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EARLY ASSESSMENT OF GROWTH AND SURVIVAL RATE OF EUROPEAN BEECH (*Fagus sylvatica* L.) IN PROVENANCE TRIAL ON GOČ MOUNTAIN

Vladan POPOVIĆ[1], Sanja JOVANOVIĆ[1], Aleksandar LUČIĆ[1], Ljubinko RAKONJAC[1], Danijela MILJKOVIĆ[2]

Abstract: *Different scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades. Due to climate change, European beech will face a change in phenology, mortality, and reduced tree growth, with a particular tendency to reduce forest productivity in the southern part of its distribution range. Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time.*

This research aims to determine and describe the growth and survival rate of European beech seedlings from 29 provenances in a trial established on Goč Mountain.

The trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe. The European beech provenance trial was established in the spring of 2021 on Mt. Goč in central Serbia. At the end of the vegetation period in 2021, the height and root collar diameter of seedlings were measured, and the survival rate was recorded. The seedling survival rate ranged from 40.7% to 84%. Statistically significant differences between the provenances were determined for the height and root collar diameter, and the correlation values of the measured traits.

The Mt. Goč provenance trial remains a valuable resource for studying the performance of European beech provenances and can provide guidelines for their tolerance and adaptation.

Key words: beech, provenances, adaptation, survival, seedlings.

РАНА ПРОЦЕНА РАСТА И ПРЕЖИВЉАВАЊА БУКВЕ (*Fagus sylvatica* L.) У ПРОВЕНИЈЕНИЧНОМ ТЕСТУ НА ГОЧУ

Извод: *Према различитим сценаријима, у наредним деценијама драматично ће се смањити макроклиматски погодна подручја за букву. Као последица климатских промена доћи ће до промене фенологије, повећања морталитета и умањења раста*

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стабала, са нарочитом тенденцијом смањења продуктивности шума у јужном делу ареала. Провенијенични тестови представљају управо истраживање прилагођавања популација различитог порекла исте врсте на одређене услове средине и дају јединствен увид у одговор биљке на измењено стање околине, у реалном времену.

Циљ истраживања у овом раду био је да се утврде и опишу подаци раста и преживљавања садница букве из 29 провенијенција у провенијеничном тесту на Гочу.

За успостављање провенијенишног теста одабрано је 29 провенијенција букве са подручја ареала у центаралној и југоисточној Европи. Провенијенични тест је основан на планини Гоч у централној Србији у пролеће 2021. године. На крају вегетационог периода 2021. године, извршена су мерења висине, пречника кореновог врата и регистровање преживљавања садница. Преживљавање садница се кретало од 40,7% до 84%. Утврђене су статистички значајне разлике између провенијенција за висине и пречник кореновог врата садница, као и за вредности корелационих односа мерених особина.

Провенијенични тест на Гочу остаје вредан ресурс за проучавање учинака европских провенијенција букве и може дати смернице за њихову толеранцију и адаптацију.

Кључне речи: буква, провенијенције, адаптација, преживљавање, саднице.

1. INTRODUCTION

European beech (*Fagus sylvatica* L.) is one of the most important species of forest trees in Europe, both ecologically and commercially. It is susceptible to spring frosts and extended dry periods (Granier et al, 2007), which makes it very vulnerable to predicted climate scenarios (Piovesan et al., 2008). Projections based on IPCC scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades (Czúcz et al., 2011). Due to climate change, European beech will face a change in phenology, increased mortality, and reduced tree growth (Gárate-Escamilla et al., 2019), with a particular tendency to reduce forest productivity in the southern part of its distribution range (Del Castillo et al., 2022). The central part of Europe is already suffering the adverse effects of climate change to a certain extent (Zimmermann et al., 2015). It is estimated that an increase in temperature will cause a significant decrease in the number of European beech trees at elevations below 500 m in some southern parts of the range by the end of the 21st century (Pavlović et al., 2019). Additionally, complex disturbances caused by biotic factors occur as a consequence of reduced tree vitality (Langer and Bußkamp, 2023). Understanding key functional indicators of adaptability is especially necessary in mitigating the impact of climate change (Kramer et al., 2010). However, until now, there has not been enough research comparing selected populations from the Western Balkans and Central Europe, especially indicating their potential for growth as a parameter of adaptation to climate change.

One of the main features of the living world is diversity, and the main features of the species are their variability and the ability of different genotypes to adapt to various environmental conditions. Local adaptation enabled the persistence and maintenance of broad distribution areas of particular plant species (Brancalion et al., 2018; Klisz et al., 2023). Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time. They, in effect, represent programs or plans for establishing and restoring forests, enabling the monitoring of various parameters to determine the best-adapted origin to the given conditions (White et al., 2007). Provenance trials involve collecting seeds by selecting mother trees of different origins, producing seedlings, and planting them in a unique, homogeneous area. They also provide subsequent measurements and data analysis of various plant characteristics (Atiken, 2004).

Provenance trials have been established in forestry since ancient times, when they were primarily used to increase production capacity (Mátyás, 1996). Today, climate change is at the epicenter of environmental research, so provenance trials are established for selecting future reproductive material for maintaining existing forest ecosystems and establishing new, more resistant ones. Data such as growth and survival rate, resistance to diseases and pests, flowering, phenological data, as well as the characteristics of the trunk essential for the utilization in the industry (Potts, 2004) are very significant as they represent the basis for the selection of adequate genetic material, greatly facilitating forest management in the future. Climate changes are happening rapidly, and their effects are becoming visible and measurable through the increasing number of rehabilitation plans for damages caused by wind-breaks, ice-breaks, droughts, floods, fires, or pest attacks. Plant organisms cannot keep up with this rate of change in environmental conditions or the rate of natural migration of species, so human assistance is mandatory to prevent adverse predictions (Loreto and Atzori, 2024).

Beech is, in addition to particular oak species, the most important forest species in the Serbian growing stock. European beech forests are the most widespread in Serbia and have the largest share of wood volume. They inhabit a wide range of elevations, ranging from very low (70 m near Negotin) to over 1500 m (Stojanović et al. 2005). One of the models that predict climate change in Serbia, taking extreme values into the calculations, predicts a decrease in the area of European beech forests by 90% by the end of the 21st century (Stojanović et al., 2013). European beech provenance trials have been established throughout Europe, and the data are monitored even today (Muhs and von Wuehlisch, 1993; von Wuehlisch, 2004; von Wuehlisch et al., 2010; Stojnić et al., 2010; Horvath et al., 2016; Mohytych et al., 2024). A new European beech provenance trial covering 29 provenances from distribution areas in Central and Southeastern Europe was established on Goč Mountain in Central Serbia, and this research aims to determine and describe the growth and survival rate of these beech seedlings. The findings will be a valuable resource for future research on the performance of European beech populations and may provide insights into their adaptation abilities.

2. MATERIAL AND METHODS

Experimental site

The trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe, and their general characteristics are shown in Table 1. In the fall of 2018, about 1 kg of visually healthy seeds were collected from each provenance. The collected seeds were processed in the laboratory of the Institute of Forestry in Belgrade. After analyzing their quality and health status, a nursery test was established in the spring of 2019 at the nursery of the Institute of Forestry in Belgrade.

Table 1. *Data on the studied provenances of European beech*

Provenance label	Provenance name	Latitude	Longitude	Elevation (m)
BG1	Centralni Balkan	42.86444	24.24941	1100
BG2	Rila	42.26417	23.28333	1280
SRB1	Mali Jastrebac	43.39092	21.65006	830
SRB2	Rudnik	44.10531	20.6136	700
SRB3	Povlen	44.16111	19.69861	870
SRB4	Javor	43.44913	20.06806	1350
SRB5	Goč	43.56351	20.75001	920
SRB6	Fruška Gora	45.14194	19.62289	370
SRB7	Severni Kučaj	44.12941	21.79868	730
SRB8	V. Jastrebac	43.36242	21.56092	810
SRB9	Južni Kučaj	44.07015	21.75708	700
SRB10	Stara Planina	43.38065	22.60313	1260
SRB11	Dubašnica	44.10063	21.88801	900
SRB12	Miroč	44.57029	22.37021	450
SRB13	Kukavica	42.79124	21.97133	1200
SRB14	Boranja	44.38997	19.28981	650
SRB15	Kačer-Zeleničje	42.82314	22.21206	1180
MNE1	Borak	42.82738	19.99544	1250
MNE2	Kovač	43.40833	19.11611	960
BIH1	Javor	44.15611	18.94333	1010
BIH2	Lisina	45.02522	17.00861	400
HR1	Bukovača	45.34747	15.22334	435
HR2	Građevačka Biogora	45.79191	17.12667	185
HR3	Južni Papuk	45.50722	17.63802	685
HR4	Bublen	45.23139	15.84747	205
SI1	Hrastovec	46.35667	15.96667	300
SI2	Osankarica	46.45325	15.38333	1240
CZ1	Malužin	49.27334	16.66171	360
DE1	Harz	51.78503	10.51716	820

Country abbreviations: BG-Bulgaria; SRB-Serbia; MNE-Montenegro; BIH-Bosnia and Herzegovina; HR-Croatia; SI-Slovenia; CZ-Czech Republic; DE-Germany.

The European beech provenance trial is situated on Goč Mountain (Latitude 43.56139 Longitude 20.80056) at 980 m.a.s.l., a northeast exposition in the central part of Serbia, in Management Unit "Gračac", department 20a, Public Enterprise "Šume Goč" Vrnjačka Banja. The climate on the mountain is temperate continental. Mean air temperature is 7.5°C, and annual precipitation is 856 mm. The trial was established in spring 2021 by planting two-year-old seedlings. The seedlings were planted with a spacing of 2 × 1 m, resulting in a density of 4350 plants in 1 ha (50 seedlings per provenance × 3 replicates (blocks) × 29 provenances = 4350 seedlings). The experimental design is a randomized complete block with three replicates, which was used for all trials in this series. One replicate of each provenance consisted of 50 plants planted in five rows of 10 planting sites (10 × 10 m plot). According to von Wühlisch (2004), the plots are large enough to maintain the trials for 60 years. At the end of the vegetation period in 2021, the height and root collar diameter of seedlings aged 2+1 (two-year-old seedlings after one year of growth in the field trial) were measured, and the survival rate was recorded. The height was measured with a ruler with an accuracy of 0.5 cm, and the root collar diameter with a vernier caliper with an accuracy of 0.1 mm.

Statistical methods

The measured morphometric traits of the seedlings included the root collar diameter (**d**, in mm) and seedling height (**h**, in cm), which were analyzed using the SAS statistical package (SAS Institute, Inc. 2011). The mean values of all analyzed seedling traits were calculated using the MEANS procedure. The significance of the differences between the mean values of the provenances for the analyzed parameters was confirmed using one-way ANOVA (GLM Procedure). Correlations between **d** and **h** were obtained in the CORR Procedure. To examine the differences between the provenances, a multivariate statistical analysis, Agglomerative hierarchical clustering (AHC), was performed, which grouped the provenances based on the differences in the analyzed seedling characteristics using the pair-group average method.

3. RESULTS AND DISCUSSION

Provenance BIH2 (Lisina) with 84% surviving plants proved to be the best, followed by provenance HR4 (Bublen) with 82% surviving plants, HR2 (Građevačka Biogora) with 74.7% surviving plants, HR3 (Južni Papuk) with 74% surviving plants, and SRB13 (Kukavica) with 70.7% surviving plants. The worst survival rate had the provenances CZ1 (Malužin) with 40.7% surviving plants, SRB6 (Fruška Gora) and SRB14 (Boranja) with 48% surviving plants, and SRB10 (Stara Planina) with 49.3% surviving plants. The plant survival rate above 60% was determined in 19 out of 29 provenances, while in 6 provenances the plant survival rate was between 50% and 60% (Figure 1).

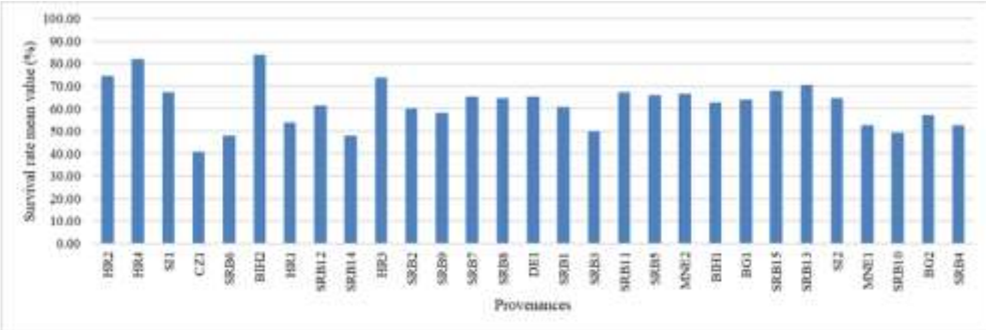

Figure 1. *Survival rate at the provenance trial*

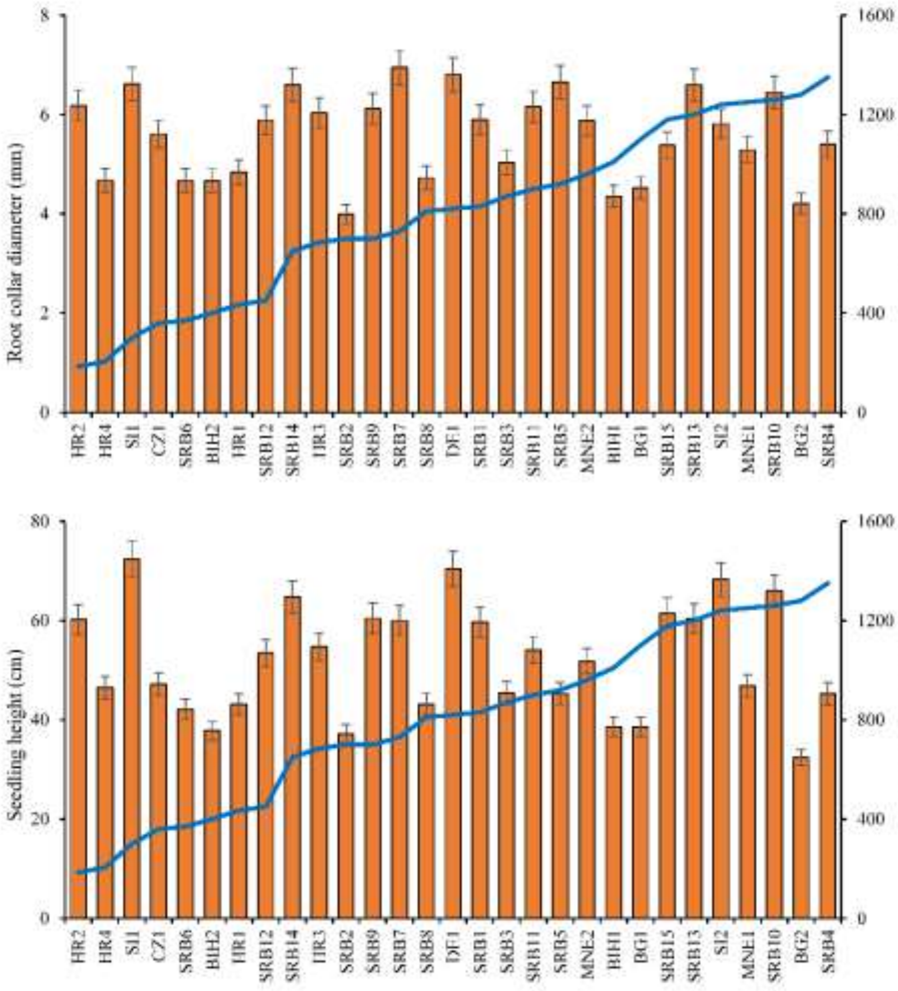

Figure 2. *Histogram showing the mean values of root collar diameter (mm) and seedling height (cm) (bars with standard error) from 29 provenances in a provenance trial set on Goč Mountain across elevation (m.a.s.l.) (blue line).*

The mean values of root collar diameter and seedling height were not correlated with the elevation of the provenance origin. Root collar diameter values ranged from 3.99 mm SRB2 (Rudnik) to 6.94 mm SRB7 (North Kučaj). For the seedling height trait, the values ranged from 32.38 cm BG2 (Rila) to 72.37 cm SI1 (Hrastovec) (Figure 2). The results of one-factor ANOVA confirmed statistically significant differences between provenances for both analyzed traits (all p<0.0001).

The correlation values of the measured traits were statistically significant (all p<0.0001) in the range from 0.77 SRB1 (Mali Jastrebac) to 0.29 BIH2 (Lisina) (Figure 3).

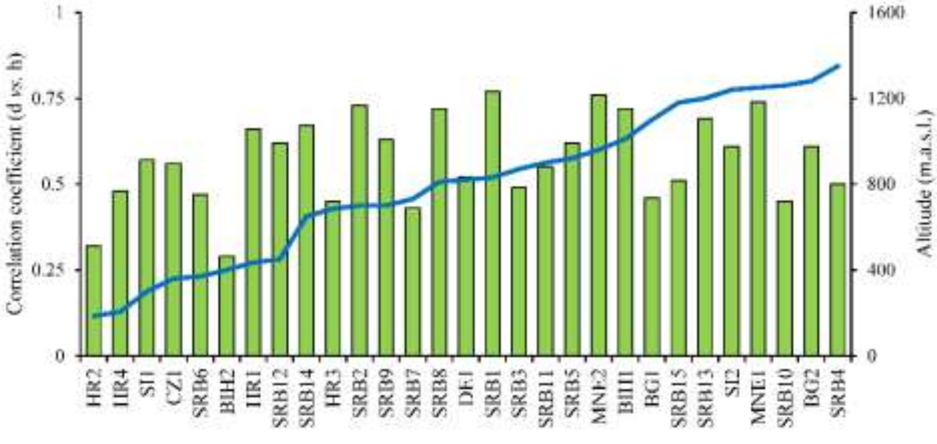

Figure 3. *Histogram showing the correlation coefficient values (d - root collar diameter vs. h - seedlings height (green bars) from 29 provenances in a provenance trial set on Goč Mountain across elevation (m.a.s.l.) (blue line).*

Following the results of the applied multivariate statistical cluster analysis (AHC) for the analyzed traits, the provenances are divided into three clusters based on differences. The first cluster includes 10 provenances, the second has five with more similar differences, and the third contains 14 provenances (Figure 4).

Despite their demands on time and establishment costs, provenance trials are still very important and informative when selecting a planting site and seeds of suitable origin (Risk et al., 2021). The higher percentage of survival rate of specific provenances can be interpreted through better adaptation to local environmental conditions. However, the cause of the lower percentage of survival rate of other provenances may be rodent attack, issues of planting microsite conditions, or ecological effects of transplanting (Horváth et al., 2016). Mohytych et al. (2024) also highlighted the impact of the microenvironment on the survival of beech trees in their 28-year-old provenance trial in the Ukrainian trial site.

Unterholzner et al. (2024) studied, among other things, tree-ring width (TRW), diameter at breast height (DBH), and climate-growth relationships of 24 beech provenances at three trial sites in Germany along the latitudinal gradient. Despite greater differences between trial sites, the differences between provenances within one field were minor, indicating the remarkable plasticity of beech as a species. Our work showed statistically significant differences between the traits studied and the provenances. Therefore, the observed variances represent differences in the genotypes of the studied provenances. Significant differences between the tested provenances of beech for the height and root collar diameter were reported by I. Ballian, Zukić (2011), and I. Stojnić et al. (2010). However, grouping provenances into three clusters, in which each group is mutually heterogeneous in terms of elevation of origin, indicates a similar strategy of phenotypic plasticity.

Additionally, Unterholzner et al. (2024) also indicated the greater importance of climate conditions in habitat conditions compared to seed origin. This aligns with our research findings, which show no correlation between the elevation of provenance origin and height and root collar diameter values.

Although the goal of such trials is to select provenances that will best adapt to the targeted environmental conditions and show the best performance, which is also associated with stronger physiological resistance of seedlings, Hoffman (1961) indicates that the measured height of seedlings at a younger age cannot be a reliable parameter in assessing the growth of provenances, because differences are manifested at a later age. On the other hand, these studies are necessary in the selection process and represent initial steps in the long-term monitoring of provenance adaptations.

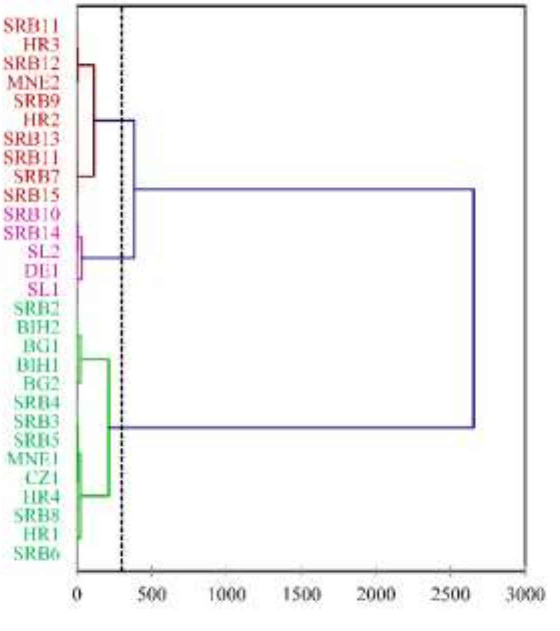

Figure 4. *Dendrogram illustrating hierarchical clustering of 29 provenances in a provenance trial set on Goč Mountain based on ACH dissimilarity. The height of each branch indicates the level of dissimilarity between clusters, with shorter branches representing more similar ACH profiles.*

4. CONCLUSION

This research provides valuable information about the qualitative and quantitative traits of beech seedlings, which result from possible adaptation to naturally drier and warmer or colder and wetter environmental conditions. The adaptive potential of beech seedlings plays a key role in adapting to projected climate changes and will enable the survival of this species.

The seedling survival rate ranged from 40.7% to 84%. The root collar diameter values ranged from 3.99 mm to 6.94 mm, while seedling heights ranged from 32.38 cm to 72.37 cm. Statistically significant differences between the provenances were determined for the height and root collar diameter, as well as for the correlation values of the measured traits.

The provenance trial conducted on Mt. Goč showed significant variability in survival rate and growth among different European beech provenances. This variability and adaptive potential of beech seedlings provide opportunities for further research and breeding programs that will enable the survival and reproduction of this species in the face of predicted rapid climate change.

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EARLY ASSESSMENT OF GROWTH AND SURVIVAL RATE OF EUROPEAN BEECH (*Fagus sylvatica* L.) IN A PROVENANCE TRIAL ON GOČ MOUNTAIN

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Summary

European beech (*Fagus sylvatica* L.) is one of the most important species of forest trees in Europe, both ecologically and commercially. Projections based on different scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades. Due to climate change, European beech will face a change in phenology, increased mortality, and reduced tree growth, with a particular tendency to reduce forest productivity in the southern part of its distribution range. Understanding key functional indicators of adaptability is especially necessary in mitigating the impact of climate change. Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time.

They represent guidelines for programs/plans for establishing and restoring forests, enabling the monitoring of various parameters to determine the best-adapted origin to the given conditions. Until now, there has not been enough research comparing selected populations from the Western Balkans and Central Europe, especially indicating their potential for growth as a parameter of adaptation to climate change.

This research aims to determine and describe the growth and survival rate of European beech seedlings from 29 provenances within this provenance trial established on Goč Mountain.

The provenance trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe. It was established on Mt. Goč in spring 2021 by planting two-year-old seedlings. The seedlings were planted with a spacing of 2 × 1 m, resulting in a density of 4350 plants in 1 ha (50 seedlings per provenance × 3 replicates (blocks) × 29 provenances = 4350 seedlings). One replicate of each provenance consisted of 50 plants planted in five rows of 10 planting sites (10 × 10 m plot). At the end of the vegetation period in 2021, the height and root collar diameter of seedlings were measured, and the survival rate was recorded.

The seedling survival rate ranged from 40.7% to 84%. The root collar diameter values ranged from 3.99 mm to 6.94 mm, while seedling heights ranged from 32.38 cm to 72.37 cm. Statistically significant differences between the provenances were determined for the height and root collar diameter, as well as for the correlation values of the measured traits.

This research provides valuable information on the qualitative and quantitative traits of beech seedlings, which result from possible adaptation to naturally drier and warmer or colder and wetter environmental conditions. The adaptive potential of beech seedlings plays a key role in adapting to projected climate changes and will enable the survival of this species. The provenance trial conducted on Mt. Goč showed significant variability in survival rate and growth among different European beech provenances. This variability and adaptive potential of beech seedlings provide opportunities for further research and breeding programs that will enable the survival and reproduction of this species in the face of predicted rapid climate change. The Mt. Goč provenance trial remains a valuable resource for studying the performance of European beech provenances and can provide guidelines for their tolerance and adaptation.

РАНА ПРОЦЕНА РАСТА И ПРЕЖИВЉАВАЊА БУКВЕ (*Fagus sylvatica* L.) У ПРОВЕНИЈЕНИЧНОМ ТЕСТУ НА ГОЧУ

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Резиме

Буква (*Fagus sylvatica* L.) је једна од најважнијих састојинских врста шумског дрвећа у Европи, како у еколошком тако и у комерцијалном смислу. Према различитим сценаријима, у наредним деценијама драматично ће се смањити макроклиматски погодна подручја за букву. Као последица климатских промена доћи ће се промене фенологије, повећања морталитета и умањења раста стабала, са нарочитом тенденцијом смањења продуктивности шума у јужном делу ареала. Познавање кључних функционалних показатеља адаптибилности је посебно неопходно у ублажавању утицаја климатских промена. Провенијенични тестови представљају управо истраживање прилагођавања популација различитог порекла исте врсте на одређене услове средине и дају јединствен увид у одговор биљке на измењено стање околине, у реалном времену. Представљају својеврсне водиче програма/планова за подизање и обнову шума, омогућавајући да се кроз праћење различитих параметара одреди порекло које се најбоље адаптира на дате услове. До сада није било довољно истраживања која су вршила поређење одабраних популација из Западног Балкана и Централне Европе, нарочито као показатеља њиховог потенцијала за раст као параметра прилагођавања насталим климатским променама.

