THE STUDY OF *JASMINUM NUDIFLORUM* LINDL. IN URBAN GREEN INFRASTRUCTURE IN CONDITIONS OF CLIMATE CHANGE IN BELGRADE, SERBIA

OCOKOLJIĆ, M.[1] – PETROV, DJ.[1*] – GALEČIĆ, N.[1] – SKOČAJIĆ, D.[1] – ŠIŠAKOVIĆ, N.[2] – SIMOVIĆ, I.[3]

[1]*University of Belgrade - Faculty of Forestry, Kneza Viseslava 1, Belgrade 11000, Serbia*

[2]*JKP Zelenilo Beograd, Rajkova 15, Novi Beograd 11070, Serbia*

[3]*BioSense Institute, University of Novi Sad, Dr Zorana Djindjića 1, Novi Sad 21000, Serbia*

[*]*Corresponding author*
e-mail: djurdja.stojicic@sfb.bg.ac.rs; phone: +381-113-053-814; fax: +381-112-545-485

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Abstract. The research aims to assess the significance of early (winter) jasmine as a fundamental component within Belgrade's urban green infrastructure (UGI) in Serbia. Through a specific case study, it investigates the intricate interplay between climate, biodiversity, and vegetation across spatial and temporal scales influenced by climate change. The study analizes the layout of UGI, its various spatial typologies, and the importance of relation between these characteristics, morphology and phenology for the social and cultural context. Results demonstrate that Weeping Winter Jasmine, particularly during its cold-season flowering phase, enhances visual appeal and attractiveness without conflicting with ethical, spiritual, or cultural values. Morphological analysis of 2,250 flowers revealed a distinction between trimmed and free-growing plants, yet differing characteristics did not impact flowering abundance or visual perception. Flowering phenology was monitored across the municipalities of Savski venac, Vračar, and Čukarica to assess shifts in flowering patterns. Over the autumn, winter, and spring of 2022/2023, 30,925 phenological observations were recorded, while 125,600 from the period 2007-2022 were utilized to determine key flowering phases and events important for landscape design. Cluster analysis delineated location 3 from locations 1 and 2, which share similarities and are influenced by the urban heat island (UHI) effect, confirming phenological changes are a prominent indicator of climate change. Despite belonging to the oldest group, location 3 individuals exhibited the longest flowering phenophase, commencing 54.5 days earlier and concluding 15 days later compared to the previous sixteen-year period. The study confirmed the importance of *Jasminum nudiflorum* Lindl. as a UGI element in Belgrade, sustaining vibrant and cascading displays throughout the colder months and maintianing social and cultural contribution of the location amidst climate change.
Keywords: *climate change, social context, flowering shrub, landscape design, urban heat island (UHI), greenery layout*

Introduction

More than half of the world's population lives in urban areas, and further population growth is expected to be mainly in cities (United Nations, 2019). Furthermore, the increase in the urban population leads to a higher degree of urbanization and the awareness of the importance of UGI is stronger (Schwarz et al., 2011). Reconciling ecological and other ecosystem services is a challenging because UGI elements are mostly small-sized and fragmented (Summers et al., 2012). Taxon richness, ecological uniqueness, and assessment of flora quality are used for the preservation of the identity and revitalization of UGI elements (Schetke et al., 2010). Ecological uniqueness identifies sites with a specific composition of plant material that contributes to local diversity (Schetke et al., 2010).

The integration of design and scientific expertise establishes a shared foundation, facilitating decision-making for landscape transformation among scientists and practitioners. Design plays a pivotal role in enhancing landscape functionality and elucidating the interconnections between individual elements. Landscape science, coupled with design methodologies and patterns, serves as a valuable instrument for devising strategies and implementing landscape alterations. Adhering to design principles aids in problem-solving and contributes to the enhancement or preservation of landscape value for future generations (Nassauer and Opdam, 2008).

Landscape design serves as a framework for comprehending interactions and patterns, offering solutions for adaptive management to enhance sustainability in the face of climate change (Liao et al., 2020). Numerous studies have explored the impact of climate change on urban green infrastructure (Wilby and Perry, 2006; Gill, 2006). Research in forest communities in the USA has focused on enhancing the adaptability of tree communities to potential future climates through landscape management assessments (Olson et al., 2017). Climate change, among other factors, affects urban landscapes and consequently influences the well-being of urban residents and building occupants. Effective design of public spaces with appropriate plant selections requires an understanding of the adaptation process to climate change. In response to climate change, incorporating non-native species alongside indigenous ones can increase species diversity and enhance aesthetic value while mitigating adverse effects. Urban planners, architects, landscape architects, and professionals are challenged with addressing climate change sustainably, necessitating a shift towards more resilient landscape approaches (Alizadeh and Hitchmough, 2019b). Resident perceptions of urban greenery remain largely unaffected by whether species are native or introduced, although decision-makers prioritize user participation in urban green area management for ecosystem service provision, including cultural services (Fish et al., 2016).

Climate change is expected to prompt the substitution of currently applied species with more resilient ones, favoring faster-growing species and introducing new non-native species to better cope with changing conditions (Grimshaw and Bayton, 2009). In a study conducted in Shanghai, the adaptability of 40 tree species was assessed over 55 years, revealing shifts in species selection priorities driven by climate change impacts on landscape tree adaptability (Liu and Zhang, 2018). Similarly, in the UK, researchers investigated the effects of climate change on green space design using 18 plant species with varying sensitivities to climate change scenarios. Their findings suggest designing dynamic public landscapes with multi-layered plant communities comprising species resilient to current and future climate conditions (Alizadeh and Hitchmough, 2019a). It's crucial to distinguish between climate tolerance and design effectiveness; while certain species like birch may withstand summer drought stress, they may lack aesthetic contributions to urban landscapes due to sparse leaf cover. Trees, being the most visible and vulnerable greenery components, face significant risks from climate change, experiencing prolonged exposure and susceptibility to extreme weather events. Shrubs are also impacted, albeit to a lesser extent due to their smaller size and shorter lifespans. Certain species, such as Corylus colurna, Cupressus sempervirens, Juglans nigra, Liriodendron tulipifera, Platanus acerifolia, and Pyrus pyraster, may benefit from increased heat, as indicated by authors Bisgrove and Hadley (2002). Local biodiversity is affected by global warming, with many phenotypic traits influenced by climate

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variables, and plant life cycle phases affected by abiotic environmental factors (Münzbergová et al., 2017). Temperature plays a crucial role in shaping flowering phenological patterns, with regional and local assessments necessary due to varying temperature thresholds and cumulative effects on phenological responses (IPCC, 2014; Jochner et al., 2016). The speed of phenological responses is also influenced by local climatic conditions (Güsewell et al., 2017).

The traditional focus of environmental studies has predominantly centered on conservation and ecology, yet emerging research suggests a necessary shift towards considering the socio-cultural context and the services urban greenery offers to residents. Kaplan et al. (2023) discovered that people's perceptions of Urban Green Infrastructure (UGI) and its significance vary depending on additional attributes. Beyond addressing climate change concerns, urban planners must integrate social considerations and cultural dimensions of urban greenery into decision-making processes to meet the diverse needs of urban inhabitants (Jim and Chen, 2006; de Kleyn et al., 2020). Urban greenery planning will increasingly embrace innovative approaches that cater to the evolving physical and social landscape, benefiting both decision-makers (Teixeira et al., 2022) and the general public (Hoyle et al., 2017). To mitigate the Urban Heat Island (UHI) effect, design strategies increasingly utilize natural features to enhance shading effectiveness, employing trees and vegetation (Wilby and Perry, 2006).

Our research centers on assessing the phenology and morphology of *Jasminum nudiflorum* Lindl. (Weeping Winter Jasmine) as a component of Urban Green Infrastructure (UGI) in Belgrade. The objective is to examine how this flowering species influences both social and landscape design contexts by investigating variations in morphology and phenology attributed to climate change. We discuss the implications of elevated temperatures resulting from current and projected climate shifts to determine their effects and identify potential adaptations aligning with urban adjustment imperatives. The study explores how the diverse UGI layouts influence changes in flowering patterns and visual appeal. Additionally, we analyze the species' aesthetic value in relation to the economic and cultural significance of the surrounding neighborhood. By contextualizing vegetation science within social studies, our findings facilitate a comprehensive assessment of flowering species for Belgrade's UGI. These insights can inform the modification of public spaces to cultivate a sustainable UGI (Summers et al., 2012), preserving their social function and contributing to shared values of importance.

