SUSTAINABLE FORESTRY
COLLECTION 93, 2026

ODRŽIVO ŠUMARSTVO
ZBORNIK RADOVA 93, 2026

UDK: 712.252:504.5“2025“(497.11)=111
DOI: 10.5937/SustFor2693047M
Original scientific paper

AIR QUALITY IN BELGRADE DURING 2025: SEASONAL DYNAMICS, METEOROLOGICAL CONDITIONS, AND THE POTENTIAL OF URBAN FORESTS AND GREENERY IN MITIGATING AIR POLLUTION

Miroslava MARKOVIĆ[1], Goran ČEŠLJAR[1], Bojan KONATAR[1], Katarina MLADENOVIĆ[1]*

Abstract: *Air pollution is one of the key environmental and public health problems of contemporary cities. The aim of this paper was to examine the seasonal dynamics of air pollution in Belgrade during 2025, with particular attention to the role of meteorological conditions and the potential of urban forests and green infrastructure in mitigating population exposure to pollution. The paper is based on a literature review and an analysis of publicly available secondary data, including additional sources on the structure and maintenance of urban greenery in Belgrade. The results indicate a pronounced seasonal variability in air quality, with dominant episodes of suspended particles during the colder part of the year and a greater importance of ground-level ozone during the warmer period. It was observed that meteorological conditions, particularly wind and air ventilation, play an important role in the formation and dispersion of air pollution episodes. The literature review shows that urban forests and green infrastructure can contribute to reducing population exposure to pollution, but that their effect depends on spatial scale, urban form, vegetation structure, and local climatic conditions. The most useful urban planting approach is not based on a single species, but on site-adapted combinations of tolerant trees with high leaf area and suitable crown architecture, including tree avenues and shade trees where ventilation is not obstructed. It is concluded that urban greenery represents an important complementary measure, but not a substitute for reducing emissions at the source.*

Keywords: particulate matter; ground-level ozone; tree avenues; green zones; shade trees.

KVALITET VAZDUHA U BEOGRADU TOKOM 2025. GODINE: SEZONSKA DINAMIKA, METEOROLOŠKI USLOVI I POTENCIJAL URBANIH ŠUMA I ZELENILA U UBLAŽAVANJU AEROZAGAĐENJA

Sažetak: *Zagađenje vazduha predstavlja jedan od ključnih ekoloških i javnozdravstvenih problema savremenih gradova. Cilj ovog rada bio je da se sagleda sezonska dinamika aerozagađenja u Beogradu tokom 2025. godine, uz razmatranje uloge*

[1] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
*Corresponding author. E-mail: mira019@gmail.com

meteoroloških uslova i potencijala urbanih šuma i zelene infrastrukture u ublažavanju izloženosti zagađenju. Rad je zasnovan na pregledu literature i analizi javno dostupnih sekundarnih podataka, uključujući dodatne izvore o strukturi i održavanju urbanog zelenila u Beogradu. Rezultati ukazuju na izraženu sezonsku promenljivost kvaliteta vazduha, sa dominantnim epizodama suspendovanih čestica u hladnijem delu godine i većim značajem prizemnog ozona tokom toplijeg perioda. Uočeno je da meteorološki uslovi, naročito vetar i ventilacija vazduha, imaju važnu ulogu u formiranju i disperziji epizoda aerozagađenja. Pregled literature pokazuje da urbane šume i zelena infrastruktura mogu doprineti ublažavanju izloženosti stanovništva zagađenju, ali da njihov efekat zavisi od prostorne razmere, urbanog oblika, strukture vegetacije i lokalnih klimatskih uslova. Najkorisniji pristup ozelenjavanju ne zasniva se na jednoj vrsti, već na lokalno prilagođenim kombinacijama tolerantnih stabala sa velikom lisnom površinom i odgovarajućom arhitekturom krošnje, posebno u drvoredima i zelenim zonama u kojima se ne ometa ventilacija. Zaključuje se da urbano zelenilo predstavlja važnu dopunsku meru, ali ne i zamenu za smanjenje emisija na izvoru.

Ključne reči: suspendovane čestice; prizemni ozon; drvoredi; zelene zone; stabla senke.

1. INTRODUCTION

Air pollution is one of the most significant environmental and public health problems of contemporary cities. Suspended particles, particularly PM2.5 and PM10, as well as NO2 and ground-level O3, are associated with an increased risk of respiratory and cardiovascular diseases, which is why air quality occupies an important place in contemporary urban and public health policies. Additional weight is given to this issue by the more recent guidelines of the World Health Organization, which have tightened the recommended values for key pollutants (WHO, 2021).

Belgrade has long stood out as an urban area where air pollution is pronounced particularly during the colder part of the year. Official monthly reports of the Serbian Environmental Protection Agency for 2025 confirm a marked seasonal pattern, with a higher number of exceedances of the daily limit value for PM10 at several Belgrade monitoring stations during the winter months. For example, in January 2025, 5 days with exceedances were recorded at the Belgrade Stari Grad station, 7 in Novi Beograd, 11 at Mostar, 6 at Vračar, and 5 at Zeleno brdo, clearly indicating a pronounced problem of suspended particles during the winter period (SEPA, 2025).

In addition to emissions themselves, air quality in Belgrade also depends on meteorological conditions, especially ventilation and the dispersion of air pollutants. In this respect, the Košava wind is of particular importance, as it can contribute to the dilution of pollution and the mitigation of smog episodes. Therefore, air pollution in Belgrade cannot be interpreted solely through emission intensity, but also through local climatic and anemological specificities (Milošević Pantović et al., 2024).

