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DOI: **10.5937/greenb26053M**
Research paper

URBAN LANDSCAPE EVAPOTRANSPIRATION IN THE CITY OF NIŠ

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Abstract

Rapid urbanization and climate uncertainty, caused by climate change, present cities with new environmental challenges. Urban landscapes are recognized as one of the measures for mitigating the adverse environmental issues, caused by rapid urbanization, as well as for improving urban sustainability. A heterogeneous urban environment has complex microclimatic conditions, which can lead to pronounced water requirements for urban landscapes. Such water requirements can vary due to different vegetation types, the influence of buildings and water management. Evapotranspiration is a key element for the optimal estimation of plant water requirements, because it links water and energy cycles, i.e. urban evapotranspiration controls the hydrological performance of urban green areas.

The aim of the paper is to analyze landscape evapotranspiration (ET_L) in the urban conditions of the city of Niš, Serbia, during the period of 2022-2024. The Water Use Classifications of Landscape Species (WUCOLS) approach was used to estimate ET_L, for the crop growing season. The results show that the maximum ET_L value was in July 2022, while the minimum ET_L was in April 2023, with average daily values of 3.703 mm day^{-1} and 0.911 mm day^{-1}, respectively. This approach provides the necessary data for sustainable water management and improved water use efficiency in urban areas.

Key words: *landscape evapotranspiration, WUCOLS, Niš, Serbia*

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1. INTRODUCTION

Urbanization is a complex process in which a rural environment is transformed into an urban one. This process occurs through functional environmental changes, characterized by pronounced structural and morphological transformations. Sustainable urban development implies the construction of diverse structures and green spaces. Urban vegetation mimics natural green areas and represents a strategy for combating urban vulnerability. Owing to its great cooling potential, green infrastructure is a primary adaptation measure for climate change in urban areas. In order to enable the most effective development of green infrastructure, it is necessary to apply an integral approach to water management.

Sustainable water management requires a better understanding of water requirements for the purpose of preventing environmental risks and increasing water use efficiency, especially in urban conditions [1]. Water conservation in urban areas is vital, due to limited water resources, rising temperatures, droughts and population growth. Therefore, it is necessary to develop strategies that combine the efficiency of water use with minimal plant water requirements.

Precise calculations of water demands are essential since drinking water is often used for irrigation, and since over-irrigation frequently occurs in private urban landscapes [2,3]. Urban water requirements are similar to those in agriculture, but they are modified according to the specificities of vegetation in the green infrastructure. In terms of the water quantity, there are two main differences between agricultural crops and landscape species [4]: the characteristics of urban landscape ecosystems (heterogeneity, small yards, vegetation types, impact of structures and microclimatic conditions) and irrigation objectives (agriculture focuses on the production of high-quality crop yields, whereas urban areas prioritize plant aesthetics and health).

Optimal irrigation efficiency of urban vegetation can be achieved through a reliable estimation of landscape evapotranspiration [5]. According to [6], the measurement and modeling of evapotranspiration represents a challenge in urban areas due to heterogeneous vegetation and surrounding structures. There are numerous papers in which urban landscape evapotranspiration was analyzed [5,7,8,9,10]. A detailed review of different studies on measuring the water requirements of urban landscapes is presented by Nouri et al. (2013) [5]. The authors concluded that the Water Use Classifications of Landscape Species (WUCOLS) method is a practical approach for initially estimating the urban landscape water demand, but emphasized that it should be further refined. The health and aesthetic condition of the vegetation should be the main criterion for further improvement. Furthermore, the authors recommended calibrating the WUCOLS method with the soil water balance method.

Two approaches, i.e. the WUCOLS and the Landscape Irrigation Management Program (LIMP), were investigated by Shojaei et al. (2018) [10] to measure the water demand of a botanic garden and a sparse forest park. Comparative results showed that the annual water requirements estimated by WUCOLS were 5% lower for the garden and 44% lower for the park than those calculated by LIMP. Moreover, the results revealed that water savings for irrigation can be achieved by applying the LIMP method.

