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MONITORING FRAMEWORK FOR PAIRED EXPERIMENTS TO ASSESS THE CHANGES IN THE WATER BALANCE IN URBAN FORESTS AND GRASS-COVERED PLOTS

PREDLOG MERITEV NA PARNIH PLOSKVAH ZA POTREBE OCENE RAZLIK V VODNI BILANCI URBANEGA GOZDA IN TRAVNATIH POVRŠIN

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Abstract

Understanding the water balance-modifying effects of urban forests is important for mitigating the impacts of climate change and urbanization. We established a paired plot-based hydrological research area in the Botanical Garden of the University of Sopron as part of a Slovenian–Hungarian OTKA project. The research area is designed for a paired plot examination of water balance (interception, transpiration, groundwater dynamics, infiltration, and runoff) with a forested plot and a grass-covered (control) parcel. Since the plots are located in the university's botanical garden, the proximity allows for diverse and frequent data collection and continuous monitoring. Long-term hydrological measurements offer significant opportunities for studying the water balance in forested areas (as is required for assessing the regime). The monitoring results based on only two years as the observational period can illustrate peculiarities and indicate the significant variability that must be captured, along with the factors required when designing such monitoring. The study presents a monitoring framework that provides insights into the complex water dynamics under the black pine canopy and compares the soil moisture and groundwater dynamics between grass and forest plots.

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Keywords: water balance, precipitation, throughfall, interception, soil moisture, ground water level, urban forest, pine trees.

Izvleček

Razumevanje učinkov, ki jih imajo drevesa na spremembe padavin, je pomembno za ublažitev posledic podnebnih sprememb in urbanizacije. V okviru slovensko-madžarskega projekta OTKA smo v botaničnem vrtu Univerze v Šopronu vzpostavili hidrološko raziskovalno območje na parnih ploskvah. Raziskovalna ploskev je zasnovana za primerjavo vodne bilance (prestrezanje, transpiracija, dinamika podzemne vode, infiltracija in odtok) med površino v gozdu in površino na travniku (kontrola). Ker se ploskvi nahajata v botaničnem vrtu univerze, bližina omogoča raznoliko in pogosto zbiranje podatkov ter stalno spremljanje. Dolgoročne hidrološke meritve ponujajo pomembne možnosti za preučevanje vodne bilance v gozdovih, ki so pomembne za oceno stanja. Predhodni rezultati, ki temeljijo na dveh letih meritev, lahko ponazorijo posebnosti in nakazujejo na precejšnjo spremenljivost, ki jo je treba zajeti, ter potrebne dejavnike pri načrtovanju spremljanja parnih ploskev. Predstavljene meritve ponujajo izhodišče za zasnovo meritev, ki omogočajo vpogled v kompleksno dinamiko vode pod krošnjami črnega bora ter primerjavo dinamike vlage v tleh in podtalnice med travnatimi in gozdnimi površinami.

Ključne besede: vodna bilanca, padavine, prepuščene padavine, prestrezanje, vlaga v tleh, nivo podzemne vode, urbani gozd, borovci.

1. Introduction

The strategic planting and proper management of trees in urban environments play a crucial role in influencing hydrological processes. Therefore, studying these factors is essential for mitigating the impacts of climate change and urbanization. The primary goal of the study was to gain a better understanding of the complexities of water balance (Figure 1) within the research site under the black pine tree canopy.

Hydro-meteorological measurements have been conducted at the University of Sopron Botanical Garden since 1925. This hydrometeorological dataset was recently homogenized by Lili Muraközy. This new reconstruction paved the way for various meteorological and hydrological analyses (Muraközy et al., 2025). Nevertheless, the ongoing climate changes in the region also stress the need to introduce new monitoring programs. Nevertheless, the ongoing climate changes in the region also stress the need to introduce new monitoring programs.

As part of an international Slovenian–Hungarian OTKA project, a paired-plot hydrological experiment was established in the botanical garden. The research area, located under black pine trees (*Pinus nigra Arnold*) near the main building, allows for detailed studies of water dynamics under the tree canopy. In close proximity to the pine trees, an open-air plot was designated as a control for comparison. The proximity to educational facilities allows for frequent measurements, regular equipment maintenance, and the involvement of students in practical research.

A dedicated research area was established in the botanical garden, which provides an ideal framework for investigating these issues. This article introduces the dedicated specialized monitoring of water balance processes in an urban forest and illustrates the usefulness of collecting such data in the preliminary analysis of the initial two years of measurement results from the two study plots.

