood risk

Nišava River and its tributaries will experience sharper flood peaks during short, intense rainfall events, raising the risk of inundation in river-adjacent neighborhoods. Urban drainage systems will frequently fail during cloudbursts, particularly in the dense commercial and industrial districts of Medijana. Slopes in Pantelej and Crveni Krst will face increased erosion and landslide activity during wet extremes. Without major adaptation, late-century flood events will regularly exceed the protection levels of existing infrastructure, making current design standards inadequate.

The City of Niš is increasingly exposed to the risk of pluvial floods, primarily due to intense short-term rainfall events that exceed the capacity of the existing urban drainage system. The frequency and intensity of pluvial floods are projected to increase under climate change scenarios, with more frequent extreme precipitation events expected in Southeast Europe. In Niš, this poses risks not only to residential areas and transport infrastructure, but also to cultural heritage sites and key public services. A large share of the city's surface is highly impermeable—dominated by asphalt, concrete, and other sealed surfaces—which significantly reduces natural water infiltration and accelerates surface runoff. The absence of a separate stormwater collection system across much of the city further aggravates the problem, as stormwater is discharged into the combined sewer network together with household and industrial wastewater. During heavy rainfall, this system often becomes overloaded, leading to localized flooding in low-lying urban zones. Particularly vulnerable are densely built neighborhoods with insufficient green areas and limited drainage capacity, such as parts of Medijana, Palilula, and Crveni Krst municipalities. In addition, riverbanks of the Nišava and tributary streams face elevated risks during episodes of intense rainfall, when runoff converges rapidly from surrounding hills and urbanized areas.

4.2.2.4 Energy

The city's energy system will experience a fundamental shift in seasonal demand. Whereas heating dominates today, by mid- to late-century electricity demand for cooling will surge, placing stress on transformers, distribution lines, and substations already weakened by high summer temperatures. Floods and severe storms will also threaten substations and feeder lines, causing outages. Winter heating demand may decline somewhat, but the summer peak will overtake winter as the most critical planning challenge. By late-century, unless reinforced and decentralized, the grid will face reliability concerns under compound heat and storm conditions.

4.2.2.5 Buildings and housing

The built environment will face both gradual and sudden stresses. Apartment blocks and uninsulated masonry houses will suffer from chronic overheating, making them uncomfortable and, at times, unsafe during heatwaves. Ground floors and basements in older buildings will be increasingly vulnerable to flooding, while heritage buildings, such as those in Niš Fortress and the old city core, will deteriorate faster under alternating cycles of heat, drought, and humidity. By the late century, maintaining habitable indoor conditions without substantial retrofits will become a major challenge, particularly in multi-story housing estates.

4.2.2.6 Transport and mobility

Niš's transport systems will be strained on multiple fronts. High summer temperatures will soften asphalt, causing rutting on heavily trafficked roads, and increase the risk of rail buckling. Intense rainfall will wash out smaller roads and flood underpasses, leading to frequent transport interruptions. Pedestrians and cyclists will face dangerous conditions in heatwaves, reducing the resilience of sustainable transport modes. By late-century, transport life-cycle costs will rise sharply unless roads, rails, and drainage systems are upgraded with heat- and flood-resistant materials.

4.2.2.7 Industry and business

Industrial and commercial sectors will be exposed to both direct and indirect risks. Higher workplace temperatures will reduce productivity and increase cooling costs, while process-water constraints may limit operations. Supply chains will be disrupted by floods that block transport corridors, and stored goods in low-lying warehouses could be repeatedly damaged. Toward the end of the century, businesses without adaptive facilities will face competitive disadvantages as insurance costs rise and lenders increase credit-risk premiums for climate-exposed sites.

4.2.2.8 Agriculture and rural areas

In the wider Nišava district, agriculture will be shaped by heat and water stress. Yields of maize, fruits, and other crops will decline without irrigation, but irrigation demand will increasingly conflict with urban water needs. Severe convective storms and hail will cause physical damage to crops, while warmer conditions will extend pest and disease pressures. By late-century, viable agriculture will depend on crop diversification and a shift to heat-tolerant species, supported by highly efficient irrigation systems.

4.2.2.9 Urban green, biodiversity and ecosystems

Urban parks and green corridors, which today provide vital cooling and recreation, will come under pressure from heat and drought. Without additional watering and species

diversification, trees will suffer higher mortality rates, reducing shade and further amplifying urban heat. Riparian ecosystems will be stressed by more variable river flows — drought shrinking habitats, floods scouring banks. Wildfire threats will increase along the urban fringe, while invasive species take advantage of shifting conditions. Without proactive planning, the city's green infrastructure will lose much of its resilience function by late-century.

4.2.2.10 Tourism, culture and recreation

Tourism and cultural life in Niš will undergo significant seasonal shifts as climate change progresses. While some impacts are still perceived as limited today, they are expected to intensify rapidly in the mid- to long-term, reshaping the sector's economic performance. Direct impacts include losses in visits and rising operational costs as high climate variability discourages both local and international tourists. Indirect impacts stem from the deterioration of local biodiversity — a key element of the region's tourism appeal — and from damage to essential infrastructure under the pressure of floods and other hazards.

The traditional peak summer season is projected to lose attractiveness, as extreme heat reduces comfort and leads to the cancellation of outdoor festivals and events at sites like Niš Fortress. Cultural heritage, already vulnerable to cycles of heat, humidity, and flooding, will deteriorate more quickly, requiring intensified conservation. Without adaptation of cultural venues and open spaces, Niš risks losing competitiveness as a year-round destination, with tourism potentially shifting toward spring and autumn.

At the same time, revenues are increasingly threatened by rising costs. Local operators must contend not only with declining visitor numbers, but also with growing expenses for insurance and repairs in response to damages from floods and other climate pressures. These dynamic risks creating a downward spiral:

- Losses in ecosystems and cultural heritage reduce the appeal and quality of tourism assets, weakening the city's ability to attract particularly international visitors.
- Severe weather undermines the quality and reliability of infrastructure, driving up repair costs and undermining the provision of basic services that tourists depend upon.

4.2.2.11 Waste and sanitation

Waste systems will experience operational difficulties. High temperatures will accelerate decomposition and odors at landfill sites and increase health risks for sanitation workers. At the same time, extreme rainfall will overwhelm sewer systems, leading to overflows and contamination events. Toward the end of the century, rising

costs for operation, maintenance, and odor control will place strain on municipal budgets.

4.2.2.12 Emergency management and civil protection

The frequency and complexity of emergencies will increase. Heatwaves may overlap with wildfire smoke or storm-related power outages, creating compound crises that stretch resources. Shelters and cooling centers will see growing demand, and communication systems will need to handle more frequent alerts and public guidance. By late-century, Niš will require a fully integrated multi-hazard early warning and rapid response system to prevent cascading disasters.

4.2.2.13 Finance, insurance and governance

Financial and governance systems will also feel the weight of climate risks. Repeated flood and storm damages will drive up insurance premiums, with some zones becoming uninsurable. Municipal budgets will face shocks from repeated recovery costs, while capital projects risk delays if not designed to meet new climate standards. Without embedding climate resilience into governance and investment planning, Niš could face significant fiscal pressure by the late century.

5 Demands for new public policies for the adaptation to climate change impact

The findings of this analysis underline the urgent need for local and regional climate adaptation planning. Strategic actions should prioritize enhancing urban resilience, managing water resources sustainably, upgrading infrastructure to withstand extreme events, and implementing early warning systems and health protections. Climate change is no longer a distant risk—it is a current reality with escalating impacts. Immediate and sustained mitigation and adaptation efforts are critical to safeguard the well-being of the residents of the City of Niš and ensure the region's sustainable development.