Циљ истраживања у овом раду био је да се утврде и опишу подаци раста и преживљавања садница букве из 29 провенијенција у провенијеничном тесту на Гочу.

За успостављање провенијеничног теста одабрано је 29 провенијенција букве са подручја ареала у центаралној и југоисточној Европи. Провенијенични тест је основан на планини Гоч у централној Србији у пролеће 2021. године садњом двогодишњих садница. Саднице су засађене са размаком од 2 × 1 м, што је резултирало густином од 4350 биљака на површини од 1 ha (50 садница по провенијенцији × 3 понављања (блок) × 29 провенијенција = 4350 садница). Једно понављање сваке провенијенције састојало се од 50 биљака засађених у пет редова на 10 места за садњу (парцела 10 × 10 м). На крају вегетационог периода 2021. године, извршена су мерења висине, пречника кореновог врата и регистровање преживљавања садница.

Преживљавање садница се кретало од 40,7% до 84%. Вредности пречника у кореновом врату су биле у опсегу од 3,99 мм до 6,94 мм, док су се вредности висине саднице кретале 32,38 цм од 72,37 цм. Утврђене су статистички значајне разлике

између провенијенција за висине и пречника кореновог врата садница, као и за вредности корелационих односа мерених особина.

Резултати овог истраживања дају корисне информације о квалитативним и квантитативним особинама садница која је резултат могуће адаптације на природно сувље и топлије или хладније и влажније услове. Адаптивни потенцијал садница букве има кључну улогу у прилагођавању пројектованим променама климатских фактора и омогућиће опстанак ове врсте. Истраживања у провенијеничном тесту на Гочу показује значајну варијабилност у преживљавању и расту међу европским провенијенцијама букве. Добијена варијабилност и адаптивни потенцијал садница букве отвара могућности за даља истраживања и програме оплемењивања који ће омогућити опстанак и репродукцију врсте у новоствореним пројекцијама брзих климатских промена. Провенијенични тест на Гочу остаје вредан ресурс за проучавање учинака европских провенијенција букве и може дати смернице за њихову толеранцију и адаптацију.

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THE IMPACT OF TEMPERATURE AND NUTRIENT MEDIA ON THE GROWTH OF *EPICOCCUM NIGRUM*

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Abstract: *Fungus Epicoccum nigrum is one of the most important potential biocontrol agents of plant pathogens. To optimise the application methods, the study investigated the influence of temperature and nutrient media on Epicoccum nigrum mycelium growth. The optimal temperature for Epicoccum nigrum growth ranged from 17 to 25⁰C. At 9 ⁰C, Epicoccum nigrum showed a delayed beginning of the growth compared to the other temperatures. The lowest mycelial growth was recorded on Sabouraud maltose agar (SMA), while cultures on malt extract agar (MEA), cornmeal agar (CMA) and potato dextrose agar (PDA) showed the same growth. The colour of cultures varied depending on temperature and nutrient media. The application of Epicoccum nigrum in biotechnical purposes was discussed.*

Keywords: growth conditions, strain, cultivation, biological control

UTICAJ TEMPERATURE I HRANLJIVE PODLOGE NA RAZVOJ *EPICOCCUM NIGRUM*

Sažetak: *Gljiva Epicoccum nigrum je jedan od najvažnijih potencijalnih agenasa biokontrole parazita biljaka. U cilju unapređenja metoda korišćenja, izvršeno je ispitivanje uticaja temperature i hranljive podloge na rast micelije Epicoccum nigrum. Optimalna temperatura za rast Epicoccum nigrum je bila u rasponu 17-25 ⁰C. Na temperaturi 9 ⁰C Epicoccum nigrum je pokazao kasniji početak rasta u odnosu na ostale temperature. Najmanji porast micelije je zabeležen na sabouraud maltoznom agaru (SMA) hranljivoj podlozi, dok su kulture na malc ekstrakt agar (MEA), kukurzna kaša agar (CMA) i krompir dektroza agar (PDA) hranljivim podlogama pokazale isti rast. Boja kultura je varirala u zavisnosti od temperature i hranljive podloge. Primena Epicoccum nigrum u biotehničke svrhe je diskutovana.*

Ključne reči: uslovi rasta, soj, gajenje, biološka kontrola

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1. INTRODUCTION

The genus *Epicoccum* was first described in 1815 by Link (Kirk et al., 2008). Species within this genus are ubiquitous ascomycetes, some of which are plant pathogens, while others serve as biocontrol agents against plant diseases (Taguiam et al., 2021). Fungi of the *Epicoccum* genus produce a wide range of metabolites that are not only valuable for biological control but also hold significant medical importance (Braga et al., 2018; Harwoko et al., 2021). Among them, *Epicoccum nigrum* Link is particularly notable, as it causes damage to various plant species while also acting as a biocontrol agent against other pathogens. Notably, *Epicoccum nigrum* exhibits high genetic variability (Fávaro et al., 2011; Li et al., 2022), with differences among strains often reflected in the morphological diversity of various isolates (Arenal et al., 2002).

Given these characteristics, it is essential to investigate different strains of this fungus to identify potential similarities and differences in their development. Temperature is one of the most critical factors influencing fungal growth. Studying the impact of temperature on the growth of *Epicoccum nigrum* can provide insights into its adaptation to various environmental conditions and help determine optimum conditions for its proliferation. Furthermore, combining these findings with data on the influence of nutrient media on mycelial growth enhances our understanding of the cultivation characteristics of this species. These results have practical applications in the cultivation and preservation of *Epicoccum nigrum* cultures, ultimately contributing to the improved production of its bioactive metabolites.

2. MATERIALS AND METHODS

2.1 Effect of Temperature on Culture Growth

The *Epicoccum nigrum* isolate, strain Z1MNE, was obtained from the mycological collection of the Institute of Forestry, Belgrade. Mycelial fragments measuring 6 × 6 mm were placed in the center of Petri dishes containing 3% malt extract agar (MEA; Biolab, Hungary; Torlak, Serbia) as the nutrient medium. The Petri dishes were incubated at four different temperatures: 9°C, 17°C, 25°C, and 30°C. The experiment was concluded after seven days, when the first culture had filled the Petri dish. Each temperature included 8–12 replicates. The culture diameter was measured in two perpendicular directions from the center of the Petri dish. Cultures exhibiting minimal growth were returned for further observation to allow for precise measurement.

2.2 Effect of Nutrient Medium on Culture Growth

An *Epicoccum nigrum* isolate identical to the one used in the temperature study was employed in this analysis. Four types of nutrient media were selected: malt extract agar (MEA; Lab M, UK), cornmeal agar (CMA; Himedia, India), Sabouraud maltose agar (SMA; Torlak, Serbia), and potato dextrose agar (PDA; Lab M, UK). Each medium was tested with 10 replicates. The experiment followed the same procedure as the temperature study.

2.3 Statistical Methods

The dimensions of the cultures in the experiments were tested for normality, homogeneity of variance, and normality of residuals. Since the conditions for parametric tests and models were not met, nonparametric tests were applied.

The Kruskal-Wallis test was used to test differences in culture dimensions across different temperatures and nutrient media. Dunn's post hoc test was conducted to compare individual culture pairs within the tested temperature and nutrient medium conditions.

All statistical analyses were performed using SPSS 27 (IBM Corp.) and Microsoft Office Excel 2021 (Microsoft Corp.).

3. RESULTS AND DISCUSSION

A statistically significant difference in *Epicoccum nigrum* mycelial growth was observed across different temperatures ($H = 37.344$; $p < 0.001$). No mycelial growth was recorded at 9°C and 30°C within the seven-day experimental period (Figure 1).

The highest growth rate was observed at 17°C and 25°C, which were identified as the optimum temperatures for *Epicoccum nigrum* growth (Figure 1). At 9°C, substantial mycelial growth was noted after 21 days, with an average colony diameter of 46.25 mm, i.e., 2.2 mm per day.

The colonies were flattened, compact, and slightly concentric. At 17°C and 25°C, the mycelium exhibited a yellow colouration with distinct zonation, whereas at 9°C, it developed a red colour, similar to that observed on the other tested nutrient media (Figure 1).

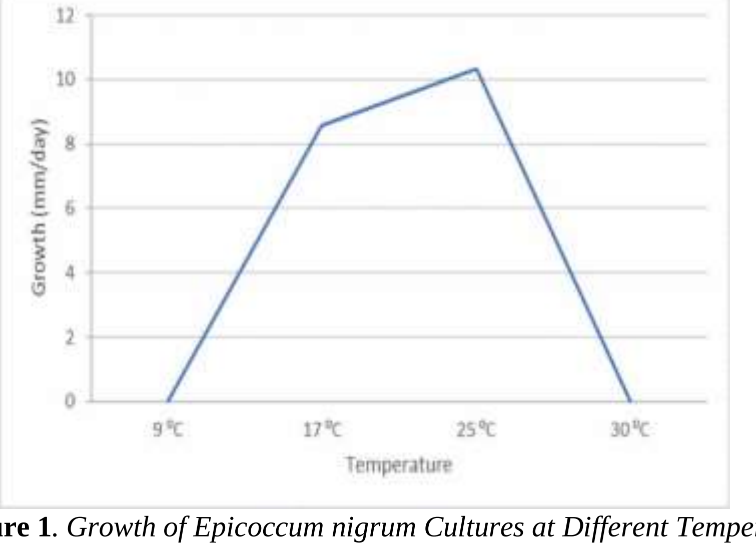

Figure 1. *Growth of Epicoccum nigrum Cultures at Different Temperatures*

A statistically significant difference was observed in the colony diameter of *Epicoccum nigrum* depending on the nutrient medium (H = 18.859, $p < 0.001$). The slowest growth was recorded on SMA, while growth on MEA, CMA, and PDA was comparable (Table 1).

On MEA nutrient medium, the cultures had the same characteristics as those observed in the temperature experiment—compact, flat, and zoned, with a yellow colour and multicoloured margins (Figure 1). On CMA, the colonies were compact and zoned, displaying a reddish-brown center with lighter edges (Figure 1). The cultures on SMA were also compact and zoned but appeared slightly darker than those on CMA (Figure 1). On PDA nutrient medium, the cultures were darker than on CMA and SMA, while similarly compact and flat (Figure 1).

Table 1. *Colony Diameter of Epicoccum nigrum on Tested Nutrient Media*

Nutrient Medium	Number of Replicates	Mean (mm)	Std. deviation (mm)
MEA	10	81.60a	1.81
CMA	10	83.80a	2.25
SMA	10	78.00b	3.21
PDA	10	82.20a	1.42

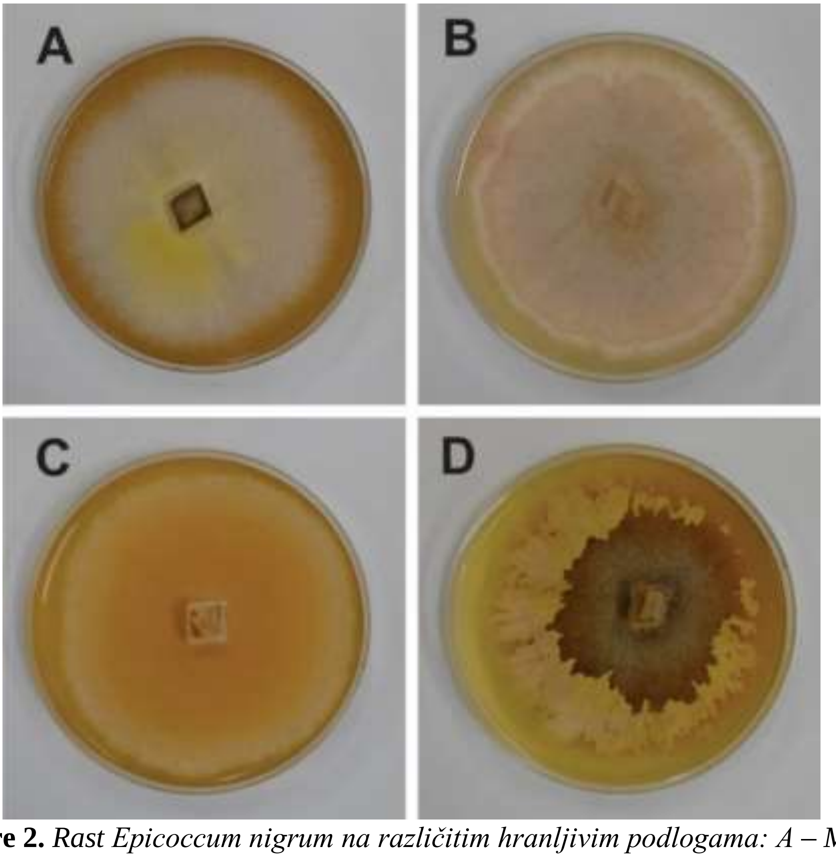

Figure 2. *Rast Epicoccum nigrum na različitim hranljivim podlogama: A – MEA, B – CMA, C – SMA, D – PDA*

Figure 2. *Growth of Epicoccum nigrum on Different Nutrient Media: A – MEA, B – CMA, C – SMA, D – PDA*

The following section presents the impact of *Epicoccum nigrum* on the suppression of specific plant pathogens in biotechnology, with a particular focus on forestry (Table 2).

Table 2. *Application of Epicoccum nigrum in the Suppression of Plant Pathogens*

Harmful organism	Type of damage	Reference
Aleternaria solani	Black spot Downy mildew	Abdel-Hafez et al. (2016)
Aspergillus flavus	Mould	Baldzhieva et al. (2024)
Botrytis cinerea	Gray mould	Christova & Slavov (2021) Baldzhieva et al. (2024)
Colletotrichum acutatum	Anthracnose	Angilè et al. (2025)
Diaporthe eres	Dieback, necrosis	Vemić et al. (2024a)
Fusarium graminearum	Damping-off, necrosis	Li et al. (2022) Nzabanita et al. (2022)
Fusarium sambucinum	Damping-off, necrosis	Vemić et al. (2024b)
Fusarium solani	Damping-off, necrosis	Ali et al. (2024)
Hymenoscyphus fraxineus	Tip dieback, necrosis	Kosawang et al. (2017)
Neonectria ditissima	Canker wounds	Papp-Rupar et al. (2023)
Phytophthora cinamomi	Root rot, dieback, ink disease	García-Latorre et al. (2022)
Pythium debaryanum	Root rot, damping-off	Hashem & Ali (2004)
Pythium ultimatum	Root rot, damping-off	Hashem & Ali (2004)
Pseudomonas savastanoi pv. *savastanoi (Psv)*	Tumors	Berardo et al. (2018)
Vericilum dahliae	Wilting	Angilè et al. (2025)
Sclerotinia sclerotiorum	White mould	Baldzhieva et al. (2024)

Epicoccum nigrum has extensive applications in various biotechnology-related fields. In short, polyketides, polyketide hybrids, and diketopiperazines are secondary metabolites of *Epicoccum nigrum* (Braga et al., 2018). Certain compounds, such as kinase and epicoccone, act as antioxidants (El Amrani et al., 2014). Other compounds, such as flavipin and its derivatives, exhibit antimicrobial, antialgal, and antinematodal properties (Braga et al., 2018). Additionally, some compounds, primarily pigments, have industrial applications (Mapari 2010). When analysing the metabolites of *Epicoccum nigrum*, differences were found in the genomes of isolates obtained from different substrates (Oliveira et al., 2017; Rutledge & Challis 2015). Therefore, it is essential to investigate the ecological characteristics of different isolates.

The obtained results are consistent with the study by Kaur et al. (2019), which identifies PDA as the most suitable nutrient medium for the growth of

Epicoccum nigrum. The nutrient medium can influence the pigment production of *Epicoccum nigrum* (Kaur et al., 2019). The yellow pigments include flavipin, 3-methoxyepicoccone, 7-methoxy-4-oxo-chroman-5-carboxylic acid methyl ester, epicoccalone, epicoccolides A-B, acetosellin, and β-carotene (Bamford et al., 1961; El Amrani et al., 2014; Foppen & Gribanovski-Sassu 1968; Kemami Wangun et al., 2008; Lee et al., 2007; Talontsi et al., 2013). The red pigments include epipyridone, epicoccarines A-B, 2-methyl-3-nonyl prodiginine, rhodoxanthin, and quinizarin (Dzoyem et al., 2017; Gribanovski-Sassu & Foppen 1967; Kemami Wangun & Hertweck 2007; Perveen et al., 2017).

Thus, this research facilitates the utilisation of the tested *Epicoccum nigrum* strain, which demonstrated the secretion of yellow and red pigments as well as antagonistic activity against the pathogens *Diaporthe eres* and *Fusarium sambucinum* (Vemić et al., 2024a, b).

4. CONCLUSIONS

This study examined the effect of temperature and nutrient media on the growth of *Epicoccum nigrum* cultures. The results of this study can be summarised as follows:

- There was a statistically significant difference in the growth rate of *Epicoccum nigrum* cultures exposed to different temperatures.
- The highest growth of *Epicoccum nigrum* cultures was recorded at 17°C and 25°C.
- At 9°C, culture growth started later and was slower compared to 17°C and 25°C.
- The mycelium was compact and flat at all temperatures. At optimal growth temperatures, the mycelium was yellow with zones of different coloUrs, while at 9°C, it was red.
- No mycelial growth was observed at 30°C.
- There was a statistically significant difference in the dimensions of cultures grown on MEA, CMA, SMA, and PDA nutrient media.
- The smallest growth of *Epicoccum nigrum* cultures was observed on SMA nutrient medium.
- No differences in culture growth were observed on MEA, CMA, and PDA media.
- The culture colour varied significantly depending on the type of nutrient medium. On MEA, the cultures were yellow with zones of different colours. Cultures grown on CMA and SMA were red with lighter edges, with darker colouration observed on CMA medium. PDA medium resulted in the darkest cultures, which were reddish-brown with lighter edges.

The obtained results can be applied to improve the cultivation and utilisation of *Epicoccum nigrum* cultures. Furthermore, the findings from this study contribute to the easier identification of specific *Epicoccum nigrum* strains and enable more accurate predictions of its spread in response to global changes.

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THE IMPACT OF TEMPERATURE AND NUTRIENT MEDIA ON THE GROWTH OF *EPICOCCUM NIGRUM*

Aleksandar VEMIĆ, Sanja JOVANOVIĆ, Katarina MLADENOVIĆ, Danilo FURTULA, Jelena BOŽOVIĆ, Radojica PIŽURICA

Summary

The need for biological plant disease control necessitates an understanding of the bioecological characteristics of various fungal species and their strains. This study examined the effects of temperature and nutrient media on the growth of a tested *Epicoccum nigrum* strain.

Variability in the growth rate of the *Epicoccum nigrum* strain was observed depending on temperature and nutrient media after seven days from the beginning of the experiment. The optimum temperature range for culture growth was 17–25 °C, while its growth slowed at 9 °C. No growth was recorded at 30 °C. Malt extract agar (MEA), cornmeal agar (CMA), and potato dextrose agar (PDA) nutrient media had the same effect on culture growth, whereas growth was slower on Sabouraud maltose agar (SMA).

Mycelial colouration varied depending on temperature and nutrient media. *Epicoccum nigrum* cultures exhibited a red colour at 9 °C, while at higher temperatures, the mycelium appeared yellow with multi-coloured zones towards the edges of Petri dishes. On MEA, the culture colour remained consistent with that observed in the examination of the temperature effect. In contrast, cultures grown on CMA and SMA exhibited a red centre with lighter edges, with the CMA cultures appearing slightly darker than those on SMA. On PDA, the mycelium displayed a reddish-brown colour with lighter edges, appearing darker than those on CMA and SMA.

Finally, a literature review is provided on the potential application of *Epicoccum nigrum* for controlling some of the most significant plant pathogens, with a particular focus on forestry.

UTICAJ TEMPERATURE I HRANLJIVE PODLOGE NA RAZVOJ *EPICOCCUM NIGRUM*

Aleksandar VEMIĆ, Sanja JOVANOVIĆ, Katarina MLADENOVIĆ, Danilo FURTULA, Jelena BOŽOVIĆ, Radojica PIŽURICA

Rezime

Potreba za biološkim merama zaštite protiv biljnih bolesti uslovljava poznavanje bioekoloških karakteristika različitih vrsta gljiva i njihovih sojeva. Ova studija je ispitivala uticaj temperature i hranjive podloge na rast kultura testiranog soja *Epicoccum nigrum*.

Utvrđena je varijabilnost brzine rasta testiranog soja *Epicoccum nigrum* u zavisnosti od temperature i hranljive podloge posle 7 dana od početka ogleda. Temperaturni raspon 17-

25 ºC je bio optimalan za rast kultura, dok je na 9 ºC dolazilo do usporenog rasta kultura *Epicoccum nigrum*. Na temperaturi 30 ºC nije zabeležen rast. Hranljive podloge malc ekstrakt agar (MEA), kukuruzna kaša agar (CMA) i krompir dektroza agar (PDA) su pokazale isti efekat na rast kultura, a koji je bio sporiji na sabouraud maltoznom agaru (SMA).

Boja micelije se razlikovala u zavisnosti od temperature i hranljive podloge. Kulture *Epicoccum nigrum* su imale crvenu boju na temperaturi 9 ºC dok je na višim temperaturama micelija bila žuta, sa šarenim zonama prema ivicama petri šolja. Na MEA hranljivoj podlozi, boja kultura je bila ista kao prilikom ispitivanja uticaja temperature. Sa druge strane, boja kultura na CMA i SMA hranljivoj podlozi se odlikovala crvenim centrom sa svetlijim ivicama. Kulture su bile nešto tamnije na CMA hranljivoj podlozi u odnosu na SMA hranljivu podlogu. Na PDA hranljivoj podlozi, micelija je bila crveno braon boje sa svetlijim ivicama, odnosno tamnija u odnosu na CMA i SMA hranljivu podlogu.

Na kraju, naveden je literaturni prikaz mogućnosti primene *Epicoccum nigrum* za suzbijanje nekih od najznačajnijih patogena biljaka, sa posebnim osvrtom na oblast šumarstva.

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COMPARATIVE ANALYSIS OF DETECTED FIRES IN THE REPUBLIC OF SERBIA AND NEIGHBOURING COUNTRIES (2012–2024)

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Abstract: *This study aims to provide an overview of fire occurrences in the Republic of Serbia over the past twelve years and to compare these findings with those from neighbouring countries. The analysis is based on data obtained from the online platform Global Forest Watch, sourced from Copernicus Sentinel-2 and processed by the European Space Agency (ESA). In comparison with the selected neighbouring countries, Serbia demonstrates moderate to slightly above-average values in terms of the annual number of fires, the total number of fires, and fire density per square kilometre. A significant proportion of the fires detected by satellite imagery are associated with agricultural areas. The period with the highest number of fire events is the fourth quarter of the year, which numerous sources attribute to the burning of agricultural residues following the harvest. Beyond providing numerical indicators of the fire situation in Serbia, this study also serves as a foundation for more detailed analyses that may inform strategies for the prevention and mitigation of fire spread into forests and forest land.*

Keywords: fires, satellite fire detection, forest fires, fire occurrence density

КОМПАРАТИВНА АНАЛИЗА ДЕТЕКТОВАНИХ ПОЖАРА У РЕПУБЛИЦИ СРБИЈИ И ЗЕМЉАМА ОКРУЖЕЊА У ПЕРИОДУ 2012-2024. ГОДИНА

Izvod: *Овај рад има за циљ да пружи приказ појаве пожара у претходних 12 година у Републици Србији као и да уради поређење са земљама окружења. У раду су коришћени подаци доступни на online платформи Global Forest Watch. Извор података добијен је од стране Copernicus Sentinel-2, а подаци сајта су обрађени од стране Европске Свемирске Агенције (European space agency ESA). У поређењу са земљама окружења за које су подаци обрађени Република Србија по броју пожара на нивоу године, укупном броју пожара као и густини пожара по km^2 има средње вредности или вредности које су мало изнад просека. Велики број пожара који је евидентиран путем сателита везује се углавном за пољопривредне површине, а период настанка пожара са највећим бројем пожара је четврти квартал што бројни извори потврђују и везују за паљење пољопривредних површина након жетве. Овај рад осим што пружа нумеричке показатеље стања у Републици Србији служи и као основ за*

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детаљнију анализу која може да има утицаја на превенцију и ширење пожара на шуме и шумско земљиште.

Кључне речи: пожари, сателитска детекција пожара, шумски пожари, густина пожара

1. INTRODUCTION

The Forest Law of the Republic of Serbia (Article 47) strictly prohibits the ignition of open fires within forests or on land situated less than 200 meters from the forest boundary (*Official Gazette of the Republic of Serbia*, Nos. 30/2010, 93/2012, 89/2015, and 95/2018). Predicting fire spread represents a critical task for fire management and mitigation, with satellite-derived data being an up-and-coming source of information for these purposes (Shadrin et al., 2024).

In the Republic of Serbia, forest fires are recognised as one of the most severe disturbances to forest ecosystems and the most significant challenges to sustainable forest management practices (Brovkina et al., 2019). In order to deepen the understanding of both the causes and the potential consequences of fire events, this study conducts an analysis of data spanning the period from 2012 to 2024, sourced from the *Global Forest Watch* platform.

By examining the current situation through data analysis, the underlying causes of fires can be better understood, enabling adjustments to forest management practices to help prevent fires. Forest trees absorb atmospheric carbon dioxide (CO_2) and store it within living biomass, dead organic matter, and soils, thereby substantially contributing to the mitigation of climate change (Osman et al., 2023).

The devastating scale of forest fires is exemplified by the massive wildfire event in eastern Siberia, where approximately 22 million hectares of forested land were lost, as reported by the California Institute of Technology. Given the above, it is crucial to monitor fire events that can threaten forests or lead to large-scale destruction of forested areas.