The paper presents an analysis of landscape evapotranspiration (ET_L) for an urban area. The landscape evapotranspiration is defined as the product of reference evapotranspiration (ET_0) and the landscape coefficient (K_L).

2. MATERIALS AND METHODS

2.1. Study area and data

The study focuses on the urban part of Niš (Serbia). The city of Niš is located in the southeastern part of Serbia. The climate in this region is humid subtropical with continental influences (moderately hot summers and cold winters). The wettest month is June, while the driest month is February. The average annual precipitation is approximately 600 mm. Precipitation is slightly more concentrated during late spring and early summer than in other seasons. The average air temperature is approximately 11 °C and the sunniest month is August, while the cloudiest one is December. The average daily temperature in August is 29.8 °C and the average insolation is approximately 300 hours per month.

The data used for this study were collected from an automatic weather station located in the urban area of Niš (43°19' N, 21°56' E and 197.2 m a.s.l.). The weather station is equipped with several sensors for: air temperature and relative humidity (HC2S3-L, Campbell Scientific), wind monitor (05103-5 RM Young, Campbell Scientific) and pyranometer (CS300-L, Campbell Scientific). The datalogger (CR1000, Campbell Scientific) was used for data acquisition and control of the entire automatic weather station. Daily data were used in the study and the analyzed time period covers 2022 (July-September) and the crop growing period for 2023 and 2024.

2.2. Water use classifications of landscape species method

The Water Use Classifications of Landscape Species method was developed to estimate urban landscape evapotranspiration, while maintaining an acceptable appearance and health of the plants [11]. This approach is based on the Landscape Coefficient Method to determine the water requirements of urban landscapes. According to the WUCOLS, urban landscape evapotranspiration can be calculated using the following equation:

$$ET_L = K_L ET_0 \quad (1)$$

where:

ET_L – landscape evapotranspiration [mm day^{-1}]
K_L – landscape coefficient
ET_0 – reference evapotranspiration [mm day^{-1}]

The landscape coefficient includes three main factors that determine the evapotranspiration of heterogeneous vegetation, which usually characterizes urban landscapes, i.e. the species factor, the density factor and the microclimate factor:

$$K_L = k_s k_d k_{mc} \quad (2)$$

where:

k_s – species factor

k_d – density factor

k_{mc} – microclimate factor

The k_s factor accounts for the differences in a species' water requirements. What is more, WUCOLS provides a list of estimated water requirements for over 4000 urban species, which are classified into four categories, such as high, moderate, low and very low. This classification is based on the studies of water use for different landscape species, rather than the vegetation type (groundcover, shrub, tree, etc.).

k_d accounts for variations in vegetation density across different urban landscapes. Vegetation density is defined by the collective leaf area of all plants. The k_d factor is assigned average values when the tree canopy cover is greater than 70% (for shrubs, it is 90%). This classification is based on orchard studies, which demonstrated that water loss from orchards did not increase when the canopy cover increased from 70% to 100% [11]. However, if the canopy cover falls below 70%, water loss is reduced (there is a significant portion of bare soil, which directly receives solar radiation).

k_{mc} refers to the microclimate conditions in the urban environment. The microclimate of urban areas is distinct due to the influence of buildings, streets, pavements, etc. on temperature, wind and solar radiation; thus, k_{mc} accounts for the impact of all climate parameters.

2.3. Reference evapotranspiration

The FAO 56 Penman-Monteith equation was used for the determination of reference evapotranspiration [12]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (3)$$

where:

ET_0 – reference evapotranspiration [mm day^{-1}]

R_n – net radiation at the crop surface [MJ m^{-2} day^{-1}]

G – soil heat flux density [MJ m^{-2} day^{-1}]

T – air temperature at 2 m height [°C]

U_2 – wind speed at 2 m height [m s^{-1}]

e_s – saturation vapour pressure [kPa]

e_a – actual vapour pressure [kPa]

e_s-e_a – saturation vapour pressure deficit [kPa]

Δ – slope vapour pressure curve [kPa °C^{-1}]

γ – psychrometric constant [kPa °C^{-1}]