Urban forests and green infrastructure are increasingly being considered as complementary measures for mitigating the effects of air pollution. Trees and other forms of urban greenery can contribute to particle deposition, changes in microclimatic conditions, reductions in air temperature, and reduced population exposure to certain pollutants. However, recent literature shows that their impact is

not unambiguous: at the broader urban scale, greenery may contribute to improved air quality, but this effect is most often moderate, while at the level of street canyons and densely built-up areas it may depend on spatial configuration, vegetation type, and aerodynamic conditions (Venter et al., 2024). Similarly, some studies indicate that the more favorable effects of green spaces on PM10 become more apparent only above a certain threshold of spatial coverage, which further supports a cautious interpretation of the relationship between greening and air quality (Islam et al., 2024).

An additional methodological problem is the fact that the concepts of forest cover, green spaces, and tree canopy cover cannot be used as synonyms. Therefore, it is scientifically more justified to speak of reference greening targets than of a single universal, optimal level of urban forest cover (UNP+, 2025; EEA, 2025).

Based on the above, a review of the relationship between the seasonal dynamics of air pollution in Belgrade, meteorological conditions, and the state of urban forests and greenery can provide a relevant basis for an interdisciplinary understanding of this issue, while at the same time taking into account the limitations of the available data and the complexity of the urban system itself (Venter et al., 2024; European Environment Agency, 2025).

2. AIMS OF THE STUDY AND RESEARCH QUESTIONS

The aim of this paper is, based on a review of the available literature and publicly available data, to examine the seasonal dynamics of air pollution in Belgrade during 2025, to consider the significance of meteorological conditions in the formation and dispersion of pollution episodes, and to assess the potential of urban forests, tree avenues, and green infrastructure as complementary measures for reducing population exposure to polluted air (Venter et al., 2024; SEPA, 2025; UNP+, 2025).

A specific aim of the paper is to critically consider to what extent the available literature supports the contribution of urban forests and green infrastructure to air pollution mitigation, and whether it is scientifically justified, in the case of Belgrade, to speak of a single optimal level of forest cover, or whether it is more appropriate to use the concept of reference greening targets, taking into account local climatic, spatial, and urban planning specificities (Venter et al., 2024; Islam et al., 2024; EEA, 2025).

The following research questions were considered in the paper:

1. What is the seasonal dynamics of air pollution in Belgrade during 2025, as observed through the available monthly and annual air quality indicators (SEPA, 2025)?
2. To what extent do meteorological conditions, especially wind and air ventilation, influence the intensity and spatial manifestation of air pollution episodes in Belgrade (Milošević Pantović et al., 2024)?
3. What does the contemporary literature show about the role of urban forests, green spaces, tree avenues, and tree canopy cover in mitigating pollutant concentrations in cities, and which vegetation traits and commonly used tree genera may be relevant for reducing exposure to particulate pollution

(Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Islam et al., 2024)?

4. Can one speak of a single optimal level of forest cover for Belgrade, based on the available data on urban greenery and the literature on urban tree cover, or is it scientifically more justified to speak of indicative and locally adapted greening targets (UNP+, 2025; EEA, 2025)?
5. To what extent can urban forests and green infrastructure represent a realistic complementary measure for mitigating air pollution in Belgrade, given that they cannot replace emission reductions at the source (Venter et al., 2024)?

3. MATERIAL AND METHODS

This paper was conceived as a literature review with elements of publicly available secondary data analysis. Such an approach was chosen because it enables the integration of official air quality data, data on urban greenery, and contemporary literature on the role of urban forests and green infrastructure in mitigating air pollution (Grant & Booth, 2009; Snyder, 2019).

The analysis was based on publicly available data and documents. To assess the seasonal dynamics of air pollution, monthly reports of the Serbian Environmental Protection Agency on detected exceedances of air pollutant limit values during 2025 were used, with particular emphasis on data for the Belgrade area. To examine the state of urban greenery and forests, available data and descriptions from the Urban Nature Plans Plus platform were used, as well as relevant European sources referring to indicators of green infrastructure and tree canopy cover (SEPA, 2025; Urban Nature Plans Plus, 2025; European Environment Agency, 2025). Additional information on the maintained tree avenues and park forests in Belgrade was obtained from the official pages of JKP "Zelenilo-Beograd", while planning aspects of Belgrade's green infrastructure were interpreted using published analyses of the Belgrade green space system and green infrastructure planning (Marić et al., 2015; JKP "Zelenilo-Beograd", n.d.a, n.d.b).

In addition to official sources, contemporary scientific literature was also used, addressing four key thematic areas: the seasonal dynamics of air pollution in urban environments, the influence of meteorological conditions on the dispersion of air pollutants, the role of urban forests and greenery in improving air quality, and species- or trait-related differences in particulate matter retention by urban trees. Particular attention was paid to recent papers and review studies indicating that the effects of urban greenery depend on spatial scale, urban form, local climatic conditions, and leaf and crown traits (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Islam et al., 2024).

In the analytical part of the study, seasonal patterns of air pollution in Belgrade were first identified on the basis of the available monthly reports for 2025. These patterns were then interpreted in light of the literature on meteorological factors, particularly wind and air ventilation, and in relation to the existing state of urban forests and greenery in Belgrade. Special consideration was given to the fact that the concepts of forest cover, green spaces, tree avenues, and tree canopy cover do not represent the same category and cannot be directly equated (European Environment Agency, 2025; JKP "Zelenilo-Beograd", n.d.a, n.d.b).