2. MATERIAL AND METHODS

This study analyses data on fire occurrences in the Republic of Serbia for the period 2012–2024, obtained from the *Global Forest Watch* platform. The dataset includes nine countries Bosnia and Herzegovina, Bulgaria, Montenegro, Croatia, the Czech Republic, Hungary, Romania, Slovenia, and the Republic of Serbia and incorporates only those records with a high confidence level (>80% Cl).

All data were consolidated into a single file and subsequently analysed to identify extreme values, fire occurrence frequency, and the locations of fires that could potentially threaten forested areas in the Republic of Serbia. The analysis was conducted across several categories: the number of fires per year, the total number of fires over the entire observation period, fire counts for each country annually and cumulatively, extreme values (maximum and minimum), and fire density per square kilometre relative to each country's total area. Corresponding graphs and a thematic map were generated to visually represent the results.

The analysis was performed using comparative analysis and descriptive statistics, which is shown in the part related to the research results.

It is important to note that each recorded fire is associated with the exact week of occurrence; using these data, calculations were performed to determine the corresponding month and quarter, which served as the basis for further statistical analysis.

3. RESULTS

During the observation period from 2012 to 2024, a total of 17,975 fires were recorded across the nine countries analysed, based on data from the *Global Forest Watch platform*. The highest number of fires was detected in Romania (6,832), followed by Bulgaria (3,928) and the Republic of Serbia (2,422), while the lowest number was recorded in the Czech Republic (97). The average number of fires detected over the past 12 years was 1,997.22, placing the Republic of Serbia slightly above the regional average.

As shown in Figure 1, a decreasing trend in the number of recorded fires can be observed from 2012 toward 2024, with the exception of 2017 and 2019, when an increase in fire activity was registered, particularly in Romania and Bulgaria. Map 1 illustrates the spatial distribution of fires across the countries, where lighter shades indicate a lower number of fires, while darker shades represent higher values.

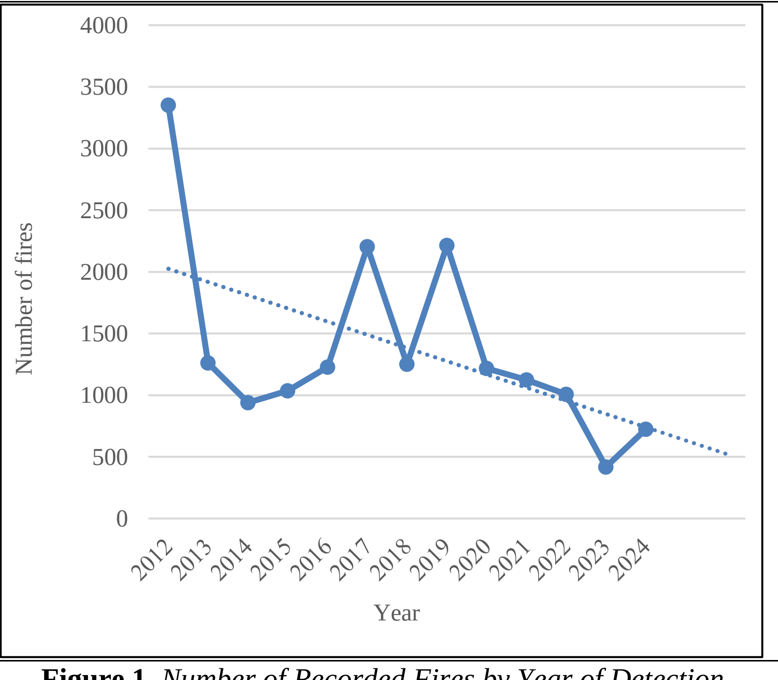
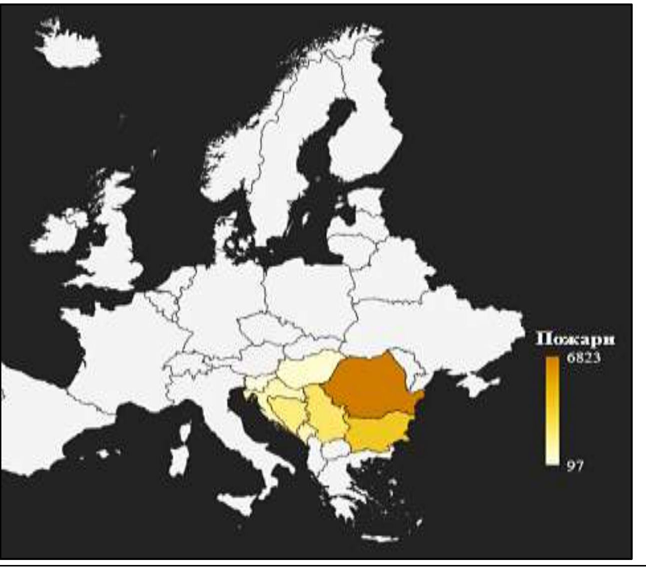


Figure 1. *Number of Recorded Fires by Year of Detection*



Map 1. *Distribution of Recorded Fires across Europe*

In addition to the total number of fires, it is important to consider fire density relative to the area of the selected countries. This approach reveals that although Romania and Bulgaria lead in the total number of recorded fires, Montenegro has the highest fire density, while the Czech Republic has the lowest. The average fire density across these countries is 0.0256 fires per km². The Republic of Serbia again shows values slightly above the average, positioning it near the middle among the observed countries.

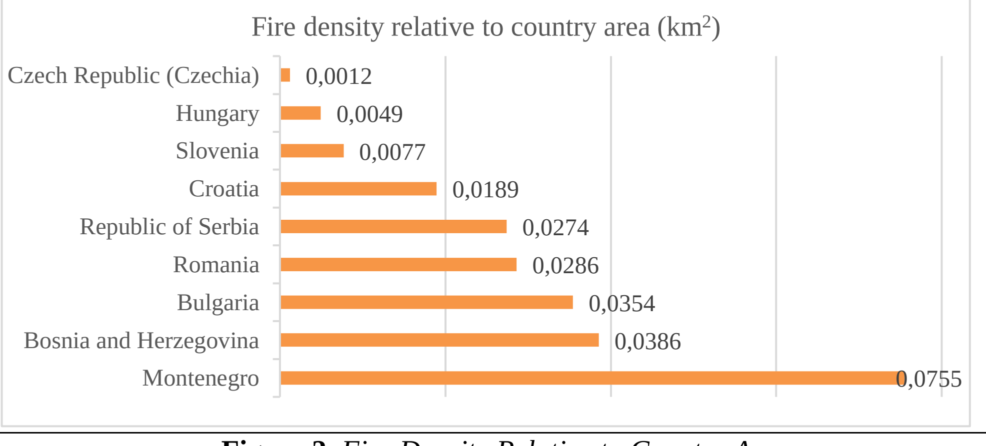


Figure 2. *Fire Density Relative to Country Area*

Maps 2 and 3 illustrate the periods from 1 September to 1 December in 2018 and 2019, respectively, which, according to the data, represent the intervals with the highest number of fires recorded in the Republic of Serbia over the past 12 years.

The maps reveal that the majority of fires were concentrated in the Autonomous Province of Vojvodina, as well as along the A1 motorway.

Map 2. *Fire Incidents adjusted Map for the Period 1 September – 1 December 2018*

Map 3. *Fire Incidents adjusted Map for the Period 1 September – 1 December 2019*

As the majority of fires were concentrated in the territory of the Autonomous Province of Vojvodina, and given that the *Global Forest Watch* platform recorded these fires in the fourth quarter of both 2018 and 2019, it can be assumed that they were primarily caused by the burning of agricultural land following harvest. Another fire event clearly observable on Map 2 is along the A1 motorway, which may be attributed to human activity. The fire incident, along with numerous others, was documented in newspaper articles from 2019 and 2023, which consistently emphasised the need to refrain from burning crop residues and agricultural land during the autumn period after harvest operations.

Figure 3. *A1 Motorway, 10 October 2023. Photo: https://x.com/i/status/1711474713732489482*

Figure 4. *E75 Motorway, 9 October 2023. Photo: https://x.com/i/status/1711819491460423939*

Figure 5. *Mala Kamenica near Negotin, 29 August 2024. Photo: Bojan Konatar*

Figure 6. *Burning of land near the forest edge, Sjenica, 11 April 2025. Photo: Bojan Konatar*

Figure 7. *Burning of land near the forest edge, Sjenica, 11 April 2025. Photo: Bojan Konatar*

4. DISCUSSION

The primary focus of the analysis is on the territory of the Republic of Serbia, while data from the other countries are used for comparative purposes and to encourage further research on this topic.

As previously stated, the Forest Law prohibits the use of open fires within 200 metres of the forest edge. This regulation aims to protect natural resources, flora and fauna, property, and human lives. Open fires near forests pose a significant risk, particularly under adverse meteorological conditions such as prolonged drought, low humidity, or strong winds. According to a 2020 WWF report titled *Fires, Forests and the Future*, human activity—either intentional or accidental—was estimated to be responsible for 75% of open fires globally. In Europe, approximately 95% of fires are caused by human negligence, compared to 84% in the United States. The report also highlights that the *slash and burn* method, often used to prepare land for agricultural purposes, frequently escapes control. Fire-favourable weather conditions—high temperatures, low humidity, and strong winds—have become increasingly common, fuelling wildfires worldwide. Such conditions are associated with the most dangerous types of fires (Jolly et al., 2015).

A study conducted across Europe, including Estonia, Finland, Latvia, Lithuania, Sweden, Bulgaria, Germany, Poland, Romania, Slovenia, Slovakia, Switzerland, France, Greece, Italy, Portugal, and Spain, found that for 79.33% of recorded fires the cause was known. Of these, 4.17% were attributed to natural causes, 7.97% to accidental causes, 45.83% to human negligence, and 42% to deliberate actions.

In 2017, Portugal experienced a record-breaking wildfire that burned approximately 500,000 hectares (Turco, 2019), of which 213,633 hectares were forested areas (San-Miguel-Ayanz et al., 2017). Unprecedented weather conditions, including strong winds that contributed to the formation of Hurricane Ophelia and extremely low relative humidity, facilitated the rapid spread of fires (San-Miguel-Ayanz et al., 2017).

Numerous studies have demonstrated that wildfires significantly affect human health through the emission of smoke during burning events. Consequences include increased concentrations of nitrogen, phosphorus, and dissolved organic carbon in the environment. In addition, noticeable changes occur in plant species composition, geology, topography, water bodies, and lakes near burned areas (Bolan et al., 2025).

5. CONCLUSIONS

The results of this study indicate that, although the Republic of Serbia records a relatively high number of wildfires annually compared to the other analysed countries, it does not represent an extreme case. Instead, it ranks near the middle among the observed countries. The concentration of fires in specific regions and periods suggests cyclical patterns, highlighting areas that should be prioritised during the development of strategic planning documents. Prolonged periods of extremely high temperatures, a lack of precipitation, and strong winds create optimal conditions for wildfire spread, underscoring the need for special attention to regions with higher fire occurrence rates. The observed positive trend of decreasing wildfire detection over the years, despite noticeable climate change effects, reflects the success of efforts and methods implemented over the past twelve or more years.

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COMPARATIVE ANALYSIS OF DETECTED FIRES IN THE REPUBLIC OF SERBIA AND NEIGHBOURING COUNTRIES (2012–2024)

Bojan KONATAR, Snežana KONATAR, Jovana CVETKOVIĆ, Sabahudin HADROVIĆ, Nenad ŠURJANAC, Jelena BOŽOVIĆ, Goran ČEŠLJAR

Summary

This research aims to analyze the occurrence of fires in the Republic of Serbia in the period 2012-2024 using data from the online platform Global Forest Watch. The focus of the research is the temporal and spatial distribution of fire occurrence in the Republic of Serbia and a comparison of the results with eight other European countries. The analysis showed 17,975 recorded fires, of which 2,422 fires were detected in Serbia, which ranks it in the middle of the analyzed countries in terms of the number and density of fires per square kilometer. The largest number of fires was detected in the period 2018 and 2019 in the third and fourth quarters, the fires were mostly concentrated in the part of the AP Vojvodina and along the A1 highway. The data analysis determined that there are indications of seasonal and regional fires, and the attached maps show which critical areas are. The text draws attention to the importance of the human factor as the main cause of fires and the need to comply with regulations, legal prohibitions on lighting fires near forests, and the importance of preventive planning and management of forest resources, especially in conditions of climate change and long-term dry periods without rainy days.

КОМПАРАТИВНА АНАЛИЗА ДЕТЕКТОВАНИХ ПОЖАРА У РЕПУБЛИЦИ СРБИЈИ И ЗЕМЉАМА ОКРУЖЕЊА У ПЕРИОДУ 2012-2024. ГОДИНА

Bojan KONATAR, Snežana KONATAR, Jovana CVETKOVIĆ, Sabahudin HADROVIĆ, Nenad ŠURJANAC, Jelena BOŽOVIĆ, Goran ČEŠLJAR

Резиме

Ово истраживање за циљ има да анализира појаву пожара у Републици Србији у периоду 2012-2024. година користећи податке online платформе Global Forest Watch. Фокус истраживања је временска и просторна дистрибуција појаве пожара у Републици Србији и поређење резултата са осам других земаља Европе. Анализа је показала 17.975 евидентираних пожара од чега 2.422 пожара који су детектовани у Србији, што је по броју и густини пожара по квадратном километру сврстава у средину анализираних земаља. Највећи број пожара детектован је у периоду 2018 и 2019. године у трећем и четвртом кварталу, пожари су највећим делом концентрисани у делу АП Војводине и дуж аутопута А1. Анализом података је утврђено да постоје индикације сезонских и регионалних пожара а на приложеним мапама се може видети која су критична подручја. У тексту се скреће пажња на значај људског фактора као главном узрочника појаве пожара и потреба за поштовањем прописа, законских

забрана паљења ватре у близини шума и значај превентивног планирања и управљања шумским ресурсима, посебно у условима климатских промена и дуготрајних сушних периода без кишних дана.

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Original scientific paper

ASSESSMENT OF SOIL EROSION INTENSITY USING THE EROSION POTENTIAL METHOD: A CASE STUDY OF THE GRDELICA GORGE, SERBIA

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Abstract: *The South Morava River Basin was considered one of the most erosion-prone and flash flood-affected areas in the Republic of Serbia. This paper aims to apply the Erosion Potential Method (EPM) within a GIS environment to determine the spatial and temporal changes in the soil erosion coefficient, sediment production and transport, and to identify the factors contributing most significantly to erosion risk in the Grdelica Gorge for two reference years: 1970 and 2025. The intensity of soil erosion was analysed using the Erosion Potential Method according to Gavrilović. The results indicate that most of the area (62.03%) fell into slope category IV (27–70%), with all erosion categories represented. Processes of very slight erosion were predominant, covering 71.31% of the surface area (306.94 km²). The total annual sediment production (W_{year}) amounted to 110,233.97 m^3year^{-1}, while the specific sediment production (W_{sp}) was 256.1 $m^3km^{-2}year^{-1}$. The mean annual sediment transport was 81,573.14 m³/year, and the specific annual sediment transport was 189.51 m³/km²/year. A decline in population and the abandonment of arable land at higher elevations and steeper slopes, along with the implementation of extensive technical, biological, and biotechnical erosion control measures, contributed to erosion mitigation and enhanced vegetation recovery. Compared to the erosion intensity in 1970, the extent of severe erosion had notably decreased by 2025, while the proportions of slight and moderate erosion significantly increased. The mean erosion coefficient (Z_{mean}) had decreased from 0.50 to 0.23.*

Keywords: Grdelica Gorge, soil erosion, Erosion Potential Method (EPM), GIS

PROCENA INTENZITETA EROZIJE ZEMLJIŠTA METODOM POTENCIJALA EROZIJE: STUDIJA SLUČAJA GRDELIČKA KLISURA (SRBIJA)

Izvod*: U delove Republike Srbije koji su bili najugroženiji erozijom zemljišta i bujičnim poplavama svrstava se sliv Južne Morave. Cilj ovog rada je da se primenom Metode potencijala erozije u GIS okruženju utvrde prostorne i vremenske promene koeficijenta*

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erozije zemljišta, produkcije i pronosa nanosa i identifikuju faktori koji najviše doprinose riziku od pojave erozije na području Grdeličke klisure za dva referentna perioda – 1970. i 2025. godinu. Intenzitet erozije zemljišta analiziran je primenom Metode potencijala erozije (MPE), prema Gavriloviću. Rezultati rada pokazuju da najveći deo područja (62,03%) pripada IV kategoriji nagiba (27–70%) i zastupljene su sve kategorije erozije. Na području su dominantni procesi vrlo slabe erozije i zahvataju 71,31% površine (306,94 km^2*). Ukupna godišnja produkcija nanosa (*W_{year}*) iznosi 110233,97 m*^{3}*god*$^{-1}$*, a specifična produkcija nanosa (*W_{sp}*) iznosi 256,1 m*^{3}*km*$^{-2}$*god*$^{-1}$*. Srednjegodišnji transport nanosa na području je 81573,14 m*^{3}*km*$^{-2}$*god*$^{-1}$* i specifični godišnji transport nanosa je 189,51 m*^{3}*km*$^{-2}$*god*$^{-1}$*. Opadanje broja stanovnika i napuštanje obradivih površina na većim nadmorskim visinama i nagibima, te veliki obim tehničkih, bioloških i biotehničkih protiverozionih radova, doveli su do ublažavanja erozije i pojačane obnove vegetacije. U odnosu na stanje intenziteta erozije u 1970. godini, stepen jake erozije je u opadanju, dok je procenat slabe i srednje erozije rapidno porastao. Srednja vrednost koeficijenta erozije (Zsr) smanjena je sa 0,50 na 0,23.*

Ključne reči: Grdelička klisura, erozija zemljišta, metod potencijala erozije (MPE), GIS

1. INTRODUCTION

Water erosion is one of the most pressing environmental challenges worldwide. This process has long-term ecological consequences, leading to the degradation of natural resources, loss of biodiversity, deterioration of water and soil quality, sedimentation of reservoirs and fertile arable land, damage to roads and settlements, and sometimes even the loss of human life. Many countries face this issue, particularly those located in regions characterised by high-intensity, short-duration rainfall, improper land use practices, and terrain configurations susceptible to erosion processes.

In the Republic of Serbia, erosion processes of varying intensity affect 86% of the national territory, 35% of which south of the Sava and Danube Rivers is exposed to excessive, severe and moderate erosion intensity (Lazarević, 1983; Dragićević et al., 2011; Ristić et al., 2012). More than 12,500 torrential streams have been recorded (Kostadinov et al., 2022). One of the most erosion-prone regions in Serbia is the South Morava River Basin, particularly the Grdelica Gorge, which has experienced the highest number of flash floods (Petrović et al., 2014; Braunović, 2013).

A holistic approach to addressing water erosion is essential, as soil erosion and flash floods are closely interrelated phenomena (Poesen & Hooke, 1997). The Erosion Potential Method (EPM), developed by Professor Slobodan Gavrilović, was originally designed to assess erosion in the southern and southeastern regions of the former Yugoslavia, now the Republic of Serbia (Gavrilović, 1970; 1972). The method has shown a high degree of reliability in determining erosion intensity and calculating sediment production and transport (Ristić et al., 2011). Over time, EPM has been adopted in Iran, Croatia, Bosnia and Herzegovina, Slovenia, Italy, Montenegro, and Chile (Dragičević, Karleuša, & Ožanić, 2016; Kouhpeima, Hashemi, & Feiznia, 2011; Globevnik et al., Holjevic, Petkovsek, & Rubinic, 2003).

Between 1907 and 2006, numerous technical and biotechnical erosion control measures were implemented, including riverbed regulation, the construction of check dams, afforestation on ridges and terraces, and contour trenching (Kostadinov, 2007). According to EPM-based research by Veličković et al. (2022), a significant reduction in soil loss—from 10.64 to 5.97 t ha^{-1} $year^{-1}$—was observed between 1970 and 2018 in suburban areas located approximately 20 km from Belgrade. Ristić et al. (2011a) demonstrated that the implementation of appropriate erosion control measures in the Jelašnica River Basin would reduce the annual sediment transport by 44.1%, specific annual transport by 43.6%, and the representative erosion coefficient (Z) from 0.555 to 0.379. Similarly, Polovina et al. (2016) reported that the mean erosion coefficient (Z_{mean}) in the Likodra River Basin, the largest left tributary of the Jadar River, decreased from 0.275 in 1983 to 0.204. Despite Serbia's considerable technical and biotechnical erosion mitigation solutions, there remains a critical need for increased accountability and the implementation of concrete actions to address erosion risks (Ristić et al., 2011b).

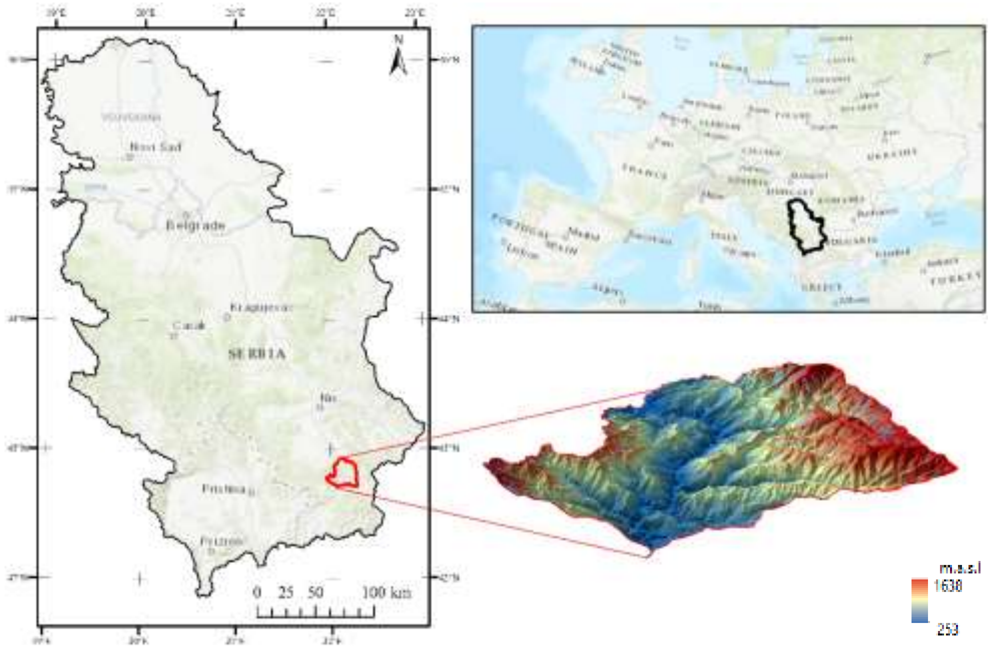
Our study aims to apply the Erosion Potential Method (EPM) within a GIS-based framework to assess spatial and temporal changes in the erosion coefficient, sediment production, and sediment transport in the Grdelica Gorge. The analysis focuses on identifying the primary contributing factors to erosion risk in the Grdelica Gorge area for two reference years: 1970 and 2025.

2. MATERIAL AND METHODS

2.1 Study area

The area comprising the Grdelica Gorge and the Vranje Valley was designated as a unified erosion control region under the Law on Erosion Control and Torrent Regulation adopted in 1954. This law identified the region as a distinct erosion-prone area in Serbia, highlighting its specific environmental features and challenges and granting it the highest priority for erosion control management (Official Gazette of the People's Republic of Serbia, No. 36/54). The boundaries defined by the law differ slightly from its natural geographic borders.

The Grdelica Gorge, covering an area of 430.44 km^2, belongs to the South Morava River Basin, extending from Grdelica to Vladičin Han. Administratively, it spans the municipalities of Leskovac, Grdelica, Vladičin Han, Surdulica, and Crna Trava. Along this stretch of the South Morava River, there are 137 torrential tributaries of different types and categories, ranging from minor gullies with insignificant catchment areas to highly destructive torrential rivers (District Section for Soil Erosion Control and Torrent Regulation, Vladičin Han, 1964). The hydrographic network density in the area is 0.64 $km \cdot km^{-2}$ (Table 1). In most mountain massifs of the Grdelica Gorge, the topography exhibits a highly dissected terrain shaped by complex tectonic structures and the torrential character of its hydrographic network (Cvijić, 1900). The hydrographic and topographic characteristics of the Grdelica Gorge are summarised in Table 1 and illustrated in Figure 1.



Source: *Author*

Figure 1. *Location of the Grdelica Gorge*

Table 1. *Hydrographic and Topographic Characteristics of the Grdelica Gorge*

Parameter	Unit	Value
Area	km^2	430.44
Perimeter	km	99.57
The length of main stream	km	29.50
Confluence point	m.a.s.l.	324.00
Peak point	m.a.s.l.	253.00
Stream winding coefficient		0.69
Number of torrential tributaries		137
Average channel gradient of the section	%	2.41
Total length of the waterways	km	277.01
Density of the hydrographic network	$km \cdot km^{-2}$	0.64
Mean width of the area	km	14.59
Asymmetry coefficient of the drainage basin		0.82
Shape coefficient of the drainage area		0.54
Highest elevation point in the basin	m.a.s.l.	1638.00
Mean elevation	m.a.s.l.	789.57
Medium elevation difference	m	536.57

Source: *District Section for Soil Erosion Control and Torrent Regulation, Vladičin Han, 1964*

Between 1947 and 1977, a total of 5.96 km of channel regulation and 1,087 transverse structures (including check dams, sills, and cascades) were constructed along 58 tributaries of the South Morava River in the Grdelica Gorge. On the slopes of 19 catchments, 11,282.6 meters of wattling, 11,822 meters of terraces, 68,000 meters of bench terraces, 95.00 meters of horizontal walls, 93.43 hectares of orchards, and 35.4 hectares of reclaimed pastures were established. In addition, 1,041.2 hectares were afforested, and 1,210.5 hectares were grassed in this area (Kostadinov et al., 2018).

According to the Soil Map of the Grdelica Gorge and Vranje Valley at a scale of 1:50,000 (Institute of Pedology and Agrochemistry, 1960), the predominant soil types within the study area are Distric Cambisol, occupying 356.42 km² (82.80%), and Eutric Cambisol, covering 36.58 km² (8.50%). Other identified soil types include Calcocambisol (9.09 km², 2.11%), Regosol (8.70 km², 2.02%), Haplic Leptosol (8.49 km², 1.97%), Fluvisol (7.21 km², 1.68%), and Vertisol (3.95 km², 0.92%). The spatial distribution of these soil types is presented in Figure 2.