3. RESULTS AND DISCUSSION

3.1. Water use classifications of landscape species coefficients

The values of the species factor are determined according to the water requirement recommendations for the different species, given in the WUCOLS methodology [11]. k_s is defined for each vegetation cover, and the final values are then calculated by weighting according to the corresponding area, Table 1. Owing to the changes in the vegetation cover area during the analyzed period, the monthly factor is determined as the average value for each month of the growing period across the study years and the observed area. The corresponding species areas for each month are determined via on-site observations. Trifolium repens has the highest value of the k_s factor and is the most prevalent species, which accounts for approximately 50% of the vegetation in the study area. Rosmarinus officinalis has the lowest k_s value (0.2) and occupies approximately 2% of the vegetation.

Table 1. List of the common plants at the study area and assigned species factors (Gc – groundcover, S – shrub, P – perennial, V – vine, T - tree)

Species	Plant type	k_s
Trifolium repens	Gc	0.7
Buxus sempervirens	S	0.4
Rosmarinus officinalis	S/P	0.2
Melissa officinalis	P/Gc	0.5
Vinca major variegata	Gc	0.4
Rosa	S	0.4
Malus domestica	T	0.4
Vitis vinifera cardinal	V	0.3

The k_d values are defined according to species density (percentage share). In this context, it is important to highlight that study area is covered by vegetation, including groundcovers, shrubs, perennials, vines and trees. The percentage share of plants is determined through field observations. Furthermore, plant density was not the only parameter for defining k_d. In fact, ground coverage by tree canopy and leaves played a significant role, exerting a direct impact on the assigned k_d values on monthly basis. Foliage development in deciduous plants was specifically taken into account during the crop growing period. A comprehensive survey of the study area reveals that the vegetation is divided into two layers, which are complemented and provide full groundcover. The first layer consists of groundcovers and shrubs. Trifolium repens is the dominant groundcover species, while Buxus sempervirens and Vinca major variegate are the dominant shrub/groundcover species. Rosmarinus officinalis and Melissa officinalis are the species with the lowest density, accounting for 2% and 3% of the vegetation, respectively. The second layer consists of taller species, such as vines and trees, i.e. Malus domestica and Vitis vinifera cardinal. Malus domestica has a higher k_d value due to its coverage of approximately 60% of the second layer. According to [11], mixed-species plantings have a greater collective leaf area than single-species plantings. These plantings are assigned a k_d factor in the high category (1.1 – 1.3). The assigned k_d factor value in this study is 1.2 during the peak of the vegetation period.

The values of k_{mc} are fixed at 1.1 during the entire analyzed period, considering the impact of urban conditions. The k_{mc} value is derived from on-site observations and the WUCOLS recommendations [11]. Plantings surrounded by heat-absorbing surfaces, reflective surfaces, or exposed to windy conditions, would be assigned high values (1.1 – 1.4). The main part of the study area is sunny during the entire day and it is located south of the urban family houses. A small part of the area is on the east side of the houses and it is sunny only until noon. In addition, there is no atypical (extremely strong) wind. There are situations with a slightly stronger wind from the south. Moreover, the analyzed area is surrounded by family houses and intersected by streets, parking lots and pavements. The results of the established factor values are presented in Table 2.

The K_L value of 0.752 indicates the highest plant water requirement, i.e. considering the time of the year, the species are the most sensitive to water scarcity in July and August. April is the month when species adapt relatively well to available water (K_L is 0.449).

Table 2. Coefficients of the WUCOLS method

	Apr	May	Jun	Jul	Aug	Sep
k_s	0.51	0.53	0.56	0.57	0.57	0.53
k_d	0.8	1	1.1	1.2	1.2	1.1
k_{mc}	1.1	1.1	1.1	1.1	1.1	1.1
K_L	0.449	0.583	0.678	0.752	0.752	0.641

3.2. Landscape evapotranspiration

The landscape evapotranspiration values are shown in Figure 1. The maximum values of ET_L are during the summer period (June, July and August). July stands out as the month with the highest ET_L, whereas April is the month with the lowest ET_L values, for the whole observed period. The maximum ET_L (average daily value on a monthly basis) of 3.703 mm day^{-1} is reached in July 2022, while the lowest value is in April 2023 (0.911 mm day^{-1}). A comparison between ET_0 and ET_L demonstrates that the percentage difference is the highest in April (55.12%), while the lowest one is in July and August (24.76%). This relationship between ET_0 and ET_L is expected, considering the K_L values in Table 2.