A limitation of this approach is that the paper is not based on original field measurements or spatially explicit modelling, but rather on the interpretation of secondary data and available literature. Nevertheless, such a methodological framework is suitable for a review paper whose aim is to synthesize existing knowledge and point out the main patterns and limitations in considering the relationship between air pollution, meteorological conditions, and urban greenery in Belgrade (Snyder, 2019).

4. SEASONAL DYNAMICS OF AIR POLLUTION IN BELGRADE DURING 2025

The seasonal dynamics of air pollution in Belgrade during 2025 show a clear annual pattern, with episodes of suspended particles being more pronounced during the colder part of the year, while ground-level ozone episodes become more important during the warmer part of the year. Such a pattern corresponds to the general characteristics of urban air pollution in temperate climatic conditions, where winter is dominated by emissions from heating and traffic combined with less favorable dispersion conditions, whereas in summer photochemical processes in the atmosphere become more important (World Health Organization, 2021).

Official monthly reports of the Serbian Environmental Protection Agency for 2025 confirm this pattern for the Belgrade area as well. Separate monthly reports for 2025 are available on the SEPA website, containing information on exceedances of hourly and daily limit values for SO2, NO2, PM10, CO, and ground-level ozone.

In January 2025, exceedances of the daily limit value for PM10 were recorded at several Belgrade monitoring sites, with 11 days of exceedance at the Belgrade Mostar station and 5 days at the Belgrade Zeleno brdo station. In July 2025, the pattern was different: 1 exceedance of PM10 was recorded at the Belgrade Mostar station, while 14 days with exceedance of O3 were recorded at the Belgrade Zeleno brdo station. With the onset of late autumn, the problem of suspended particles became more pronounced again, so in November 2025, 6 days with PM10 exceedances were recorded at the Belgrade Mostar station and 1 day at the Belgrade Zeleno brdo station. These data confirm that the problem of suspended particles is more pronounced during winter and late autumn, whereas the importance of ground-level ozone increases during the summer months.

To illustrate spatial differences in the seasonal dynamics of air pollution within Belgrade, Table 1 presents the monthly number of days with exceedances of the limit/target values for PM10 and O3 at the Belgrade Mostar and Belgrade Zeleno brdo stations during 2025 (SEPA, 2025).

Table 1. *Comparative overview of the monthly number of days with exceedances of the daily limit value for PM10 and the target value for O3 at the Mostar and Zeleno brdo stations during 2025*

Month 2025	Mostar – PM_{10}	Zeleno brdo – PM_{10}	Mostar – O_3	Zeleno brdo – O_3
January	11	5	0	0
February	11	6	0	0
March	10	1	0	0
April	0	0	0	0
May	0	0	0	3

Month 2025	Mostar – PM_{10}	Zeleno brdo – PM_{10}	Mostar – O_3	Zeleno brdo – O_3
June	3	0	0	11
July	1	0	0	14
August	0	0	0	11
September	0	0	0	1
October	5	1	0	0
November	6	1	0	0
December	13	9	0	0
Total	**60**	**23**	**0**	**40**

The results show that a considerably higher number of days with PM10 exceedances was recorded at the Mostar monitoring station, indicating a greater burden of suspended particles at this central, traffic-intensive location. In contrast, at the Zeleno brdo station, a higher number of days with exceedances of the target value for O3 was recorded during the warmer part of the year. This pattern indicates that spatial differences in air quality within Belgrade cannot be explained solely by the presence of greenery, but also by the type of pollutant, traffic intensity, the location of the monitoring station, and local meteorological conditions. Therefore, this comparison should be regarded as an illustration of the spatial variability of air pollution in urban conditions, rather than as direct evidence of the influence of forest cover or greenery on pollutant concentrations.

Such a seasonal shift in dominant pollutants shows that air pollution in Belgrade is not a single, uniform problem, but rather a set of seasonally variable phenomena with different origins. The winter period is primarily burdened by suspended particles, whereas during summer the importance of secondary photochemical pollutants becomes more pronounced. This dynamic indicates that air quality in Belgrade must be viewed as the result of the interaction between emission sources, atmospheric processes, and meteorological conditions, which provides an important basis for further consideration of the role of wind, dispersion, and the potential contribution of urban forests and greenery.

5. METEOROLOGICAL CONDITIONS AND THE DISPERSION OF AIR POLLUTANTS IN BELGRADE

In addition to emission intensity, air quality in Belgrade also depends to a large extent on meteorological conditions, particularly wind, atmospheric stability, and the possibility of pollutant dispersion. This means that episodes of air pollution cannot be interpreted solely through the presence of emission sources, but also through the atmosphere's ability to dilute and transport these pollutants. In urban areas, low wind speeds and stable conditions favor the accumulation of suspended particles, whereas stronger winds most often contribute to the reduction of their concentrations (Đurić et al., 2020; Davidović et al., 2021).

In this respect, the Košava wind is especially important for Belgrade. It is a regionally characteristic wind that represents one of the significant natural factors of ventilation of the urban atmosphere. In domestic and regional studies, Košava is described as a wind that can significantly influence air exchange and the dispersal of pollution, particularly during episodes when it blows for several consecutive days. As a result, more favorable dispersion of air pollutants is often recorded in Belgrade

under Košava conditions than during calm and stable weather (Milošević Pantović et al., 2024).