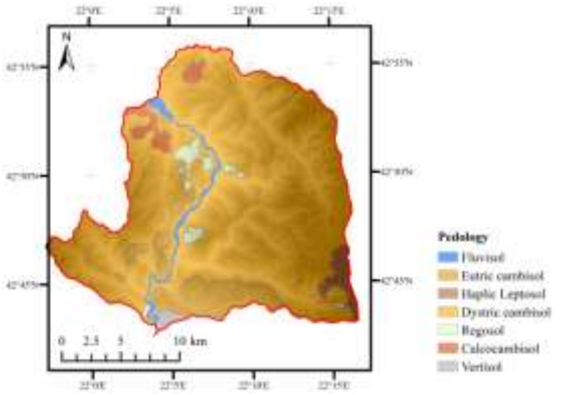


Figure 2. *Soil map*

According to the CORINE Land Cover (CLC) dataset (2018), the predominant land use in the study area is classified as broadleaved forests, covering 302.4 km² (70.25%). It is followed by land principally occupied by agriculture, with significant areas of natural vegetation 46.10 km² (10.71%), Complex cultivation patterns (32.38 km², 7.52%), transitional woodland/shrubs (24.36 km², 5.66%), mixed forests (8.76 km², 2.03%), pastures (5.68 km², 1.32%), natural grasslands (3.45 km², 0.80%), and coniferous forests (3.30 km², 0.77%). Land use classes with a share below 0.5% include construction sites (1.57 km², 0.36%), discontinuous urban fabric (1.56 km², 0.36%), mineral extraction sites (0.54 km², 0.13%), and non-irrigated arable land (0.34 km², 0.08%). The spatial distribution of land use categories is illustrated in Figure 3.

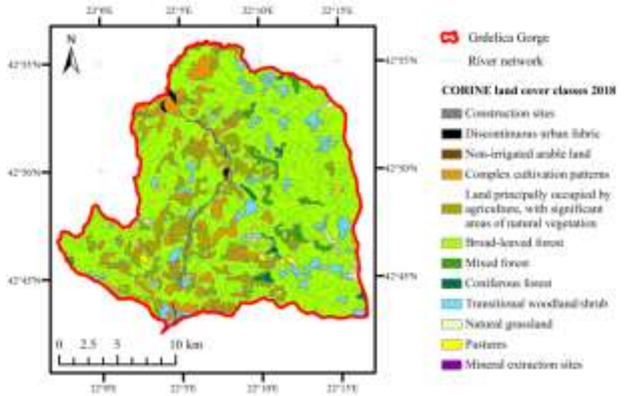


Figure 3. *Land use map*

The average annual rainfall in Grdelica Gorge for the period 1991–2020 amounted to 746.9 mm while the mean annual temperature was 8.9 °C.

The values and spatial distribution of mean annual precipitation and air temperature for the Grdelica Gorge area are presented in Figures 4 and 5, respectively.

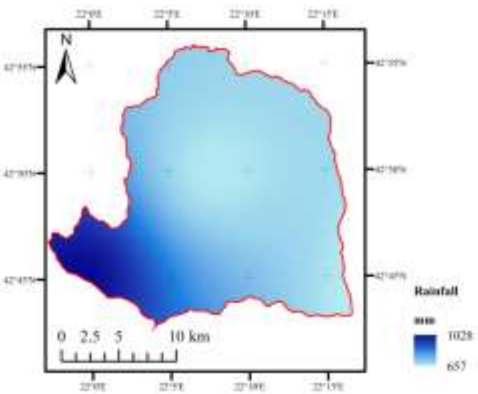


Figure 4. *Mean Annual Precipitation Totals*

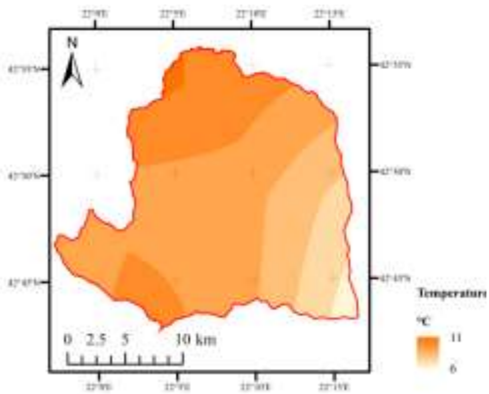


Figure 5. *Mean Annual Air Temperatures*

2.2 Method

The intensity of soil erosion in the study area was analysed using the Erosion Potential Model (EPM) developed by Gavrilović (1972).

In order to calculate the specific annual erosion per km^2 Equation (1) was used:

$$W_{sp} = T \cdot H_{year} \cdot \pi \cdot \sqrt{Z^3}$$

where W_{sp} is the specific annual erosion (m^3·km^{-2}·year^{-1}), T is the temperature coefficient, H_{year} is the mean annual precipitation (mm), π is Ludolf number (Archimedes' constant) and Z is the erosion coefficient. Temperature coefficient (T) is calculated by the following equation (Equation 2):

$$\mathrm{T} = \sqrt{\frac{t^0}{10} + 0{,}1}$$

Where t is the mean annual temperature in °C.

Data on the mean annual precipitation totals for the period from 1991 to 2020 were obtained from the Meteorological Yearbooks (RHMS, 2025) for the stations in Leskovac, Kukavica, Babušnica, Predejane, and Vlasina. Data on mean annual air temperatures were sourced from the Digital Atlas of Climate and Climate Change of the Republic of Serbia (Ministry of Environmental Protection, 2022). The spatial distribution of mean annual precipitation was derived using the Inverse Distance Weighting (IDW) interpolation method in a GIS environment.

The erosion coefficient (Z) depends on factors such as soil types, erosion area management, visible erosion processes, and terrain slope. It is calculated using the following equation (Equation 3):

$$Z = Y \cdot X \cdot a\left(\varphi + \sqrt{I_{mean}} \right)$$

Where Y represent the coefficient of soil resistance to erosion, X·a is the land use coefficient, φ the coefficient of the observed erosion process and I_{mean} is the mean slope of terrain.

To determine the soil resistance to erosion, coefficient values according to Gavrilović (1972) were assigned to soil types identified based on the Soil Map of the Grdelica Gorge and Vranje Valley at a scale of 1:50,000 (Institute of Pedology and Agrochemistry, 1960).

The land use coefficient**,** which ranges from 0 to 1, was determined based on the CLC 2018 database for the study area.

To identify visible and clearly expressed erosion processes, Sentinel-2 L2A satellite imagery was used for the period from January 1 to December 31, 2024, with cloud cover below 10%. Based on the available satellite images, the Bare Soil Index (Rikimaru et al., 2002) was calculated, serving as the primary input for determining the coefficient of visible and clearly expressed erosion processes (Polovina et al., 2024).

The slope was derived from a Copernicus Digital Elevation Model (COP-DEM_GLO-30-DTED) (Copernicus, 2020).

The calculation of the annual gross erosion W_{year} in $m^3 \cdot year^{-1}$ for the entire study area was performed by multiplying the specific annual erosion (W_{sp}) with the area in km^2. In order to determine the specific sediment transport (G_{sp}) in $m^3\ km^{-2} god^{-1}$ and total sediment transport which reaches the hydrographic profile (G_{year}) in $m^3 year^{-1}$, W_{sp} and W_{year} were multiplied with the sediment delivery ratio (Ru) calculated using the following equation (Equation 4):

$$R_u = \frac{\sqrt{O \cdot D}}{0{,}25(L + 10)}$$

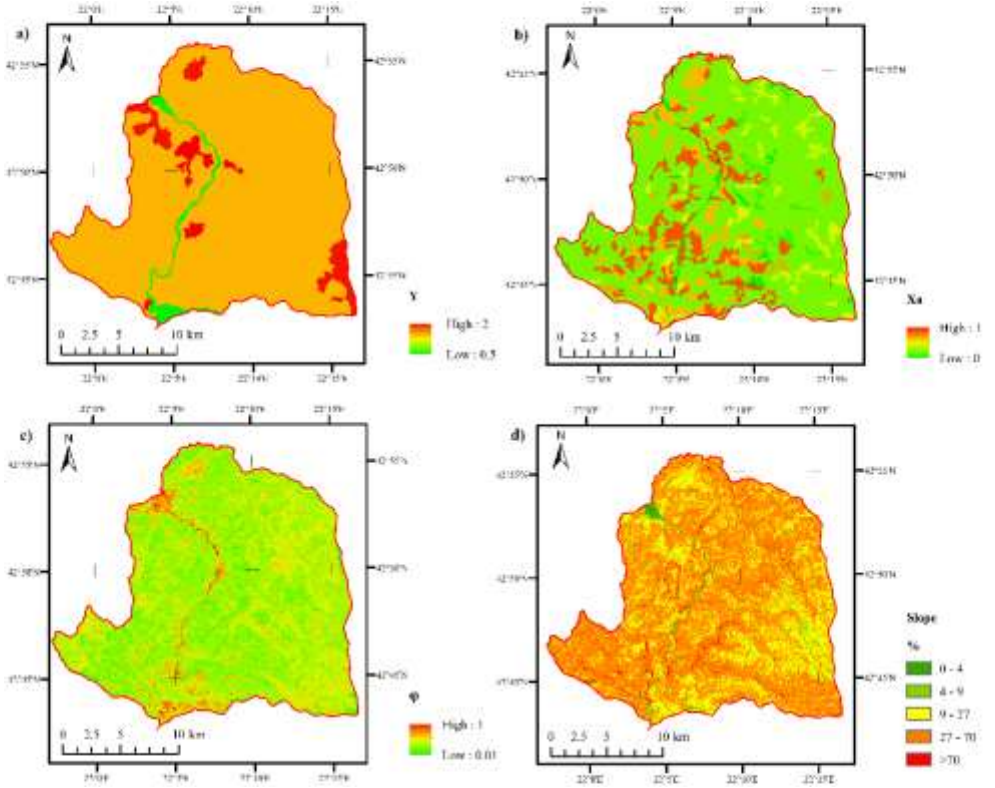
Where O is the perimeter of catchment (km), D is the average difference in elevation of the catchment (km) and L is the length of catchment (km).

The morphometric attributes were derived from a topographic map, scale 1:25,000.

The analysis of population change was conducted using census data from the years 1961, 1971, 1981, 1991, 2002, 2011, and 2023 for the following municipalities (or their parts) within the study area: Leskovac (25 settlements), Crna Trava (7 settlements), Vladičin Han (21 settlements), and Surdulica (4 settlements). Data were collected and analysed for a total of 57 cadastral municipalities (Statistical Office of the Republic of Serbia, 2023).

3. RESULTS AND DISCUSSION

By processing geospatial data in a GIS environment, thematic maps were generated (Figures 2–6), along with a synthesised map of erosion intensity (Figure 7).



Source: Author

Figure 6. S*patial distribution of the reciprocal value of the soil erosion resistance coefficient Y (a), the erosion control coefficient Xa (b), the numerical equivalent of visible and clearly expressed erosion processes φ (c), and the slope map (d)*

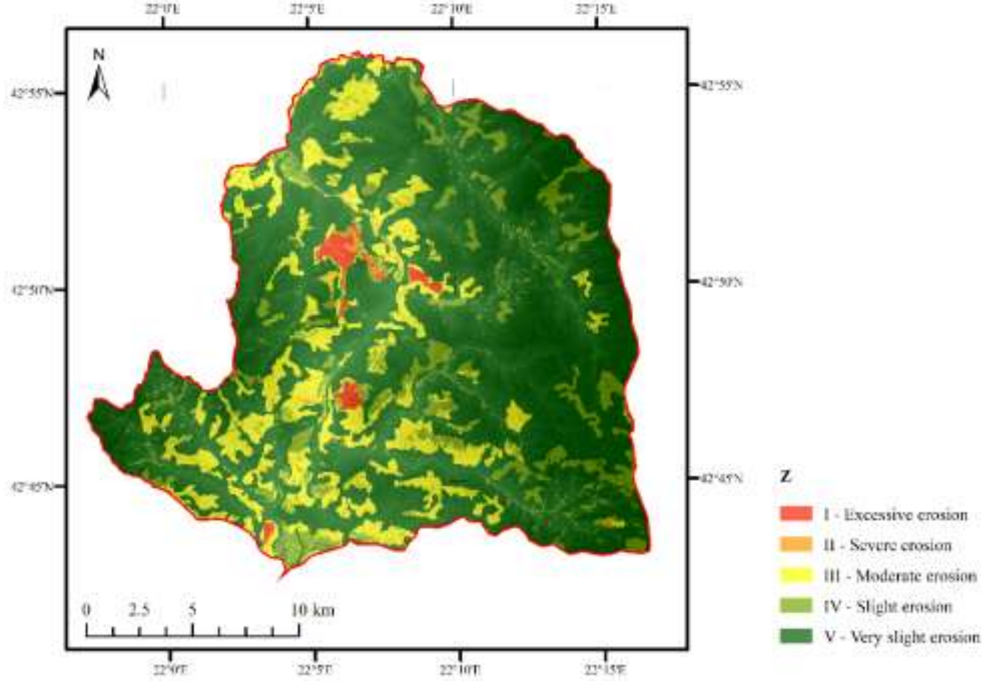
Table 2 presents the distribution of surface areas by slope categories (I–V) according to the International Geographical Union (IGU) slope classification from 1968, while their spatial distribution is shown in Figure 6d.

The majority of the Grdelica Gorge area (62.03%) falls within Category IV slopes, ranging from 27% to 70%.

Table 2. *Slope Classification According to the International Geographical Union (IGU, 1968)*

Category	Slope	Characteristics	Area	
	%		km^2	%
I	0-4	No visible signs of mass movement. Surface runoff reduced to minimum.	5.01	1.16
II	4-9	Visible indications of movement are present. Pronounced surface wash, soil flow, and landslides are present.	13.07	3.04
III	9-27	Severe erosion. Intense surface wash and mass movement are present.	138.43	32.16
IV	27-70	Excessive erosion. Enhanced surface wash and material removal are evident.	267.02	62.03
V	>70	Mass movement is so pronounced that the accumulated material is only sporadically retained, and predominantly bare rocky surfaces occur.	6.91	1.61
		Total	430.44	100.00

The erosion map (Figure 7) presents the spatial distribution of erosion processes at a resolution of 30 m, providing insight into their intensity. All categories of erosion are present within the Grdelica Gorge (Table 3). Based on the calculated mean erosion coefficient (Z_{mean} = 0.23) for the year 2025, the Grdelica Gorge is predominantly affected by low-intensity erosion processes.



Source: *Author*

Figure 7. *Erosion Processes in the Grdelica Gorge – Current Status*

Table 3. *Distribution of Erosion Categories in the Grdelica Gorge*

Erosion category	Qualitative name of erosion category	In 2025	
		km^2	%
I	Excessive erosion	4.73	1.10
II	Severe erosion	2.96	0.69
III	Moderate erosion	62.45	14.51
IV	Slight erosion	53.37	12.40
V	Very slight erosion	306.94	71.31
Total		430.44	100.00
Mean value of coefficient Z		Zmean = 0.23	

Source: *Author*

Processes of excessive erosion affect an area of 4.73 km², accounting for 1.10% of the Grdelica Gorge. These processes are concentrated within the immediate catchment of the South Morava River as it flows through the gorge, occurring on slopes ranging from 9% to over 70%, primarily on Regosol and soils predominantly used for agriculture, with substantial areas of natural vegetation. These areas include the surroundings of Predejane and the villages of Garinje, Kopitarce, Repište, and Balinovce (Vladičin Han municipality), as well as Graovo and Koraćevac (Leskovac municipality). Severe erosion occurs on slopes of 9% to 70%, primarily on Regosol, Distric Cambisol, and Eutric Cambisol soils, particularly in areas characterised by complex land cultivation practices and agricultural land use with notable natural vegetation cover. Affected areas include the surroundings of Predejane, the villages of Graovo and Koraćevac (Leskovac municipality), Mrtvice (Vladičin Han municipality), and Kijevac (Surdulica municipality). Very slight erosion processes are dominant in the Grdelica Gorge, covering 71.31% of the area (306.94 km²). These processes are mainly associated with Distric Cambisol under broadleaved, coniferous, and mixed forests. Moderate erosion affects 62.45 km², or 14.51% of the area, while slight erosion is present on 12.40% of the area.

The total annual sediment yield (W_{year}) in the Grdelica Gorge is estimated at 110,233.97 $m^3 \cdot year^{-1}$, with a specific sediment yield (W_{sp}) of 256.1 $m^3 \cdot km^{-2} \cdot year^{-1}$. The mean annual sediment transport amounts to 81,573.14 $m^3 \cdot year^{-1}$, while the specific annual sediment transport is 189.51 $m^3 \cdot km^{-2} \cdot year^{-1}$.

According to the 1970 Erosion Map of Serbia, the Grdelica Gorge was affected by erosion processes of varying intensities. In the immediate catchment of the South Morava River, processes of severe and excessive erosion were recorded, with excessive erosion also present in the higher (peripheral) areas of the gorge (Lazarević, 1983). The development of these processes was influenced not only by natural conditions but also by inappropriate land use practices, such as cultivation on steep slopes, ploughing along the slope gradient, overgrazing, leaf stripping, and high settlement density. The mean erosion coefficient at that time was $Z_{mean} = 0.50$, indicating a predominance of moderate erosion processes.

To quantify the changes in erosion intensity within the Grdelica Gorge, a comparative analysis was conducted between the erosion status in 1970 and 2025 (Table 4). The analysis revealed that slight erosion (Category IV) is the dominant process in the study area. The area affected by very slight erosion has increased by 34.36%, while slight erosion shows a marginal increase in 2025 compared to 1970. Moderate erosion has also increased by 11.27%. In contrast, the area under severe erosion has decreased by 47.67%. Excessive erosion, which was not recorded in

1970, is now present in only 1.10% of the total area (Table 4). In 1970, 48.36% of the catchment was affected by severe erosion. The current status shows a reduction in this category to 0.69%. The area affected by moderate erosion has increased from 14.51 km² in 1970 to 23.94 km² in 2025—an increase of 11.27%.

The mean erosion coefficient has decreased from Z_{mean} = 0.50 in 1970 to Z_{mean} = 0.23 in 2025 (Table 4).

Table 4. *Erosion categories in the Grdelička Gorge – 1970 and 2025*

Erosion category	Qualitative name of erosion category	1970[1] year		2025[2] year	
		km²	%	km²	%
I	Excessive erosion	0.00	0.00	4.73	1.10
II	Severe erosion	208.18	48.36	2.96	0.69
III	Moderate erosion	13.96	3.24	62.45	14.51
IV	Slight erosion	49.25	11.44	53.37	12.40
V	Very slight erosion	159.05	36.95	306.94	71.31
Total		430.44	100	430.44	100
Mean value of coefficient Z		Zsr = 0.50		Zsr = 0.23	

Source: [1] Erosion Map, 1970 (Lazarević, 1983); [2] Author

The total annual sediment yield in the Grdelica Gorge was 377,679.07 m³ year⁻¹ in 1970 and decreased to 110,233.97 m³ year⁻¹ in 2025. The specific sediment yield was reduced from 878.42 m³ km⁻² year⁻¹ in 1970 to 256.10 m³ km⁻² year⁻¹ in 2025. In other words, due to changes in the intensity of erosion processes, the mean annual sediment transport in the study area was reduced by 197,909.4 m³ year⁻¹, while the specific sediment transport decreased by 460.36 m³ km⁻² year⁻¹.

Table 5. *Sediment Production and Transport in the Area of the Grdelica Gorg*

Year	Catchment area km²	Sediment yield		Retention coefficient	Sediment transport	
		Specific	Total		Specific	Total
		Wsp $m^3 km^{-2} year^{-1}$	Wyear $m^3 year^{-1}$	Ru	Gsp $m^3 km^{-2} year^{-1}$	Gyear $m^3 year^{-1}$
1970	430.44	878.20	377,679.07	0.74	649.87	279,482.51
2025		256.10	110,233.97	0.74	189.51	81,573.14

Source: *Author*

In addition to the previously mentioned factors influencing the occurrence, development, and intensity of erosion processes, demographic changes have also played a significant role in the Grdelica Gorge. The most pronounced population decline during the study period occurred in the municipality of Crna Trava, where the number of inhabitants decreased by a factor of 28. In the municipality of Vladičin Han, the population was reduced fourfold, in Surdulica by 2.5 times, and in Leskovac by 1.8 times (Table 6).

Table 6. *Population by Municipality and Census Years*

Municipality	1971	1981	1991	2002	2011	2022
Leskovac	14242	14055	13229	12366	10611	8142
Crna Trava	1292	727	359	199	94	46
Vladičin Han	8679	7484	6029	4682	3304	2143
Surdulica	2271	1901	1185	665	339	288
Total	26484	24167	20802	17912	14348	10619

Source: *Author*

Of particular importance is the population decline in the municipalities of Crna Trava, Vladičin Han, and Surdulica, due to the area's topography and the abandonment of villages located at higher elevations, which has consequently led to the abandonment of agricultural land. Population decline has changed land use patterns, resulting in the overgrowth of former arable land and the natural regeneration of vegetation on these areas.

The results from the 1970 erosion intensity assessment differ significantly from those observed today. Very slight erosion was present on approximately 18% of the area, slight erosion on 25.2%, moderate erosion on 16.6%, while severe erosion affected 36.8% of the catchment.

A decreasing trend in erosion intensity is evident in catchments throughout Serbia. In the Grdelica Gorge, the mean erosion coefficient (Z) decreased from 0.84 in 1953 to 0.34 in 2010 (Braunović, 2013). In the Velika Morava catchment, soil erosion decreased by 21% between 1971 and 2011, with the Z value dropping from 0.529 to 0.420 (Srejić, 2023). In the hilly suburban area of Belgrade, the mean erosion coefficient declined from 0.506 to 0.332 over the period 1970–2018 (Veličković et al., 2022). Similarly, in the Rasina River basin, the erosion coefficient fell from 0.62 in 1968 to 0.35 in 2022 (Stefanović et al., 2024).

4. CONCLUSIONS

To assess land degradation in the study area, the Erosion Potential Method (EPM) originally developed for application in the Grdelica Gorge was employed.

The results indicate a significant difference in erosion intensity between 1970 and 2025, with the most notable changes occurring in the categories of very slight and severe erosion. While slight erosion is currently widespread across the entire study area, severe erosion remains concentrated on slopes ranging from 27% to 70% in the immediate catchment of the South Morava River through the gorge.

A continuous decline in population from 1971 to 2023, accompanied by the abandonment of arable land, particularly in areas with steep slopes and higher elevations and the implementation of extensive technical, biological, and biotechnical erosion control measures, has contributed to the mitigation of erosion processes and facilitated the spontaneous regeneration of vegetation.

It can be concluded that the extent of severe erosion is decreasing, whereas the proportions of slight and moderate erosion have increased considerably. Consequently, the average erosion coefficient (Z_{mean}) for the Grdelica Gorge currently stands at 0.23, indicating that the area is predominantly affected by slight erosion.

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ASSESSMENT OF SOIL EROSION INTENSITY USING THE EROSION POTENTIAL METHOD: A CASE STUDY OF THE GRDELICA GORGE, SERBIA

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Summary

The catchment area of the South Morava River, particularly the Grdelica Gorge, is among the most vulnerable regions in Serbia to soil erosion and torrential floods. Despite Serbia's notable achievements in technical and biotechnical erosion control, there remains a need for increased accountability and the implementation of concrete actions to mitigate erosion-related risks.

This study aims to assess the spatial and temporal variations in the erosion coefficient, sediment yield, and sediment transport within the Grdelica Gorge by applying the Erosion Potential Method (EPM) developed by Gavrilović (1972), within a GIS framework. The objective is to identify the primary contributing factors to erosion risk for two reference years—1970 and 2025.

The analysis revealed that the majority of the study area (62.03%) falls within the slope category IV (27–70%), encompassing all erosion intensity classes. According to the mean erosion coefficient (Z_{mean} = 0.23) for 2025, the Grdelica Gorge is predominantly affected by slight erosion. Areas of excessive erosion cover 4.73 km² (1.10% of the total area), occurring on slopes ranging from 9% to over 70%, primarily on regosols and agricultural land with large areas of natural vegetation. These zones include the surroundings of Predejane and the villages of Garinje, Kopitarce, Repište, and Balinovce (municipality of Vladičin Han), as well as Graovo and Koraćevac (municipality of Leskovac). Severe erosion is found on slopes from 9% to 70%, mostly on regosols, dystric, and eutric cambisols, associated with complex land management practices and predominant agricultural use with substantial natural vegetation cover. Very slight erosion is the most prevalent process, affecting 71.31% of the area (306.94 km²), mainly occurring on dystric cambisols under broadleaved, coniferous, or mixed forest cover. The estimated total annual sediment yield (W_{year}) for 2025 is 110,233.97 m^3year^{-1}, with a specific yield (W_{sp}) of 256.1 $m^3km^{-2}year^{-1}$. The average annual sediment transport is 81,573.14 m³/year, while the specific transport is 189.51 $m^3km^{-2}year^{-1}$.

A comparative analysis of erosion conditions between 1970 and 2025 shows that low-intensity erosion (Category IV) now predominates. The area affected by very slight erosion increased by 34.36%, while the extent of severely eroded land decreased by 47.67%. In 1970, severe erosion affected 48.36% of the catchment area, whereas by 2025, this figure had dropped to just 0.69%. The mean erosion coefficient (Z_{mean}) declined from 0.50 to 0.23. Total sediment yield decreased from 377,679.07 $m^3/year^{-1}$ in 1970 to 110,233.97 $m^3/year^{-1}$ in 2025, and specific sediment yield fell from 878.42 to 256.10 $m^3/km^2/year^{-1}$. The reduction in erosion intensity is attributed to population decline between 1971 and 2023, abandonment of arable land at higher altitudes and steeper slopes, and the extensive implementation of technical, biological, and biotechnical erosion control measures. These factors have mitigated erosion processes and enhanced vegetation recovery.