1.1. Water balance and its changes in urban forests under a changing climate

Temperatures will rise in all European areas at a rate that exceeds global mean temperature changes; however, observations have both regional and seasonal patterns (IPCC, 2022). Droughts are becoming more frequent and severe, with impacts on agriculture, ecosystems, etc. At the same time, more intense precipitation events are causing flash floods in some areas (Jánosi et al., 2023).

In Hungary, the countrywide average temperature has increased by 1.2 °C from 1901 to 2020. However, in the region of Sopron (the location of the study area), the average temperature rise is higher (1.6 °C), with the majority of the increase mostly detectable in the last forty years (Muraközy et al., 2024). Summers were the most affected by warming, namely by 1.3 °C. Precipitation changes are less clear, with a slight decrease of 4% in the annual amount for the same investigation period. The seasonal pattern is projected to show more extreme precipitation events with larger variation within a year (Bartholy and Pongrácz, 2017). The seasonal sum increased in winter and summer, but a significant decrease was observed in spring (Lakatos et al., 2021, Ilona et al., 2022). The changes in precipitation patterns can either help or hinder the recharge of underground water supplies (Keszeilová et al., 2022).

Due to the warming, the atmosphere will have a higher energy potential, and the resulting intensification of driving forces will influence the hydrological cycle (IPCC, 2022). The Carpathian Basin is a particularly vulnerable area to the changing water cycle, as it has many different climate factors that change over time and place (it is a mix of continental and temperate influences, with temperature and precipitation patterns varying significantly across the region and throughout the year), along with various local conditions and flow processes that occur during the different seasons and over events. Because of this complexity, it is hard to create general explanations for how certain weather patterns and events develop (Szolgay et al., 2020). Jánosi et al. (2023) pointed out an increasing trend in the Penman–Monteith reference evapotranspiration (ET) on a daily scale, with an average of 0.868 mm/year in Hungary from 1961 to 2010, resulting in a 42.5 mm mean increase of reference ET during these five decades. On the other hand, groundwater table declines indicate a mean value of approximately –5.7 mm/year (which is higher than the Western, Central, and Eastern Europe averages of –1.5 mm/year) (Xanke and Liesch, 2022).

Rising average temperatures are accompanied by significant changes in forest water use (Tölgyesi et al., 2020) and increasing water demand in general.

Trees in urbanized areas contribute to reducing air pollution (as well as CO_2 concentrations) (Chen, 2015, Abhijith et al., 2017), and they can lessen urban stormwater runoff through canopy interception loss and water uptake (Berland et al., 2017; Nordman et al., 2018).

The redistribution of rainfall as throughfall and its spatial variability can be crucial for soil and understory vegetation wetting, soil erosion, and the potential for runoff generation. The temporal delay in reaching the ground due to throughfall compared to open rainfall may also be of importance for the timing of stormwater's peak flows (Asadian and Weiler, 2009; Ossola et al., 2015). Much work is needed to understand the complex interactions between transpiration, interception loss, climate, and soils in urban areas (Carlyle-Moses et al., 2020). Hydrological measurements, especially those conducted on paired plots, offer essential data for analyzing the effects of different land covers.

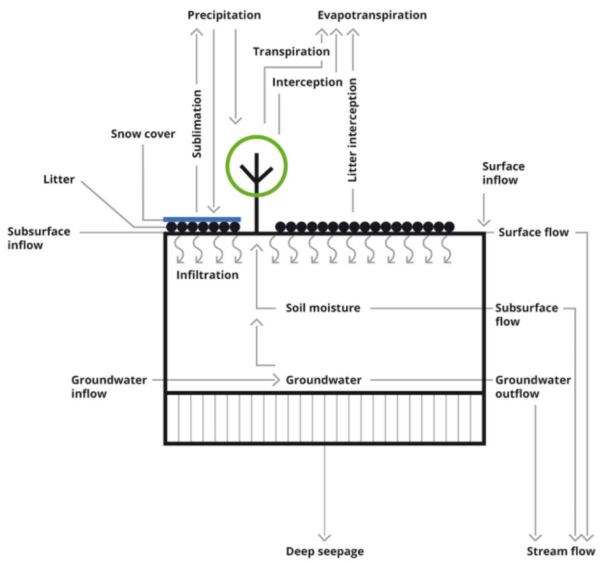

Figure 1: *Water balance of the tree-covered area (Gribovszki et al., 2019).*

Slika 1: *Vodna bilanca površine, porasle z drevesi (Gribovszki et al., 2019).*

Trees (as any type of vegetation) nevertheless alter the amount and spatial distribution of precipitation that without them reaches the impervious surfaces or permeable bare soil below. By canopy interception, a portion of the precipitation received by a tree canopy can be stored on the foliage and evaporated from that without reaching the ground. The portion of rainfall that reaches the ground can be throughfall (rainfall that passes directly through canopy gaps, or falls to the ground by either dripping or splashing from canopy surfaces) or stemflow (the drainage from the canopy that reaches the ground by flowing down the tree trunk). Stemflow is a concentrated input of water, being delivered to the proximal area around the tree base, whereas throughfall is a diffuse input being transported over a much larger area under the tree canopy and, occasionally, extending beyond the canopy area (Carlyle-Moses et al., 2020).