The relationship between wind speed and pollution levels has also been confirmed in studies analyzing winter air pollution episodes in Belgrade. Đurić et al. (2020) showed that wind speed is an important predictor of the air pollution index, while Davidović et al. (2021) found that stronger winds alter the composition of local air pollution and contribute to a reduction in the concentration of the fine particle fraction. Such findings indicate that meteorological conditions do not act merely as an accompanying factor, but rather as an important regulator of the intensity and duration of air pollution episodes in the city.

In the context of this study, this is particularly important because it shows that the relationship between air pollution and urban forests in Belgrade cannot be considered in isolation from local ventilation conditions. In other words, the potential of greenery to contribute to reducing exposure to pollution must be interpreted together with specific meteorological conditions, with Košava representing one of the important modulators of air quality in Belgrade. It can therefore be regarded as a significant local factor that mitigates part of the adverse effects of air pollution, although it does not affect the emission sources themselves (Đurić et al., 2020; Milošević Pantović et al., 2024).

6. URBAN FORESTS, GREEN SPACES, AND TREE CANOPY COVER IN BELGRADE

Considering the role of urban forests and greenery in mitigating air pollution in Belgrade first requires a clear distinction between several terms that are often confused in practice: forest cover, green spaces, tree avenues, and tree canopy cover. These indicators are not identical and do not describe the same spatial or functional category. In its urban assessments, the European Environment Agency specifically distinguishes tree cover as a separate indicator based on Urban Atlas data, and it cannot be directly equated with the area under forests or with total green spaces. Therefore, these terms must be used carefully and consistently in the analysis of Belgrade (European Environment Agency, 2025).

Available sources indicate that Belgrade possesses significant green resources, although they are unevenly distributed in spatial terms. According to the Urban Nature Plans Plus platform, approximately 16% of the city's territory is covered by forests and around 15% by green spaces, confirming that natural and semi-natural vegetation represents an important component of the urban environment (Urban Nature Plans Plus, 2025; https://interlace-hub.com/urban-nature-plan-plus/belgrade-serbia). These data, however, do not provide sufficient information on the distribution of greenery within the compact urban tissue, nor on the degree to which its effects are available to the population in the most polluted and densely built-up zones.

Additional information on the maintained urban greenery is provided by JKP "Zelenilo-Beograd". According to this source, the enterprise maintains 56,513 trees in street avenues in 743 streets of Belgrade. The tree avenues include about 50 tree species and around 28 genera, with the most represented genera being Acer, Platanus, Aesculus, Tilia, and Fraxinus. The same source states that one avenue tree

corresponds to approximately 20 inhabitants of Belgrade, and that the largest number of avenue trees is located in the municipality of Novi Beograd, while fewer are found in Rakovica, Vračar, and Čukarica (JKP "Zelenilo-Beograd", n.d.a; https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/drvoredi).

In addition to avenue trees, JKP "Zelenilo-Beograd" maintains about 400 ha of park forests, including 16 ha of protective belts. The maintained park-forest areas include Milićevo brdo, Zvezdara, Crveni breg, Banjički vis, Lisiciji potok, Hajd park, parts of Topčider, Rejsova padina, Jajinci, Šumice, Kijevo-Kneževac, Petlovo brdo, Repište, and Bežanijska kosa (JKP "Zelenilo-Beograd", n.d.b; https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/odrzavanje-suma). These data show that Belgrade's green system is composed not only of compact forests and large parks, but also of linear elements, small green spaces, protective belts, and tree avenues.

The importance of such a networked approach is also supported by the planning literature. Marić et al. (2015) note that the Master Plan of Belgrade introduced the concept of an urban green space system that includes suburban forests, private forests and shrubs, urban forests, urban gardens, urban parks, and tree avenues. The same authors emphasize that the Belgrade Green Regulation project was based on the principles of connectivity, multifunctionality, accessibility, biodiversity preservation, and improvement of the state of the environment. Therefore, the issue of greenery in Belgrade should be interpreted not only through total area, but also through connectivity, continuity of green corridors, and the position of trees in relation to traffic corridors and zones of high exposure.

For the subject of this paper, it is particularly important that the state of greenery in Belgrade cannot be reduced to the simple question of whether there is enough of it or not. Scientifically, it is more precise to say that the total amount of greenery and forest cover represents only one part of the picture, while for air quality equally important factors are likely to include spatial distribution, connectivity, the presence of tree lines and smaller green areas in zones of highest population exposure, species composition, crown density, and the relationship between vegetation and urban ventilation. For this reason, in the further analysis Belgrade cannot be assessed solely through the total percentage of forest cover, but rather through the broader concept of urban green infrastructure.

7. THE ROLE OF URBAN FORESTS AND GREEN INFRASTRUCTURE IN MITIGATING AIR POLLUTION

Contemporary literature generally confirms that urban greenery can contribute to the mitigation of air pollution, while at the same time showing that this effect is neither simple nor universal. Vegetation can influence air quality through several mechanisms, including the deposition and retention of suspended particles on leaf surfaces, changes in local turbulence, reductions in temperature, and modifications of microclimatic conditions. However, recent studies warn that the actual effect is most often moderate and that its magnitude depends on spatial scale, urban form, vegetation type, and leaf and crown traits (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022; Venter et al., 2024; Sun et al., 2024).

It is particularly important that the positive effects of urban greenery are not equally expressed at all spatial levels. Venter et al. (2024) conclude that greening may contribute to improved air quality at the level of a neighborhood or an entire city, but that this contribution is generally limited, whereas at street level the effects may even be unfavorable, especially if vegetation obstructs ventilation. This means that simply increasing the amount of greenery does not automatically guarantee a proportional reduction in pollution in every urban context.