The findings indicate a marked reduction in severe erosion, accompanied by an increase in slight and moderate erosion. The current erosion coefficient (Z_{mean} = 0.23) suggests that the Grdelica Gorge is now predominantly affected by slight erosion.

PROCENA INTENZITETA EROZIJE ZEMLJIŠTA METODOM POTENCIJALA EROZIJE: STUDIJA SLUČAJA GRDELIČKA KLISURA (SRBIJA)

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Rezime

U delove Republike Srbije koji su bili najugroženiji erozijom zemljišta i bujičnim poplavama svrstava se sliv Južne Morave, posebno Grdelička klisura. Iako Srbija ima značajnih tehničkih i biotehničkih rešenja, postoji potreba za većim stepenom preuzimanja odgovornosti i konkretnih koraka za problem erozije. Cilj ovog rada je da se primenom metode potencijala erozije u GIS okruženju utvrde prostorne i vremenske promene koeficijenta erozije zemljišta, produkcije i pronosa nanosa i identifikuju faktori koji najviše doprinose riziku od pojave erozije na području Grdeličke klisure za dva referentna perioda – 1970. i 2025. godinu.

Intenzitet erozije zemljišta na istraživanom području analiziran je primenom metode potencijala erozije (MPE) prema Gavriloviću (1972). Obradom geoprostornih podataka u GIS-u dobijene su tematske karte i sintezna karta intenziteta erozije.

Rezultati istraživanja pokazuju da najveći deo područja (62,03%) pripada IV kategoriji nagiba (27–70%) i zastupljene su sve kategorije erozije. Prema srednjoj vrednosti koeficijenta erozije (Zsr = 0,23) za 2025. godinu, Grdelička klisura je ugrožena procesima slabe erozije. Procesi ekscesivne erozije javljaju se na površini 4,73 km^2 (1,10% područja), na nagibima od 9% do preko 70%, na regosolu i pretežno poljoprivrednom zemljištu s velikim površinama prirodne vegetacije (okolina Predejana, okolina selâ Garinje, Kopitarce, Repište i Balinovce u opštini Vladičin Han i sela Graova i Koraćevca, u opštini Leskovac). Jaka erozija je prisutna na nagibima od 9% do 70%, na regosolu, distričnom i eutričnom kambisolu, sa složenim načinima obrade i zemljištu koje se pretežno koristi u poljoprivredne svrhe, s velikim površinama prirodne vegetacije. Na području su dominantni procesi vrlo slabe erozije i zahvataju 71,31% površine (306,94 km^2), uglavnom na distričnom kambisolu, pod listopadnim, četinarskim i mešovitim šumama. Ukupna godišnja produkcija nanosa (W_{year}) iznosi 110233,97 m^3god^{-1}, a specifična produkcija nanosa (W_{sp}) iznosi 256,1 $m^3km^{-2}god^{-1}$. Srednjogodišnji transport nanosa na području je 81573,14 $m^3km^{-2}god^{-1}$ i specifični godišnji transport nanosa je 189,51 $m^3km^{-2}god^{-1}$.

Poređenjem stanja erozije u 2025. sa stanjem u 1970. godini, utvrđeno je da na području dominanira erozija slabog intenziteta (IV kategorije). Povećana je površina zemljišta zahvaćena veoma slabom erozijom za 34,36%. Površine pod jakom erozijom su smanjene za 47,67%. Prema stanju iz 1970. godine 48,36% površine sliva bilo je zahvaćeno kategorijom jake erozije, dok sadašnje stanje pokazuje da je ova kategorija erozije smanjena na 0,69%. Vrednost Zsr smanjena je sa 0,50 na 0,23. Ukupna godišnja produkcija erozionog nanosa u 1970. bila je 377,679.07 m^3god^{-1}, a u 2025. je smanjena na 110,233.97 m^3god^{-1}. Specifična produkcija erozionog materijala je sa 878,42 $m^3km^{-2}god^{-1}$ smanjena na 256,10 $m^3km^{-2}god^{-1}$. Opadanje broja stanovnika od 1971. do 2023. godine i napuštanje obradivih površina u delovima sliva na većim nadmorskim visinama i nagibima, te veliki obim izvedenih tehničkih, bioloških i biotehničkih protiverozionih radova, doveli su do ublažavanja erozivnih procesa i pojačane obnove vegetacije.

Zaključuje se da je stepen jake erozije u opadanju, dok je procenat slabe i srednje erozije rapidno porastao, tako da Zsr na području Grdeličke klisure iznosi 0,23 (slaba erozija).

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GRONDWATER MONITORING AT THE AREA OF THE FLOODING FORESTS

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Abstract: *The Danube is a natural habitat for a diverse range of flora and fauna, and its floodplain forests provide numerous ecosystem services that directly contribute to an improved quality of life for people. The dominant tree species in the river's floodplain areas are willow, poplar, and alder. These forests play a crucial role in water filtration, shoreline protection from erosion, and carbon storage. Continuous monitoring of groundwater is essential for preserving this resource. The goal is to monitor groundwater level fluctuations to influence the selection of silviculture and management measures based on the results of long-term research, and to implement planned activities in forest management. In the "Apatinski rit" management unit, it is recommended to establish a network of piezometers.*

Keywords: Danube, floodplain forests, groundwater, groundwater monitoring, network of piezometer

MONITORING PODZEMNIH VODA NA PODRUČJU PLAVNIH ŠUMA

Sažetak: *Dunav je prirodno stanište raznovrsnoj flori i fauni, a njegove plavne šume pružaju niz ekosistemskih usluga koje direktno doprinose boljem životu ljudi. Dominantne vrste drveća u plavnim područjima reka su vrba, topola i lužnjak. Ove šume igraju ključnu ulogu u filtriranju vode, zaštiti obala od erozije i u skladištenju ugljenika. Stalan monitoring podzemnih voda je ključan za očuvanje ovog resursa. Na području gazdinske jedinice „Apatinski rit" se preporučuje postavljanje mreže pijezometara. Cilj je praćenje oscilovanja nivoa podzemnih voda, kako bi, na osnovu rezultata višegodišnjih istraživanja, uticali na izbor uzgojno-gazdinskih mera i sproveli planske aktivnosti u domenu gazdovanja šumama.*

Ključne reči: Dunav, plavne šume, podzemne vode, monitoring podzemnih voda, mreža pijezometara

1. INTRODUCTION

In the process of water circulation in nature, part of the atmospheric and surface waters infiltrates into the lithosphere, forming aquifer zones under the

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influence of gravity. Due to the specific hydrogeological characteristics of water-bearing rocks, groundwater occurs as aquifers of compacted and broken types, with the phreatic aquifer belonging to the compacted type. Phreatic waters constitute the shallowest aquifer in loose sediments above the impermeable layer and extend continuously throughout the entire area. Changes in the level of the first aquifer are caused by uneven inflow and outflow of water, which is related to the distribution of precipitation, temperatures and evaporation. (Josipović, Soro, 2012). Decline of lowland flood forests is a consequence of changeable ecological conditions, first of all due to huge groundwater level fluctuations and duration of surface water stagnation as well. (Nikolić, 2017). Decline of forests situated on alluvial soils on the banks od the Sava and Danube rivers was investigated from many different aspects such as: fluctuations of groundwater level and decline intensity (Dekanić, 1974; Đorović, Letić, 2002; Letić et al. 2014), species response to changeable site conditions (Prpić, 1976), intensity of radial increment as indicator of changed site conditions (Pranjić and Lukić, 1989), bioecological (Prpić et al., 1994) and silvicultural reasons (Bobinac et al. 1997). The important impact of groundwater on the characteristics of lowland sites is related to the fact that it leads to an increase in soil moisture, so that is impossible to compensate directly through rainfalls (Nikolić Jokanović et al. 2023 a). Many destructive human activities caused deviations of natural watering regime which affected the increased fluctuations of groundwater and surface waters and, as a result, stability and vitality of lowland forest ecosystems was very endangered (Nikolić Jokanović et al. 2024). According to global warming and long dry periods, pattern of decreased groundwater level was established, which negatively affects development and productivity of forest associations located in alluviums and that is especially harmful for pedunculate oak whose needs for water mainly are mainly satisfied from groundwater (Nikolić Jokanović et al. 2023 b). Based on the aforementioned, we can conclude that knowing of groundwater trend is a of great practical significance.

The main goal of the paper is conducting the permanent monitoring related to groundwater fluctuations in the alluvium of the Danube river in order to define as more precise as possible pattern of groundwater behaviour. This will give us a possibilty of carrying out a comprehensive management of lowland forests at this area, whose development depends the most on the available groundwater content.

2. MATERIAL AND METHODS

2.1. General features of MU „Apatinski rit“

The management unit "Apatinski rit" is located within the North Bačka Forest Area, managed by the Forest Management "Sombor" from Sombor, as an integral part of the Public Enterprise "Vojvodina šume", Petrovaradin. This management unit is located in the western part of Bačka, on the territory of the Apatin municipality. The management unit complex is divided into the districts of Harčas, Poluostrvo, Zverinjak, Duboki jendek, Staklara and Bakulja (Figure 1).

Forests, forest cultures and forest land make up 80.6% of the total area of the management unit, where forest cultures make up 54.0%. The area covered by this management unit is a lowland area, in a protected area along the Danube River.

The microrelief is very pronounced, the area is intersected by ponds, micro-depressions and channels. Alluvial surfaces, which are intersected by long and narrow depressions, are in fact former river arms.

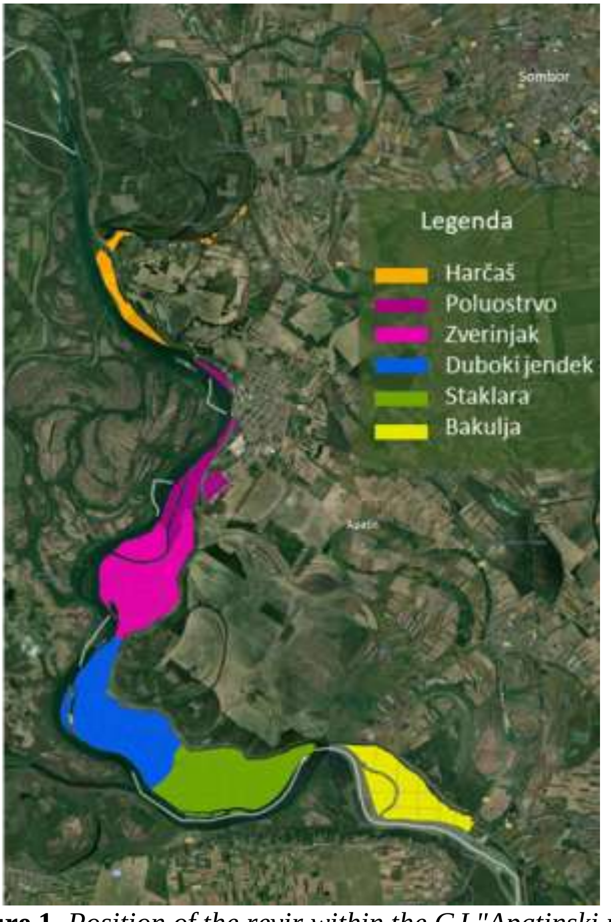

Figure 1. *Position of the revir within the GJ "Apatinski rit"*

The geological base is alluvium, which can be very heterogeneous in composition, depending on whether sand or clay predominates in the sediment. Fluvisols (alluvial soils), semigleys (meadow soils) and eugleas (swampy gley soils) are represented within the management unit (Figure 2).

The “Apatinski rit” management unit is located in an area protected from direct flooding by the Danube River. After the construction of the embankment, significant changes in the water regime occurred (removal of flood waters and lowering of groundwater levels), which led to drying of the soil and negatively affected domestic hygrophilous species. As for forest associations, there are most dominant willow and poplar forests, which are directly depending on the watering regime. At low positions, the most represented is white willow, while at upper parts of the relief are monocultures and mixed stands with black poplar, that is connected with the complexity of the whole ecosystem.

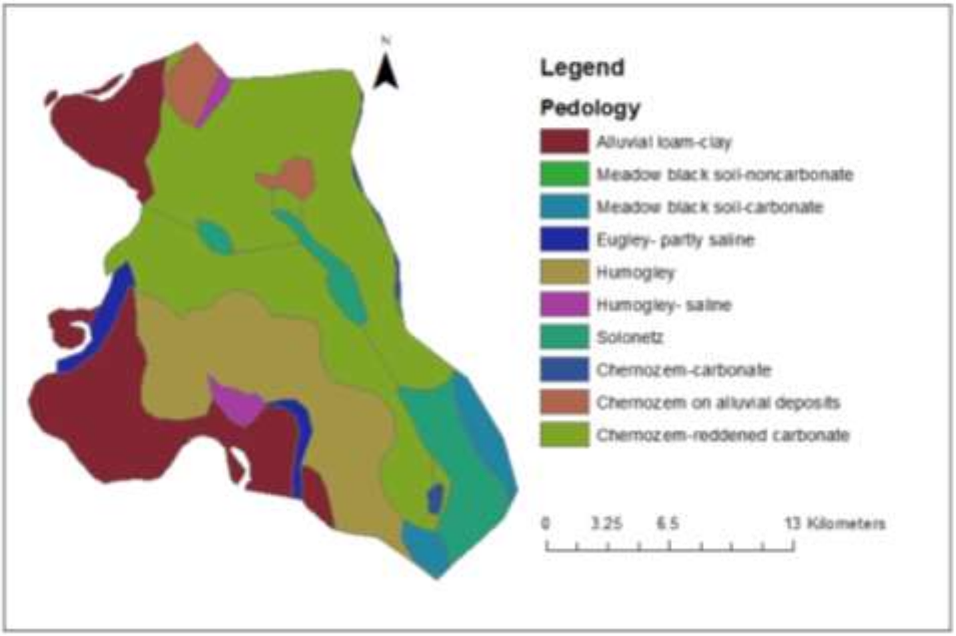

Figure 2. *Pedological map of the area*

2.2. Methodology

The investigation in the paper is divided into following phases:

First phase – Collecting and description of the ecological features of the researched area – in this phase, based on collected data from published scientific papers, and based on available technical documentation, as well, was described the studied area.

Second phase – The analysis of climate data – in this phase, based on the analysis of data for ten-years long period (2013-2022) from meteorological station Sombor, was conducted the analysis of climatological characteristics of the studied area.

Third phase – The analysis of hydrological data - within the third phase, there was carrying out the analysis of the river Danube water level based on available data recorded at the measuring station located in Apatin for period 2013-2022.

Fourth phase – Defining of piezometric net at the investigated area within the MU "Apatinski rit" – in this phase, based on all previously obtained results at the researched area, there was proposed the net of objects for groundwater level monitoring.

In the lowland forests of Serbia, piezometers are installed to monitor groundwater levels. Their construction consists of a 5/4" galvanized pipe, a 0.5 m sedimentation tank, a 1.5 m filter, and a part of the structure above the ground surface of 20 cm. The filter structure is a pipe perforated with circular holes with a diameter of 4 mm, around which a gravel fill is installed to a depth of 0.5 m from the ground surface, and a clay buffer is placed in this zone. The piezometer cap and the bottom of the sedimentation tank are closed with a metal screw cap. The top of the piezometer structure should be placed 20 cm above the ground surface and should be flush with the concrete reinforcement.

Data loggers – Figure 3 (diver) are probes that are installed in observation facilities and are used for permanent monitoring of groundwater levels in wells (piezometers).

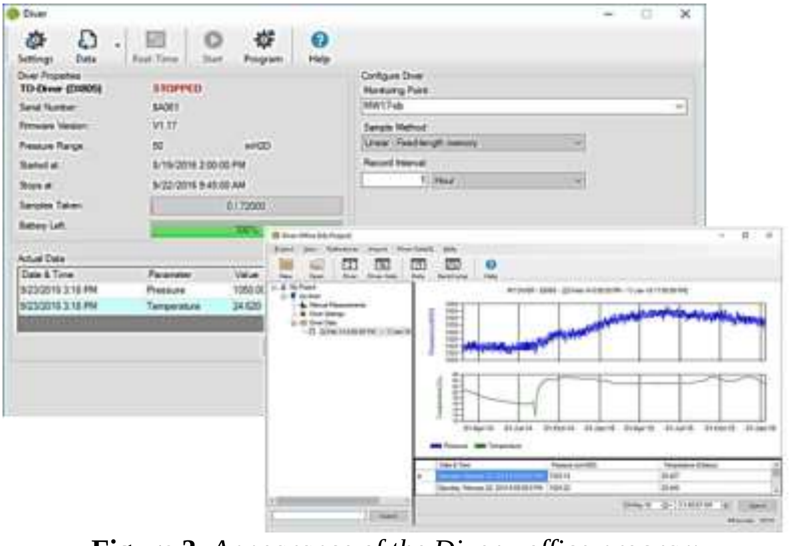

Figure 3. *Appearance of the Diver - office program*

3. RESULTS

3.1. The analysis of climate characteristics

In order to display climate characteristics of the investigated area, there was used data from meteorological measurements in period 2013-2022, at Sombor climate station, which is on 88 m elevation (19º09'E, 45º46'N). Based on the conducted analysis, for ten-years long period, we can deduce:

Air temperature is one of the most significant climate elements. During the observed period (2013-2022), the mean annual air temperature was 12.3 °C. The highest annual air temperature was 25,1 °C in July 2012, while the lowest was recorded in January 2017 (-5,3 °C) – Figure 4.

In addition to air temperature, rainfalls are the most important climate factor. Form, distribution, frequency, and level of the rainfalls during the whole year shows the continental character, not only of Serbian climate, but also of investigated area. They represent all forms of condensed and sublimated water vapor in the air, which appear on the Earth's surface in a liquid or solid state.

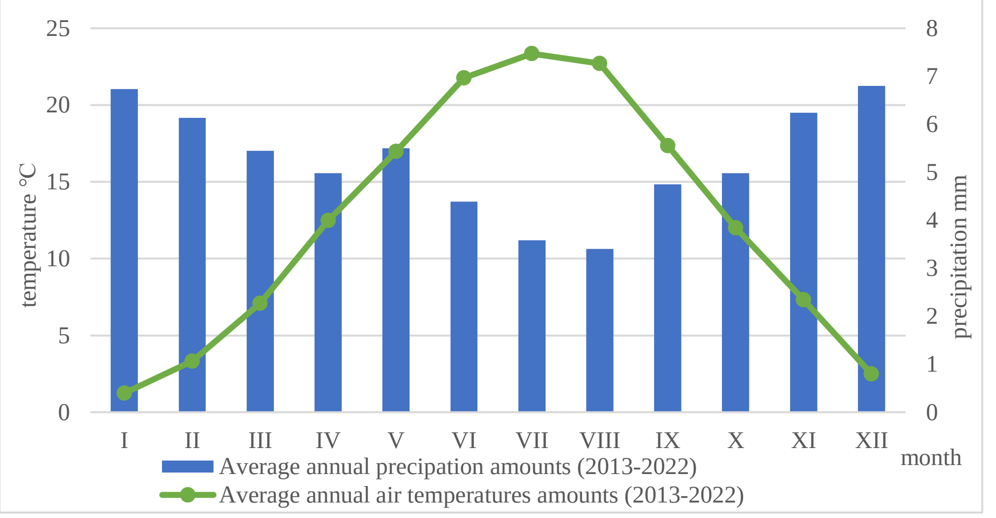

Figure 4. *Average annual air temperatures and average annual rainfalls amounts (2013-2022)*

In the period from 2013 to 2022, the average precipitation during the year is partially uniform, with a pronounced minimum in August. The total precipitation amounts during the growing season make up a large part of the total precipitation amounts during the year (Figure 5). The largest difference between the total and rainfalls during growing season was recorded in 2022.

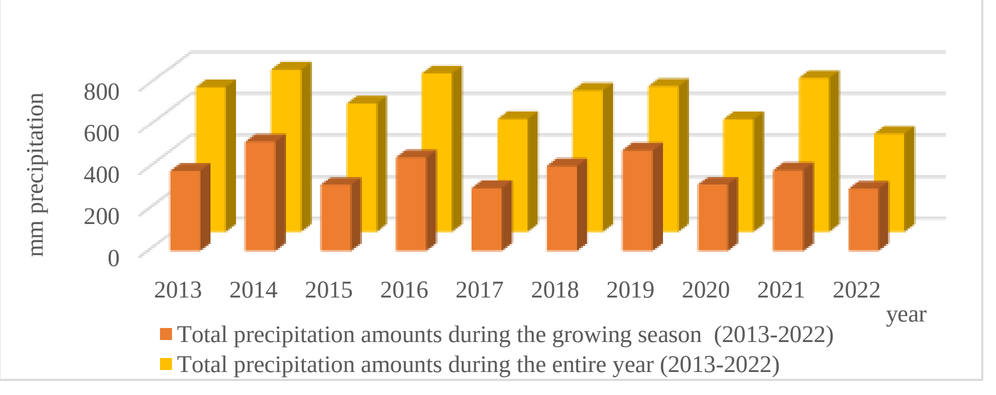

Figure 5. *Total rainfalls during the growing season and throughout the entire year (2013-2022)*

Relative air humidity, which expresses the degree of air saturation with water vapor, is an important climatic element. This value on an annual basis is inversely proportional to the annual air temperature. Relative air humidity is highest in the winter half of the year, more precisely in November and December (86%, 87%), and lowest in July (63%) – Figure 6. The annual variation in relative humidity ranges between 71% and 81%. The average relative humidity is 74%, while the average value during the growing season is 65%.

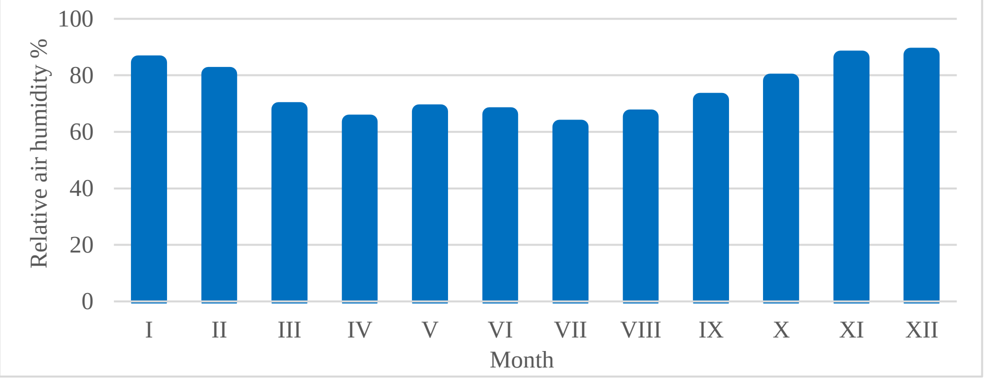

Figure 6. *Relative air humidity (2013-2022)*

3.2. The analysis of hydrological characteristics

The water level regime of the Danube River was analyzed based on data from the Apatin water gauging station (Figure 7). The zero point of the water gauging station is at 78.84 m above the Adriatic Sea, and the basin area up to Apatin is 211.139 km^2. Data at this station have been recorded since 1876, and the ten-year period from 2013 to 2022 was analyzed (Figure 8) and the following can be concluded:

The Danube in the territory of the Apatin municipality is characterized by a nival regime. The highest average monthly water levels occur at the beginning of summer, in June.

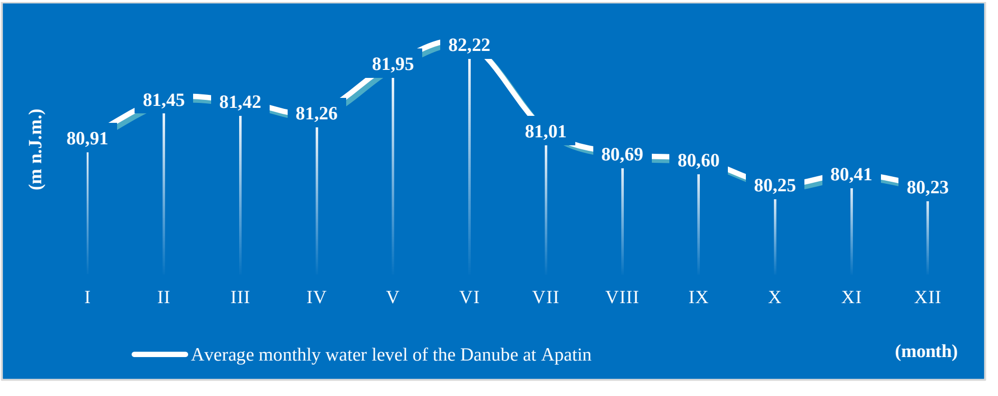

Figure 7. *Average monthly water level of the Danube at Apatin from 2013 to 2022*

High and extremely high water levels occur in early summer and late spring, while low water levels in autumn occur due to low rainfall in late summer and autumn. Extremely low water levels are also often recorded during the winter months. This condition occurs if an extremely dry autumn is followed by an extremely cold winter, without a previous rainy period. High water levels, in contrast to low water levels, are of exceptional importance. They, among other things, raise groundwater levels and extremely high water levels lead to flooding.