To avoid or minimize climate-related risks, the City of Niš should adopt a “green first, grey if necessary” approach across all sectors and territories. This strategy prioritizes nature-based solutions (NbS) as the primary means to prevent, mitigate, and adapt to climate impacts, while reserving structural or engineered measures for areas where natural interventions alone cannot provide sufficient protection.

5.1 Territorial planning

Given the high likelihood and severity of climate impacts, the City of Niš must take proactive steps to adapt and build resilience. The

high priority is to **develop a Local Climate Adaptation Action Plan**, aligned with Serbian 2023 – 2030 Climate Change Adaptation Programme (NAP), and international commitments (e.g., the Paris Agreement).

Moreover, Niš's territorial/urban planning documents should be upgraded and explicitly aligned with climate-risk and vulnerability (heat, floods, drought, landslides, wildfire, air quality), with the freshest pointers to each:

- New Spatial Plan for Niš's administrative area (Prostorni plan grada Niša) is currently in preparation. The updates should embed climate-hazard zoning, blue-green infrastructure standards, and risk-based land-use rules.
- Given the new cycle of General Urban Plan – GUP is under preparation, a 2025 Urban Heat Island (UHI) assessment (City of Niš, 2025) should be mainstreamed, regulating tighten floodplain controls, ventilation corridors, tree-canopy targets, and cool-materials guidance.
- Master plans (Plans of General Regulation – PGR) by city municipalities Palilula, Medijana, Pantelej, Crveni Krst, Niška Banja (incl. current amendments) should all be harmonized with updated flood/landslide/wildfire maps and UHI mitigation measures (shade quotas, permeable surfaces).
- Detailed Regulation Plans (PDR) and Urban Projects require parcel-level climate adaptation criteria (runoff coefficients, retention, NbS, heat-resilient public space) as part of approvals.
- City Disaster-Risk documents – Disaster Risk Assessment (2021) and related Civil Protection/Protection & Rescue plans should be revised with current climate baselines and linked directly into Spatial/GUP zoning decisions.
- Flood Defence Operational Plan for II-order waters (annual) (City of Niš, 2024a) should be aligned maintenance/works and trigger levels with updated hazard maps and with PGR/PDR rules (no new sealing in micro-basins, mandatory retention).
- City Development Plan 2021–2027 (City of Niš, 2021) should be updated to mainstream adaptation key performance indicators (cooling-degree days, tree-canopy %, runoff capture, heat-mortality risk), and bind funding to climate-positive projects.
- Move from the older SEAP (2014) to a full SECAP 2030 (decision to join Covenant and prepare SECAP already adopted); then legally cross-link SECAP measures with GUP/PGR (e.g., district cooling, PV siting, building retrofits targeted to heat-vulnerable blocks).
- Tie climate-risk indicators and land-use outcomes in Voluntary Local Review (VLR) on SDGs (e.g., % residents within a 5-minute walk to shade/water, %

critical facilities out of flood zones) to the VLR monitoring.

Moreover, some quick, high-impact alignment moves should be taken:

- Put the UHI assessment (City of Niš, 2025) into the legal “planning basis” for the new GUP/PGRs (cool surfaces, shading ratios, street-tree spacing by street width).
- Instruct all PDRs to include runoff retention targets (e.g., L/s/ha caps) and minimum unsealed soil per plot.
- Update risk overlays (flood/landslide/wildfire) in the Spatial Plan and make them binding constraints for zoning and infrastructure corridors.
- Finalize SECAP 2030 and cross-reference its measures directly in building codes and permitting checklists.

5.2 Infrastructures for prevention and mitigation of heatwaves and the urban heat island effect

Niš is increasingly vulnerable to heatwaves and the urban heat island (UHI) effect due to rising temperatures, longer heat events, and extensive heat-retaining surfaces like asphalt, concrete, and dark roofs. Limited vegetation and tree canopy reduce natural cooling, keeping nighttime temperatures high and heightening health risks for vulnerable groups, including the elderly, children, and those with chronic illnesses. Public spaces and busy corridors often lack shade or cooling features, further increasing exposure. To mitigate the effects of heatwaves and the urban heat island phenomenon, the following additional measures are recommended:

- City of Niš should prioritize a coordinated program of nature-based cooling infrastructure aimed at increasing shading, evapotranspiration, and surface reflectivity. Continuous street tree corridors along the streets Bulevar Nemanjića, Nikole Pašića, and Voždova would cool high-use pedestrian streets, particularly where asphalt dominates, provided that planting strips are at least 1.5 meters wide and linked to stormwater infiltration trenches. In dense neighborhoods such as Pantelej and Palilula, vacant or underused parcels could be transformed into shaded pocket parks with seating, permeable surfaces, and dense vegetation to lower local surface temperatures. Public buildings—including City Hall, the Cultural Center, and schools in Medijana and Crveni Krst—should lead the way in adopting green roofs and walls, ideally integrated with photovoltaic panels to deliver both cooling and renewable energy benefits. Finally, urban forest buffers along the Nišava riverbanks and railway corridors should be expanded to act as natural ventilation channels, connecting with

existing parks to form continuous ecological corridors that channel cooler air into the city and provide long-term climate resilience.

- To further reduce urban heat retention and manage stormwater effectively, Niš should implement a targeted program of reflective and permeable surface retrofits designed to lower surface temperatures and increase water infiltration. High-albedo, “cool pavement” coatings should be applied to bus stops, pedestrian plazas, and schoolyards, with priority given to heavily used streets in the city center and areas surrounding major marketplaces, such as the Tvrdava market. Parking areas at key sites, including the Čair sports complex and Sveti Sava Park, should be retrofitted with permeable concrete or asphalt to both decrease heat buildup and allow rainwater to infiltrate on-site. On the building scale, the city can incentivize the use of light-colored, reflective paint or membranes on flat-roofed residential and commercial properties, reducing cooling energy demand while contributing to overall UHI mitigation.
- To provide localized evaporative cooling during extreme heat events, Niš should integrate water-based cooling features into key public spaces. Low-water misting systems can be installed in Čair Park, Sveti Sava Park, and the city’s main squares, activated specifically on red-alert heatwave days to offer immediate relief for pedestrians. Historic fountains, such as those in the Fortress Park, should be restored to working order, while shaded water curtains can be added to prominent plazas to combine visual appeal with cooling benefits. In the city’s green belts in Medijana and Crveni Krst, stormwater-fed retention ponds should be constructed to serve a dual role: functioning as biodiversity habitats while providing microclimate cooling for surrounding neighborhoods.
- To ensure immediate relief from extreme heat for pedestrians and outdoor workers, Niš should expand shading and shelter infrastructure across high-exposure public areas. Bus stops should be upgraded with green roofs or vine-covered structures, providing both cooling and visual comfort, and supplemented with drinking fountains where space and utilities allow. In marketplaces, public squares, and playgrounds, seasonal tensile fabric canopies can create flexible shaded zones during the summer months, reducing heat stress for vendors, visitors, and children. In redevelopment projects—particularly along sunny pedestrian corridors—developers should be encouraged to incorporate colonnades or arcades, offering permanent shaded walkways that combine climate adaptation with urban design enhancement.
- To reduce heat gain in buildings and limit radiated heat into surrounding public spaces, Niš should adopt climate-responsive building and urban design measures. New developments should incorporate ventilated double-skin facades and operable shading systems to improve thermal performance while

allowing for seasonal adaptability. Urban planning regulations should be adjusted to preserve and enhance ventilation corridors carrying cooler air from Suva Planina toward the city core, ensuring that building orientation and spacing support natural airflow. Existing public housing blocks can be retrofitted with passive cooling measures—such as shading louvers, light-colored exterior coatings, and upgraded insulation—to improve indoor comfort, reduce cooling energy demand, and strengthen resilience to prolonged heatwaves.