Species selection is nevertheless important because particulate matter retention differs among tree species and is influenced by traits such as leaf area, leaf surface roughness, waxes, trichomes, canopy density, phenology, and tolerance to urban stress. Review studies emphasize that broad leaf area and complex leaf surfaces may increase particle capture, while evergreen and coniferous species can provide longer seasonal retention, although their use in streets must be balanced with drought tolerance, allergenic potential, maintenance needs, and the need to preserve ventilation (Rodríguez-Santamaría et al., 2022; Gaglio et al., 2022).

In Belgrade, the most represented avenue genera are Acer, Platanus, Aesculus, Tilia, and Fraxinus (JKP "Zelenilo-Beograd", n.d.a). These genera can therefore be considered relevant not only because they are already established in the city, but also because they include broadleaved trees with relatively large crowns and substantial leaf area, which can be useful for shading and particle deposition when properly placed and maintained. However, no single genus should be recommended universally. Planting should be adapted to street width, underground infrastructure, available rooting space, exposure to de-icing salt, drought risk, pest susceptibility, and the need for air flow through narrow urban canyons.

From the perspective of reducing exposure to air pollution, the most suitable practical approach for Belgrade would be to combine: (i) large-crowned shade trees in parks, squares, schoolyards, and wider boulevards; (ii) continuous but well-spaced tree avenues along traffic corridors where ventilation is not obstructed; (iii) shrub and hedge belts or mixed vegetation barriers between traffic lanes and pedestrian zones where space allows; and (iv) coniferous or evergreen elements primarily in park forests, protective belts, and wider open spaces where they can contribute to year-round filtration without worsening street-canyon ventilation. Such recommendations should be interpreted as planning guidelines rather than as a fixed list of mandatory species.

In addition, some studies indicate that a certain threshold of green space coverage is probably needed for a clearer effect on suspended particles. Islam et al. (2024) state that at least about 27% green space within the land cover structure could be associated with a more significant reduction in PM10 fluxes, while at the same time emphasizing that this threshold is not universal and depends on the local climatic and urban context. This finding is important because it supports the idea that one should not speak of a single fixed optimal value, but rather of indicative reference targets that require local verification.

One of the main limitations of the action of urban greenery relates to densely built-up areas and so-called street canyons. Under such conditions, trees and other vegetation may reduce air flow velocity and hinder the dispersion of air pollutants, so the local effect may be opposite to what is expected. For this reason, an increasing number of studies emphasize that the influence of urban forests on air quality must

be considered together with urban morphology, street width, building height, vegetation permeability, and ventilation corridors, rather than separately from them (Buccolieri, 2021; Venter et al., 2024).

For the purposes of this study, the most important point is that the literature does not support the oversimplified thesis that greater forest cover by itself will solve the problem of air pollution. It is scientifically much more justified to conclude that urban forests, tree avenues, and green infrastructure may represent complementary measures for reducing population exposure to pollution, but that their effect depends on local conditions and cannot replace emission reduction at the source. In other words, the potential of urban greenery is real, but it is contextual, spatially conditioned, and as a rule smaller than is often assumed in public discourse (Venter et al., 2024; Sun et al., 2024).

8. LIMITATIONS OF THE APPLICATION OF THE CONCEPT OF OPTIMAL FOREST COVER IN THE URBAN CONDITIONS OF BELGRADE

The concept of optimal forest cover in urban conditions should be used with great caution, because contemporary literature and planning practice do not provide a single, universally applicable value that would be valid for all cities. The reason is primarily methodological: indicators of land under forests, green spaces, and tree canopy cover do not describe the same category and cannot be directly equated. The European Environment Agency treats urban tree cover as a separate indicator based on Copernicus/Urban Atlas data, which in itself shows that the question of how much greenery is enough cannot be reduced to a single simple figure.

In addition, recent literature indicates that the effect of urban greenery on air quality depends on spatial scale and urban context. Venter et al. (2024) conclude that greening may contribute to improved air quality at the level of a neighborhood or an entire city, but that this effect is generally moderate and may even be unfavorable at street level if vegetation interferes with ventilation. This means that even a high proportion of greenery does not by itself guarantee an optimal effect on air pollution.

Similarly, Islam et al. (2024) indicate that more significant effects of green spaces on PM10 reduction may be expected only above a certain threshold of coverage, with their analysis suggesting that around 27% green space cover could be associated with a more pronounced effect. However, the same authors emphasize that this threshold depends on local urban and climatic conditions and should therefore not be interpreted as a universal optimal value.

In the case of Belgrade, an additional problem is that available sources describe the state of urban greenery through different indicators. Urban Nature Plans Plus states that Belgrade has approximately 16% of its territory under forests and around 15% under green spaces, while JKP "Zelenilo-Beograd" provides operational data on maintained street avenues and park forests, including 56,513 avenue trees in 743 streets and about 400 ha of maintained park forests (Urban Nature Plans Plus, 2025; JKP "Zelenilo-Beograd", n.d.a, n.d.b). These indicators do not provide the same type of information and do not fully describe tree canopy continuity, crown condition, age structure, connectivity, or exposure reduction in the most densely built-up parts of the city. For this reason, the overall percentage of forest cover

cannot serve as a sufficient criterion for assessing whether the situation is optimal from the point of view of air quality and population exposure.

For all these reasons, under the urban conditions of Belgrade it is scientifically more justified to speak of locally adapted greening targets than of a single optimal forest cover. Such an approach makes it possible to take into account the climatic characteristics of the city, the role of wind and ventilation, the distribution of traffic corridors, building density, and the actual accessibility of greenery to the population. In this sense, the concept of optimal forest cover may be useful as a planning and research framework, but not as an exact, predefined value that could be directly applied to Belgrade.