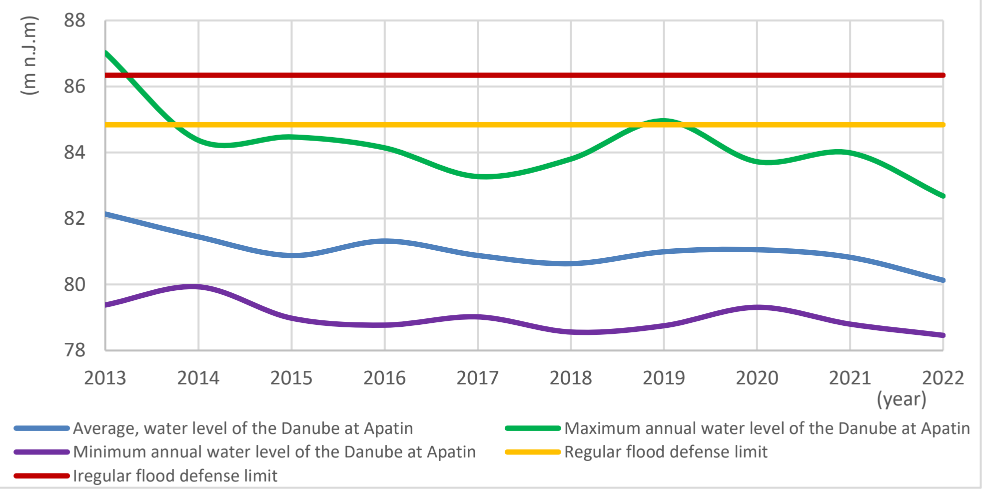

Figure 8. *Average, minimum, and maximum annual water level of the Danube at Apatin from 2013 to 2022*

The value of the absolute highest water level (June 24, 1965) is 825 cm, which means that its absolute height is 87.09 m. This shows that the Danube level was higher than the average height of the alluvial plain by about 3.6 m, and then the lower parts by 5-6 m.

Hydrogeological studies found that the thickness of the Quaternary deposits in the Danube coast is between 60 m and 70 m, most of which is made up of sediments of the older quarter, while above are situated up to the ground sediments originate from Halocene. The entire complex is made up of clayey, sandy, sandy-gravelly and gravelly deposits, with the proportion of coarser-grained sediments increasing with depth (Hajdin, 2013)

The influence of the river and good hydraulic connectivity have been confirmed by regime observations carried out at the Apatin water supply source. Moving away from the river, its influence weakens, and the importance of terraced deposits increases. In a wider area, the influence of precipitation in feeding the aquifers is significant, especially in zones where the surface layer is made up of sandy deposits with more favorable filtration characteristics. Part of the groundwater of this aquifer originates from tertiary deposits from which, under appropriate conditions, water overflows from the deep aquifer (Lazić, 2005).

3.3. Defining of bioindication profiles and piezometric distribution at the area of the part of MU “Apatinski rit”

Determining the position of bioindication lines (BIL) on which piezometer structures are installed in the research area depends on the position of the forest complex in relation to the Danube River (as well as its water regime), habitat characteristics (orographic conditions, soil types, etc.), vegetation types (forest types, cover, age, etc.), road network and other characteristics of the area being researched.

The forest area of the management unit "Apatinski rit" includes departments 14 to 29, where it is proposed to install a network for monitoring groundwater (piezometers). In this area, alluvial soil (fluvisol) is present in the coastal part of the river floodplain, where natural forests of white willow, white poplar, as well as Euro-American poplars occur (Figure 9). In the central part of the plain, where the clayey alluvium is deposited, there is fluvial meadow soil (humofluvisol), on which forests of white willow, black poplar, field ash with elms and pedunculate oak are present. Marsh mulberry forests are highly productive habitats of hardwood forests, primarily pedunculate oak and ash forests. Pseudogley is a soil of lowland terrain, most often occurring in the depressions of old river and lake terraces. Pseudogley is also the habitat of natural forest communities such as pedunculate oak forests.

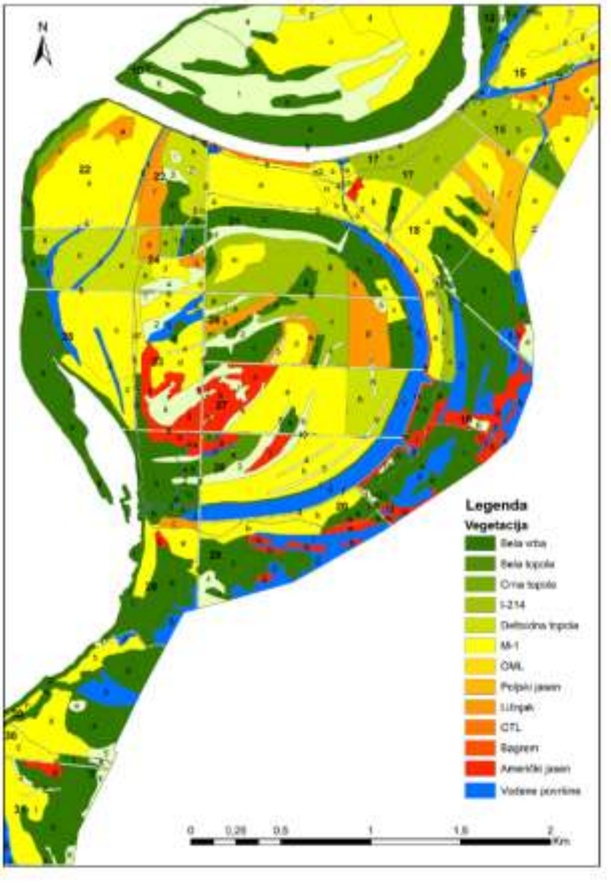

Figure 9. *Tree species distribution in GJ "Apatinski rit," revir Zverinjak*

In order to conduct monitoring of groundwater level at investigated area, it was proposed to install 3 bioindication profiles perpendicular on the river Danube river. Distribution of piezometers is shown in Figure 10.

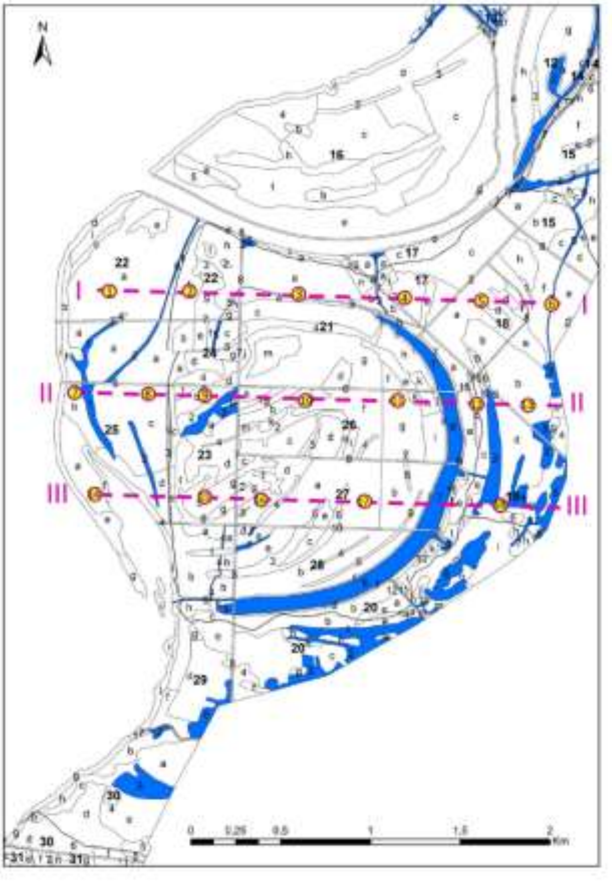

Figure 10. *Piezometer distribution in the studied area of the GJ "Apatinski rit"*

4. DISCUSSION

The installing of piezometric net at the area of Apatin represents the key activity related to groundwater level monitoring and its quality, as well, which contributes a lot to the conservation and management of forests. Piezometers together with special probes (diver) enable a precise groundwater fluctuations monitoring. Presence of some hygrophilous woody species such as willow, poplar, and pedunculate oak occurs as a consequence of specific watering regime in the alluvium of the river Danube. During artificial regeneration of the forest ecosystems in this area, preference should be given to native forest species that are already adapted to current site conditions. A special attention has to be paid to the area of Apatin, because some negative changes related to the groundwater level may endanger present vegetation. The obtained results in some papers (Nikolić-Jokanović et al. 2024) found that pedunculate oak prefers soils with a dominant participation of groundwater. Several studies (Matić and Skenderović, 1993; Prpić and Anić, 2000; Vrbek, 2003) have investigated the relation between radial increment and minimal groundwater level by pedunculate oak during growing season. Mayer (1994) found that both long dry period or a great rainfalls quantity negatively affect groundwater level, which causes unsuitable site conditions for trees located in lowland forests. Nikolić-Jokanović et al. (2023 a) established significant deviations of groundwater level compared to reference level during extreme years (wet and dry period) in the area of Donji Srem. These deviations are good indicators of potential risk zones existing where forest species (first of all, pedunculate oak) may be endangered. Based on the determination of the risk zones, an appropriate management measures can be conducted. This action may prevent some significant damages in case of extreme climate scenario.

5. CONCLUSION

Water is a key ecological factor which affects development and productivity features of the lowland forests in the alluvium of the river Danube. The object of the paper is the analysis of the ecological conditions at the part of the MU "Apatinski rit" with the aim of piezometers installing in order to conduct the groundwater level monitoring. Based on the analysis of climate parameters in ten-years long period (2013-2022), there were obtained following values: an average annual air temperature was 12.3°C, while an average annual total rainfalls quantity was 652,2 mm, with more than 59 % occurred during growing season, which positively affects vegetation development at the investigated area. Presence of hygrophilous woody species such as willow, poplar, and pedunculate oak, is a result of the watering regime in the alluvium of the river Danube. During artificial restoration of the forest ecosystems in this area, natural vegetation should be represented due to its adaptability to the current site conditions. Within this paper was proposed forming of 3 bioindication profiles with total of 18 piezometers (6 at first, 7 at second, and 5 piezometers at third profile). Forming of piezometric net serves to monitor groundwater level fluctuations, and based on the obtained results during many years, adequate silvicultural and management strategy can be applied.

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GRONDWATER MONITORING AT THE AREA OF THE FLOODING FORESTS

Sofija PAREZANOVIĆ, Vesna NIKOLIĆ JOKANOVIĆ

Summary

Groundwater infiltrates into the lithosphere, forming outcrop zones under the influence of gravity. The type of these zone depends on several factors such as water feeding and release, rock characteristics, position, and circulation, and can be either compacted or fractured. The freatic aquifer belongs to the compact type. Changes in the water levels of the first aquifer are primarily due to uneven inflow and outflow, influenced by precipitation distribution, air and soil temperatures, and evaporation. The goal of the paper is multi-year groundwater level fluctuations monitoring within MU "Apatinski rit", so for that purpose was proposed installing of piezometric net at this area. The investigation includes detailed description of ecological (pedology and vegetation), climate (air temperature, relative air humidity, sum of precipitation), and hydrological (level of the river Danube and groundwater fluctuations) parameters. The decision about piezometric net installing should be made based on the results of papers related to this issue which are carried out at the area of MU "Apatinski rit". Permanent monitoring of the groundwater fluctuations would contribute a lot to conducting an appropriate management and silviculture measures in lowland forests of the river Danube alluvium.

MONITORING PODZEMNIH VODA NA PODRUČJU PLAVNIH ŠUMA

Sofija PAREZANOVIĆ, Vesna NIKOLIĆ JOKANOVIĆ

Rezime

Podzemne vode infiltrirajući se u litosferu formiraju izdanske zone, čiji tip zavisi od različitih faktora kao što su hranjenje i izdavanje, kao i karakteristike stena i cirkulacija vode. Freatska izdan pripada zbijenom tipu, a promene u nivou vode su posledica neujednačenog hranjenja i izdavanja, koji zavise od raspodele padavina, temperatura i isparavanja. Cilj rada je višegodišnji monitoring oscilovanja nivoa podzemnih voda u okviru gazdinske jedinice "Apatinski rit" i u tu svrhu se predlaže postavljanje mreže pijezometara na ovom području. Istraživanje obuhvata detaljan opis ekoloških (pedološko-vegetacijskih), klimatskih (temperature vazduha, relativna vlažnost vazduha, količina padavina) i hidroloških (vodostaj Dunava i oscilovanje nivoa podzemnih voda) parametara. Odluka o postavljanju mreže pijezometara donosi se na osnovu rezultata istraživanja koja su iz domena ove problematike sprovođena na području GJ "Apatinski rit". Redovan monitoring nivoa oscilovanja podzemnih voda veoma bi doprineo sprovođenju odgovarajućih gazdinskih i uzgojnih mera u nizijskim šumama priobalja Dunava.

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Original scientific paper

CLIMATE CHARACTERISTICS AND DIAMETER INCREMENT OF INCENSE-CEDAR: POTENTIAL USE IN AFFORESTATION IN BELGRADE AREA (REPUBLIC OF SERBIA)

Tatjana DIMITRIJEVIC[1], Mihailo RATKNIC[1] Sasa EREMIJA[1], Sabahudin HADROVIĆ[1], Violeta DJORDJEVIĆ[2], Snežana KONATAR[3]*

Abstract: *The paper presents the results of research dealing with the influence of climatic factors on the size of earlywood and latewood and the total diameter increment of incense-cedar (Calocedrus* decurrens (Torr.) Florin*). Samples taken from 30 trees at a height of 1.3 m were used in the analysis. The values were correlated with the mean monthly air temperature and precipitation sums (from April to September). In addition, the tree age expressed in years was included as an important factor. The analysed parameters explained 64.8% of the current diameter increment, 64.8% of the latewood, and 55.8% of the earlywood share.*

Keywords: *Calocedrus decurrens*, climate change, REG_IN model, early wood, late wood, total growth

КЛИМАТСКЕ КАРАКТЕРИСТИКЕ И ДЕБЉИНСКИ ПРИРАСТ ЛИБОКЕДРА:ПОТЕНЦИЈАЛНА УПОТРЕБА У ПОШУМЉАВАЊУ НА ПОДРУЧЈУ БЕОГРАДА (РЕПУБЛИКА СРБИЈА)

Извод: *У раду су приказани резултати истраживања утицаја климатских фактора на величину раног и касног дрвета и укупан прираст Calocedrus decurrens (Torr.) Florin). У анализи су коришћени узорци узети са 30 стабала на висини од 1,3 м. Вредности су у корелацији са средњом месечном температуром ваздуха и сумом падавина (од априла до септембра). Поред тога, као важан фактор укључена је старост дрвета изражена у годинама. Анализирани параметри објаснили су 64,8% укупног дебљинског прираста, 64,8% касног дрвета и 55,8% раног дрвета.*

Ključne reči: *Calocedrus decurrens*, климатске промене, REG-IN модел, рано дрво, касно дрво, укупни прираст

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1. INTRODUCTION

According to the ND-GAIN index, Serbia ranks 76th out of 182 countries in terms of vulnerability to climate change and global challenges, as well as its readiness to improve resilience. The purpose of this index is to assist governments, businesses, and communities in prioritizing investments that will effectively address the immediate global challenges ahead (Notre Dame Global Adaptation Initiative, 2023). These changes will significantly impact forest ecosystems. Human activities have destroyed numerous habitats, which are often fragmented or damaged due to long-term pollution from various sources (Ratknić et al., 2019b). In the Belgrade area, existing and future vegetation will experience increased temperatures compared to current conditions. The isotherms of the average annual air temperature have shifted approximately 160 km north, and by the end of the 21st century, this shift is expected to exceed the tolerances of many tree species, potentially leading to their extinction in regions where they are currently found (Barnes, 2009; Iverson et al., 2008; Kirschbaum and Fischlin, 1996; Joyce and Rehfeldt, 2012). Climate change will result in significant alterations to the forest ecosystems of Belgrade as they will struggle to adapt to the new climatic conditions (Dimitrijević and Ratknić, 2023).

Climate change presents challenges for choosing the most effective methods of forest management. The rapid pace of climate change hinders the timely adaptation of forest ecosystems, jeopardizing their sustainable use. One potential solution to these challenges lies in understanding climatic niches (Joyce and Rehfeldt, 2013). Utilizing climate characteristics to describe species niches forms the foundation of "much ecological thinking and theory" (Pulliam, 2000, as cited in Joyce and Rehfeldt, 2013). The relationship between growth and environmental factors, such as climate, is crucial for defining species niches and selecting suitable habitats as climate conditions evolve (Dimitrijević and Ratknić, 2023). According to Pearson (2007, as cited in Joyce and Rehfeldt, 2013), "the central premise of this approach is that the currently realized niche of a species provides the best available metric for projecting the future distribution of suitable habitat." Research based on climate models and changes in forest ecosystems (Ratknić et al., 2019a) suggests that most native tree species may struggle to adapt to future climate conditions. This could prompt the introduction of non-native species in the urban forests of Belgrade that are better suited to future climates, potentially increasing the overall number of species in the area. So far, the impact of climatic factors on species such as Douglas fir (Ratknić et al., 2019), Cedar (Dimitrijević et al., 2022), Red oak (Dimitrijević et al., 2023), and eastern white pine (Dimitrijević et al., 2024) has been identified in Belgrade's urban forests.

Incense-cedar is a species commonly found in the mixed forests of the Sierra Nevada, where it typically grows either alone or in small groups. Its range spans about 15° of latitude and a variety of climates from the southern slope of Mount Hood in Oregon, southward through the Siskiyou, Klamath, and Warner Mountains, Cascade and Coast Ranges, and Sierra Nevada to the dry Hanson Laguna and Sierra de San Pedro Martir Ranges in Baja California (Grifin and Critchfield, 1972). Incense-cedar grows from the coastal fog belt eastward to the desert fringes. It can be found in the Washoe Mountains of west-central Nevada

(McDonald) (Map 1). Incense cedar grows at altitudes ranging from 50 to 2010 m in the limits and from 910 to 2960 m in the southern limits of its range. In the Sierra Nevada, it can be found at altitudes from 610 to 2100 m.

Incense cedar is a good competitor on hot, dry sites and commonly shares an upper canopy position on southwestern slopes. On cooler, moister aspects, it is usually subdominant to other species.

"Incense-cedar grows on many kinds of soils developed from a wide variety of parent rocks- rhyolite, pumice, andesite, diorite, sandstone, shale, basalt, peridotite, serpentinite, limestone, and granitic or metamorphic: equivalents. It is particularly adept at extracting soil phosphorus and calcium and excluding surplus magnesium. Incense-cedar grows on many kinds of soil developed from a wide variety of parent rocks- rhyolite, pumice, andesite, diorite, sandstone, shale, basalt, peridotite, serpentinite, limestone, and granitic or metamorphic equivalents. It is particularly adept at extracting soil phosphorus and calcium, and excluding surplus magnesium" (Powers and Oliver).

Map 1. *Distribution of Lybocedra in Natural Habitats Across the USA.*

2. MATERIAL AND METHODS

The research was conducted in an artificially raised stand of Libocerus located at Šuplja Stena. The coordinates of the sample site are X = 7463396, Y = 49448501, and the altitude is Z = 278 meters. The studied stand is 60 years old, well-preserved, and fully assembled, situated at an altitude of 278 meters with a 50-degree slope and western exposure. The study examined the relationship between the current increase in diameter and the width of early and late wood in relation to climatic factors. These factors include the total monthly precipitation and the average monthly air temperature during the growing season, which spans from April to September.

The independent variables assessed were:

- age
- Total precipitation in April (AP_P), May (MA_P), June (JU_P), July (JL_P), August (AV_P), and September (SE_P)
- Average air temperature in April (AP_T), May (MA_T), June (JU_T), July (JL_T), August (AV_T) and September (SE_T).

3. RESULTS

3.1. Pedological Characteristics

Soil Type: Eutric Cambisol , Soil Profile Structure: A (0-4 cm) - (B) (4-60 cm)

Based on its texture, the soil is classified as clay loam, which is poorly permeable to water and poorly aerated. The reaction of the soil solution is moderately acidic, and the degree of saturation with base cations is high. The surface layer (0-20 cm) is adequately supplied with nutrients, while the deeper layers contain low levels of humus. The soil is well-supplied with total nitrogen. However, the availability of easily accessible phosphorus for plants is low, and the levels of accessible potassium are at the lower end of the medium range. The chemical properties of the soil in this experimental field are detailed in Table 1, while the physical properties are outlined in Table 2.

Table 1. *Chemical Properties of Soil*

Depth	pH		Adsorption complex.					Total		Accessible	
	H_2O	KCl	T	S	T-S	V	Y1	hummus	N	P_2O_5	K_2O
cm			cmol/kg			%	cm^3	%	%	mg/100g	
0-20	6.42	5.49	27.37	22.17	5.20	81.01	7.99	3.77	0.22	1.90	13.00
20-40	6.10	4.73	26.06	19.19	6.87	73.64	10.57	1.87	0.11	2.31	11.90
40-60	5.84	4.28	26.88	18.86	8.02	70.15	12.34	1.36	0.08	6.44	11.40

Source: *Miletić, Z. and Eremija, S., 2019*

Table 2. *Physical properties of soil*

Depth	Coarse Sand	Fine Sand	Dust	Clay	Total Sand	Total Clay	Texture Class
cm	%	%	%	%	%	%	
0-20	0.90	39.10	31.30	28.70	40.00	60.00	Clayey loam
20-40	0.40	34.40	32.00	33.20	34.80	65.20	Clayey loam
40-60	0.30	34.40	29.80	35.50	34.70	65.30	Clayey loam

Source: *Miletić, Z. and Eremija, S., 2019*

3.2 Phytocenological characteristics

Habitat belongs to the forest community of Italian oak and Turkey oak with a broom, a variant of hornbeam (Ass. *Quercetum farnetto-cerris Rud. aculeatetosum* Job.). The following species are recorded in the stand (Stajić, S., 2019):

- **Tree layers**: Canopy (0.9) Calocedrus decurrens (4.2); Quercus cerris (1.1).
- **Shrub layer**: Canopy: (0.6); mean height 2 m Rosa canina (2.2); Crataegus monogyna (2.1); Fraxinus ornus (2.1); Ulmus carpinifolia (1.2); Lonicera caprifolium (1.2); Cornus mas (1.2); Acer campestre (1.2); Acer tataricum (1.2); Carpinus betulus (1.2); Acer pseudoplatanus (1.1); Prunus avium (1.1); Quercus frainetto (1.1); Tilia argentea (1.1); Calocedrus decurrens (+.1).
- **Ground flora layer**: Coverage (0.6) Lonicera caprifolium (3.2); Galium aparine (3.2); Quercus cerris (3.1); Ruscus aculeatus (3.3); Geranium robertianum (2.3); Ligustrum vulgare (2.3); Hedera helix (2.2); Alliaria petiolata (2.2); Rubus hirtus (2.2); Cardamine bulbifera (2.1); Fragaria vesca (1.2); Carex sylvatica (1.2); Crataegys monogyna (1.2); Clematis vitalba (1.2); Bilderdykia convolvulus (1.1); 188 Tilia argentea (1.1); Acer campestre (1.1); Tamus communis (1.1); Fraxinus ornus (1.1); Viola silvestris (1.1); Brachypodium sylvaticum (+.2); Ulmus carpinifolia (+.1); Polygonatum odoratum (+.1).

3.3 Stand Characteristics

The studied stand is located at an altitude of 278 meters, on a slope of 50 degrees, with a western exposure. The stand is 60 years old, well-preserved, and fully intact. There are a total of 1,007 trees per hectare. The highest number of trees is found in the thickness grade of 37.5 cm, accounting for 34.6% of the total. The average diameter of the stand, based on the logs, is 31.1 cm, while the arithmetic mean diameter is 32.5 cm.

Table 3. *Statistical indicators of diameter (D), height (H), and Volume Distributions (V).*

Size	Xsr	Min.	Max	Quartile		σ	V	sd	Distribution coefficient	
				Q1	Q3		%		α_3	α_4
D (cm)	32.5	21.7	43.8	29.0	37.7	5.85	17.99	1.07	-0.125	-0.824
H (m)	17.2	11.7	20.9	16.2	18.6	4.76	2.18	0.41	-0.760	0.863
V (m^3)	0.5	0.0	1.0	0.3	0.7	0.05	0.23	0.04	0.039	-0.495

Source: *Original*

The stand has distribution lines of trees and volume by diameter classes typical of even-aged stands. The total basal area is 76,94 m^2ha^{-1}, while the total wood volume amounts to 519,9 m^3ha^{-1}. The maximum volume is in the diameter class of 37.5 cm._Data regarding the mean stand diameter, along with basic statistical information, is presented in Tables 3 and 4.

Table 4. Basic Data on Incense-cedar Stand

Diameter degree (cm)	N		H	G	V	
	per ha	%	(m)	m^2/ha	$m^{3/}$ha	%
22,5	104	10,3	13,2	4,13	27,9	5,4
27,5	243	24,1	16,48	14,43	97,5	18,8
32,5	243	24,1	17,72	20,16	136,2	26,2
37,5	348	34,6	18,94	28,43	192,1	37,0
42,5	69	6,9	19,3	9,79	66,2	12,7
Σ	1007	100,0		76,94	519,9	100,0

Source: *Original*

3.3 The Influence of Climatic Factors on Current Diameter Increase

Using the correlation method for estimating weights, we constructed a model to analyze how age and various climatic factors influence the current increase in diameter, as well as the sizes of late wood (Ka) and early wood (Ra). The parameters of these models are detailed in Table 4.

The size of early wood is negatively influenced by several factors, including age (AGE), total precipitation in April (AP_P), as well as mean air temperatures in April (AP_T) and August (AU_T), a positive impact on early wood size was observed with the amount of precipitation in May (MA_P), June (JU_P), July (JL_P), August (AP_P) and September (SE_P), along with mean air temperatures in May (MA_T), June (JU_T), July (JL_T) and Septembar (SE_T). The correlation coefficient for this model is 0.3457, indicating that 55,31% of the variation in early wood size is explained by these factors. The F-test value suggests a significant level of 3.90.

For late wood, the size is negatively influenced by age (AGE), total precipitation in May (MA_P), August (AU_P), and September (SE_P), as well as the mean monthly air temperature in April (AP_P), May (MA_P), June and September (SE_T). However, a positive influence is noted from precipitation in April (AP_P), June (JU_P), and July (JU_P), along with mean air temperatures in July (JL_T) and August (AU_T). The regression coefficient for late wood size is

1.5408, explaining 49.89% of the variation. The F-test value indicates a significant level of 3.14.

Overall, the total current diameter increase is negatively influenced by age (AGE), total precipitation in April (AP_P), August (AU_P), and September (SE_P), as well as mean temperatures in April (AP_T), May (MA_T), June (JU_T) and September (SE_T). Positive influences are associated with total precipitation in May (MA_P), June (JU_P), and July (JL_P), along with mean air temperatures in July (JL_T) and August (AU_T). The results of the analysis are presented in Tables 5 and 6.