Materials and Methods

Study area

The research covered public green spaces in Belgrade, Serbia (*Fig. 1*), in the municipalities of Savski venac (Bulevar Vojvode Mišića - location 1), Vračar (St. Sava’s Park in front of the St. Sava temple - location 2) and Čukarica (Banovo brdo - location 3). The locations were selected based on satellite maps, cartographic materials, planning documents of PUC "Zelenilo Beograd", the degree of urbanization and field research. The criterion for choosing the location was the presence of the species *Jasminum nudiflorum* Lindl. due to its adaptability, resilience, and ornamental values in the winter period (Ocokoljić and Petrov, 2022), which makes it a candidate as an integral component that provides additional value to the UGI. Another criterion was the type of space according to Selivanova et al. (2019) these were the followings: a) closed

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spatial structure (horizontal (single-story) and vertical closure (multi-story), with plants without or with the limited visual perception that are in psychophysical isolation with coverage 0.6-1.0 (where 1.0 is the maximum coverage), b) semi-open spatial structure (with a grouped or uniform distribution of plants, with a coverage of 0.5-0.2) and c) an open spatial structure (with a smaller number of plants and coverage of less than 0.2) to determine socio-cultural differences.

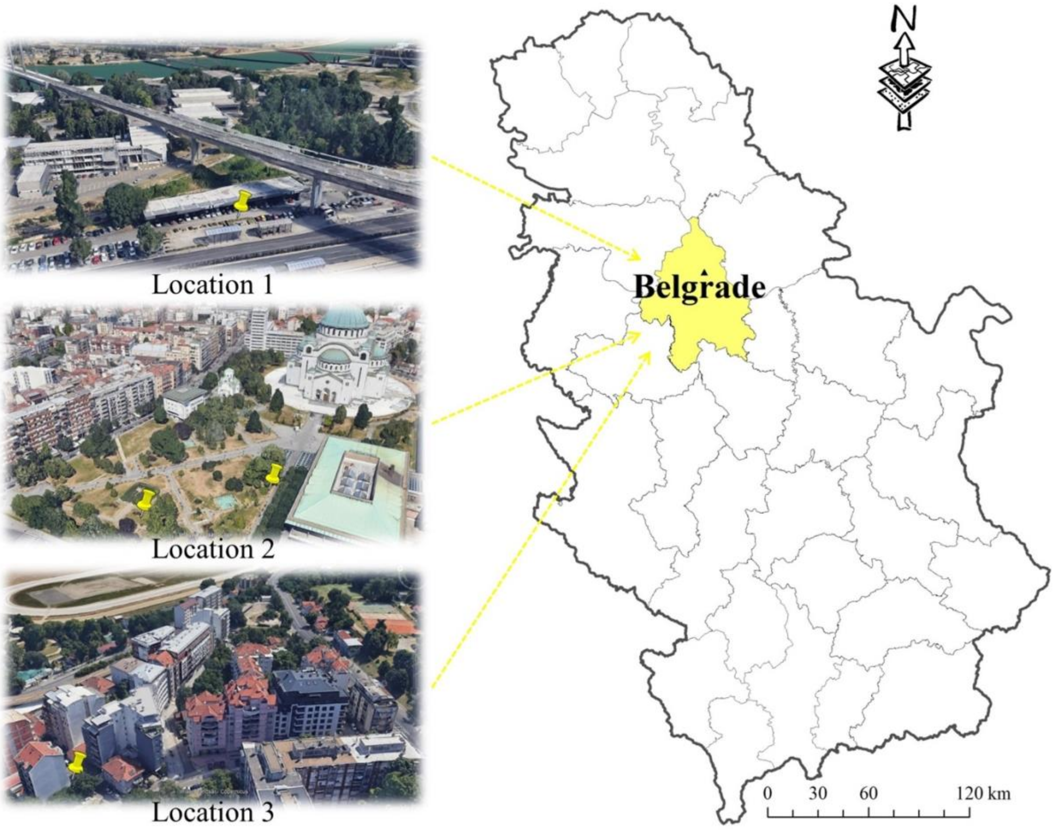

Figure 1. *Study area, Belgrade, Serbia*

Location 1 is along Vojvoda Mišić Boulevard (44º47'47.01"N, 20º26'27.07" Egr, 71 m.a.s.l.), in the "Belgrade Fair" zone. The 13-year-old plants are in plant pots, on unexposed ground. The soil type was not determined because it was not possible to sample the material for analysis. Location 2 is St. Sava’s Park in front of St. Sava temple (44º47'52.34"N, 20º28'01.44" Egr, 128 m.a.s.l.). The 23-year-old plants are in haplic cambisol (eutric) soil type (Škorić et al., 1985), on unexposed terrain. Location 3 is in Mirosavljeva Street on Banovo brdo (44º47'04.24"N, 20º25'16.59" Egr, 87 m.a.s.l.). The 3-year-old plants are located in a northwest-oriented (NW) terrain, on luvic chernozems soil type (Škorić et al., 1985) within the block greenery.

According to the Köppen classification, for the period 1991-2020 (data of the Republic Hydrometeorological Institute - RHMZ), the research area is labeled C(f)wa "Cfa - moderately warm climate with hot summer: moderately warm rainy climate, with hot summer (a), without a particularly dry period (f), with the least precipitation in the winter season (w)". Belgrade, with its local specificities, is located in the zone of moderately continental climate, where the intensity of continentality increases towards

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the northeast. Within such a complex situation is the "košava" wind area, whose characteristics are influenced by the mountains of Serbia, the Carpathians, and part of the border with the Pannonian Plain (RHMZ).

Plant material

The criteria for the selection of plants were: 1) age (young (1-9 years), old (more than 20 years), and middle-aged plants (10-20 years), 2) growth method (trimmed and free-growing) and, 3) location where they grow (planted in open space and in plant pots). The height of the plants was measured with a Vertex V altimeter and the crown diameter with a meter. A visual evaluation of the ornamentality and vitality (*Table 1*) of the selected plants was performed based on biomorphological characteristics: crown density, texture, matching of the size and color of flowers and appearance on the branches, deviations from the texture, drying or appearance of dry branches according to Morozova and Debelay (2018).

Table 1. *Grades of the ornamentality and vitality Weeping Winter Jasmine*

Characteristic Grade	Ornamentality	Vitality
1	Plant without or with a few dry branche	Vital plant of good growth on loose soil
2	Plant in good condition with very few dry branches	Vital plants on compacted soil
3	Plant in good condition	Plant with signs of growth retardation
4	Plant with many dry branches	Plant with clearly visible signs of growth retardation, poor vitality that does not fulfill its purpose
5	Plant with very poor growth, almost completely dry	Diseased plant that poses a threat to neighbors and needs to be removed urgently

The analysis of the flowers included the 1) length of the calyx, 2) the length of the elongated corolla, 3) the diameter of the flowers, 4) the number of lobes, and the 5) number of stamens and pistils. The flowers for analysis were taken from the southern part of the canopy during the period when the plants were in full flowering phenophase. Samples of 50 flowers were taken from each individual and morphometric analysis was performed by software (UTHSCSA Image tool). The total number of collected flower samples is 2,250. Quantitative data were statistically processed using descriptive statistics, ANOVA, and cluster analysis. ANOVA included the analysis of variance within the group of individuals from the same location and the differences between 3 locations for all five floral parts. The morphology was further included in cluster analysis where we research the distinction between the morphological and phenological characteristics of winter jasmine depending on the location.

Phenological and meteorological data

Phenological observations were made visually twice a week on predetermined dates, simultaneously for all plants. The extended BBCH scale (Meier, 1997) was used, and the following were determined: the day of the opening of the flower bud scales (BB, numerical code 01), the beginning of flowering (BF, numerical code 61) - the day when more than 10% of the flowers are open, full flowering (FF, numerical code 65) - the day when more than 50% of flowers are open and end of flowering (EF, numerical code 69)

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- day with less than 10% open flowers in the canopy. Based on the system of digital messages according to Koch et al. (2007), dates were converted to the day of the year (DOY). The specific DOY range is defined by the first (BF) and last observed date of flowering, which began in December 2022 and ended in April 2023. DOYs are therefore expressed on a scale of -31 DOY to 96 DOY, where DOY 1 corresponds to the date January 1st.

Given that temperatures are very important for the beginning of certain phenophases, although other factors can also affect them (Lalić et al., 2021), cold hours (CH) and growing degree days (GDD) were determined. The required number of cold hours (CH) for the opening of the flower buds was determined according to Cosmulescu & Ionescu (2018). According to the mentioned model, CH is noted when the temperature is lower than 7°C and excluding the hours when the temperature is below 0°C. November 1st was taken as the date from which CH is calculated, according to the aforementioned authors and other researchers (Crepinšek et al., 2012), because before the mentioned date the temperatures are too high to contribute to the accumulation of cold hours in the moderate continental climate. Based on phenological observations, CHs were calculated until December 30, 2022. After the opening of flower buds, the sum of growing degree days (GDD) was determined according to Lalić et al. (2021). The elements of this method are daily air temperatures and the sum of effective temperatures, which is an adequate substitute for unknown amounts of received net insolation (Vučetić, 2009). Degree days (DD) are determined based on the maximum (Tmax) and minimum (Tmin) temperature in one day and the temperature threshold (Tt) (Lalić et al., 2021). When Tmin > Tt the following formula is used:

$$DD = \frac{T_{max} + T_{min}}{2} - T_t \qquad \text{(Eq.1)}$$

When Tmax < Tt then DD = 0.