9. DISCUSSION

The available data for 2025 show that air pollution in Belgrade follows a clear seasonal pattern, with exceedances of PM10 being more pronounced during the colder part of the year, while ground-level ozone episodes become more important during the warmer period. Such dynamics are consistent with the official SEPA monthly reports for 2025, which present exceedances of PM10, O3, and other pollutants for each month, as well as with the general health and environmental framework emphasizing the importance of suspended particles and ozone in urban environments (SEPA, 2025; WHO, 2021).

At the same time, this pattern confirms that the problem of air quality in Belgrade cannot be interpreted solely through the presence of emission sources. Local meteorological conditions, especially wind and air ventilation, represent important regulators of the intensity and duration of pollution episodes. Under Belgrade conditions, this is particularly important because of the Košava wind, which can contribute to more efficient dispersion of air pollutants and to the mitigation of pollutant accumulation. For this reason, the seasonal dynamics of air pollution must be viewed as the result of the combined action of emissions, atmospheric chemistry, and meteorological conditions, rather than as the consequence of a single factor (Milošević Pantović et al., 2024).

The available literature also shows that urban forests and greenery may have a positive effect on air quality, but that this effect is generally moderate and strongly dependent on spatial scale and urban context. Venter et al. (2024) indicate that greening may contribute to improved air quality at the neighborhood or city level, but that the effects are mostly moderate and may even be unfavorable at street level if vegetation interferes with ventilation. Similarly, Islam et al. (2024) report that a more significant effect of green spaces on PM10 reduction may be associated with a higher proportion of green space cover, with an estimated indicative value of around 27%, while clearly emphasizing that this threshold depends on local conditions and is not universally applicable.

In the case of Belgrade, an additional methodological complexity arises from the fact that the state of urban greenery is described through different indicators. SEPA monthly reports provide an overview of exceedances of air pollutants, whereas the EEA uses urban tree cover as a separate indicator, Urban Nature Plans Plus for Belgrade reports approximately 16% of the territory under forests and around 15% under green spaces, and JKP “Zelenilo-Beograd” reports operational

data on maintained tree avenues and park forests. Since these indicators do not represent the same category, it is not scientifically justified to translate them directly into a single optimal level of forest cover for the city. It is much more precise to speak of locally adapted greening and green infrastructure improvement targets than of one universal optimal value for Belgrade.

Based on all of the above, it can be concluded that urban forests and green infrastructure in Belgrade have real potential as complementary measures for reducing population exposure to air pollution, but they cannot replace emission reduction at the source. The most useful contribution can be expected from spatially planned combinations of park forests, connected green zones, tree avenues, shade trees, and vegetation barriers, with species selection based on tolerance to urban stress and on leaf and crown traits relevant for particulate matter retention. Their contribution should be considered together with local meteorological conditions, the distribution of traffic corridors, building density, and the existing spatial distribution of greenery. For this reason, the most scientifically defensible approach for Belgrade is to treat the issue of optimal forest cover as a planning and research concept, rather than as a predefined and universally valid figure.

10. CONCLUSION

Based on the available data and the reviewed literature, it can be concluded that air pollution in Belgrade during 2025 exhibited a pronounced seasonal pattern, with suspended particle episodes being more dominant during the colder part of the year, while ground-level ozone episodes became more important during the warmer period (SEPA, 2025; WHO, 2021). This pattern confirms that air quality in the city cannot be interpreted solely through emission intensity, but also through the action of meteorological factors, especially wind and the dispersion of air pollutants. In this respect, the Košava wind represents an important local factor that can mitigate the intensity of air pollution episodes, although it does not affect the emission sources themselves (Milošević Pantović et al., 2024).

A review of the contemporary literature shows that urban forests and green infrastructure can contribute to mitigating population exposure to air pollution, but that their effect is generally moderate and strongly dependent on spatial scale, urban form, and local climatic conditions. Therefore, it is not scientifically justified to reduce the issue of air quality in Belgrade to the simple assumption that greater forest cover will automatically lead to a proportional reduction in pollution (Venter et al., 2024; Islam et al., 2024).

At the same time, the available data on the state of urban greenery in Belgrade indicate that the concepts of forest cover, green spaces, tree avenues, park forests, and tree canopy cover cannot be used as synonyms, which is why the concept of optimal forest cover in urban conditions must be applied with caution. The available operational data show that Belgrade has a substantial but uneven green system, including maintained avenue trees and park forests, with Acer, Platanus, Aesculus, Tilia, and Fraxinus among the most represented avenue genera (JKP "Zelenilo-Beograd", n.d.a, n.d.b). In the case of Belgrade, it is scientifically more justified to speak of locally adapted greening and green infrastructure improvement

targets than of a single optimal value that would be universally applicable (EEA, 2025; UNP+, 2025).

Overall, urban forests and green infrastructure in Belgrade should be regarded as important complementary measures in mitigating the effects of air pollution, but not as a substitute for emission reduction at the source. In practical terms, priority should be given to maintaining existing park forests and tree avenues, improving connectivity between green zones, and selecting site-appropriate shade trees and mixed vegetation barriers in locations where they reduce exposure without obstructing air circulation. The practical significance of such an approach lies in the fact that it opens space for an integrated consideration of air quality, urban planning, and green infrastructure, while taking into account the local specificities of the city.