Table 5. The influence of age and analysed climatic factors on current diameter increment (Zi), share of latewood (Ka), and share of earlywood (Ra)

Independent variable	Dependent variable					
	Ra		Ka		Zi	
	Parameters	Error	Parameters	Error	Parameters	Error
Constant	-2.2269	1.4135	3.5293	6.2989	1.3023	6.9469
AGE	-0.0226	0.0048	-0.0859	0.0214	-0.1086	0.0237
AP_P	-0.0018	0.0021	0.0015	0.0096	-0.0003	0.0106
MA_P	0.0016	0.0013	-0.0001	0.0058	0.0014	0.0064
JU_P	0.0021	0.0012	0.0043	0.0055	0.0064	0.0061
JL_P	0.0013	0.0011	0.0084	0.0051	0.0098	0.0056
AU_P	0.0008	0.0017	-0.0049	0.0075	-0.0041	0.0083
SE_P	0.0022	0.0015	-0.0161	0.0075	-0.0139	0.0078
AP_T	-0.0333	0.0337	-0.0494	0.1503	-0.0827	0.1657
MA_T	0.1320	0.0404	-0.2041	0.1798	-0.0721	0.1984
JU_T	0.0176	0.0455	-0.0578	0.2029	-0.0402	0.2237
JL_T	0.0666	0.0523	0.4176	0.2334	0.4842	0.2574
AU_T	-0.0328	0.0429	0.2067	0.1911	0.1738	0.2108
SE_T	0.0027	0.355	-0.4068	0.1582	-0.4041	0.1745
R						
R^2	55.31		49.89		52.14	
Standard error	0.3457		1.5408		1.6993	
F-test	3.90		3.14		3.44	

Source: Original

4. DISCUSSION

Natural habitats are characterized by dry summers, typically receiving less than 25 mm of precipitation per month, and experiencing extreme annual temperatures ranging from -34°C to +48°C. The total annual precipitation can vary from 510 mm to 2030 mm, though amounts around 380 mm per year are not uncommon, especially on the eastern side of the Cascades and in the Warner Mountains in Oregon and California (Schubert, 1965). During the notably dry period from 2012 to 2016, there was a relatively low level of drying observed (Fettig et al., 2018), yet a high degree of survival following forest fires was noted, just behind that of redwood trees (Stephens and Finney, 2002). Overall, it can be concluded that this species is adaptable to climate change and holds significant potential. It is important to note that its commercial wood value is high (Powers and Oliver, 1990). In habitats with high production rates, this species tends to grow more slowly, while it plays a dominant role on dry, warm slopes compared to other tree species (Powers and Oliver, 1990). The root system is well-developed, featuring pronounced lateral roots. Arbuscular mycorrhizae are present on the roots, allowing for increased drought tolerance compared to other species (Auge, 2001). In summary, sycamore trees are shade-tolerant, drought-tolerant, and host relatively few harmful insects and pathogenic organisms (Powers and Oliver, 1990).

Table 6. Type of Effect on the Size of Earlywood (Ra), Latewood (Ka), and Total Current Volume Increment (Zi)

Effect	Size		
	Earlywood (Ra)	Latewood (Ka)	Total current diameter increment (Zi)
Positive	• Precipitation in May • Precipitation in June • Precipitation in July • Precipitation in August • Precipitation in September • Temperature in May • Temperature in June • Temperature in July • Temperature in September	• Precipitation in April • Precipitation in June • Precipitation in July • Temperature in July • Temperature in August	• AGE • Precipitation in May • Precipitation in June • Precipitation in July • Temperature in July • Temperature in August
Negative	• AGE • Precipitation in April • Temperature in April • Temperature in August	• AGE • Precipitation in May • Precipitation in August • Precipitation in September • Temperature in April • Temperature in May • Temperature in June • Temperature in September	• AGE • Precipitation in April • Precipitation in August • Precipitation in September • Temperature in April • Temperature in May • Temperature in June • Temperature in September

Source: Original

Current climate change projections for Serbia indicate a trend of increasing temperatures under both the A1B and A2 scenarios for three observed periods: 2011-2040, 2041-2070, and 2071-2100 (MPZŽS, 2015).

The expected temperature changes for these periods are as follows:

1. 2011-2040: Temperature increase of 0.5-0.9°C for the A1B scenario and 0.3-0.7°C for the A2 scenario.
2. 2041-2070: Temperature increase of 1.8-2.2°C for the A1B scenario and 1.6-2.0°C for the A2 scenario.
3. 2071-2100: Temperature increase of 3.6-4.0°C for the A1B scenario and 3.2-3.6°C for the A2 scenario.

The most significant warming, exceeding 4.0°C by the end of the century, is anticipated during the summer and autumn seasons (MPZŽS, 2015). Serbia is expected to experience a greater increase in air temperature compared to the global average, along with a higher prevalence of severe droughts and intense precipitation events. Summer temperatures in the Balkans and western Turkey may rise by 5-6°C during the period of 2071-2100 under the A2 scenario (Giorgi, F. et al., 2009). The ICTP-RegCM3 model predicts a temperature increase of 7.0°C over the Balkan countries, including Serbia, for the same period and scenario (Önol & Semazzi, 2009). When comparing these projections to the average air temperature and total precipitation in the Belgrade area (according to the REG_IN model) for the period from 2021 to 2100, it becomes evident that these projections fall within the ecological limits for all measured parameters (Table 7.).

Table 7. *Values of climatic parameters for the analyzed periods obtained based on the REG -IN model*

Size by REG-IN model	Periods (year)	Months					
		April	May	June	July	August	September
Average air temperature (^{0}C)	2021-2050	14,6	20,0	23,0	24,0	24,6	19,0
	2051-2080	15,0	20,6	23,4	24,2	25,1	19,2
	2081-2100	15,4	21,1	23,9	24,5	25,6	19,5
Average maximum air temperatures (^{0}C)	2021-2050	19,3	24,1	27,6	29,7	30,1	24,3
	2051-2080	20,3	24,8	28,5	30,9	31,4	24,4
	2081-2100	21,5	25,5	29,7	32,3	33,1	24,5
Average minimum air temperatures (^{0}C)	2021-2050	10,5	14,8	17,8	18,7	18,1	13,3
	2051-2080	12,4	16,7	19,3	19,8	18,6	12,8
	2081-2100	14,4	18,6	20,9	20,8	19,0	12,3
Absolute maximum air temperatures (^{0}C)	2021-2050	26.6	30.5	33.0	35.6	35.4	31.6
	2051-2080	26.8	30.6	33.0	35.6	35.3	31.5
	2081-2100	26.9	30.7	32.9	35.7	35.2	31.4
Absolute minimum air temperatures (^{0}C)	2021-2050	2.8	7.0	10.3	12.9	12.0	8.1
	2051-2080	3.5	7.5	10.5	13.3	12.3	8.6
	2081-2100	4.2	8.1	10.7	13.7	12.6	9.0
Average precipitation (mm)	2021-2050	55.7	90.1	83.9	74.3	55.7	69.4
	2051-2080	52.7	85.3	79.5	70.4	52.7	65.7
	2081-2100	49.8	80.6	75.1	66.5	49.8	62.1
Lowest precipitation (mm)	2021-2050	28.8	39.8	32.8	18.1	27.8	7.4
	2051-2080	27.3	37.7	31.1	17.2	26.4	7.0
	2081-2100	25.8	35.6	29.3	16.2	24.9	6.6

Source: Dimitrijevic and Ratknic, 2019

These parameters indicate that Incense – cedar can survive in the newly opened conditions of climate change, which is why it’s more excellent representation in the urban forests of Belgrade should be enabled.

5. CONCLUSION

To sustain forest ecosystems in a given area, it is crucial to develop strategies that mitigate future risks, even amid uncertainties in precise forecasting (Millar et al., 2007). One effective approach is to manage specific tree species that can fulfill some of the functions that non-adapted species can no longer provide. By actively replanting after stand-replacing disturbances or proactively transitioning to new species compositions, we can potentially lessen the impacts of climate change (Nagel et al., 2017).

The evidence presented in this paper indicates that incense-cedar may be a species of the future, as its ecological niche aligns well with the conditions generated by climate change, particularly concerning air temperature and precipitation.

These parameters suggest that Incrense - cedar has the potential to thrive under the new conditions created by climate change. Therefore, it is essential to promote its increased presence in the urban forests of Belgrade.

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CLIMATE CHARACTERISTICS AND DIAMETER INCREMENT OF INCENSE-CEDAR: POTENTIAL USE IN AFFORESTATION IN BELGRADE AREA (REPUBLIC OF SERBIA)

Tatjana DIMITRIJEVIĆ, Mihailo RATKNIC, Sasa EREMIJA, Sabahudin HADROVIĆ, Violeta DJORDJEVIĆ, Snežana KONATAR

Summary

The paper investigates how climate influences the early, late, and total tree growth of Calocedrus decurrens in the Belgrade area. It compares data on habitat changes with habitat characteristics found in natural localities across North America. Early tree size is negatively impacted by several factors, including age (AGE) and precipitation in May (MA_P), June (JU_P), and July (JL_P), as well as average air temperatures in April (AP_T), May (SE_P), and July (OK_T). Conversely, there is a positive correlation with the total sum of precipitation in April (AP_P), August (AU_P), and September (SE_P). The correlation coefficient for early growth is 0.8054, indicating that 64.87% of the variation in early tree size can be attributed to these factors. The F-test value shows a significance level of 3.56.In contrast, late tree size is negatively influenced by age (AGE), as well as precipitation in April (AP_P), May (MA_P), and June (JU_P). Additionally, the average air temperature in September (SE_T) has a detrimental effect. Positive influences are associated with the total sum of precipitation in July (JL_P), August (AV_P), and September (SE_P), as well as the average air temperatures in April (AP_T), May (MA_T), June (JU_T), July (JL_T), and August (AV_T). The regression coefficient for late tree growth is 0.7471, explaining 55.81% of the variation in late tree size. The F-test value indicates a significance level of 2.44. Moreover, the total growth of tree thickness is negatively affected by age (AGE), the total sum of precipitation in May (MA_P) and June (JU_P), as well as temperatures in April (AP_T), May (MA_T) and September (SE_T). Positive influences are noted with precipitation in July (JL_P), August (AU_P), and September (SE_P), along with average air temperatures in June (JU_T) and July (JL_T). According to the REG_IN climate model, these findings suggest that the habitat conditions in Belgrade's urban forests are becoming favorable for the successful establishment of new plantations.

KLIMATSKE KARAKTERISTIKE I DEBLJINSKI PRIRAST LIBOKEDRA:POTENCIJALNA UPOTREBA U POŠUMLJAVANJU NA PODRUČJU BEOGRADA (REPUBLIKA SRBIJA)

Tatjana DIMITRIJEVIĆ, Mihailo RATKNIC, Sasa EREMIJA, Sabahudin HADROVIĆ, Violeta DJORDJEVIĆ, Snežana KONATAR

Rezime

U radu je vršeno istraživanje na koji način klima utiče na veličinu ranog, kasnog drveta i ukupnog tekućeg prirasta stabala Calocedrus decurrens na području Beograda. Podaci promene staništa poređeni su sa karakteristikama staništa na prirodnim nalazištima na području Severno Američkog kontinenta.Veličina ranog drveta je pod negativnim uticajem starosti (AGE), sume padavina u maju (MA_P), sume padavina u junu (JU_P), sume padavina u julu (JL_P), kao i srednje temperature vazduha u aprilu (AP_T), maju (MA_T), avgustu (AU_U), septembru (SE_T) i oktobru (OK_T). Pozitivan uticaj je konstatovan sa sumom padavina u aprilu (AP_P), avgustu (AU_P), septembru (SE_P).

Koeficijent korelacije iznosi 0,8054 i objašnjeno je 64.87% vrednosti ranog drveta. Vrednost F-testa ukazuje na nivou značajnosti od 3.56. Veličina kasnog drveta je pod negativnim uticajem starosti (AGE), sumom padavina u aprilu (AP_P), maju (MA_P), junu (JU_P) kao i sa srednjom mesečnom temperaturom vazduha u septembrom (SE_T). Pozitivan uticaj utvrđen je sa sumom padavina u julu (JL_P), avgustu (AV_P), septembru (SE_P) i sa srednjom temperaturom vazduha u aprilu (AP_T), maju (MA_T),junu (JU_T), julu (JL_T) i avgustu (AV_T). Koeficijent regresije iznosi 0,7471 i objašnjeno je 55.81% vrednosti kasnog drveta. Vrednost F testa ukazuje na nivo značajnosti 2.44. Veličina ukupnog tekućeg debljinskog prirasta pod negativnim uticajem je starosti (AGE), sume padavina u maju (MA_P), junu (JU_P) kao i temperature aprilu (AP_T), maju (MA_T), septembru (SE_T) i oktobru (OK_T). Pozitivan uticaj konstatovan je sa sumom padavina u julu (JL_P), avgustu (AU_P) i septembru (SE_P) i sa srednjom temperaturom vazduha u junu (JU_T), julu (JL_T). Na osnovu klimatskog modela REG_IN ukazuje se da se stvaraju stanišni uslovi koji omogućavaju uspešno podizanje novih plantaža u urbanim šumama grada Beograda.

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SPATIAL DISTRIBUTION AND CONCENTRATION OF NICKEL (NI) IN ORGANIC HORIZON AND SURFACE MINERAL SOIL OF FOREST ECOSYSTEMS IN THE REPUBLIC OF SERBIA

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Abstract: *This scientific paper investigates the spatial distribution and concentration of nickel (Ni) in the organic layer and surface soil (0-10 cm) of forest ecosystems in the Republic of Serbia. The aim of the research is to determine the influence of regional affiliation (Eastern, Western, Northern, Southern, and Central Serbia) and altitude on nickel accumulation in these forest soil components. Samples of organic layer and soil were collected from representative locations across Serbia. Nickel content was determined after digestion of the samples with aqua regia, and concentrations were analysed using inductively coupled plasma mass spectrometry (ICP-MS). It is expected that the results will show significant variations in nickel content depending on geographical location and altitude, which may be related to the geological substrate, specific pedogenetic processes, climatic conditions, and anthropogenic influences. The significance of the research lies in assessing the potential risk of nickel toxicity to flora, microorganisms, and other ecosystem components, as well as contributing to the understanding of metal biogeochemical cycles in forest soils. The obtained data will serve as a basis for future research and monitoring of soil quality in forest ecosystems in Serbia.*

Keywords: Forest soil, Organic horizon, Nickel, Regional distribution, ICP-MS

PROSTORNA DISTRIBUCIJA I KONCENTRACIJA NIKLA (NI) U ORGANSKOJ PROSTIRCI I POVRŠINSKOM SLOJU ZEMLJIŠTA ŠUMSKIH EKOSISTEMA REPUBLIKE SRBIJE

Apstrakt: *Ovaj naučni rad istražuje prostornu distribuciju i koncentraciju nikla (Ni) u organskoj prostirci i površinskom sloju zemljišta (0-10 cm) šumskih ekosistema u Republici Srbiji. Cilj istraživanja je utvrditi uticaj regionalne pripadnosti (Istočna, Zapadna, Severna, Južna i Centralna Srbija) i nadmorske visine na akumulaciju nikla u ovim komponentama šumskog zemljišta. Uzorci organske prostirke i zemljišta sakupljeni su sa reprezentativnih lokacija širom Srbije. Sadržaj nikla određen je nakon digestije uzoraka carskom vodom, a koncentracije su analizirane korišćenjem induktivno kuplovane plazme sa*

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masenom spektrometrijom (ICP-MS). Očekuje se da će rezultati pokazati značajne varijacije u sadržaju nikla u zavisnosti od geografskog položaja i nadmorske visine, što može biti povezano sa geološkom podlogom, specifičnim pedogenetskim procesima, klimatskim uslovima i antropogenim uticajima. Značaj istraživanja leži u proceni potencijalnog rizika od toksičnosti nikla za biljni svet, mikroorganizme i druge komponente ekosistema, kao i u doprinosu razumevanju biogeohemijskih ciklusa metala u šumskim zemljištima. Dobijeni podaci će služiti kao osnova za buduća istraživanja i monitoring kvaliteta zemljišta u šumskim ekosistemima Srbije

Ključne reči: Šumsko zemljište, Organska prostirka, Nikl, Regionalna distribucija, ICP-MS

1. INTRODUCTION

Soil is a fundamental component of forest ecosystems, providing physical support for plants, acting as a reservoir for water and nutrients, and serving as habitat for numerous organisms. The quality of soil directly influences forest productivity and health. Among the many chemical elements present in soil, heavy metals including nickel (Ni) draw significant attention due to their potential toxicity to living organisms and their capacity for accumulation within various ecosystem components. Nickel is an element found in the Earth's crust, and its soil content depends on the geological substrate (Kabata-Pendias & Pendias, 2001). However, anthropogenic activities such as industry (notably metallurgy), transportation, agriculture (use of fertilizers and pesticides), and fossil fuel combustion can substantially increase nickel concentrations in the environment, including forest soils (Alloway, 2013).

The organic horizon, as the first surface layer of soil (comprising the Ol, Of, and Oh subhorizons according to forestry pedology classification), plays a vital role in biogeochemical processes, including the cycling of heavy metals. It acts as a reservoir for metals deposited from the atmosphere (dry and wet deposition) or leached from tree canopies. Through the decomposition of organic matter, heavy metals are gradually released into the mineral soil fraction, increasing their bioavailability to plants and microbes. The surface soil layer (0–10 cm) is the most active part of the soil profile, rich in organic matter and microorganisms, and consequently most susceptible to heavy metal accumulation due to intense sorption, complexation, and biological transformation processes (Sparks, 2003).

Geographical location and altitude significantly influence the distribution and accumulation of heavy metals in soil. Different geological substrates across Serbia naturally contain varying levels of nickel (Manojlović et al., 2012). Climate conditions—varying with geographic position and elevation affect pedogenic processes, leaching, and element accumulation in soils (Buol et al., 2011). Additionally, population density and industrial activity vary regionally, leading to differences in anthropogenic nickel input (Saljnikov et al., 2009).

Previous studies have shown that soil metal content can vary considerably depending on region and altitude (Alloway, 2013). Specific research in Serbia indicates variability in metal concentrations in forest soils based on location and elevation (Saljnikov et al., 2009). However, a comprehensive analysis of nickel content in the organic horizon and surface mineral soil across Serbian forest ecosystems – focusing on regional differences and elevation effects has not yet been systematically conducted to enable thorough assessments and identify potential risk areas.

The aim of this study is to determine the total nickel content in the organic horizon and surface mineral soil (0–10 cm) of forest ecosystems in Serbia, analysing the influence of regional affiliation (Eastern, Western, Northern, Southern, Central Serbia) and altitude on its concentration. The results will improve understanding of the biogeochemical cycle of nickel in Serbian forests and provide a basis for ecological risk assessment related to elevated nickel levels, supporting informed decision-making in environmental protection and sustainable forest management.

Nickel is an essential trace element for plants at very low concentrations, involved in activating specific enzymes such as urease (Marschner, 2012). However, at elevated levels, nickel becomes toxic. High soil nickel concentrations can inhibit plant growth, cause chlorosis, necrosis, and other toxicity symptoms, as well as disrupt biochemical processes in plants (Kabata-Pendias & Pendias, 2001). Nickel can also accumulate in plant tissues and enter the food chain, posing potential risks to animals and humans. Furthermore, elevated nickel levels can adversely affect soil microbial activity, which is crucial for organic matter decomposition, nutrient cycling, and soil structure formation (Giller et al., 1998). Therefore, monitoring and understanding the distribution of nickel in soils are vital for ecosystem health assessment and sustainable forest management, especially in the context of climate change and increasing anthropogenic pressures.

2. MATERIAL AND METHODS

Samples of organic matter and soil were collected from representative sites across Serbian forest ecosystems. Locations were carefully selected to cover five major geographic regions (Eastern, Western, Northern, Southern, Central Serbia) and a broad range of altitudes (approximately 100 m to over 1500 m above sea level). At each site, samples of humified organic horizon (Oh) and organic-mineral soil layer (0–10 cm) were collected. Multiple sub-samples were taken within a radius of 10–20 meters around a central point at each site, then homogenized to produce a representative composite sample. In total, 89 organic matter samples and 115 soil samples were collected.

Collected samples were transported to the laboratory, where they were air-dried until reaching a constant weight. Soil samples were sieved through a 2 mm mesh to remove coarse fragments and visible debris. Organic samples were ground in a plant material mill and sieved through a 0.25 mm mesh. Both soil and organic samples were then milled into fine powder (<100 µm) using an agate mortar, ensuring complete homogenization for chemical analysis.

Total nickel content was determined after acid digestion. Approximately 0.2 g of dried, ground sample was digested in a mixture of concentrated nitric acid and hydrochloric acid (aqua regia) in a 1:3 ratio, using a Milestone Ethos Easy microwave digestion system in closed Teflon vessels. After digestion, the solutions were filtered and diluted to 100 ml with deionized water. Nickel concentrations were measured via inductively coupled plasma mass spectrometry (ICP-MS, PerkinElmer NexION 1000G). Multi-element standard solutions of known concentration were used for calibration. Results are expressed in milligrams per kilogram of dry weight (mg/kg).

Data were processed using Microsoft Excel, enabling distribution analysis of nickel in the organic horizon and soil across Serbia and by individual regions.

3. RESULTS AND DISCUSION

The findings reveal significant spatial variability in nickel concentrations in both the organic horizon and the surface mineral soil of Serbian forest ecosystems. Graphical representations (Figures 1 and 2) illustrate the heterogeneity of nickel distribution across regions.

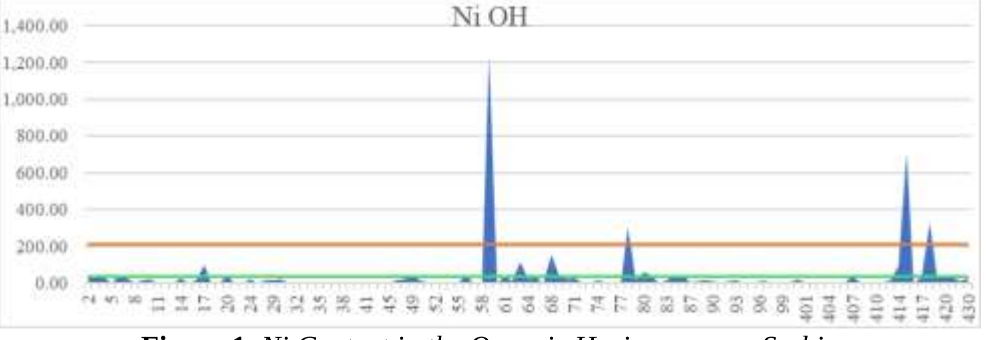

Figure 1. *Ni Content in the Organic Horizon across Serbia*

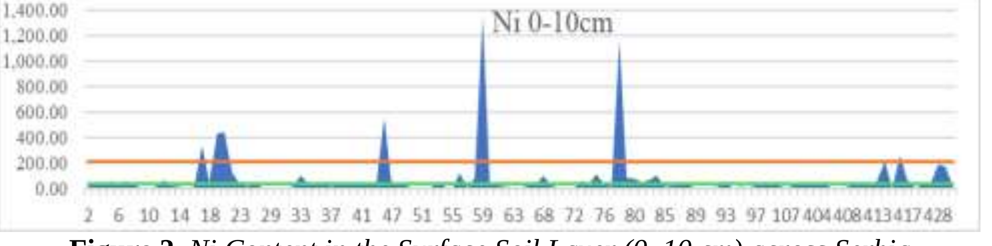

Figure 2. *Ni Content in the Surface Soil Layer (0–10 cm) across Serbia*

Comparison of nickel levels in the organic horizon and mineral soil highlights the higher sorption capacity of the organic layer, attributable to organic matter's ability to form complexes with metal ions. Consequently, nickel concentrations are generally higher in the organic horizon, especially at sites with significant anthropogenic input or geologically rich in nickel-bearing ultramafic rocks. The ratio of nickel in organic matter to mineral soil indicates the metal's mobility and transport dynamics within the soil profile.

In the organic horizon, nickel concentrations ranged from below detection limits to extremely high values. Spatial distribution maps (Figures 3–5) demonstrate elevated concentrations in Western and Southern Serbia. Western Serbia exhibits the most extreme values, with some points reaching 1235 mg/kg (Point 59), 711 mg/kg (Point 415), 328 mg/kg (Point 418), and 99 mg/kg (Point 17), indicating local sources of nickel accumulation, likely from ultramafic geology.