In case Tmax > Tt > Tmin, the following formula was used:

$$DD = \varepsilon\, f(R) \qquad \text{(Eq.2)}$$

Where the coefficient is as follows:

$$\varepsilon = \frac{T_{max} - T_{min}}{2}$$

and

$$R = \frac{T_t - T_{min}}{T_{max} - T_{min}}$$

A temperature threshold of 5°C was used as recommended by WMO (2009) for moderate continental climate conditions. Using the mentioned method for each location, the required GDD of *Jasminum nudiflorum* Lindl. in certain phenophases (from the opening of flower buds to the beginning of flowering, etc.) was determined by a combination of phenological and climatological data. In this study, GDDs were determined by summing the active temperature sums from BB to BF, BF to FF, and FF to EF for each location separately. During the phenological observations, photographic material documenting seasonal changes was also collected. Data obtained from phenological observations were statistically processed using descriptive statistics, and the relationships between temperature and phenological events were determined using

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Spearman's correlation coefficient (ρ) and cluster analysis. The values of the Spearman coefficient (ρ) were used for relation between GDD and DOY. Spearman's correlation coefficient, which determines the strength and direction of correlation between the order of values of statistical variables was applied, whereby it does not matter whether the correlations are linear or non-linear: -1 is complete and negative, -1 to -0.75 very good to excellent and negative, -0.75 to -0.50 moderate and negative, -0.50 to -0.25 weak and negative, -0.25 to 0 slight and negative, 0 no correlation, 0 to 0.25 slight and positive, 0.25 to 0.50 weak and positive, 0.50 to 0.75 moderate and positive, 0.75 to 1 very good to excellent and positive and 1 completely and positive (Horvat and Mioč, 2012).

The cluster analysis was used to take into account all 3 parameters: morphology, phenology and location to determine the distance between observed groups in their appearance. The data were compared with the literature, with each other, and with data from a previous study in which the flowering phenophases of *Jasminum nudiflorum* Lindl. in Belgrade were observed for 16 consecutive years (Ocokoljić et al., 2023).

Taking into account climate changes and high temperatures, the research period was from October 2022 to the end of April 2023, although in the moderately continental climate, the flowering phenophase of Weeping Winter Jasmine should be in the period February-March (Kikuchi et al., 1989). Climate data for the reference period 1991-2020 and 2022/23. are well checked and downloaded from RHMZ https://www.hidmet.gov.rs/index.php (accessed on May 5, 2023) for the Main Meteorological Station Belgrade (44º 47' 54.44"N; 20º 27' 53.35" EGr).

The obtained data were processed in IBM SPSS Statistics 21, XLSTAT 2020, and ArcGIS/ArcMap 10.3 programs.

Results

Type of UGI space and social context

Based on the collected data and field research of UGI elements in the municipalities of Savski venac, Vračar, and Čukarica, the following were distinguished: the greenery of first and second-order roads, parks, and block greenery (*Table 2*). The mentioned areas have the potential as an important blue-green infrastructure (BGI) corridor because they are on the right bank of the Sava River, but the discontinuity of the UGI from the periphery to the city center is evident (*Fig. 2*). Namely, the degree of urbanization increases towards the city center, which, without taking into account the green urban, sports, and recreational areas, amounts to 100% in Vračar municipality, 91.89% in Savski venac, and 25.91% in Čukarica because it also includes the sub-urban zone of Belgrade (https:/ /land.copernicus.eu/local/urban-atlas/urban-atlas-2018, accessed on 6 May 2023).

Table 2. *Overview of UGI elements within the jurisdiction of the PUC "Zelenilo Belgrade" in the municipalities of Vračar, Savski venac, and Čukarica (plan documentation of the PUC "Zelenilo Belgrade")*

UGI type	**Parks**		**Side road greenery**		**Block greenery**		**Number of streets with trees**	**Number of trees in alleys**	**Street length (km)**
Municipality	Number	Area (m^2)	Number	Area (m^2)	Number	Area (m^2)			
Vračar	8	124.315	20	36.536	13	93.333	64	3.329	24
Savski venac	12	353.911	30	290.501	7	233.098	75	6.409	49
Čukarica	3	199.494	11	139.639	26	1.260.027	71	4.950	35

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Figure 2. *Green infrastructure (GI) of research area in Belgrade municipalities (marked elements of UGI are in jurisdiction of PUC "Zelenilo Beograd")*

Location 1 layout: In Savski venac municipality, which has the most streets with trees (75) among the studied municipalities, the total length of which is 49 km, the number of trees is 6,409, and the total area of greenery along the roads is 290,501 m^2. By type, location 1 belongs to open spatial structures with a smaller number of plants. The surface of location 1 area is 967 m^2, and the PUK "Zelenilo Beograd" maintains an area called "Baštice" with a total area of 47 m^2, where plant pots' sizes 1x1 m are set around the monument to Živojin Mišić along Vojvode Mišić Boulevard. In addition to *Platanus* × *acerifolia* (Aiton) Willd. which is lining the street, the studied part has 39 plant pots, in which 35 individuals *Jasminum nudiflorum* Lindl. are planted, which are visually dominant in the cold part of the year. Their average rating of ornamentality and vitality is 2. The height of the plants varies from 0.25 m to 0.74 m, and the crown diameter is 0.80m because all plants are regularly shaped by pruning. Perennials are planted around the monument.

Social context: Location 1 is well-maintained and representative because it is located at the entrance to the harmonized ensemble of exceptional spatial and architectural values "Belgrade Fair" built in the period 1954-1957 (Mišić, 2012). The "Belgrade Fair" covers the area along the right bank of the Sava, from the "Mostar" intersection along Obrenovački Road then, and now Vojvoda Mišić Boulevard. The compositional accent is on the three exhibition pavilions under the domes interconnected by footbridges, which are placed in such a way that they do not block the view of the Sava landscape and the panorama of Belgrade, and with their position they alleviate the shortcomings of the triangular geometry of the narrowing space (Mišić, 2012). The fair complex gained importance in the seventies of the twentieth century with the design of the "Bratstvo i jedinstvo" highway, the construction of the "Gazela" bridge over the Sava and the intersection of the "Mostarska petlja" highway (Mišić, 2012).

Location 2 layout: In the central parts of the city (the municipality of Vračar includes only this zone), parks are the main type of green area. The largest park in the

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municipality of Vračar is Karadjoredje park, which adjoins St. Sava Park. Their total area is 28,132 m^2, of which 18,047 m^2 is covered with vegetation, namely: 17,719 m^2 of lawn, 47 m^2 of flowering species, 34 m^2 of perennials, and 137 m^2 of rose bushes, while 1,010 m^2 is under bushes. There is a total of 9,185 m^2 of sealed soil. Location 2 – St. Sava Park with the National Library, the old and new Sveti Sava temple, their accompanying buildings, and the park, is a semi-open spatial structure with an area of 62,621 m^2. Two groups of three individual species are located in front of the Karadjordje monument, and four plants of *Jasminum nudiflorum* Lindl. form a linear structure that directs the viewer toward the entrance to the new temple. Their average rating of ornamentality is 1 and vitality is 2. Plant heights are from 0.67 m to 0.93 m, and diameters are from 1.10 m to 3.40 m. All plants are free-growing.

Social context: It is especially emphasized that the St. Sava Park with the temple, in front of which it is located, is a legacy of civilization and a historical heritage that is irreplaceable as a place of remembrance, a traditional cultural landscape heritage, and a place of religious values for the expression of worship or belief. These ecosystem services play a key role in protecting cultural and historical heritage and raising awareness of cultural identity and tradition (Bastian et al., 2014). The elements of the landscape, especially in the cold part of the year, the flowering phenophases of *Jasminum nudiflorum* Lindl., ensure the continuity of visual impact and attractiveness without disturbing ethical, spiritual, and religious values (Valles-Planells et al., 2014).

Location 3 layout: Based on the plans and documentation of the PUK “Zelenilo Beograd”, compared to the other two municipalities, Čukarica has a significantly larger area of block greenery (1,260,027 m^2). Therefore, location 3 on Banovo brdo, which is a type of closed spatial structure (both horizontally and vertically), stands out. Along with *Prunus laurocerasus* 'Zabeliana' and *Cornus alba* 'Sibirica', two young free-growing plants of *Jasminum nudiflorum* Lindl. 0.5 m and 0.7 m tall were observed. The diameter is not determined because the plants are attached to the support elements. Their average rating of ornamentality and vitality is 1.

Social context: Field research proved their preferences for an aesthetically pleasing environment and their readiness to pay a high price for living in buildings near parks or attractive green areas for a nice view of the landscape. Research confirms that a sense of place identity, cultural identity and belonging is essential for human beings. The sense of identity affects the improvement and consolidation of social cognition, and also strengthens the recognition of the hometown and community (Depietri, 2022). In general, these feelings are aroused and inspired by the elements of the landscape and the environment.