- To minimize health risks during extreme heat events, Niš should implement early warning systems, community cooling options, and social protection measures. Cooling centers can be established in accessible public facilities such as libraries, schools, and sports halls, opening specifically during forecasted heatwave periods to provide safe, air-conditioned refuges. A targeted heat health alert system—using SMS notifications—should prioritize outreach to elderly residents, chronically ill individuals, and other vulnerable groups. Additionally, municipal regulations should require flexible work schedules or adjusted hours for outdoor laborers during extreme heat, ensuring occupational safety while maintaining productivity.

Table 2. Priority locations and recommended heatwave and UHI adaptation measures in Niš

Location	Type	Actions	Priority
Čair park	Park	Shade trees, misting during heat alerts, permeable paths, drinking fountains	High
Sveti Sava park	Park	Rain gardens, permeable play areas, shade structures	High
Niš Fortress park	Park	Restore fountains, dense tree canopy, reflective plaza treatments	High
Sports center Čair	Cooling Center	Open as cooling center during heatwaves; signage + water	High
City library	Cooling Center	Cooling refuge, extended hours on red-alert days	High
Palilula industrial zone	Hotspot	Cool pavements, shade sails over walkways, tree clusters	High
Tvrđava Market Area	Hotspot	Fabric canopies, reflective coatings, misting on peak days	High
Niška Banja Center	Park Town	Shaded promenades, drinking water, cool roof program	High
Bulevar Nemanjića	Cooling Corridor	Green street retrofits: continuous street trees, tree trenches, permeable parking, bus stop shade	High
Nikole Pašića street	Cooling Corridor	Permeable parking lanes, high-albedo sidewalks, tree trenches	High
Voždova street	Cooling Corridor	Bioswales, shade trees, cool pavement at crossings	High

Nišava River Greenway	Cooling Corridor	Riparian canopy expansion, permeable paths, rest areas with water	High
Medijana Core (Duvanište blocks)	Priority District	Courtyard greening, cool roofs, permeable parking, schoolyard shade	High
City Core (Center)	Priority District	Market canopies, reflective plazas, pocket parks, drinking fountains	High
Crveni Krst–Railway Belt	Priority District	Street trees, cool pavements, noise barriers with vines, shaded bus stops	High
Palilula Industrial zone	Priority District	Tree clusters, solar+shade carports, permeable yards, truck route misting points	High

5.3 Infrastructures for prevention and mitigation of climate change geo-hydro hazards (landslides, floods, erosion)

Regarding **floods and stormwater**, the city should prioritize riparian buffers, bioengineered riverbanks, wetlands, infiltration trenches, and permeable pavements to slow, capture, and infiltrate runoff before it overwhelms drainage networks or destabilizes riverbanks and slopes. Levees, reinforced channels, and retention basins are employed only in critical flood-prone areas where nature-based measures cannot fully manage extreme events, such as downstream of Medijana and Crveni Krst along the Nišava River. In drought-prone areas and agricultural zones, nature-based measures include reforestation, watershed protection, terraced farming, and soil conservation practices.

- River regulation and flood defences:
 - Levee and embankment reconstruction – Reconstruct and reinforce levees and embankments along the Nišava River, with priority downstream of Medijana (Nišava, central-city quay around the pedestrian bridge (roughly ±250–300 m); urban reach covered by the WB FERP project¹ (≈ km 11+340–12+945, plus the upstream 303 m tie-in); Suvodolski potok through Brzi Brod (newly diverted/regulated channel)) and Crveni Krst (Nišava left bank immediately downstream of Medoševac bridge (collector Ø1500 outlet area) and the adjacent ±500–900 m.; Nišava through the western urban edge (toward Donji Komren / Crveni Krst frontage); confluence/transition works at minor urban

¹ Floods Emergency Recovery Project in Serbia, financed by the World Bank, <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/409561468116048196/serbia-floods-emergency-recovery-project>

- torrents draining into Nišava on the Crveni Krst side (e.g., outfalls and small collectors)), to improve flood protection for adjacent urban areas.
- Tributary channel upgrades – Increase channel capacity and stabilize banks of key tributaries, including Gabrovačka reka, Suvodolski potok, Toponička reka, and Jelašnička reka, using a combination of structural reinforcement and nature-based solutions where feasible, to reduce the risk of overflow and erosion during high-flow events.
 - Floodplain restoration – Restore and expand natural floodplain areas in peri-urban zones of Medijana (Nišava left bank, downstream of the center toward Donja Vrežina - urban edge of Medijana → Pantelej border), Crveni Krst (lower Kutinska reka corridor - last 1–2 km before the confluence with the Nišava; Lower Gabrovačka reka corridor - peri-urban band around Gabrovac/Široke Padine → approach to Niš), and Niška Banja (Jelašnička reka alluvial fan and valley mouth between Jelašnica/Čukljenik and the Nišava, just west/northwest of the spa zone), allowing temporary water retention during high-flow events and reducing downstream flood peaks. Prioritize “room-for-the-river” over new concrete, and utilize native wetland vegetation to enhance water absorption and biodiversity. Design for ~0.5–1.5 million m³ combined across sites (5–10% of a 10-year peak volume on these small basins), and split into multiple cells to stage filling/draining. Also, design the hydraulic controls (simple notched berms and gated culverts so areas drain within 24–72 h after peaks, limiting mosquito issues).
 - Retention and infiltration structures – establish retention basins, swales, and constructed wetlands in upstream catchments and urban neighborhoods to attenuate peak runoff before it reaches vulnerable slopes or riverbanks. Focus on areas of Palilula, Pantelej, and southern Niš hills where rapid urban runoff is a concern. Possible locations for water retention include:
 - Multi-cell dry polders along Nišava main corridor (Pantalej City Municipality, upstream of the Fortress – Donja Vrežina left bank: widen the active floodplain in low-value strips, create seasonally dry basins with controlled inlets/outlets; Medijana City Municipality between Most Mladosti and Medijana bank: use municipal parcels for shallow polders tied to bike-greenway upgrades.
 - Confluences (Crveni Krst City Municipality, confluence Gabrovačka Reka - Nišava: flank both banks with tiered berms to form 2–3 connected dry detention cells; Palilula–Pantelej edge,

confluence Toponička Reka - Nišava: off-channel detention lagoon (normally dry) with backflow-controlled culverts).

- Peri-urban floodplain expansions: downstream toward Donje Međurovo / Trupale (Palilula City Municipality): designate agricultural set-back areas as controlled retention fields with seasonal use agreements; Niška Banja valley bottom (Spa Park outskirts): small landscape berms + meadow basins to hold flashy hillside runoff before it hits channels.