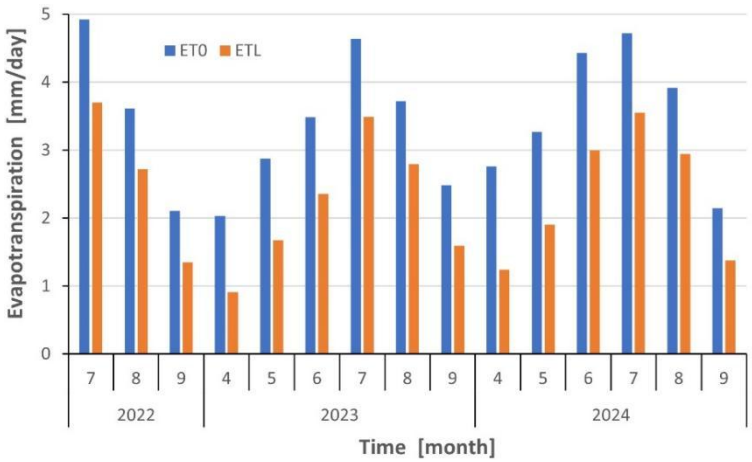


Figure 1. Monthy mean landscape evapotranspiration for the observed period

The maximum daily ET_L i.e. the value of 4.132 mm day^{-1}, occurred on 8th July 2024, while the minimum one was 0.314 mm day^{-1} on 5th April 2023. There is a significant dispersion of ET_L values during the first half of the analyzed period (April, May and June), Figure 2. Moreover, the same pattern of ET_L behavior is observed across the three analyzed years, i.e. there is a pronounced vegetation water requirement during the summer period.

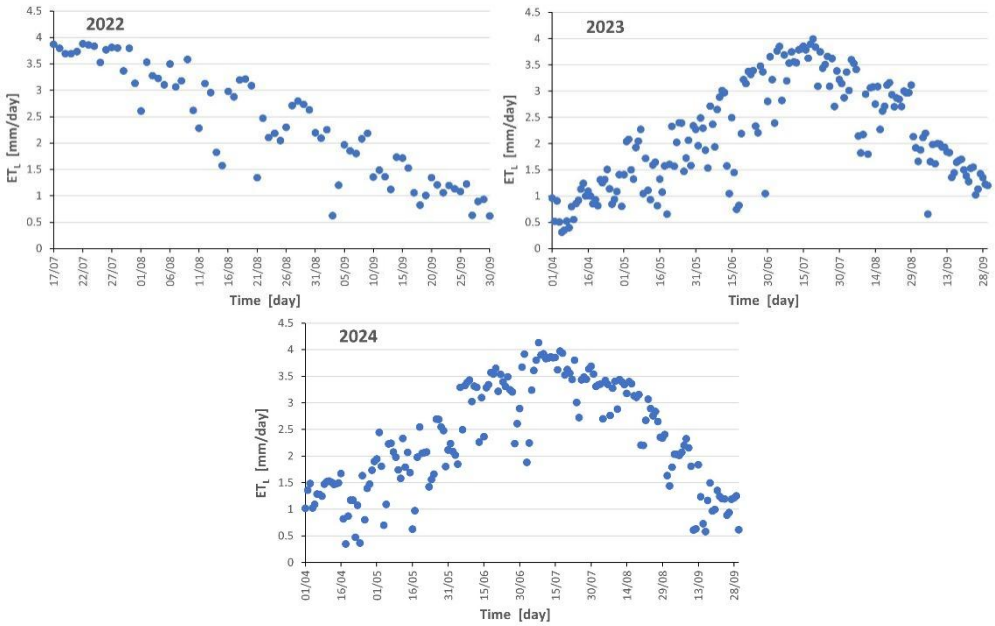


Figure 2. Daily landscape evapotranspiration for the analyzed period

4. CONCLUSION

The landscape evapotranspiration was analyzed in the urban conditions of Niš using the WUCOLS methodology. The methodology was based on three estimated factors which characterized the urban landscape. The FAO-56 Penman-Monteith equation was used for defining the reference evapotranspiration. According to the landscape coefficient, the analyzed species are the most sensitive to water scarcity during July and August, i.e. landscape evapotranspiration reaches the maximum values during the summer period (especially in July).