Morphometric study of the floral structures

This study provides essential information about the morphological elements of flowers and contributes to the knowledge about the acclimatization of *Jasminum nudiflorum* Lindl. (*Fig. 3*): the length of the calyx was between 10.8 mm (Location 2) and 11.2 mm (Location 3), the standard deviations were small, as were the correlation coefficients at all three locations which illustrates low variability. Insignificant differences between locations were confirmed by one-way ANOVA test ($p<0.0001$, $F=0.31$). The dimensions of the corolla are important characteristics of floral decorative plants. The results of the study showed the exceptional length of the corolla tube, which was between 1.59 cm (Location 2) and 1.73 cm (Location 3), as well as the diameter of the saucer-shaped part of the corolla with dimensions between 2.05 cm (Location 2) and

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2.5 cm (Location 3). Low variability is confirmed by low values of standard deviation and coefficients of variation at all locations. Statistically non-significant differences were confirmed by the one-way ANOVA test ($p<0.0001$, $F=5.3$ and $F=4.5$, respectively).

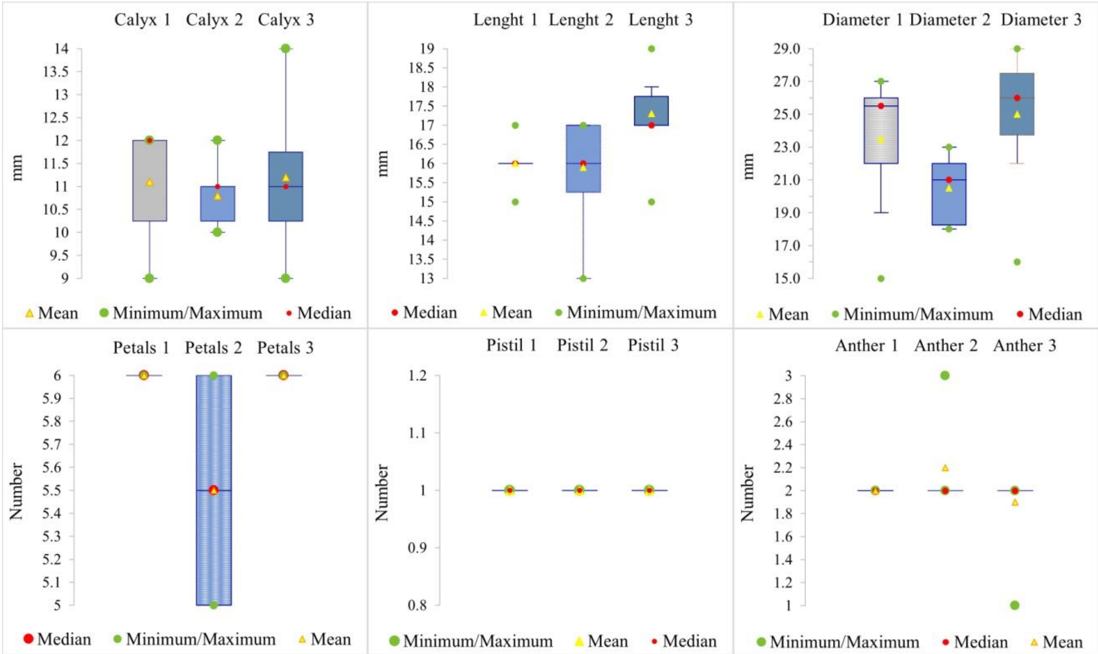

***Figure 3.** Floral morphological and metric characteristics: calyx length (mm), corolla tube length (mm), corolla diamaeter (mm), number of petals, pistils and anthers of Jasminum nudiflorum Lindl. on location 1 (1), location 2 (2) and location 3 (3)*

The number of lobes of the petals of the saucer-shaped corolla was 6 (Locations 1 and 3), while at Location 2, where the plants were trimmed, flowers with both 5 and 6 lobes were recorded. The standard deviation and the coefficient of variation are small, which confirms that there is approximately the same number of flowers with 5 and 6 lobes at Location 2 (one-way ANOVA $F=9$). At all locations, only one pistil was recorded in a flower, while the number of stamens was usually 2, but flowers with 1 or 3 stamens were also recorded. In older plants, flowers with 1 stamen were recorded, so in location 3 the number of stamens was on average 1.9, and in middle-aged and trimmed ones, 2.2. The low frequency of occurrence is confirmed by the low values of standard deviation and correlation coefficients and the non-significant value of F one-way ANOVA of 2.5.

Cold hours requirement (CH), heat requirements (GDD) and the correlation with the days of the year (DOY) and their influence on phenological patterns of flowering phenophase

All woody taxa have specific requirements for the accumulation of cold hours (CH) which are important for exiting the dormancy phase. The maximum biological effect of 1h is obtained according to Cosmulescu and Ionescu (2018) when the temperature is between 0°C and 7°C. The need for CH is variable depending on the taxon and genotype, so according to Luedeling (2012), CH values vary for apples 400-1000 h,

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pears 600-800 h, quinces 300-500 h, apricots 500-600 h, almonds 500-600 h, walnut 600-700 h and sweet chestnut 400-500 h. In this study, the number of accumulated cold hours from November 1st, 2022, until flower bud opening varied from 11 h (location 2), through 281 h (location 1) to 600 h (location 3). To get out of the dormancy phase, young plants had the biggest need for CH, and the oldest plants had the least, with a variation of 589 h. Spearman's correlation coefficients were determined ($p<0.05$), which confirmed the complete positive (1.00) correlations between CH and the number of days from November 1st - BB and the number of days FF-EF and the number of days BF-FF, as well as the maximum negative (- 1.00) correlations of CH and № of days of FF-EF and CH and № of days BF-EF. The analysis indicates that CH increases with an increase in the number of days from November 1st to BB, but also a direct correlation of CH with the number of days from FF to EF, as well as from BF to FF, that is, that CH affects the phenological patterns of flowering. Genotypes that required less CH had a longer FF to EF period and a longer overall flowering phenophase from BF to EF, as well as a greater number of days from FF to EF which are directly correlated with the length of the flowering phenophase (BF-EF). Other correlations were not significant.

Plant growth and development is proportional to accumulated heat units – growth degree day (GDD) which is a measure of heat accumulation above a temperature threshold during 24 hours, rather than daily air temperatures during phenophases (Réaumur, 1735). To determine the GDD from BB to EF, as well as from one to another phenophase of *Jasminum nudiflorum* Lindl. at the three study locations, data from the RHMZ from the Belgrade station were used.

The oldest genotypes (Location 2) required the smallest sum (14.3) for BF (period from BB to BF), the middle-aged ones (Location 1) slightly higher (31.6), and the highest was for young plants at Location 3 (58.7). In the previous study for the period 2007-2022 (Ocokoljić et al., 2023) BF started with 41.8 (*Fig. 4*). Compared to the sixteen-year average, the plants at locations 2 and 1 needed 27.5 and 10.2 less, while at location 3 16.9 more accumulated heat units were required. For all researched plants and locations, on average a sum of 34.9 was needed for BF, which is 6.9 less than the value determined in the previous study (Ocokoljić et al., 2023). For FF (period from BF to FF) the plants at location 3 needed the smallest sum (97.7), the oldest a little more (115.3), and the largest requirement was for plants at location 1 (153.6). In the previous study (Ocokoljić et al., 2023) for the period 2007-2022, FF started with 130.7. Compared to the sixteen-year average, the plants at locations 3 and 2 needed 33.0 and 15.4 less, while at location 1 22.9 more accumulated heat units were needed. For all researched plants and locations, on average 8.7 less sum was needed for FF than determined in the previous study (average 122.2). The oldest genotypes ended flowering phenophase (EF - period FF to EF) with the highest sum (473.1), middle-aged with 450.1, and the youngest with the lowest sum of 333.5. In the study for the period 2007-2022, EF was completed with the sum of 198.4. Compared to the sixteen-year average for all plants, at all locations in this study, less heat was necessary for Location 2 (274.7), Location 1 (251.7) and Location 3 (135.1). For all researched plants and locations, on average a sum of 418.9 was needed for EF, which is 220.5 less than the value determined in the previous study. Data obtained by descriptive statistics confirm that temperature sums initiate flowering, and standard deviations indicate differences between locations. For the comparison of GDD and mean daily air temperatures in *Fig. 4*, during the flowering phenophase of *Jasminum nudiflorum* Lindl. 2022/2023, both values are graphically presented. Statistical analysis of mean daily air temperatures

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and phenological observations revealed that the average value of mean daily air temperatures for the period BF-EF during the period 2007-2022 was 6°C, and during the research 2022/2023 7.2°C (location 1), 6.9° C (location 2) and 6.7°C (location 3). An increase in mean daily temperatures during the flowering phenophase by 0.7-1.2°C is evident, which is associated with a longer flowering phenophase due to climate change (WMO, 2009).