Possible locations for improved water infiltration include:

- At the territory of Medijana City Municipality: Čair Park (edges, not heritage core - chain of bioswales around paths, plus a shallow detention green at the lowest corner); park Sveti Sava + school campuses around Bulevar Nemanjića (retrofit lawns into rain-meadow basins and subsurface rock galleries); block courtyards along Bulevar Nemanjića (convert portions to permeable parking with underdrains to stone trenches).
 - At the territory of Crveni Krst City Municipality: MIN / railway-adjacent brownfields (post-remediation - large infiltration galleries and dry ponds; phase them as sites redevelop).
 - At the territory of Pantelej City Municipality: school sports fields (e.g., near Pantelej church axis - under-pitch storage (modular crates) with overflow to swales).
 - At the territory of Palilula City Municipality: industrial plots east of the river (clean roofs): roof disconnection → gravel trenches; truck yards → permeable concrete pads.
 - At the territory of Niška Banja City Municipality: Spa Park periphery + hotel parking: permeable paving, tree trenches, and pocket wetlands for hillside springs and storm bursts.
- Urban drainage and stormwater management
 - Upgrade stormwater systems – Expand and modernize the separated stormwater sewer network to prevent overloads in combined sewers during heavy rainfall events.
 - Permeable surfaces – Install permeable pavements in parking areas, plazas, and other high-impermeability surfaces to reduce surface runoff and promote infiltration. Priority should be to convert paved schoolyards to permeable surfaces with sub-base storage.
 - Green infrastructure in public spaces – Implement rain gardens and infiltration trenches in parks, squares, and streetscapes to detain

stormwater, slow runoff, and enhance groundwater recharge. Possible location is Čair Park, where swales should be retrofitted and bioretention planters to boulevard medians should be added. On corridors like Bulevar Nemanjića, Nikole Pašića, and Voždova, small rain gardens can replace curbside strip plantings or serve as in-line infiltration zones in medians and parking zones. Also, add tree trenches along reconstructed streets, starting with Bulevar Nemanjića. Čair park, along with park Sveti Sava, can also be a primary location for rain gardens along its perimeters—edge planting zones can intercept and filter run-off from surrounding hardscapes. Convert sections of mowed lawn near pavements into rain garden beds to receive runoff from adjacent areas. These settings also double as educational and aesthetic enhancements, reinforcing public awareness.

- Green roofs – Encourage or mandate green roofs on public and municipal buildings to capture and delay stormwater discharge, while providing urban cooling and biodiversity benefits.
- Floodplain protection
 - Strict zoning enforcement to avoid construction in active floodplain zones.
 - Demolition/relocation programs for illegal structures blocking natural drainage.

Landslides and slope instability are a major hazard for Niš, especially in hilly and peri-urban areas where steep slopes, weak soils, and human activity intersect. While the central Nišava valley is flat, much of the city's territory includes unstable slopes vulnerable to intense rain, snowmelt, or seismic events—risks expected to increase with climate change. Integrated drainage with bioswales, vegetated terraces, and restored forest belts can both mitigate landslide risk and deliver co-benefits such as urban cooling, habitat creation, and enhanced visual landscape quality—making these measures a cornerstone of climate-resilient territorial planning for Niš.

- Mramor–Krušce corridor – Implement deep-root vegetation (willow, poplar, black locust) to bind soils; terrace slopes with vegetated cover to slow runoff; install swales to intercept rainwater. Where unavoidable, complement with low gabion walls to protect homes, farmland, and roads.
- Niška Banja – Restore native forest cover on slopes above the spa and hillside neighborhoods (Koritnjak hill, Jelašnica access road); apply vegetated geogrids on reprofiled cuts; establish managed green belts doubling as recreational areas. In steep sectors, combine bioengineered terraces with minimal structural support (anchored logs, live staking) to preserve the tourism landscape.

- Gabrovac and Prva Kutina – Use live fascine check dams and planted brush layers to slow gully erosion and stabilize cultivated hillsides; reforest with drought- and flood-tolerant native species to enhance root reinforcement and water balance.
- Gabrovačka Reka Valley, Jelašnica and Sićevo Gorge access roads – Stabilize cut slopes with bio-armoring (shrubs, grasses, geotextiles); establish vegetated rockfall catch berms near high-risk roads; increase vegetative cover along slope crests above the E-80 motorway to prevent material loosening.
- Riverbank zones (Donja Vrežina, Medijana, Lower Gabrovačka Reka, Toponička Confluence) – Create riparian buffers with layered vegetation to prevent undercutting, filter runoff, and boost biodiversity; reinforce banks with live cribwalls and willow staking to reduce reliance on hard armoring.

Also, **erosion** is an increasing hazard in the City of Niš, driven by heavy rainfall, intensified runoff, and the destabilizing effects of climate change. While urbanized areas of the Nišava River valley are relatively stable, hilly and peri-urban zones—including the Mramor–Krušac corridor, Niška Banja, Gabrovac, and Prva Kutina—experience significant soil loss, gully formation, and bank undercutting, threatening agricultural lands, infrastructure, and settlements. Recommendations for nature-based erosion prevention and mitigation in Niš include:

- Along the key watercourses of Niš, including the Nišava River, Gabrovačka reka, Toponička reka, and their smaller tributaries, the establishment of riparian buffers is essential for climate-resilient erosion management. Multi-layered vegetation—comprising grasses, shrubs, and native trees—can stabilize riverbanks, reduce undercutting, and slow the flow of surface runoff, while simultaneously enhancing biodiversity. Priority areas for these interventions include Donja Vrežina, Medijana, and the lower stretches of the Gabrovačka and Toponička rivers, where bank erosion is most pronounced and where urban-rural interactions heighten vulnerability.
- In erosion-prone sections along Niš’s rivers, particularly where urban and rural areas meet, bioengineered riverbanks offer an effective, climate-resilient solution. Techniques such as live cribwalls, willow staking, and vegetated geogrids can be applied to stabilize banks while preserving ecological functions. Priority locations include floodplain areas in Medijana, Crveni Krst, and Niška Banja, where both infrastructure and natural habitats are vulnerable to erosion.
- Apply vegetated terraces and bio-armoring (shrubs, grasses, geotextiles) on agricultural slopes and peri-urban hillsides in the Mramor–Krušac corridor,

Niška Banja slopes, Gabrovac, and Prva Kutina, slowing runoff, trapping sediment, and preventing gully formation.

- Construct live fascine and brush-layer check dams in erosion-prone gullies across Gabrovac, Prva Kutina, and Hum, reducing flow velocity, trapping sediments, and gradually stabilizing degraded lands.
- Plant drought- and flood-tolerant native species on degraded slopes in southern Niš hills, Bujanj and Koritnjak hill areas, and the Mramor–Krušac corridor, reinforcing soil structure, enhancing infiltration, and improving slope stability.
- Implement vegetated rockfall berms, anchored live barriers, and slope crest planting along the E-80 motorway, southern approach roads from Prosek, and rural access routes near Jelašnica and Sićevo Gorge, preventing soil detachment and controlling runoff while preserving the landscape.
- Incorporate bioswales, retention basins, and infiltration features in urban and peri-urban neighborhoods across Palilula, Medijana, and Pantelej, reducing surface runoff before it reaches vulnerable slopes and riverbanks.

5.4 Infrastructures for prevention and mitigation of fire hazards due to climate change

The City of Niš faces an increasing risk of forest fires due to climate change, particularly in peri-urban and forest-adjacent zones such as Niška Banja, Suvi Do, Bujanj, and the surrounding hills. To enhance resilience, a multi-faceted approach combining infrastructure development, monitoring, community engagement, and policy support is essential as follows:

- Strategically planned forest roads and access points are critical to ensuring rapid response in fire-prone areas. Roads in the peri-urban forests around Niška Banja, Suvi Do, and Bujanj hills should be maintained year-round, enabling firefighting units to reach both dense forest interiors and urban-forest interfaces. Complementing these, firebreaks and fuel management measures—such as clearing combustible vegetation along residential edges and conducting controlled burns in peripheral forest areas—can significantly reduce fire spread toward populated neighborhoods.
- Early detection is vital. Remote sensing technologies, drones, and wireless sensor networks should be deployed over high-risk forested zones, integrating data into centralized monitoring systems to allow rapid response. Firefighting resources, including specialized vehicles capable of navigating rugged terrain and strategically placed water reservoirs near forest edges, are necessary to ensure efficient fire suppression in both urban and peri-urban territories.

Regular training and simulation exercises in high-risk districts will enhance preparedness.