Canopy interception loss in various natural and plantation forests that have near-continuous canopy cover can account for 10–50% of rainfall (while stemflow also varies by tree species and can be considered as ~5% (Levia et al., 2011)), therefore canopy interception considers the significant ratio of the total evaporation (Šraj et al., 2008; Carlyle-Moses and Gash, 2011). The extrapolation of those data to urban forests can be misleading since single, isolated tree architecture differs from that of stand-grown trees. Furthermore, urban microclimates are generally relatively warmer than their surroundings and can be characterized by more evaporative demand (Xiao et al., 1998; Guevara-Escobar et al., 2007; Kuehler et al., 2017).

The canopy water storage capacity of a tree, or forest, is a function of both the canopy projection area and the canopy density (Holder, 2013; Fathizadeh et al., 2017). Isolated, open-grown, and healthy street and park trees are likely to have more voluminous canopies with greater canopy densities per projection area and thus greater water storage and interception loss potential compared to trees in closed forests (Asadian and Weiler, 2009; Pretzsch et al., 2015). However, many trees in urban forests can be stressed and unhealthy because of restricted infiltration, contaminated soils, vandalism, excessive transpiration demand, air pollution, and/or insufficient nutrient availability, wherefore, these trees may not achieve their full potential (Zipper et al., 2017).

The presence of coniferous cover has been associated with greater interception loss in urban forests in Ljubljana, Slovenia (Kermavnar and Vilhar, 2017). Thus, the benefits of coniferous (and broadleaved evergreen trees) may outweigh deciduous trees during the dormant season (Carlyle-Moses et al., 2020).

Interception loss as a percentage of rainfall decreases rapidly with increasing rainfall depth until remaining quasi-constant for relatively large events (Staelens et al., 2008; Nytch et al., 2018). The meteorological variables that influence canopy interception during an event (besides the rainfall characteristics) are temperature, relative humidity, and wind speed (Toba and Ohta, 2005; Carlyle-Moses and Gash, 2011; Van Stan et al., 2017; Zabret et al., 2018). However, the primary drivers of canopy interception loss are the intensity, frequency, and duration of rainfall, and the throughfall, which is largely the inverse of canopy interception loss. Zabret et al. (2018) measured throughfall under two urban trees (pine (*Pinus nigra Arnold*) and birch (*Betula pendula Roth.*)) in Ljubljana, Slovenia, using troughs and tipping gauges installed for more than three years. Their main conclusion was that tree canopies will reduce throughfall (and simultaneously increase interception) significantly in climates with more frequent rainfall events, but with low precipitation intensity and duration (Carlyle-Moses et al., 2020).

This study presents the design of a monitoring framework aiming at the clarification of the questions and problems outlined in the previous section, suggests and describes methods that can be applied in the data analysis, and illustrates the usefulness of such experimental research on results drawn from the first two years of the comparative monitoring.

2. Methods

The study site is situated within an experimental plot in the Botanical Garden of the University of Sopron, located in the urban area of Sopron, Hungary (47.40° N, 16.34° E, 228.2 m above Baltic Sea level). The region's climate is classified as moderately humid continental, influenced by the Carpathian Basin's position and affected by sub-Atlantic, subcontinental, and sub-Mediterranean climatic elements. Based on long-term climate data from 1989 to 2019, the area has an average annual temperature of 11 °C and receives approximately

730 mm of precipitation (Ács et al., 2015; Meraközy, 2024).

The experimental plot covers roughly 300 m² within the urban landscape. It contains seven black pine trees (*Pinus nigra*) and is bordered by a road and buildings to the south. To the north, east, and west, additional vegetation and trees offer limited buffering. There is no herbaceous vegetation in the area as undergrowth, because it is regularly removed along with regrowth. The thickness of the forest litter is ~1.5 cm (0.37), while the humus layer is 30 cm.

The research area was established under black pine trees and a weather station not far from the research site (Figure 2).