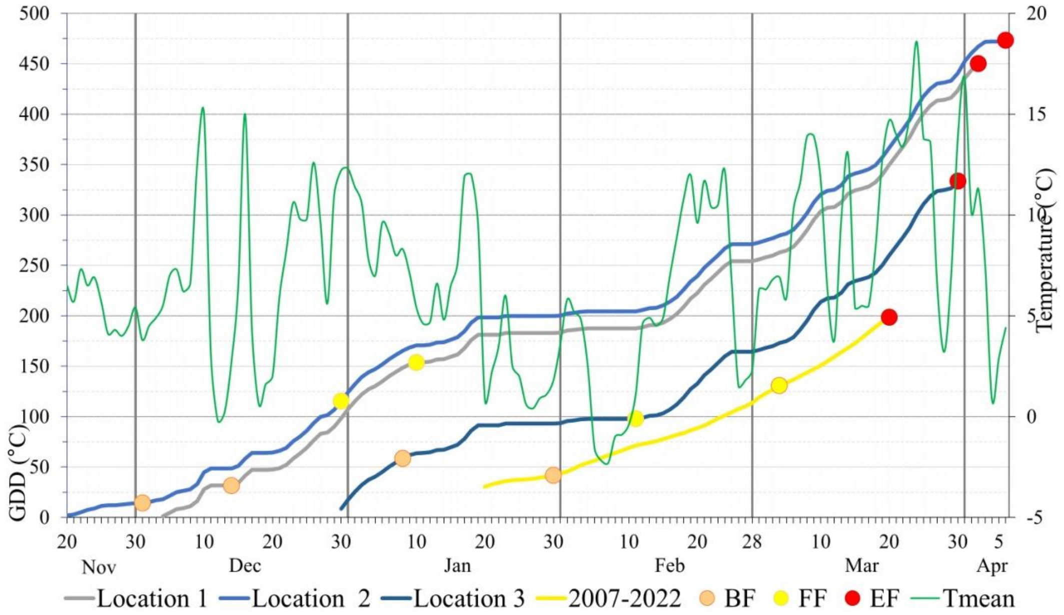

Figure 4. *Graphic representation of mean daily temperatures for autumn/winter 2022 and winter/spring 2023 at the analysed locations and temperature sums of GDD (°C) for the beginning of flowering (BF), full flowering (FF) and the end of flowering (EF) of Weeping Winter Jasmine at the three study locations and average values (°C) for the period 2007-2022 in Belgrade*

Fig. 5 shows the phenogram for Weeping Winter Jasmine at the three analyzed locations during 2022/2023 and for the period 2007-2022. Location 2 stands out with the oldest plants, where the spreading of flower buds was recorded on 28.11.2022, BF on 1.12.2022, and the end of flowering on 06.04.2023. The length of the flowering phenophase was 96 days. In middle-aged plants at Location 1, the spreading of flower buds was recorded on 30.11.2022, BF on 14.12.2022, and the end of flowering on 02.04.2023. The length of the flowering phenophase was 92 days. Young plants at Location 3 (89 days) had the shortest flowering phenophase, in which BB occurred on 25.12.2022, BF on 08.01.2023, and the end of flowering was recorded on 30.03.2023. Nevertheless, when the lengths of the current flowering phenophases are compared with the sixteen-year average value, a significantly longer flowering phenophase is observed at all three locations compared to the multi-year time series in which the length of flowering was 44 days (which is shorter by 52 (Location 2), 48 (Location 1) and 45 days (Location 3)).

Under the influence of climatic variables, the flowering phenophase was not continuous and the damage and wilting of flowers were recorded as well as the formation of new flowers in a few days, which is why two FF maxima were recorded

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during the research at all three locations (*Fig. 5*). Namely, according to the percentile method, the mean daily air temperature at the end of the first decade of February was in the cold category, while at the end of the second and beginning of the third decade, it was warm and very warm (RHMZ). During the research, there were a total of 11 days with snow cover (*Fig. 5*). Plants at locations 1 and 3 completed their flowering phenophase before April, and at location 2 the flowering phenophase was abruptly interrupted by a cold wave with snow. On April 5, a snow cover of 17 cm was recorded, which is the highest measured snow cover in Belgrade during April since 1902 (RHMZ). By analyzing the elements of the phenological patterns for the research period and the previous time series of 16 years, it was determined that the BF shifted more in older compared to young plants, and significantly compared to the previous period. Thus, flowering patterns were not constant but changed according to climatic conditions, so for all plants and all locations in the study period BF started earlier by 44 days (61 (old), 48 (middle), and 22 days (young)), and FF was recorded later by an average of 14 days (17 (elderly), 13 (middle-aged) and 10 days (young)). The decreasing trend of DOY BF confirms the earlier start, and the increasing trend of DOY EF the later end of flowering.

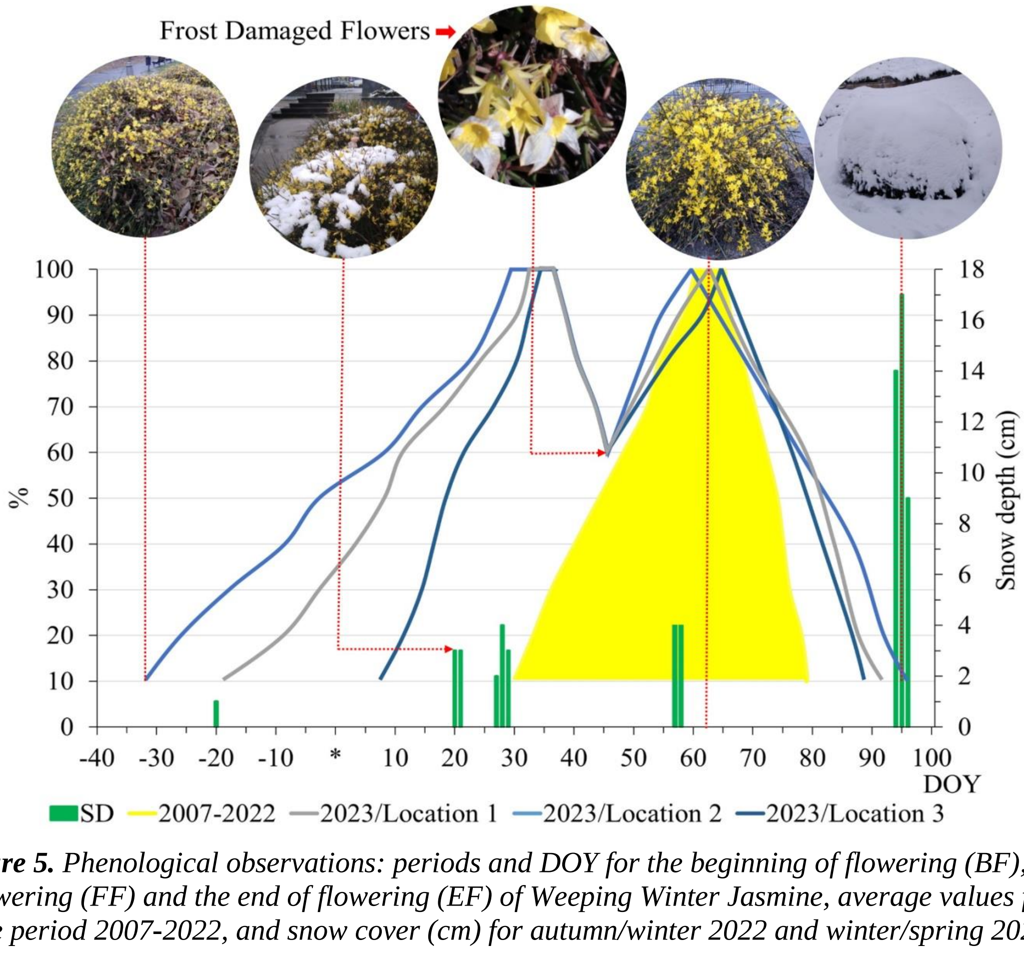

Figure 5. *Phenological observations: periods and DOY for the beginning of flowering (BF), full flowering (FF) and the end of flowering (EF) of Weeping Winter Jasmine, average values for the period 2007-2022, and snow cover (cm) for autumn/winter 2022 and winter/spring 2023*

The values of the Spearman coefficient (ρ) for GDD and DOY, which are determined as the mean values for all locations, for the corresponding periods of the flowering phenophase, as in the previous study (Ocokoljić et al., 2023), are not statistically