- Community involvement is equally important. Awareness campaigns should focus on residents in forest-adjacent neighborhoods, particularly Niška Banja, Suvi Do, and Bujanj, educating them on prevention practices, emergency response, and evacuation procedures. Volunteer fire watch programs can engage local communities in monitoring vulnerable areas.
- Finally, effective policy and institutional support is required. Land-use regulations must prioritize fire safety in urban-forest interfaces, while coordination among municipal authorities, forestry services, and local communities ensures cohesive management of fire risks. Investments in high-risk zones, supported by national and international funding, will strengthen the city's overall resilience to climate-induced forest fires.

5.5 Drought prevention and management

Climate change is increasing the frequency and intensity of droughts in Niš, affecting water availability, agriculture, urban greenery, and ecosystems. Addressing this requires both infrastructural measures and territorially targeted strategies, as follows:

- In densely populated urban districts such as urban core, Medijana, and Palilula, drought threatens water supply, urban greenery, and public spaces. To address this, the city should replace high-water-demand vegetation with drought-tolerant native species in parks and streets, and increase permeable surfaces and green corridors.
- In peri-urban and forest-adjacent areas, including Niška Banja, Suvi Do, and Bujanj hills, the focus should be on maintaining forest cover and creating small retention ponds to preserve soil moisture. Forest and hillside management—through mulching, selective planting of native species, and erosion control—can reduce the vulnerability of settlements near forest edges. Protecting wetlands and natural watercourses in these zones further enhances the capacity of ecosystems to buffer against drought conditions.
- The agricultural outskirts and rural lands surrounding Niš require sustainable water management to maintain productivity and soil health. Efficient irrigation techniques such as drip and smart irrigation, soil moisture conservation practices including cover crops and no-till farming, and the promotion of drought-resilient crops are key measures. Land use planning should avoid high water-demand activities in vulnerable areas and prioritize water-efficient agricultural practices.
- Monitoring and early warning systems are essential across all territories. Soil moisture sensors, reservoir monitoring, and real-

time drought alerts enable proactive management. Public awareness campaigns should target urban residents, peri-urban communities, and farmers, providing guidance on water-saving practices and drought preparedness.

- Finally, municipal policies must integrate drought risk management into planning, zoning, and infrastructure development. Coordinated action across urban, peri-urban, and rural authorities, supported by adequate funding and climate-informed strategies, will enhance the city's resilience to drought.

5.6 Water resources management

Climate change is intensifying existing water management challenges in the City of Niš, with expected increases in the frequency of droughts, extreme rainfall events, heatwaves, and seasonal water imbalances. To safeguard the city's water security, protect ecosystems, and ensure sustainable socio-economic development, a proactive adaptation strategy must be implemented through targeted public policies.

To strengthen drought resilience and ensure long-term water supply security, the City of Niš must prioritize targeted measures that address both urban and rural vulnerabilities.

- In the groundwater recharge zones of Niška Banja and Pantelejš, strict protection of aquifers is essential, paired with construction of new monitoring well stations equipped with automated sensors to detect early signs of depletion.
- In the agricultural belts of Crveni Krst and Donja Trnava, where irrigation demands are highest, policies should promote efficient water use through modern irrigation systems (e.g., introduction of pressurized drip irrigation networks and on-farm water storage reservoirs), and drought-tolerant crop varieties.
- Within the dense urban core, particularly in Medijana and Palilula, rainwater harvesting should become a standard practice for public buildings, commercial facilities, and multi-family residential blocks (e.g., rooftop rainwater harvesting systems), supported by subsidies and building code incentives. The city should also establish emergency modular water treatment units near key supply points, ready to be deployed during prolonged droughts or contamination incidents.
- A city-wide wastewater treatment plant must be completed and fully operational to prevent untreated discharges into the Nišava River. This infrastructure is critical not only for reducing pollution and foul odors during periods of low flow, but also for safeguarding surface and groundwater resources that serve as strategic reserves in times of drought.

- Seasonal water consumption limits for non-essential uses would further safeguard reserves, while permanent water recharge basins in peri-urban areas, such as near the Gabrovačka Reka, would help replenish aquifers naturally.

5.7 Power generation and distribution

The City of Niš faces growing energy challenges due to climate change, including higher electricity demand during heatwaves, aging distribution infrastructure, and vulnerability to extreme weather events. While most electricity is supplied through the national grid, local initiatives such as rooftop solar and district heating present opportunities to increase resilience. To ensure a stable, sustainable, and climate-adaptive energy system, the city should implement a set of forward-looking policies targeting renewable energy, grid modernization, energy efficiency, and risk preparedness, as follows:

- Renewable energy and decentralization: require all new or renovated public buildings—such as schools, hospitals, and municipal facilities—to install rooftop solar panels with battery storage, ensuring critical services have reliable, clean energy while reducing reliance on the national grid during extreme weather or peak demand periods.
- Microgrids and local energy islands: pilot local systems combining solar and storage to operate independently during outages.
- Energy efficiency and demand-side management: promote energy efficiency by subsidizing cool and green roofs to reduce summer electricity demand, encouraging the replacement of old air-conditioning units with high-efficiency models in vulnerable households, and requiring energy performance disclosure for apartments and commercial buildings to drive efficiency improvements.
- Climate resilience and risk preparedness: strengthen climate resilience by equipping critical infrastructure—such as hospitals, water pumping stations, and emergency centers—with renewable-based backup power, conducting annual climate stress tests of the electricity network, and fostering urban-rural energy partnerships that connect peri-urban renewable projects to city demand centers.

5.8 Roads and other transport infrastructures

Climate change is already affecting the transport system of Niš through more frequent flooding, heatwaves, landslides, and drought-related damage to subgrades. To safeguard mobility, reduce long-term costs, and protect citizens, the city should adopt an integrated strategy that combines engineering upgrades, nature-based solutions, and adaptive management, as follows:

- Integrate climate risk screening into all future road and bridge projects. This means that no investment—whether a new road, a rehabilitation program, or even routine maintenance—should proceed without assessing its exposure to heat, floods, and landslides. Updated design standards, based on projected climate conditions for 2050 and beyond, need to replace outdated baselines, ensuring that pavements, culverts, and bridges are built to withstand higher temperatures and more intense storms.
- Strengthen critical corridors. River crossings over the Nišava, approaches to Suva planina and Sićevo Gorge, access to the industrial zones in Crveni Krst, and the road to Niška Banja are lifelines for the city's economy and mobility. These must be reinforced, with redundant routes and safe detours in case of closures. Drainage is another priority: culverts and inlets should be upsized, streets redesigned as linear retention systems with vegetated swales, and riverbanks stabilized to reduce flood damage and bridge scour. Use cool pavements, reflective surfaces, and shade trees along major streets, and protect subgrades in shrink–swell soils with moisture barriers and drains.
- Upgrade public transport and active mobility. Shaded and heat-resilient bus stops, flood-protected depots, and safe, tree-lined pedestrian and cycling routes will support equitable and sustainable mobility. Operations and emergency management should shift toward climate-aware practices, including regular drain cleanouts before flood seasons, rapid-response teams, and clear detour playbooks for each municipality within Niš.
- Improve operations and emergency readiness. Schedule regular drain cleanouts before flood seasons.
- Nature-based solutions should be scaled wherever possible. Rain gardens, green medians, and riparian buffers can help absorb excess water, lower urban heat, and extend the life of infrastructure.
- Worker safety and public health also need attention: road crews should follow strict heat-safety protocols, while vulnerable neighborhoods—especially those souths of the Nišava—should receive priority investments in shade, crossings, and cooling corridors.
- Financing must combine municipal budgets with EU and international instruments, beginning with pilot projects on selected corridors that demonstrate the benefits of resilience-oriented design. Progress should be monitored through clear indicators such as the number of flood-related road closures, pavement damage after heatwaves, and the percentage of shaded public transport stops. These results should be reported transparently to the public.