Acknowledgement: *This study was supported by the Republic of Serbia, Ministry of Education, Science and Technological Development, under Agreement No. 451-03-33/2026-03/200027, dated 5 February 2026.*

REFERENCES

Balkan Green Energy News. (2024, November 8). Belgrade prepares draft Green Infrastructure Strategy. https://balkangreenenergynews.com/belgrade-prepares-draft-green-infrastructure-strategy/

Buccolieri, R. (2021). Urban obstacles influence on street canyon ventilation: A brief review. Engineering Proceedings, 8(1), 11.

Gaglio, M., Pace, R., Muresan, A.N., Maisto, G., & Manes, F. (2022). Species-specific efficiency in PM2.5 removal by urban trees: From leaf measurements to improved modeling estimates. Science of the Total Environment, 844, 157131. https://doi.org/10.1016/j.scitotenv.2022.157131

Grant, M.J. & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. Health Information and Libraries Journal, 26(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Davidović, M., Savić, S., Stojić, A., Kumar, P., Bartonova, A., Gramsch, E., Singh, V., Lanki T., Karttunen, A., Niemi, J.V., Hämeri, K., & Kerminen, V.-M. (2021). Diurnal, temporal and spatial variations of main air pollutants in a developing megacity: The case of Belgrade, Serbia. Applied Sciences, 11(3), 1212.

Đurić, M., Tričković, G., Šećerov, I., & Lalić, B. (2020). Short-term forecasting of air pollution index in Belgrade, Serbia. Meteorological Applications, 27(6), 1946.

European Environment Agency. (2022). Percentage of total green infrastructure, urban green space and tree cover in selected European cities.

European Environment Agency. (2025). Urban tree cover dashboards.

Islam, A., Pattnaik, N., Moula, M.M., Rötzer, T., Pauleit, S., & Rahman, M.A. (2024). Impact of urban green spaces on air quality: A study of PM10 reduction across diverse climates. Science of the Total Environment, 955, 176770. https://doi.org/10.1016/j.scitotenv.2024.176770

JKP "Zelenilo-Beograd". (n.d.a). Drvoredi. https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/drvoredi

JKP "Zelenilo-Beograd". (n.d.b). Održavanje šuma. https://www.zelenilo.rs/delatnosti/odrzavanje-zelenih-povrsina/odrzavanje-suma

Marić, I., Crnčević, T., & Cvejić, J. (2015). Green infrastructure planning for cooling urban communities: Overview of the contemporary approaches with special reference to Serbian experiences. Spatium, 33, 55-61. https://doi.org/10.2298/SPAT1533055M

Milošević Pantović, A., Ignjatović, Z. & Stevanović, V. (2024). Air quality evaluation: Insights from case studies in Belgrade. Advanced Technologies, 13 (2), 67-75.

National Ecological Association. (2026). Air 2025. (In Serbian: Nacionalna ekološka asocijacija. (2026). Vazduh 2025.)

Obradović, J., Obradović, M., & Onjia, A. (2024). Air quality assessment in Belgrade: Spatial and temporal variations. In 17th International Conference on Fundamental and Applied Aspects of Physical Chemistry: Proceedings, Volume II (pp. 451-454). https://doi.org/10.46793/Phys.Chem24II.451O

Rodríguez-Santamaría, K., Chica, E.J., & Sánchez, J. (2022). Macro-morphological traits of leaves for urban tree selection for air pollution biomonitoring: A review. Biosensors, 12(10), 812. https://doi.org/10.3390/bios12100812

Serbian Environmental Protection Agency. (2025). Information on detected exceedances of hourly and daily limit values for air pollutants: Monthly reports for 2025. (In Serbian: Agencija za zaštitu životne sredine Republike Srbije. (2025). Informacije o detektovanim prekoračenjima satnih i dnevnih graničnih vrednosti (GV) zagađujućih materija u vazduhu – mesečni izveštaji za 2025. godinu)

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sun, Y., Guan, Y., Zhang, B., Zhou, Y., Du, L., & Zhu, C. (2024). Air PM10 and PM2.5 removal by urban green space under urban realistic stressors. Atmosphere, 15(12), 1443.

Urban Nature Plans Plus. (2025). Belgrade, Serbia. https://interlace-hub.com/urban-nature-plan-plus/belgrade-serbia

Venter, Z.S., Hassani, A., Stange, E., Schneider, P., & Castell, N. (2024). Reassessing the role of urban green space in air pollution control. Proceedings of the National Academy of Sciences, 121(6), e2306200121.

World Health Organization. (2021). WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.

Serbian Environmental Protection Agency (2025). Air quality. (In Serbian: Agencija za zaštitu životne sredine Republike Srbije. (2025). Kvalitet vazduha.)

AIR QUALITY IN BELGRADE DURING 2025: SEASONAL DYNAMICS, METEOROLOGICAL CONDITIONS, AND THE POTENTIAL OF URBAN FORESTS AND GREENERY IN MITIGATING AIR POLLUTION

Miroslava MARKOVIĆ, Goran ČEŠLJAR, Bojan KONATAR, Katarina MLADENOVIĆ

Summary

Air pollution is one of the most serious environmental and public health problems in contemporary urban areas, and Belgrade has long stood out as a city where this problem is particularly pronounced. The aim of this paper was, based on a review of the available literature and an analysis of publicly available data, to examine the seasonal dynamics of air pollution in Belgrade during 2025, as well as to consider the significance of meteorological conditions and the potential of urban forests and green infrastructure in mitigating population exposure to pollution.