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significant ($p<0.05$), that is, they confirm that between GDD and DOY, there is no constantly increasing or constantly decreasing trend, as well as that the days of the year are not significant for the elements of the phenological patterns of flowering. According to Denny et al. (2014) phenophases also vary under the influence of local abiotic and biotic factors, which is why Spearman's correlation coefficients for locations were determined (*Table S1* in Supplementary material), with a probability of $p<0.05$, which confirmed: a) complete positive correlations between L1 FF GDD and L2 FF GDD; L1 EF GDD and L2 EF GDD, as well as L3 EF GDD; L2 EF GDD and L3 EF GDD; L1 BF DOY and L2 BF DOY, as well as L3 BF DOY; L2 BF DOY and L3 BF DOY; L2 FF DOY and L1 FF DOY and L1 EF DOY and L2 EF DOY, as well as L3 EF DOY and b) strong and very strong positive correlations for the following L1 BF GDD and L2 BF GDD, as well as L3 BF GDD; L2 BF GDD and L3 BF GDD; L3 FF GDD and L1 FF GDD, as well as L2 FF GDD; mutual L1, L2 and L3 EF GDD and L1, L2 and L3 EF DOY; mutual L1, L2 and L3 BF DOY and L2 and L3 FF DOY; L3 FF DOY and L1 and L2 FF DOY and L2 EF DOY and L3 EF DOY. Positive correlations were confirmed for the accumulated sums of heat for full and end of flowering for all three locations, which shows that conditions of microlocation and cultivation technology did not affect the sum of heat for the mentioned key events of the flowering phenophase of Weeping Winter Jasmine.Vrlo dobre do izvrsne pozitivne korelacije takodje potvrdjuju navedeno, a izdvaja se korelacija za tri analizirane lokacije da su DOY završetka cvetanja na sve tri lokacije u jakoj korelaciji sa akumulisanim sumama toplote za taj ključni dogadjaj što je potvrda direktnog uticaja klimatskih parametara. Strong to very strong positive correlations also confirm the above, and the correlation for the three analyzed locations stands out, that the DOY of the end of flowering at all three locations is strongly correlated with the accumulated sums of heat for that key event, which indicates the direct influence of climate parameters. The finding corresponds with previous studies by Ocokoljić et al. (2023) and Petrov et al. (2024).

Cluster analysis of morphology and phenology in relation to layout and social context

Cluster analyses were performed based on the research of morphological characteristics of flowers and phenological patterns of flowering and climatic variables at three selected locations (*Fig. 6*).

Based on the morphometric characteristics of *Jasminum nudiflorum* Lindl. flowers, locations 1 and 3 were singled out as a close pair. In the mentioned locations, there are young and the oldest plants of a free-growth. According to the analyzed features of the flowers, location 2 where the plants are in plant pots and regularly shaped by pruning is distant and significantly different. By combining the data for phenological patterns of flowering and climatic variables, the cluster analysis according to the closeness of the features separated locations 1 and 2 as a pair, and location 3 as distant.

Understanding long-term trends is an essential part of managing, mitigating the effects of climate change (*Table S2* in Supplemantary material) through phenology. From the phenological point of view, the main adaptation is the prolonged vegetation period, a delay in autumn and an earlier appearance of spring phenophases (Bertin, 2008).

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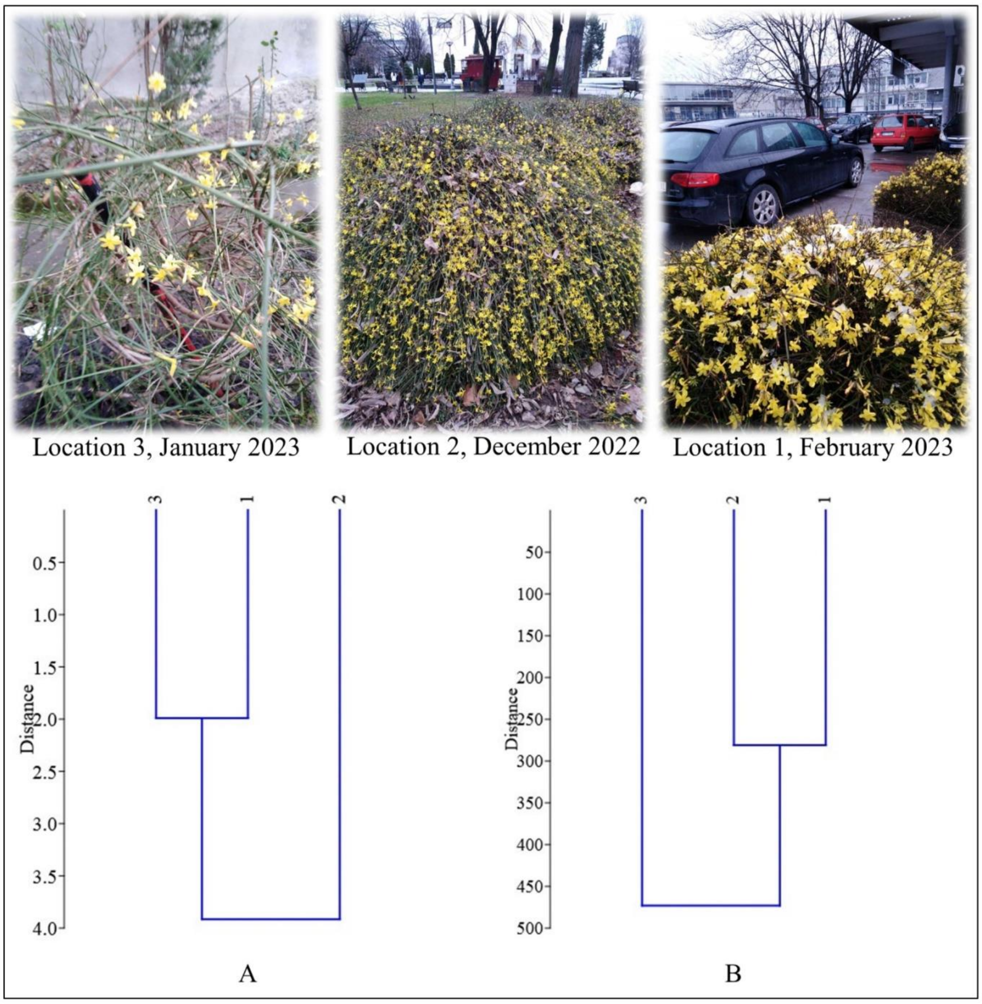

Figure 6. *Cluster analysis for the elements of UGI in Belgrade: A/based on morphometric characteristics of flowers and B/based on phenological flowering patterns and climatic variables Weeping Winter Jasmine with photographic material*

Discussion

Jasminum nudiflorum Lindl. is a non-native species that was introduced to Europe in the 1840s from China (Ocokoljić and Petrov, 2022). Weeping Winter Jasmine blooms during the cold part of the year, when a small number of taxa in UGI Belgrade are in this phenophase. As their flowering is a crucial element of winter aesthetics, the metric and morphological characteristics of these flowers were the focus of the study. Moreover, recent research trends are shifting their focus towards the ecology of specific parts of the plants and their characteristics rather than the ecology of the species (Messier et al., 2010). This brings the floral elements to the spotlight of the research as their role is significant both in landscape planning and for other ecosystem services (conservational and ecological).

The population-level observation revealed significantly larger calyx lengths compared to the findings of Kikuchi et al. (1989), who reported a calyx length variation range of 3 to 8 mm. However, the recorded lengths of the corolla tube and the number of petal lobes fell within the ranges reported in the same study. Additionally, the

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diameter measurements were notably larger, ranging between 0.8 and 1.3 cm according to the authors. The increased size of the calyx enhances the aesthetic appeal of the landscape and can be considered advantageous in terms of design. These findings validate the role of *Jasminum nudiflorum* Lindl. in urban green infrastructure (UGI) amidst climate change, as it contributes to maintaining the landscape's architectural values. This species enables the creation of vibrant and cascading effects at the end of autumn, throughout winter, and at the onset of spring. The enlarged calyx size adds further value, as the species serves as a valuable food source for birds, as noted by Kikuchi et al. (1989) and Ocokoljić et al. (2023).

The diversity within the species is widely recognized as essential for conservation research (Kapeller et al., 2012; Leites et al., 2012; Rodríguez-Quilón et al., 2019). Therefore, we conducted a comparison of three locations based on the morphology of the flowers. However, the variation observed among the three locations was similar, with no distinct group standing out in terms of floral elements or the overall flower morphology. These variations within the species play a crucial role in the dynamics and structure of the population (Bolnick et al., 2003; Clark and McLachlan, 2003; Clark, 2005), making such analyses significant for ecology. Our findings are important not only for architects and urban planners but also for biodiversity and ecosystem conservation (Garnier-Géré and Ades, 2001).

Another characteristic that demonstrates a species' ability to thrive in urban environments is its adaptability to climate change. Shifts in species phenology serve as compelling evidence of climate change. These changes can be examined by assessing the species' requirements for cold hours (CH), growing degree days (GDD), and day of year (DOY) when phenological events occur. While these measurements are interconnected, their relationship reflects the dependency of phenology on meteorological factors. Our findings align with research by Charrier et al. (2011) conducted in France, which indicates that average CH varies significantly among genotypes. This highlights the importance of individual research, revealing that *Jasminum nudiflorum* Lindl. exhibits different CH requirements at various ages for initiating the flowering phenophase. The onset of flowering is contingent upon the specific requirements of each individual and taxon for CH (Cosmulescu and Ionescu, 2018) and GDD post-dormancy (Ocokoljić et al., 2023). Early bud development following the accumulation of necessary CH increases susceptibility to damage from subsequent climatic events (Egea et al., 2003). Information on CH and GDD requirements for ornamental woody plants is scarce but crucial for designing and sustaining urban green infrastructure (UGI) elements featuring floral decorative taxa whose ornamental period is influenced by CH requirements. Winter jasmine exhibits distinct GDD requirements compared to CH requirements, consistent with literature indicating the significant influence of urban heat islands (UHI), habitat conditions, and plant age on the flowering phenophase GDD (Mohajerani et al., 2017; Ocokoljić and Petrov, 2022), unlike CH. Acclimatization is influenced by environmental conditions, with genotype playing a significant role relative to plant age (Charrier et al., 2011). Another study by Lalić et al. (2021) underscores the value of combining phenological and meteorological data to elucidate variations in phenophases, which can span several weeks, as observed in our data. There was no correlation between GDD and DOY, indicating that the day of the year is not a significant parameter for the phenological patterns of flowering; instead, cold hours and growing degree days play more crucial roles.