6 Private innovations and investments for the adaptation to climate change

As climate change intensifies, bringing rising temperatures, extreme weather, and water scarcity to the City of Niš, the tourism and cultural sectors face both challenges and opportunities to adapt and thrive. This chapter explores private sector-led innovations and investments to protect existing services and seize new business opportunities, ensuring Niš remains a vibrant, resilient destination. By focusing on climate-resilient infrastructure, energy and water efficiency, operational adjustments, strategic marketing, and innovative products like eco-tourism and digital experiences, private stakeholders—hotels, tour operators, cultural institutions, and entrepreneurs—can safeguard assets, enhance visitor experiences, and capitalize on emerging demands. These strategies, detailed in Sections 6.1 and 6.2, outline actionable steps to bolster Niš’s tourism and cultural sectors against climate risks while fostering sustainable growth and competitiveness.

6.1 Protecting and adjusting current services activities

The tourism and cultural sectors in Niš, vital to the city’s economy and identity, are increasingly vulnerable to climate change impacts such as rising temperatures, extreme weather events, and water scarcity. To safeguard these sectors, private actors must invest in innovative solutions to protect existing services and ensure visitor comfort and safety under changing conditions. This section outlines private sector-led strategies to enhance the resilience of tourism and cultural activities, focusing on infrastructure upgrades, operational adjustments, energy and water efficiency, and strategic marketing. These measures aim to maintain Niš’s appeal as a year-round destination while addressing climate-related challenges in urban, suburban, and rural zones.

6.1.1 Climate-resilient infrastructure upgrades

Private businesses, including hotels, cultural venues, and tour operators, can protect their services by investing in infrastructure that mitigates the impacts of heatwaves, floods, and storms. These upgrades ensure operational continuity and enhance visitor experiences in key areas like Niš Fortress, Mediana, and Niška Banja.

- **Shading and cooling for open-air sites:** Install pergolas, retractable canopies, or shade sails at outdoor attractions to reduce heat stress. For example, lightweight shading structures at Niš Fortress’s event spaces or Bubanj Memorial Park, costing €10,000–€50,000 per site, can extend visitor comfort during summer festivals. Private operators can fund these through direct

investments or public-private partnerships (PPPs) with the City of Niš, leveraging municipal land access.

- **Climate-controlled indoor facilities:** Upgrade museums (e.g., National Museum of Niš), galleries, and cultural centers with energy-efficient HVAC systems to maintain comfortable indoor conditions during extreme heat or cold. Retrofitting the Archaeological Hall with modern HVAC units, estimated at €100,000–€200,000, protects artifacts and ensures year-round access. Funding can come from private capital, supplemented by EU grants for cultural heritage preservation.
- **Flood- and storm-resilient facilities:** Reinforce infrastructure along the Nišava River to prevent flood damage to riverside venues, such as cafes and event spaces in Medijana and Crveni Krst. Investments in elevated platforms, flood barriers, or bioengineered riverbanks (e.g., willow staking) cost €20,000–€100,000 per site. These can be financed through private investments or joint ventures with local authorities under flood defense programs like the WB FERP project.

6.1.2 Energy and water efficiency innovations

To address energy reliability and water scarcity, private stakeholders should adopt sustainable technologies that reduce resource dependency and operational costs, particularly in high-demand areas like hotels and spa facilities in Niška Banja.

- **Renewable energy investments:** Install solar panels with battery storage on hotels, museums, and theatre to ensure energy reliability during heatwaves or grid outages. A 50 kW solar system for a medium-sized hotel in Medijana City Municipality, costing €40,000–€60,000, can power cooling systems and reduce energy costs. Government incentives for renewables, such as Serbia's feed-in tariffs, can offset initial costs, with savings recouped within 5–7 years.
- **Water-saving technologies:** Implement rainwater harvesting and greywater recycling systems to support irrigation and non-potable uses. For instance, hotels in Niška Banja can install 10,000-liter rainwater tanks, costing €5,000–€10,000, to maintain gardens during droughts, preserving the aesthetic appeal for tourists. These systems can be funded through private budgets or supported by municipal subsidies for sustainable practices.

6.1.3 Operational and service adjustments

Adapting operational practices ensures that tourism and cultural services remain viable and safe under climate pressures. Private businesses can implement low-cost, high-impact changes to enhance resilience.

- **Flexible scheduling:** Shift tour times and cultural events to cooler hours (e.g., early mornings or evenings) during heatwaves to improve visitor comfort. For example, rescheduling guided tours of Čegar Hill or Mediana to avoid peak heat (11:00 –16:00) requires minimal investment (€1,000–€5,000 for staff training) but enhances safety and satisfaction. Tour operators can coordinate with the Tourist Organization of Niš to align schedules.
- **Digital ticketing and crowd management:** Use digital platforms to reduce outdoor waiting times and manage visitor flows during extreme weather. Implementing mobile ticketing for events like the Nišville Jazz Festival, costing €10,000–€30,000 for app development, minimizes heat exposure and improves efficiency. Sponsorships from local businesses or cultural grants can cover costs.
- **Health and safety protocols:** Provide hydration stations, shaded rest areas, and cooling zones at high-traffic sites. Installing misting systems and drinking fountains at Čair Park or near Niš Fortress, costing €5,000–€15,000 per site, ensures visitor well-being. Training staff to handle heat-related emergencies, at €2,000–€5,000 per business, builds trust and enhances safety. These measures can be funded through operational budgets or PPPs.

6.1.4 Marketing and communication strategies

Strategic marketing can position Niš as a climate-resilient destination, attracting visitors despite climatic challenges and enhancing the sector's competitiveness.

- **Promoting climate-adapted tourism:** Market Niš's shaded venues, air-conditioned cultural sites, and sustainable practices as a "climate-smart" destination. For example, promoting indoor attractions like the National Museum during summer heatwaves can maintain visitor numbers. Marketing campaigns, costing €10,000–€50,000, can be co-funded by private businesses and the Tourist Organization of Niš, targeting regional and international markets.
- **Educational tours on climate adaptation:** Develop tours showcasing Niš's resilience efforts, such as bioengineered riverbanks or sustainable vineyards in the Nišava District. These tours, priced at €20–€50 per person, can generate revenue while raising awareness. Content development, costing €5,000–€15,000, can be supported by private tour operators or cultural institutions, with potential co-financing from EU tourism grants.

6.1.5 Implementation and financing models

To realize these innovations, private stakeholders must collaborate with public entities and leverage diverse funding sources:

- **Public-private partnerships (PPPs):** Collaborate with the City of Niš to access municipal land for shading installations or flood defenses, reducing costs for private operators. For example, PPPs can fund canopy installations at Niš Fortress, with the city providing permits and businesses covering materials.
- **EU and international funding:** Tap into EU programs like the Instrument for Pre-Accession Assistance (IPA) or Horizon Europe for grants supporting sustainable tourism and cultural heritage. These can cover 50–80% of costs for HVAC upgrades or renewable energy projects.
- **Private capital and incentives:** Hotels and cultural venues can use operational profits or bank loans for infrastructure upgrades, with government subsidies for renewables and water efficiency reducing financial burdens.
- **Capacity building:** Invest in staff training (€1,000–€5,000 per business) and establish a Niš Tourism Resilience Network (€10,000–€20,000) to share best practices. Membership fees or sponsorships can sustain the network.