Urban vegetation planning poses an increasingly significant challenge for optimal cooling and water resource conservation. To better adapt to climate change, it is necessary to understand how different species respond to meteorological parameters. Moreover, spontaneous species whose water requirements are met by precipitation require specific evaluation within the urban environment to serve as a basis for future urban planning.

Further study will be oriented towards the application of other methods for estimating urban landscape evapotranspiration. Additionally, special attention will be paid to urban climate factors and their changes.

ACKNOWLEDGMENT

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under the Agreement on Financing the Scientific Research Work of Teaching Staff at the Faculty of Civil Engineering and Architecture, University of Niš – Registration number: 451-03-34/2026-03/200095 dated 05/02/2026, as well as the project of the Serbian Academy of Science and Arts, Branch in Niš, grant number 0-15-18.

LITERATURE

[1] Pittenger, D. (2014). Methodology for estimating landscape irrigation demand, review and recommendations. Edwards Aquifer Conservation District.

[2] White, R., Havalak, R., Nations, J., Thomas, J., Chalmers, D., & Dewey, D. (2004). How much water is enoug? Using PET to develop water budgets for residential landscapes (TR-271). Texas Water Resources Institute.

[3] Kjelgren, R., Rupp, L., & Kilger, D. (2000). Water conservation in urban landscapes. HortScience, 35(6), 1037-1040. https://doi.org/10.21273/HORTSCI.35.6.1037.

[4] Bos, M. G., Kselik, R. A. L., Allen, R. G, & Molden, D. (2009). Water requirements for irrigation and the environment. Springer Science + Business Media B.V.

[5] Nouri, H., Beecham, S., Kazemi, F., & Hassanli, A. M. (2013). A review of ET measurement techniques for estimating the water requirements of urban landscape vegetation. Urban Water Journal, 10(4), 247-259. https://dx.doi.org/10.1080/1573062X.2012.726360.

[6] Grimmond, C. S. B., & Oke, T. R. (1999). Evapotranspiration rates in urban areas. Proceedings of IUGG 99 Symposium HS5, UK, 259, 235-243.

[7] Salvador, R., Bautista-Capetillo, C., & Playán, E. (2011). Irrigation performance in private urban landscapes: A study case in Zaragoza (Spain). Landscape and Urban Planning, 100, 302-311. https://doi.org/10.1016/j.landurbplan.2010.12.018.

[8] Allen, R. G., Dukes, M. D., Snyder, R. L., Kjelgren, R., & Kilic, A. (2020). A review of landscape water requirements using a multicomponent landscape coefficient. Journal of the ASABE, 63(6), 2039-2058. https://doi.org/10.13031/trans.13948.

[9] Cubino, J. P., Kirkpatrick, J. B., & Subirós, J. V. (2017). Do water requirements of Mediterranean gardens relate to socio-economic and demographic factors? Urban Water Journal, 14(4), 401-408. http://dx.doi.org/10.1080/1573062X.2016.1173219.

[10] Shojaei, P., Gheysari, M., Nouri, H., Myers, B., & Esmaeili, H. (2018). Water requirements of urban landscape plants in an arid environment: The example of a botanic garden and a forest park. Ecological Engineering, 123, 43-53. https://doi.org/10.1016/j.ecoleng.2018.08.021.

[11] University of California Cooperative Extension. (2000). A guide to estimating irrigation water needs of landscape plantings in California (The landscape coefficient method and WUCOLS III). California Department of Water Resources.

[12] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration guidelines for computing crop water requirements (Irrigation and Drainage No. 56). Food and Agriculture Organization.