The paper was conceived as a literature review with elements of secondary data analysis, with official monthly reports on exceedances of limit values for air pollutants being used to assess seasonal dynamics, while available data on urban forests, green spaces, and tree canopy cover were used to examine greenery and forest cover.

The results indicate pronounced seasonal variability in air quality in Belgrade. During the colder part of the year, episodes of suspended particles were dominant, which is associated with more intensive emissions from heating and traffic, as well as with less favorable dispersion conditions, whereas during the warmer part of the year ground-level ozone episodes became more important. The analysis showed that the problem of air pollution in Belgrade cannot be interpreted solely through emission intensity, but also through the action of meteorological factors, particularly wind and air ventilation. In this sense, the Košava wind has particular importance as a local factor that can contribute to the dilution of air pollutants and the mitigation of smog episodes, although it does not affect the emission sources themselves.

A review of the contemporary literature shows that urban forests and green infrastructure can contribute to reducing population exposure to air pollution, but that their effect is generally moderate and strongly dependent on spatial scale, urban form, vegetation distribution, and local climatic conditions. Additional information on Belgrade's greenery indicates that the maintained tree avenues include about 50 tree species and around 28 genera, with Acer, Platanus, Aesculus, Tilia, and Fraxinus among the most represented genera. It is particularly emphasized that the concepts of forest cover, green spaces, tree avenues, and tree canopy cover cannot be used as synonyms, which is why the concept of optimal forest cover in urban conditions requires cautious and critical application. In the case of Belgrade, it is scientifically more justified to speak of locally adapted greening and green infrastructure improvement targets than of a single optimal value.

Overall, the paper shows that urban forests and green infrastructure represent an important complementary measure in mitigating the effects of air pollution, but they cannot replace emission reduction at the source, which is why the issue of air quality in Belgrade requires an integrated approach linking environmental protection, urban planning, and the improvement of the city's green systems.

KVALITET VAZDUHA U BEOGRADU TOKOM 2025. GODINE: SEZONSKA DINAMIKA, METEOROLOŠKI USLOVI I POTENCIJAL URBANIH ŠUMA I ZELENILA U UBLAŽAVANJU AEROZAGAĐENJA

Miroslava MARKOVIĆ, Goran ČEŠLJAR, Bojan KONATAR, Katarina MLADENOVIĆ

Rezime

Zagađenje vazduha predstavlja jedan od najozbiljnijih ekoloških i javnozdravstvenih problema savremenih urbanih sredina, a Beograd se već duže vreme izdvaja kao grad u kome je ovaj problem posebno izražen. Cilj ovog rada bio je da se, na osnovu pregleda dostupne literature i analize javno dostupnih podataka, sagleda sezonska dinamika aerozagađenja u Beogradu tokom 2025. godine, kao i da se razmotri značaj meteoroloških uslova i potencijal urbanih šuma i zelene infrastrukture u ublažavanju izloženosti stanovništva zagađenju.

Rad je koncipiran kao pregled literature sa elementima analize sekundarnih podataka, pri čemu su za sagledavanje sezonske dinamike korišćeni zvanični mesečni izveštaji o prekoračenjima graničnih vrednosti zagađujućih materija u vazduhu, dok su za razmatranje zelenila i šumovitosti korišćeni dostupni podaci o urbanim šumama, zelenim površinama i pokrovu krošnji.

Rezultati ukazuju na izraženu sezonsku promenljivost kvaliteta vazduha u Beogradu. Tokom hladnijeg dela godine dominantne su epizode suspendovanih čestica, što je povezano sa intenzivnijim emisijama iz grejanja i saobraćaja, kao i sa nepovoljnijim uslovima disperzije, dok tokom toplijeg dela godine veći značaj dobijaju epizode prizemnog ozona. Analiza je pokazala da se problem aerozagađenja u Beogradu ne može tumačiti samo kroz intenzitet emisija, već i kroz delovanje meteoroloških faktora, naročito vetra i ventilacije vazduha. U tom smislu, košava ima poseban značaj kao lokalni faktor koji može doprineti razređivanju zagađujućih materija i ublažavanju smog epizoda, iako ne utiče na same izvore emisije.

Pregled savremene literature pokazuje da urbane šume i zelena infrastruktura mogu doprineti smanjenju izloženosti stanovništva aerozagađenju, ali da je njihov efekat uglavnom umeren i snažno zavisan od prostorne razmere, urbanog oblika, rasporeda vegetacije i lokalnih klimatskih uslova. Dodatni podaci o beogradskom zelenilu ukazuju da održavani drvoredi obuhvataju oko 50 vrsta drveća i oko 28 rodova, pri čemu su među najzastupljenijim rodovima Acer, Platanus, Aesculus, Tilia i Fraxinus. Posebno je naglašeno da se pojmovi šumovitosti, zelenih površina, drvoreda i pokrova krošnji ne mogu koristiti kao sinonimi, zbog čega pojam optimalna šumovitost u urbanim uslovima zahteva opreznu i kritičku primenu. U slučaju Beograda naučno je opravdanije govoriti o lokalno prilagođenim ciljevima ozelenjavanja i unapređenja zelene infrastrukture nego o jedinstvenoj optimalnoj vrednosti.

U celini posmatrano, rad pokazuje da urbane šume i zelena infrastruktura predstavljaju važnu dopunsku meru u ublažavanju posledica aerozagađenja, ali ne mogu zameniti smanjenje emisija na izvoru, zbog čega pitanje kvaliteta vazduha u Beogradu zahteva integrisan pristup koji povezuje zaštitu životne sredine, urbanističko planiranje i unapređenje zelenih sistema grada.