Table 3. Summary of possible key actions and benefits of protecting and adjusting current tourism services activities in the City of Niš regarding climate risks

Category	Key Actions	Estimated Cost (per site/project)	Expected Benefits
Climate-Resilient Infrastructure	Install pergolas, retractable canopies, or shade sails at open-air sites (e.g., Niš Fortress, Bubanj Memorial Park); upgrade museums and cultural centers with energy-efficient HVAC systems; reinforce riverside venues with flood barriers or bioengineered riverbanks (e.g., willow staking in Medijana).	€5,000–€200,000	Enhanced visitor comfort during heatwaves, protection of cultural assets from floods, and ensured operational continuity for tourism sites.
Energy and Water Efficiency	Install solar panels with battery storage on hotels and cultural venues; implement rainwater harvesting and greywater recycling for irrigation at hotels and heritage sites (e.g., Niška Banja).	€5,000–€60,000	Reduced energy and water costs, increased reliability during heatwaves or droughts, and enhanced sustainability for eco-conscious tourists.

Category	Key Actions	Estimated Cost (per site/project)	Expected Benefits
Operational Adjustments	Shift tour/event schedules to cooler hours; implement digital ticketing and crowd management systems (e.g., for Nišville Jazz Festival); provide hydration stations and shaded rest areas at high-traffic sites (e.g., Čair Park, Niš Fortress).	€1,000–€30,000	Improved visitor safety and comfort, reduced heat exposure, and enhanced efficiency in managing visitor flows during extreme weather.
Marketing and Communication	Promote Niš as a “climate-smart” destination with shaded venues and indoor attractions; develop educational tours showcasing climate adaptation (e.g., sustainable vineyards, bioengineered riverbanks).	€5,000–€50,000	Increased visitor numbers year-round, enhanced destination appeal, and new revenue streams from climate-themed tourism products.

By implementing these private sector-led innovations, Niš can protect its tourism and cultural services from climate impacts, ensuring resilience and competitiveness. These actions not only safeguard existing assets but also position Niš as a forward-thinking destination, attracting eco-conscious travelers and investors. For a phased implementation plan, prioritizing quick wins like shading and digital ticketing in the short term (1–2 years), followed by infrastructure upgrades (3–5 years) and marketing campaigns (5–10 years), could maximize impact and stakeholder engagement.

6.2 Catching new business opportunities

Private stakeholders—tour operators, hoteliers, cultural institutions, and local entrepreneurs—can seize these opportunities by developing new offerings that cater to eco-conscious travelers, leverage off-season potential, and integrate digital solutions. This section outlines private sector-led initiatives to create new business opportunities, focusing on experiential tourism, sustainable accommodations, digital services, cultural products, and strategic partnerships to position Niš as a forward-thinking destination.

6.2.1 Experiential and seasonal tourism

Private businesses can develop new tourism experiences that capitalize on Niš’s natural and cultural assets while adapting to climate-driven seasonal shifts.

- **Eco-tourism and nature-based experiences:** Develop guided river tours, hiking, and cycling routes in shaded peri-urban zones like Niška Banja, Sićevo Gorge, and Suva Planina. For example, curated eco-tours along the Nišava River, emphasizing sustainable interaction with riparian ecosystems, can attract nature enthusiasts. These tours, priced at €15–€40 per person, require initial investments of €10,000–€30,000 for trail development, signage, and guide training. Partnerships with local environmental NGOs can enhance authenticity and reduce costs.
- **Off-season cultural events:** Promote festivals, exhibitions, and performances in spring and autumn to diversify tourism beyond the heatwave-prone summer season. For instance, a spring cultural festival in Niš Fortress showcasing local music and art, costing €20,000–€50,000 to organize, can draw domestic and regional visitors. Private event organizers can fund these through ticket sales and sponsorships, leveraging Niš's growing reputation as a year-round destination.

6.2.2 Climate-smart accommodations

New lodging solutions can cater to eco-conscious travelers and adapt to climate extremes, enhancing Niš's appeal in suburban and rural areas.

- **Green hotels and lodgings:** Build or retrofit hotels with passive cooling (e.g., ventilated facades, shading louvers), solar energy, and water-efficient systems. For example, retrofitting a medium-sized hotel in Niška Banja with solar panels and low-flow fixtures, costing €50,000–€100,000, attracts eco-conscious guests and reduces operational costs by 20–30%. Government incentives for green building certifications can offset initial expenses.
- **Pop-up or modular accommodations:** Develop temporary lodging solutions in cooler, shaded areas like Koritnik or Bubanj hills for peak seasons affected by heatwaves. Modular eco-cabins, costing €15,000–€40,000 per unit, offer flexible capacity and can be deployed on leased municipal land. Private investors can recoup costs through seasonal rentals, targeting adventure and wellness tourists.

6.2.3 Digital and hybrid services

Digital innovations can provide alternative access to Niš's cultural and tourism offerings, ensuring resilience during extreme weather events.

- **Virtual tours and augmented reality (AR) experiences:** Offer virtual access to landmarks like Niš Fortress, Mediana, or the Skull Tower during heatwaves or storms. Developing AR apps for mobile devices, costing €20,000–€100,000, allows tourists to explore sites remotely or

enhance on-site visits with interactive content. Private cultural institutions can fund these through grants from EU programs like Creative Europe.

- **Online booking and climate alerts integration:** Create booking platforms that dynamically adjust schedules based on weather forecasts, suggesting climate-safe itineraries. For example, a platform for Nišville Jazz Festival or museum visits, costing €10,000–€30,000 to develop, can recommend indoor activities during heat alerts. Tour operators can finance this through operational budgets or partnerships with tech startups.

6.2.4 New cultural products

Innovative cultural offerings can highlight Niš's heritage and adaptation efforts, creating unique value propositions for tourists.

- **Climate-themed cultural packages:** Develop tours and exhibitions focused on Niš's history, climate resilience, and heritage preservation. For instance, a guided tour of bioengineered riverbanks or sustainable vineyards in the Nišava District, priced at €20–€50 per person, can educate visitors on local adaptation. Content development, costing €5,000–€15,000, can be led by private tour operators with support from the Tourist Organization of Niš.
- **Local culinary and craft products with climate story:** Promote locally sourced, sustainable products like organic wines from the Nišava Valley or climate-friendly souvenirs (e.g., pottery inspired by resilience themes). Marketing and production setup, costing €10,000–€30,000, can be driven by local artisans and funded through crowdfunding or small business grants, enhancing Niš's cultural appeal.

6.2.5 Partnerships and investment models

Strategic collaborations and innovative financing can scale these opportunities, ensuring long-term sustainability.

- **Public-private partnerships (PPPs):** Encourage PPPs to fund resilience-focused tourism infrastructure, such as eco-tour trails or modular accommodations. For example, the City of Niš can provide land access for pop-up cabins in Niška Banja, with private investors covering construction costs of €50,000–€100,000 per project. These partnerships reduce financial risks and align with municipal climate goals.
- **Attracting climate-focused investors:** Position Niš as a testbed for innovative tourism solutions by showcasing pilot projects like green hotels or AR tours. Investor pitch events, costing €5,000–€20,000 to organize, can attract climate-focused venture capital or EU funding (e.g., Horizon Europe). The Tourist

Organization of Niš can lead promotion efforts, highlighting economic and environmental benefits.