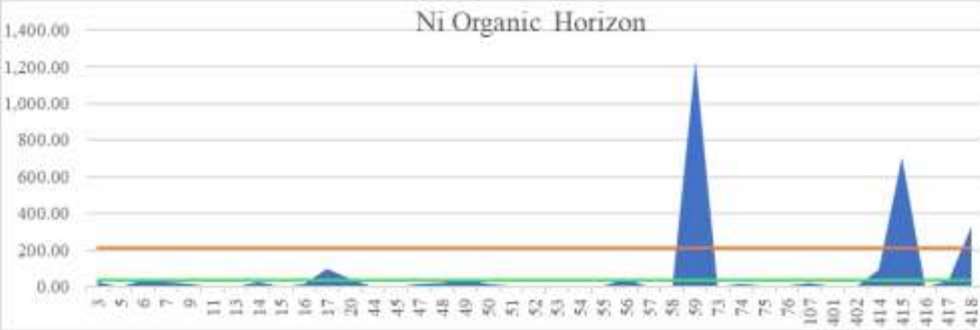

Figure 3. *Ni Content in Organic Horizon in western Serbia*

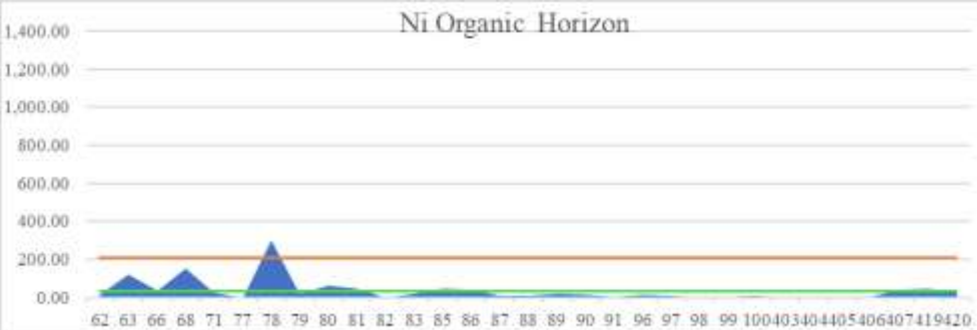

Figure 4. *Ni Content in Organic Horizon in southern Serbia and Content in the Surface Soil Layer (0–10 cm) across Serbia*

Southern Serbia also shows locations with elevated nickel concentrations (Point 78 with 301.43 mg/kg, Point 68 with 152.99 mg/kg, Point 63 with 119.03 mg/kg). Northern and Central Serbia generally show lower nickel concentrations in the organic horizon, although some variability exists. Lower nickel levels are associated with the geological substrate, which is predominantly composed of sedimentary rocks. Additionally, average nickel concentrations in the organic horizon significantly vary between regions, with a tendency toward higher values in western and southern Serbia.

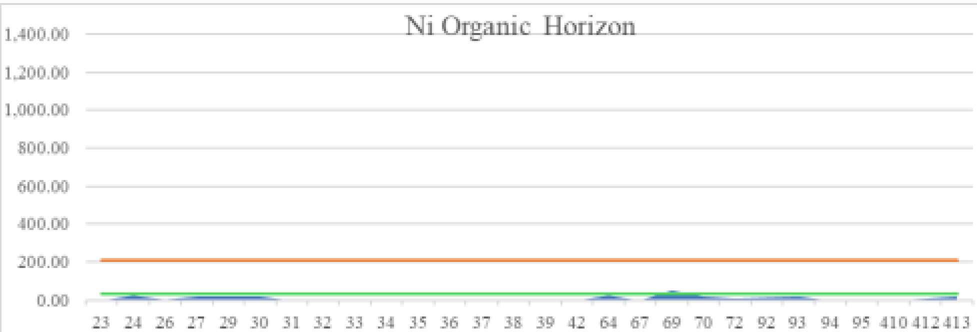

Figure 5. *Ni Content in Organic Horizon in eastern Serbia*

High nickel concentrations in the organic horizon at certain sites in Western and Southern Serbia are primarily associated to the geological substrate. It is known that parts of these regions are rich in ultramafic rocks (serpentinites and peridotites), which naturally contain high levels of nickel. As these rocks weather, they release increased amounts of nickel into the soil. The organic horizon, due to its ability to bind metals through ion exchange and complex formation with organic molecules, can accumulate substantial quantities of nickel. This process is especially pronounced in forest ecosystems, where large amounts of organic material accumulate on the soil surface.

Furthermore, atmospheric deposition should also be considered. Although forest ecosystems in remote areas may be less exposed to direct industrial pollution, the transport of pollutants through the air from distant or local sources (e.g., industrial facilities, mines, traffic) can contribute to nickel accumulation in the organic horizon.

It is also noteworthy points where nickel concentration in the organic horizon is below the detection limit (Points 53, 58, 402 in western Serbia, Points 33, 34, 36, 37, 38, 39, 410 in eastern Serbia, Point 98 and 403 in southern Serbia). Such low Ni values may result from the absence of nickel in the geological substrate from which the soil develops. In some cases, nickel may be present in the soil but in insoluble forms that are inaccessible to plants, preventing uptake. Under these circumstances, nickel does not participate in the material cycling within the ecosystem, as forest trees do not transport it to the soil surface via leaf litter, and thus, it does not accumulate in the topsoil.

Concentration of Nickel in the Surface Soil Layer (0–10 cm)

Nickel concentrations in the surface soil layer also exhibit considerable variability. As shown in the maps depicting the spatial distribution of nickel in the topsoil, western and southern Serbia stand out due to the presence of sites with exceptionally high concentrations. At these locations, values significantly exceed the stipulated remediation threshold of 210 mg/kg such as Point 59 (1346.80 mg/kg), Point 78 (1167.60 mg/kg), Point 45 (560.19 mg/kg), Point 20 (438.67 mg/kg), and Point 19 (431.32 mg/kg). These extremely high values indicate that the fundamental functions of the soil concerning nickel are severely disrupted at these sites, necessitating urgent remediation, reclamation, and other measures.

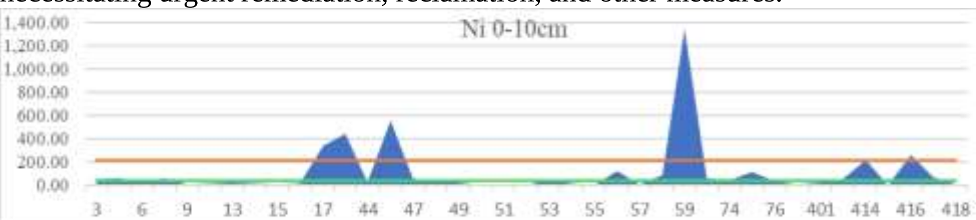

Figure 6. *Ni Content in the surface soil layer in the area of western Serbia*

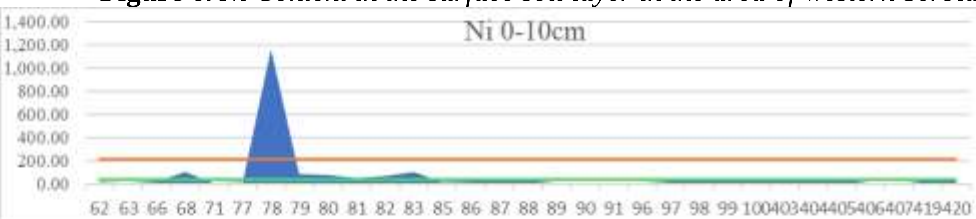

Figure 7. *Ni Content in the surface soil layer in the area of southern Serbia*

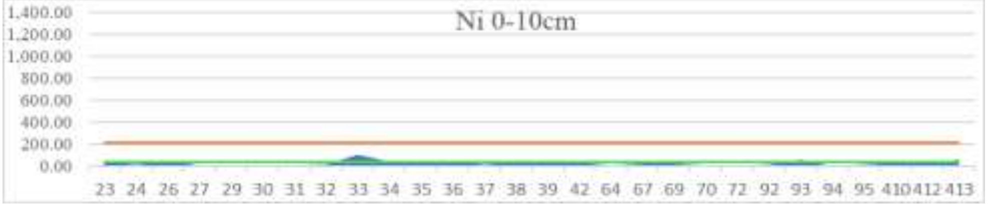

Figure 8. *Ni Content in the surface soil layer in the area of eastern Serbia*

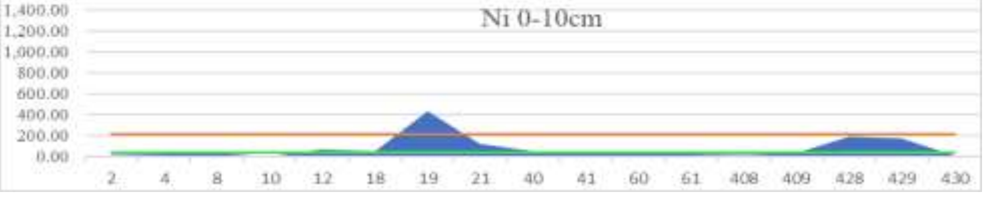

Figure 9. *Ni content in the surface layer of the soil in the area of central Serbia*

Comparing nickel concentrations in the organic horizon and the 0–10 cm mineral soil layer at the same locations can provide insights into the biogeochemical cycle of nickel. In some sites with high levels in the organic horizon, the soil also shows high nickel values (e.g., Points 59, 78, 20), suggesting that nickel from organic matter is being transported into the mineral soil layer through organic mineralization and leaching. However, at other sites, the relationship between concentrations in the organic horizon and the mineral soil can differ, which may be due to specific pedogenetic processes, soil pH (which affects nickel mobility and availability lower pH increases mobility), organic matter content in the mineral layer (which can bind nickel if humus is present or convert it into soluble forms if humic substances are abundant), and other factors influencing nickel mobility and retention in the soil.

The analysis shows that average nickel concentrations in the surface soil layer are also highest in western and southern Serbia, although intra-regional variability is significant. It is already evident that western and southern Serbia contain the largest number of sites with notably elevated nickel levels, likely due to the dominant influence of geological substrates, particularly ultramafic rocks.

Regarding the minimum threshold value of 35 mg/kg, many sites across all regions exceed this limit in both the organic horizon and the surface mineral soil. Based on Maps 1 and 2, it is clear that many points indicate an exceedance of this value. This is a positive indicator, as it signifies that the functional properties of the soil its sustainable quality have been fully achieved. Elevated nickel concentrations, even below remediation thresholds, can negatively impact sensitive plant species, soil microorganisms, and biogeochemical cycles, potentially threatening forest ecosystem health.

The effect of altitude on nickel content is complex and depends on the interaction of multiple factors. At lower elevations, anthropogenic influences such as emissions from industry and transportation are more pronounced, potentially leading to higher nickel accumulation. As elevation increases, the influence of anthropogenic sources diminishes; however, climatic conditions (temperature, precipitation) and soil types change, affecting leaching, accumulation, and nickel binding processes. In higher mountainous areas, where pedogenic processes are slower and organic matter decomposes more gradually, nickel tends to remain longer in the organic horizon. Additionally, vegetation type and soil pH both of which vary with altitude also influence nickel mobility and bioavailability.

5. CONCLUSION

Based on the analysis of the obtained results, it can be concluded that the spatial distribution and concentration of nickel in the organic horizon and surface mineral soil of Serbian forest ecosystems show significant variability. Maps clearly illustrate regional differences, with the highest concentrations recorded in western and southern Serbia. These elevated levels are primarily related to naturally high nickel content in the geological substrate, especially ultramafic rocks.

Regional analysis of nickel content revealed notable differences. Areas with geological formations rich in nickel such as serpentinites and peridotites exhibit higher soil nickel concentrations. The parts of western and southern Serbia, known for these geological features, show higher nickel levels compared to other regions. Conversely, eastern Serbia, with predominantly sedimentary and acidic silicate rocks, exhibits lower nickel concentrations. Anthropogenic factors, such as proximity to industrial zones or busy roads, also contribute to increased nickel levels in certain regions.

A considerable number of sites in western and southern Serbia show surface soil nickel concentrations exceeding the remediation threshold, indicating potential serious disruption of soil functions and the need for risk assessment and possible remediation measures. Many sites across all regions also surpass the limit value for nickel, suggesting that soil quality at these locations may not meet regulatory standards and could affect sensitive ecosystem components.

Besides the geological substrate, pedogenetic processes, soil properties (pH, chemical nature of organic matter), and atmospheric deposition influence the spatial distribution of nickel. Further analysis incorporating correlations with altitude and other soil parameters, as well as detailed spatial modelling will provide deeper insights into the factors controlling nickel distribution.

High nickel concentrations in the organic horizon and surface soil layers of forest ecosystems pose potential ecological risks. The migration of nickel into deeper soil layers and groundwater also represents a broader environmental concern.

Identifying sites with elevated nickel levels is crucial for directing future research and monitoring efforts. Additional studies should focus on assessing the bioavailability of nickel at these locations and analysing its impacts on plant life and soil microorganisms within Serbian forest ecosystems.

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SPATIAL DISTRIBUTION AND CONCENTRATION OF NICKEL (NI) IN ORGANIC HORIZON AND SURFACE MINERAL SOIL OF FOREST ECOSYSTEMS IN THE REPUBLIC OF SERBIA

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Summary

This scientific study investigated the spatial distribution and concentration of nickel (Ni) in the organic layer and the surface mineral soil layer (0–10 cm) of forest ecosystems across the Republic of Serbia. The aim was to determine the influences of regional differences, including eastern, western, northern, wouthern, and central Serbia, as well as differences in altitude, on nickel accumulation in these soil layers. Samples were collected from representative locations throughout the country, with nickel content determined through digestion with aqua regia and using ICP-MS (Inductively Coupled Plasma Mass Spectrometry), a method that offers high precision and sensitivity in element detection.

The results revealed significant regional variability in nickel concentrations. The highest levels were recorded in western and southern Serbia, consistent with the geological characteristics of these areas, known for rich ultramafic rocks such as serpentinites and peridotites, which naturally contain high levels of nickel. These regions are particularly susceptible to elevated nickel levels due to geological sources, but anthropogenic factors such as industrial activities, transportation, urbanization, and atmospheric deposition also contribute to these concentrations. In the organic soil layer, nickel levels were generally higher than in the mineral layer, owing to its ability to bind with organic matter through complexation and ion exchange, leading to increased accumulation in surface soils. Some locations exhibited nickel levels exceeding regulatory thresholds, indicating potential risks to soil quality, plant life, and microbial communities.

Across Serbia, nickel levels in soils depend on various factors, including the underlying geology, pedogenetic processes, soil properties (such as pH and organic matter content), and atmospheric influences. The complex relationship between altitude and these

factors further affects nickel mobility and accumulation, with different distribution patterns observed at varying elevations. High levels of nickel in surface soil layers can pose serious ecological risks, disrupting plant and microbial communities. Additionally, there is a potential for nickel to migrate into deeper soil layers and groundwater, representing a further environmental threat to underground water sources and overall ecosystem health. These findings underscore the importance of continuous monitoring and analysis of nickel levels in forest soils of Serbia, especially in ultramafic regions at higher risk of contamination.

In conclusion, this research contributes to a better understanding of the biogeochemical cycles of nickel in Serbia and provides a basis for developing strategies for sustainable land management and soil protection. Identified locations with elevated nickel concentrations require further studies and remediation measures to preserve soil functionality and ecosystem health. The data obtained contribute to an improved understanding of the biogeochemical cycling of nickel in Serbia and serve as a foundation for future monitoring efforts and the sustainable management of forest resources.

PROSTORNA DISTRIBUCIJA I KONCENTRACIJA NIKLA (NI) U ORGANSKOJ PROSTIRCI I POVRŠINSKOM SLOJU ZEMLJIŠTA ŠUMSKIH EKOSISTEMA REPUBLIKE SRBIJE

Jelena BOŽOVIĆ, Jovana CVETKOVIC, Bojan KONATAR, Vanja STOJANOVIĆ, Snežana KONATAR, Aleksandar VEMIĆ, Dragana ŽIVOJINOVIĆ

Rezime

U ovom radu istražena je prostorna distribucija i koncentracija nikla (Ni) u organskom sloju i površinskom mineralnom sloju zemljišta (0–10 cm) šumskih ekosistema u Republici Srbiji. Cilj je bio da se utvrde uticaji regionalnih razlika (Istočna, Zapadna, Severa, Južna i Centralna Srbija) i nadmorske visine na akumulaciju nikla u ovim slojevima zemljišta. Uzorci su prikupljeni sa reprezentativnih lokacija širom zemlje, a sadržaj nikla određen je digestijom uzoraka carskom vodom i analizom pomoću ICP-MS metode.

Rezultati pokazuju značajnu regionalnu varijabilnost, pri čemu su najviši nivoi nikla zabeleženi u Zapadnoj i Južnoj Srbiji, oblastima poznatim po bogatim ultramafičnim stijenama (serpentinitima i peridotitima) koje prirodno sadrže visok nivo nikla. Visoke koncentracije nikla u ovim regionima uglavnom su posledica geoloških izvora, ali na njih utiču i antropogeni faktori, poput industrijskih aktivnosti i atmosferskog depozicije. U organskom sloju, nivo nikla je uglavnom viši nego u mineralnom sloju, zbog njegove sposobnosti da se vezuje za organsku materiju putem kompleksacije i jona razmene. Neke lokacije pokazuju nivo nikla koji premašuje zakonske pragove, što ukazuje na potencijalne rizike po kvalitet zemljišta, biljni svet i mikroorganizme.

Na nivou Srbije, nivo nikla u zemljištu zavisi od geološke podloge, pedogenetskih procesa, svojstava zemljišta (pH, sadržaj organske materije) i atmosferskih uticaja, pri čemu složen odnos između nadmorske visine i ovih faktora dodatno utiče na mobilnost i akumulaciju nikla. Visoki nivoi nikla u površinskom sloju zemljišta mogu ugroziti zdravlje ekosistema, oštećujući biljni i mikrobiološki svet, kao i mogućnost transporta nikla na dublje slojeve i u podzemne vode.

Zaključno, istraživanje ističe važnost praćenja i analize nivoa nikla u zemljištima šumskih ekosistema Srbije, naročito u oblastima sa ultramafičnom geologijom. Identifikovane lokacije sa visokim koncentracijama nikla zahtevaju dodatne studije i moguće mere sanacije, kako bi se zaštitila funkcionalnost zemljišta i zdravlje celokupnog ekosistema. Dobijeni podaci doprinose boljem razumevanju biogeohemijskih ciklusa nikla u Srbiji i predstavljaju osnovu za buduće monitoring aktivnosti i održivo upravljanje šumskim resursima.

A GUIDE FOR WRITING RESEARCH PAPER

SUSTAINABLE FORESTRY is a scientific journal which is published original scientific papers, review papers and short communications of Forestry scientific disciplines, Environmental protection, Wood processing, Landscape architecture and horticulture and Environmental engineering (Erosion Control) at least once a year.

All papers in journal **SUSTAINABLE FORESTRY** are licensed from 2023, **license CC BY 4.0 DEED** (https://creativecommons.org/licenses/by/4.0/?ref=chooser-v1).

Categorization of papers (suggested by the author – determined by Editorial board taking into account the opinion of the reviewer):

Scientific Articles

1. Review paper (paper that contains original, detailed and critical review of the research issue or field in which the author contributed, visible on the basis of auto-citations);
2. Original scientific paper (paper which presents previously unpublished results of author's researches by scientific method);
3. Preliminary communication (Original scientific paper of full format, but small-scale or preliminary character).
4. Other known forms: scientific review, case study and others, if Editorial board finds that such paper contributes to the improvement of scientific thought.

Professional Articles

1. Professional paper (annex in which are offered the experiences for improving professional practice, but which are not necessarily based on scientific method).

This guide and the paper template can be found at the following link: https://www.forest.org.rs/?%D0%9D%D0%B0%D1%98%D0%BD%D0%BE%D0%B2%D0%B8%D1%98%D0%B8-%D0%B1%D1%80%D0%BE%D1%98-%D1%87%D0%B0%D1%81%D0%BE%D0%BF%D0%B8%D1%81%D0%B0-sustainable-forestry-

Papers (in the Template form) should be sent to the e-mail of Secretary of the Journal "Sustainable Forestry": jelena.bozovic@forest.org.rs.

- **The paper** should be written in English, **Abstract** should be written both in English and Serbian, whereas **Summary** should be written only in Serbian.
- **The paper length** should not exceed 12 typewritten pages, with normal line spacing (Single Space).
- **Paper format:** width 16,5 cm, height: 24 cm.
- **Margins:** Top 1.5cm, Left 1.5cm, Bottom 1.5cm, Right 1.5cm, Gutter 0.5 cm, mirror margins.
- The paper should be typed in Word, using the Times New Roman Font, Justify, First Line 1.27.
- **Layout:** header 0.5 cm, footer 0.5 cm.

If special signs (symbols) are used in the text, use the Symbol Font.

The paper structure is as follows:

PAPER TITLE IN ENGLISH
(capital letters, Font Size 11pt, bold, centered)
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Name and SURNAME[1] (capital letters, Font Size 11pt, italic, centered) with footnotes which indicate affiliations and addresses of each author and mark * which indicate the corresponding author.
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Abstract: *The abstract is written in English with three spaces below the name of the paper author. In abstract are given basic aim of research, materials and methods, more important results and conclusion* (maximum 700 characters (no spaces)) (Font Size 10pt, italic).

Keywords: in English, 3-6 words (Font Size 10pt, normal).

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PAPER TITLE IN SERBIAN IN LATIN ALPHABET (capital letters, 11 points, bold, centered)
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Sažetak: Text of the abstract in Serbian in Latin alphabet (Font Size 10pt, italic)

Ključne reči: in Serbian (Font Size 10pt, normal).

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1. INTRODUCTION (Font Size 11pt, bold, align left)
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The introduction should be a short review of explanation about reasons that led to the research of specific scientific issue. The introduction contains reference data of published papers that are relevant for the analyzed issue (Text Normal, Font Size 11pt, Justify, First Line 1.27).

[1] Affiliation, address (9pt, normal)
*Corresponding author. E-mail: (9pt, normal)

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2. MATERIAL AND METHODS (Font Size 11pt, bold, align left)

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Within this chapter there can be subtitles of first and second line. In the description of material, it should be given enough information to allow other researchers to repeat the experiment at a different location. It is necessary to provide information on the material, subject of the study that precisely defines its origin, physical characteristics etc. If a device or instrument is used to obtain experimental results should be specified: name of the device or instrument, model, manufacturer's name and country of origin. If a scientifically recognized method is used it has to be cited in the References, without the explanation of the steps of the used method. If changes were made in a scientifically recognized method should be provided the original literature references that will support – justify those changes.

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3. RESULTS (Font Size 11pt, bold, align left)

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Within this chapter there can be subtitles of first and second line. The paper results should be presented in the form of text, tables and figures. From the results should be clear whether the hypotheses have been confirmed or disproved and whether the aim and tasks have been achieved. It should not be avoided the presentation of the negative results or disproving the hypotheses.

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3.1. Subchapter title (Font Size 11pt, bold, align left)

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Subchapter text (Font Size 11pt, normal, justify, first line 1.27)

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Table 1. (bold, 11pt), Table title (11pt, italic, centered)

Column name (8pt, bold)		
Table content (8pt, normal)		

Note (Font Size 8pt, bold)**:** Text (Font Size 8pt, italic)
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Figure 1. 11pt, bold Figure title, (11pt, italic, centered)

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In text (Figure 1); Continuation of the text, 11pt, justify, first line 1.27.
More than one figure and table in text separated with semicolon (Figure 1; Table 1) (Figure 1; Figure 2).

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4. DISCUSSION (Font Size 11pt, bold, align left)

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Discussion should not be the simple repeating of obtained results. The results should be discussed by comparing them with the results of other authors with compulsory citing of literature sources. It is very important to give discussion of the results and the opinion of the authors. Interpretation of perceived ambiguities and illogicalities should be correctly stated (11pt, justify, first line 1.27).

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5. CONCLUSION (Font Size 11pt, bold, align left)

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Conclusions of the paper should be carefully carried out and shown clearly to the reader. Conclusions can be significantly connected with the result discussion, but in them should be given freer and wider interpretation of the paper subject and results. The special quality is the defining of suggestions for future work and identifying the issues need to be resolved (11 points, justify, first line 1.27).

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Acknowledgement (10pt, bold): If the paper is a part of a research within a project in acknowledgement are indicated: name of the project, registration number and the full name of the institution that finances the project (10pt, justify, italic).

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References should be listed in alphabetical order in the reference list.
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Citation in text: Lastname (year),
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Journal Article (more than 20 authors)**:**
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Book
Lastname, A. (year). Title of the book in sentence case (edition, Volume). Publisher. Doi

(The edition, volume, and DOI are not compulsory)
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Kostadinov, S. (2008). Bujični tokovi i erozija. Univerzitet u Beogradu – Šumarski fakultet

Book Chapter:

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Example:
Dragićević, S., Kostadinov, S., Novković, I., Momirović, N., Langović, M., Stefanović, T., Radović, M., & Tošić, R. (2022). Assessment of soil erosion and torrential flood susceptibility: Case study—Timok river basin, Serbia. In A. Negm, L. Zaharia, & G. Ioana-Toroimac (Eds.), The Lower Danube River (pp. 357–380). Springer International Publishing. https://doi.org/10.1007/978-3-031-03865-5_12

Published Thesis or Dissertation:
Lastname, A. A. (year). Title of thesis in sentence case [Doctoral, Master, or Bachelor's thesis or dissertation, Name of the Institution]. Name of Repository. www.website.com
Example:
Braunović, S. Z. (2013). Efekti protiverozionih radova na stanje erozije u Grdeličkoj klisuri i Vranjskoj kotlini [Doktorska disertacija, Univerzitet u Beogradu, Šumarski fakultet]. Phaidra. https://doi.org/10.2298/bg20131004braunovic

Conference paper in Proceedings/Book of abstracts:
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Example:
Jovanović, F., Obratov-Petković, D., Bjedov, I., Mačukanović-Jocić, M., Braunović, S., Rakonjac, L., & Nikolić, B. (2022). Pollen micromorphology of Galanthus reginae-olgae subsp. vernalis Kamari from the eastern Adriatic coast. In N. Vuković, & V. Šegota (Eds.), Book of abstracts of the 7th Croatian Botanical Symposium with International Participation. Croatian Botanical Society. https://www.hbod.hr/wp-content/uploads/2022/09/Knjiga-sazetaka_7HBS.pdf

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Republički hidrometeorološki Zavod Republike Srbije. (2022). Meteorološki godišnjak 1 klimatološki podaci. Republički hidrometeorološki Zavod Republike Srbije.
Parenthetical citation in text: (Republički hidrometeorološki Zavod Republike Srbije, 2022)

*When citing two or more works together, arrange the in-text citations alphabetically in the same order in which they appear in the reference list separated with semicolon
Example:
(e.g., Bergstrom et al., 2006; Clément, 2010; Harris & Corriveau, 2011; Harris & Koenig, 2006; Heyman, 2008; Heyman & Legare, in press; Koenig & Harris, 2005).

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Name and SURNAME (10pt, italic)

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Summary (10 points, bold, centered)

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Summary text in English (10pt, justify, first line 1.27)

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Summary text in Serbian (10pt, justify, first line 1.27).

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ISSN 1821-1046 = Sustainable Forestry
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