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Merely examining the biological characteristics of *Jasminum nudiflorum* Lindl. in the urban green infrastructure under climate change conditions is insufficient for a comprehensive discussion of its role. While its biological traits are significant, particularly in terms of providing food and shelter for native animal species, it is equally crucial to consider the species' cultural significance and its impact on public perceptions within urban settings. To holistically understand the species' role, we conducted a cluster analysis to integrate all three characteristics. By analyzing both morphology and phenology across various layouts and social contexts in which *Jasminum nudiflorum* Lindl. is present in the urban green infrastructure of Belgrade, we determined the influence of climate change and other variables on the additional ecosystem services provided by Weeping Winter Jasmine. In the realm of ecosystem services, ecological functions are often considered essential for facilitating their provision, with the principle of multiple functionalities guiding the development of a network of green spaces that collectively offer diverse social and economic benefits (Bastian, 2012).

Advocating for a comprehensive understanding of Urban Green Infrastructure (UGI) and its advantages necessitates a multifaceted approach, as outlined by Wallace (2007) and James et al. (2009). This approach entails: 1) examining UGI components, such as Weeping Winter Jasmine, and their spatial and functional interconnections across various scales within the city, considering their capacity to offer specific functions or services (ecological dimension), 2) conducting an integrated evaluation of both ecological and social dimensions, including identifying synergies and conflicts among different functions or services, and 3) organizing functions and services spatially and temporally within the same area to foster synergy. To ascertain the scope of additional ecosystem services within Belgrade's UGI, featuring Weeping Winter Jasmine, an approach tailored to the local context that incorporates interrelations is indispensable (Reyers, 2013).

Given that location 3 lies in Belgrade's central area, designated as an Urban Heat Island (UHI) with the highest level of urbanization, any phenological changes observed there would serve as a distinct indication of climate change (Jochner and Menzel, 2015). The temperature rise indicated in the findings aligns with Robeson's (2002) assertion that warming is more pronounced than the global annual average across different seasons, particularly over land. However, the analyses reveal a shift in the phenological flowering patterns of *Jasminum nudiflorum* Lindl. during 2022/2023, with all individuals, irrespective of age and other environmental factors, exhibiting a consistent shift, confirming their resilience, specifically to UHI.

The study recommends incorporating Winter jasmine in closed, open, and semi-open areas of UGI, as they provide additional ecosystem services during the colder months. The morphology and phenology of flowering taxa are closely tied to assessing the quality of green infrastructure, especially during winter when most species have concluded their vegetation season. Numerous authors highlight the importance of economic evaluations of green infrastructures (GIs) in informing landscape planning and management in urban areas (Vandermeulen et al., 2011; Mell et al., 2016), emphasizing that the composition and design of GIs influence the willingness of the population to pay more (Mell et al., 2013). Additionally, Bluestein-Livnon et al. (2023) highlight that, for urban residents, the degree of greenery, as indicated by economic characteristics, significantly impacts satisfaction levels and enhances overall quality of life in cities.

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Numerous studies typically consider the natural habitat range of species when recommending them for landscape design, often overlooking their significance in urban environments. Urban species' native status holds various meanings for people, including a sense of identity, belonging, familiarity, and cultural and political identity (Kaplan et al., 2023). To grasp the full social importance of urban greenery and its impact on people's experiences of Urban Green Infrastructure (UGI), we conducted an analysis of each location based on the specific context and type of UGI.

Location 1, situated within the Belgrade Fair (Savski venac municipality), showcases a diverse range of ornamental resources aimed at showcasing the cultural landscape of distinctive architecture and modern city landmarks to visitors. These features encompass elements of the landscape and built environment, each carrying different values that contribute to the ecosystem or landscape experience (Depietri, 2022). This approach aligns with the principles of sustainable development, emphasizing eco-environmental protection, harmonious relationship coordination, support for eco-education and ecological knowledge, and psychological satisfaction through a humanistic ecological system and environmentally acceptable practices (European Commission, 2022).

Location 2, surrounding St. Sava's Temple (Vračar municipality), serves as a significant landmark known for its pleasant environment and aesthetics, which play a crucial role in mitigating the adverse impacts of urbanization. The ecological and aesthetic values of this area are intertwined with the economic benefits that greenery brings to the city. Various studies (Gatrell and Jensen, 2002; Doick et al., 2009; Song et al., 2018; Li et al., 2020; Ai and Zhou, 2023) have focused on evaluating the economic value of urban green spaces and trees, contributing to the assessment of urban economic development, crucial for decision-makers. Field observations confirm that St. Sava Park attracts residents and tourists of all ages due to its well-maintained appearance and strategic location in front of the temple, enhancing its ornamental value through vegetation. The addition of fountains, aligning with the concept of integrating blue and green infrastructure (Pochodyła et al., 2021), would further enhance the park's value as a UGI element, embodying various landscape services outlined by Costanza et al. (2017), including provisioning, regulating, supporting, habitat, and cultural services.

Location 3, representing block greenery in the Čukarica municipality, exemplifies how the attractiveness, diversity, beauty, or uniqueness of UGI elements—such as block greenery—add value by providing users with enjoyment and a sense of identity (European Commission, 2022). In numerous regions, residential units with aesthetically pleasing block greenery command higher prices than similar units lacking such features (Supuka, 2018).

The perception and duration of the flowering phase of Winter Jasmine vary significantly across different locations, each serving diverse purposes depending on the primary function within its respective setting. In the first location, it serves to accentuate the composition of Belgrade's iconic landmark, the "Belgrade Fair," frequented by numerous tourists and business professionals year-round, providing an ideal backdrop for exhibitions and events. Conversely, in location 2, the majestic temple is complemented by surrounding greenery, where Winter Jasmine's prolonged flowering phase and prominent blooms create a natural ambiance, showcasing the temple's splendor while harmonizing with the surrounding environment. In the third location, Winter Jasmine caters to the needs of residents, fostering a sense of tranquility and

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belonging. Its extended flowering period attracts pollinators, contributing to ecosystem balance and aesthetic appeal.

The suitability of urban greenery cannot be solely determined by its biological characteristics or whether the species is native or non-native; instead, it should be evaluated within diverse urban environmental and cultural contexts. The selection of urban species should align with multiple ecological and social objectives, aiming to maintain a balance between requirements and ecosystem services that consider both the environment and human needs (Kaplan et al., 2023). The objective of urban greening is to enhance and expand Urban Green Infrastructure (UGI) in cities, offering environmental, individual, social, and cultural benefits (De Kleyn et al., 2019). Adopting such a systematic approach will enhance understanding of the fundamental values that UGI contributes to biodiversity conservation and user needs management (Manfredo et al., 2017).

Conclusions

The research findings confirmed that Weeping Winter Jasmine exhibited responses to changes in climate variables. However, these responses to temperature increases varied, sometimes exceeding and other times falling short of expectations based on the previous sixteen-year data series. Such variability may indicate non-linear reactions, taxon-specific thresholds, and the cumulative impacts of temperature, highlighting the necessity for understanding extreme climate events to accurately project the potential consequences of climate change on UGI elements and additional ecosystem services. Moreover, urban heat island (UHI) effects did not affect morphology. The largest flowers were observed on the oldest, free-growing specimens in an open spatial structure, with consistent abundance across different ages, maintenance levels, and layouts, with insignificant differences between locations. The degree of urbanization emerged as a significant factor influencing floral morphology, with larger flowers found in the city center. However, layout did not affect appearance or ecosystem services. Layout did, however, contribute to phenological differences, with species in closed spatial structures exhibiting the shortest flowering phenophases. Overall, the ecological characteristics of Winter Jasmine hold varying significance and roles depending on social context and location. Its adaptability to climate change is evident across all contexts, despite variations in UGI layout and individual ecological traits. These findings underscore the importance of the social dimension of urban greenery, alongside its conservation and biodiversity significance.