Table 4. Summary of possible key actions and benefits of catching new business opportunities in the City of Niš regarding climate risks

Opportunity	Description	Estimated Investment Scale	Benefits	Possible Financing/Partners
Eco-Tourism & Nature Packages	Climate-smart hiking, cycling, river tours, peri-urban shaded routes	€0.5–1.5M	New tourism segment, eco-branding of Niš	Private tour operators, green tourism funds
Off-Season Festivals & Cultural Events	Shift music, film, art festivals to spring/autumn; invest in seasonal event infrastructure	€0.7–2M	Extends tourist season, stabilizes revenues	Event sponsors, local hospitality sector
Green & Smart Hotels	Eco-certified hotels with passive cooling, solar energy, water reuse	€3–6M	Attracts eco-conscious visitors, lower O&M costs	Private investors, green credit lines
Modular / Pop-up Lodging	Temporary structures in cooler peri-urban zones (Niška Banja, Jelašnica Gorge)	€0.5–1.2M	Flexibility for demand peaks, resilience to heat	Innovative entrepreneurs, venture funds

Opportunity	Description	Estimated Investment Scale	Benefits	Possible Financing/Partners
Digital & Virtual Tourism	AR/VR reconstructions of Niš Fortress, Roman heritage, museum digital twins	€0.5–2M	Tourism access during extreme weather, global reach	Tech start-ups, EU digital culture funds
Climate-Themed Cultural Products	Souvenirs, food, and craft products linked to adaptation and sustainability	€0.2–0.6M	Local entrepreneurship, authentic climate branding	Local artisans, small business grants

7 International cooperation for synergic actions to face climate change

Effectively addressing the climate-related vulnerabilities of Niš’s tourism and cultural sectors demands active engagement in international cooperation and access to targeted funding instruments. International cooperation is not only a source of funding but also a channel for visibility, knowledge exchange, and innovation. By positioning itself as an active partner in global, European, and regional frameworks, Niš can amplify its adaptation efforts, build long-term partnerships, and align its strategies with EU Green Deal and European Climate Law objectives. Participation in these programs would transform climate risks into opportunities for sustainable development, enabling Niš to strengthen its profile as a resilient cultural and tourism hub in Southeastern Europe.

Niš can benefit from ongoing UNESCO initiatives that explicitly link cultural heritage with climate adaptation in Southeast Europe. In May 2025, UNESCO launched a high-level regional process in Podgorica to unlock climate finance for cultural heritage, water, and biodiversity, engaging six countries of the Western Balkans. Within this framework, the proposed CHERISH (Cultural Heritage Resilience in South-East Europe) program aims to integrate heritage preservation with climate adaptation measures. For Niš, participation in such initiatives provides access to technical expertise, heritage-sensitive adaptation methodologies, and direct readiness support for climate finance. UNESCO’s networks also offer opportunities for international

recognition of Niš's heritage under stress, positioning the city as a pilot site for innovative approaches to safeguarding culture in changing climatic conditions.

At the EU level, Creative Europe (2021–2027) allocates EUR 1.46 billion to strengthen cultural and creative sectors. Its Culture strand supports cross-border cooperation, networks, platforms, and initiatives such as European Capitals of Culture—all relevant for Niš as it seeks to strengthen its international profile and diversify tourism beyond peak seasons. The Media strand provides opportunities for audiovisual heritage promotion and digital transformation of cultural industries, while the Cross-sectoral strand fosters innovation and resilience. For Niš, tapping into Creative Europe would allow the city to finance cultural programming, strengthen links with European partners, and modernize how heritage is presented to climate-conscious visitors.

In addition, EU Cities Adapt, initiated by DG CLIMA, provides guidance and capacity-building for integrating climate adaptation into urban planning. Participation in this initiative could help Niš embed resilience considerations into its tourism infrastructure and cultural heritage management strategies, ensuring alignment with European adaptation standards.

Beyond cultural programs, Niš can access funding from broader European climate initiatives. The European Climate Initiative (EUKI) has financed more than 150 cross-border projects in 31 countries, with a budget of over EUR 79 million. Its focus on capacity-building, education, and applied climate projects creates strong opportunities for Niš to link tourism and heritage protection with low-carbon innovation and resource efficiency. Similarly, Serbia's association with Horizon Europe allows access to research and innovation projects on climate-resilient tourism, smart cultural heritage conservation, and digital adaptation tools. These instruments can provide both technical know-how and financial leverage for local adaptation projects.

Niš is strategically positioned within the Adriatic-Ionian Macro-Regional Strategy (EUSAIR) and can also engage with the Danube Strategy, both of which promote climate adaptation, sustainable tourism, and cultural cooperation. Through Interreg programmes, Niš can participate in transnational projects that integrate heritage protection with eco-tourism and climate-proof infrastructure. For example, recent Interreg calls under the EmBRACE initiative have made available over EUR 3 million for cross-border projects in sustainable tourism between Serbia and neighboring countries. Leveraging these opportunities would allow Niš to share solutions with cities facing similar challenges, while securing resources for pilot interventions.

Conclusions

The findings of this territorial analysis demonstrate that climate change poses a profound and multidimensional challenge to the tourism and cultural industries of the City of Niš. As an inland destination that combines spa and wellness tourism, eco-adventure opportunities, and a rich cultural and historical heritage, Niš is highly exposed to climate variability. Rising average temperatures and prolonged heatwaves reduce visitor comfort, shorten outdoor activity periods, and increase health risks for both residents and tourists. Irregular precipitation and sudden storm events undermine the reliability of seasonal tourism, while floods and landslides threaten the accessibility of key cultural sites and natural attractions. At the same time, droughts and reduced water availability jeopardize the functioning of spa tourism, one of the city's most distinctive assets. Cultural heritage monuments, including Roman, Ottoman, and modern landmarks, are increasingly vulnerable to accelerated physical deterioration caused by thermal stress, humidity fluctuations, and extreme weather events. Taken together, these pressures risk diminishing Niš's competitiveness in both domestic and international tourism markets, while imposing additional costs on the preservation of cultural assets and the delivery of tourism-related services.

From a policy perspective, adaptation requires a comprehensive and proactive approach that integrates cultural heritage protection, tourism development, and climate resilience. In the short term, local authorities should prioritize safeguarding vulnerable cultural monuments and collections from climate-related deterioration through preventive conservation, improved monitoring systems, and targeted restoration programs. Equally important is the protection of visitors and communities during extreme heat and flood events, requiring the development of heat action plans, early warning systems, and designated safe zones in tourist-heavy areas. Infrastructure upgrades are essential to ensure reliable water supply, wastewater treatment, energy services, and mobility during periods of climate stress, all of which are prerequisites for sustaining a functional tourism economy. In parallel, diversification of the tourism offer is needed: beyond the concentration of visits in peak summer months, Niš should promote year-round cultural events, conference and business tourism, indoor museum and heritage experiences, and wellness activities that are less dependent on weather conditions.

Over the medium to long term, the city must embed climate adaptation into its territorial planning and cultural heritage management strategies. This includes integrating climate risk assessments into spatial and tourism development plans, aligning cultural heritage protection with sustainability goals, and mainstreaming resilience criteria into all investment decisions related to tourism and culture. Incentives for private sector

engagement are critical, particularly in energy efficiency, water conservation, and the adoption of climate-smart building standards in hotels, restaurants, and leisure facilities. Sustainable mobility solutions, such as expanded cycling infrastructure, low-emission public transport, and improved pedestrian access to cultural sites, will also be essential in reducing environmental pressures while strengthening the accessibility of the tourism sector.

Finally, Niš's adaptation efforts should be positioned within regional and international frameworks. Cooperation within the ADRION region and with European networks of cultural cities can provide financial leverage, technical expertise, and shared practices for climate adaptation in tourism and cultural heritage management. Accessing EU climate funds, heritage preservation programs, and innovation partnerships can support Niš in transforming its vulnerabilities into opportunities for sustainable growth. By combining public policy innovation, infrastructure modernization, and private sector leadership, Niš can reposition itself as a resilient cultural and tourism hub in Southeastern Europe. Ensuring that adaptation strategies are fully integrated into the city's economic development agenda will not only protect its unique cultural assets but also create new opportunities for employment, investment, and international visibility, making tourism and cultural industries key drivers of a climate-resilient future for the city.

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