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APPENDIX

Table S1. *Spearman correlation coefficients for DOY and GDD of Weeping Winter Jasmine, in the period 2007-2023, in the study area*

	*L 1 BF GDD	*L 2 BF GDD	*L 3 BF GDD	L 1 FF GDD	L 2 FF GDD	L 3 FF GDD	L 1 EF GDD	L 2 EF GDD	L 3 EF GDD	L 1 BF DOY	L 2 BF DOY	L 3 BF DOY	L 1 FF DOY	L 2 FF DOY	L 3 FF DOY	L 1 EF DOY	L 2 EF DOY	L 3 EF DOY
L 1 BF GDD		0.95	0.95	0.48	0.48	0.49	0.10	0.10	0.10	0.51	0.51	0.52	0.58	0.58	0.60	0.06	0.04	0.09
L 2 BF GDD	0.95		0.81	0.33	0.33	0.37	-0.01	-0.01	-0.01	0.59	0.59	0.58	0.66	0.66	0.58	-0.04	-0.07	0.00
L 3 BF GDD	0.95	0.81		0.58	0.58	0.56	0.28	0.28	0.28	0.39	0.39	0.41	0.47	0.47	0.57	0.22	0.22	0.23
L 1 FF GDD	0.48	0.33	0.58		1.00	0.99	-0.01	-0.01	-0.01	-0.06	-0.06	-0.06	0.40	0.40	0.57	0.03	0.05	0.02
L 2 FF GDD	0.48	0.33	0.58	1.00		0.99	-0.01	-0.01	-0.01	-0.06	-0.06	-0.06	0.40	0.40	0.57	0.03	0.05	0.02
L 3 FF GDD	0.49	0.37	0.56	0.99	0.99		-0.07	-0.07	-0.07	-0.04	-0.04	-0.04	0.45	0.45	0.59	-0.02	0.00	-0.02
L 1 EF GDD	0.10	-0.01	0.28	-0.01	-0.01	-0.07		1.00	1.00	0.23	0.23	0.26	0.03	0.03	0.17	0.80	0.81	0.79
L 2 EF GDD	0.10	-0.01	0.28	-0.01	-0.01	-0.07	1.00		1.00	0.23	0.23	0.26	0.03	0.03	0.17	0.80	0.81	0.79
L 3 EF GDD	0.10	-0.01	0.28	-0.01	-0.01	-0.07	1.00	1.00		0.23	0.23	0.26	0.03	0.03	0.17	0.80	0.81	0.79
L 1 BF DOY	0.51	0.59	0.39	-0.06	-0.06	-0.04	0.23	0.23	0.23		1.00	1.00	0.79	0.79	0.71	0.44	0.40	0.48
L 2 BF DOY	0.51	0.59	0.39	-0.06	-0.06	-0.04	0.23	0.23	0.23	1.00		1.00	0.79	0.79	0.71	0.44	0.40	0.48
L 3 BF DOY	0.52	0.58	0.41	-0.06	-0.06	-0.04	0.26	0.26	0.26	1.00	1.00		0.76	0.76	0.70	0.46	0.42	0.49
L 1 FF DOY	0.58	0.66	0.47	0.40	0.40	0.45	0.03	0.03	0.03	0.79	0.79	0.76		1.00	0.95	0.32	0.28	0.36

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	*L 1 BF GDD	*L 2 BF GDD	*L 3 BF GDD	L 1 FF GDD	L 2 FF GDD	L 3 FF GDD	L 1 EF GDD	L 2 EF GDD	L 3 EF GDD	L 1 BF DOY	L 2 BF DOY	L 3 BF DOY	L 1 FF DOY	L 2 FF DOY	L 3 FF DOY	L 1 EF DOY	L 2 EF DOY	L 3 EF DOY
L 2 FF DOY	0.58	0.66	0.47	0.40	0.40	0.45	0.03	0.03	0.03	0.79	0.79	0.76	1.00		0.95	0.32	0.28	0.36
L 3 FF DOY	0.60	0.58	0.57	0.57	0.57	0.59	0.17	0.17	0.17	0.71	0.71	0.70	0.95	0.95		0.47	0.44	0.49
L 1 EF DOY	0.06	-0.04	0.22	0.03	0.03	-0.02	0.80	0.80	0.80	0.44	0.44	0.46	0.32	0.32	0.47		1.00	1.00
L 2 EF DOY	0.04	-0.07	0.22	0.05	0.05	0.00	0.81	0.81	0.81	0.40	0.40	0.42	0.28	0.28	0.44	1.00		0.99
L 3 EF DOY	0.09	0.00	0.23	0.02	0.02	-0.02	0.79	0.79	0.79	0.48	0.48	0.49	0.36	0.36	0.49	1.00	0.99	

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Table S2. *Climate variables for 2021, 2022, 2023, and the referential period 1991-2020, for meteorological station Belgrade (RHMZ)*

Mean air temperatures (°C)													
Months Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	$\bar{x}$
$\bar{x}_{2023}$	5.7	4.8	10.1	11.2	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	2.4	6.8	7.1	12.3	20.3	24.8	25.8	25.0	18.0	15.5	9.3	7.0	**14.5**
$\bar{x}_{2021}$	4.3	6.5	7.2	10.6	17.4	24.3	26.6	24.0	19.4	11.7	8.9	4.1	**13.8**
$\bar{x}_{91/2020}$	1.9	3.8	8.3	13.6	18.2	21.9	23.8	23.8	18.5	13.3	8.1	3.0	**13.2**
Mean maximum air temperature (°C)													
$\bar{x}_{2023}$	9.0	9.5	15.5	16.2	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	6.2	11.8	12.2	17.9	26.1	30.2	31.7	30.8	23.6	21.5	13.0	11.2	**19.7**
$\bar{x}_{2021}$	7.4	11.5	11.9	15.8	23.1	29.6	32.3	29.7	25.6	16.9	13.1	6.8	**18.6**
$\bar{x}_{91/2020}$	5.2	7.8	13.1	18.8	23.6	27.1	29.3	29.7	24.3	18.7	12.2	6.1	**18.0**
Mean maximum air temperature (°C)													
$\bar{x}_{2023}$	3.7	1.4	5.6	7.3	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	-0.4	3.4	2.2	6.9	14.4	18.9	19.5	19.7	14.2	11.2	6.7	4.2	**10.1**
$\bar{x}_{2021}$	2.0	2.4	2.8	5.9	12.6	18.0	21.1	18.5	14.4	8.4	6.0	1.9	**9.5**
$\bar{x}_{91/2020}$	-0.7	0.6	4.2	8.8	13.2	16.7	18.4	18.5	14.1	9.4	5.1	0.5	**9.1**
Mean relative humidity (%)													
$\bar{x}_{2023}$	80.0	68.6	59.3	65.4	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	76.1	67.8	55.2	62.0	52.1	55.3	50.5	62.9	74.7	72.5	84.7	74.8	**65.7**
$\bar{x}_{2021}$	68.6	34.4	49.3	50.7	93.4	34.2	63.1	38.2	9.4	73.4	122.8	157.8	**795.3**
$\bar{x}_{91/2020}$	78.4	72.0	63.5	60.5	62.3	62.8	60.2	59.9	66.2	71.8	75.7	79.9	**67.8**
Sums and mean precipitation sums (mm)													
Period	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Σ**
2023	79.3	62.9	37.6	79.0	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	45.7	22.2	10.5	80.1	32.2	43.3	63.9	89.7	98.0	13.1	64.9	76.1	**639.7**
$\bar{x}_{2021}$													
$\bar{x}_{91/2020}$	47.9	43.5	48.7	51.5	72.3	95.6	66.6	55.1	58.6	54.8	49.6	54.8	**698.8**
Sums and mean of sunshine duration (h)													
2023	77.6	145.6	188.2	168.9	-	-	-	-	-	-	-	-	-
$\bar{x}_{2022}$	123.2	133.0	217.3	213.7	290.4	324.3	339.3	257.0	172.6	205.4	73.8	88.2	**2438.2**
$\bar{x}_{2021}$	76.6	130.1	179.1	187.9	264.6	326.3	320.0	286.4	225.3	173.8	120.7	50.8	**2341.6**
$\bar{x}_{91/2020}$	78.6	106.9	163.0	200.0	240.7	272.0	298.7	281.3	206.4	166.1	102.3	67.0	**2183.1**

Sums and average number of days with precipitation ≥ 0.1 mm													
2023	16	11	10	15	-	-	-	-	-	-	-	-	**-**
$\bar{x}$ **2022**	9	11	6	15	6	6	4	10	15	5	13	15	**115**
$\bar{x}$ **2021**	19	7	11	15	13	9	6	7	7	13	15	18	**140**
$\bar{x}$ **91/2020**	13.5	12.3	11.3	12.4	13.5	12.2	10.0	8.4	9.5	10.5	10.8	13.8	**138.3**

Sums and average number of days with precipitation >1.0 mm													
2023	13	7	8	12	-	-	-	-	-	-	-	-	**-**
$\bar{x}$ **2022**	8	7	3	12	5	4	2	8	10	2	10	10	**81**
$\bar{x}$ **2021**	13	5	9	10	8	6	5	6	5	10	10	15	**102**
$\bar{x}$ **91/2020**	8.0	7.0	7.4	8.0	9.4	9.4	6.6	6.3	6.8	6.8	7.0	8.2	**91.0**

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