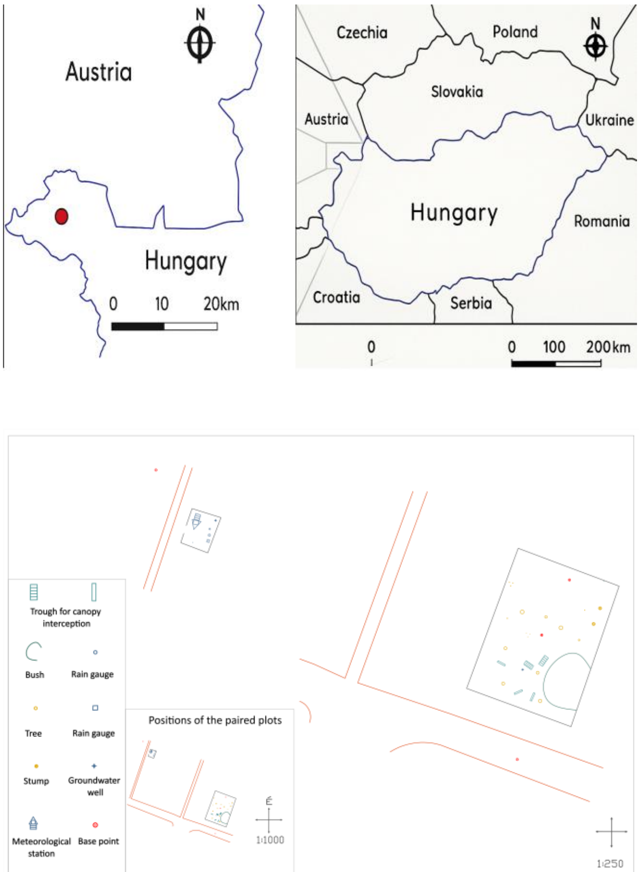

Figure 2: *Location of the research site (Zagyvai-Kiss et al., 2019).*

Slika 2: *Lokacija raziskovalne ploskve (Zagyvai-Kiss et al., 2019).*

Figure 3: *Weather station in the Botanical Garden of the University of Sopron.*

Slika 3: *Vremenska postaja v Botaničnem vrtu Univerze v Šopronu.*

Figure 4: *The experimental plot.*

Slika 4: *Raziskovalna ploskev.*

Table 1. *Basic data of black pine trees.*

Preglednica 1. *Osnovni podatki o črnem boru.*

Attribute	Value
Tree age (years)	45
Tree height (m)	18
Diameter at breast height (DBH) [cm]	42.7
Total projected crown area [m^2]	56
Leaf area index (LAI) in leafed/leafless period	2.73/2.23

Precipitation was measured in the open-air plot with a Hellmann-type rain gauge, while in the forested area, we measured the amount of precipitation passing through the canopy (throughfall), the stemflow (Kucsara, 1996), and the water retention capacity of the litter layer (Zagyvai-Kiss et al., 2019). The effect of frost and snow was excluded from the data analyzed.

Additionally, we monitored surface soil moisture and groundwater levels. In complex terms, we analyzed how precipitation events and vegetation influenced the area's water balance.

To determine canopy interception (the difference between open-air precipitation and stand precipitation), it is necessary to measure stand precipitation. Stand precipitation consists of two parts: throughfall and stemflow. Three collecting troughs, collected manually after every rainfall event, with a catching area of 0.2 m^2 (0.2 m * 1.0 m), were installed to measure throughfall. For stemflow measurements, a stem collar was placed on a tree. Stemflow was found to be insignificant for black pine trees, so we decided not to analyze it in detail. Litter interception was measured by small lysimeters (catching area of 0.08 m^2). The precipitation that was reduced by crown and litter interception (which can therefore be found below the litter layer) is the so-called effective precipitation.

Surface soil moisture (below forest litter 0-7 cm) was measured manually with daily frequency on five points at both locations in the plots (forest, open air). A Fieldscout TDR (Time Domain Reflectometry) 300 portable soil moisture meter was used to measure the soil's moisture content. The calibration equation used for converting raw data measured with the TDR probe (Nevezi, 2019):

$$VWC = (0.049 \cdot \text{Period}) - 98.23 \qquad (1)$$

Two wells were installed at the study site to monitor groundwater levels. A 5-meter-deep well was placed in the black pine plot in April 2023, and a 620 cm well was set up in the control area in July 2023. Perforation was carried out at a depth of the lower 4 meters in the open field plot's well and the lower 3 meters in the black pine plot's well.

At the black pine and open-air plot *silty clay loam physical soil type is* dominant with sandy layers up to 10 cm thick at certain depths (determined by finger test). The wilting point of the soil is 13% and the field capacity is 40% (Maidment, 1993).

The period of the data collection analyzed in this study started in July 2023 and finished in January 2024.

3. Results

Considering the short period of available data, with only two years, the results of this study do not offer enough information to perform correct and adequate statistical analysis. Therefore, the measurements can function as illustrations of the large variability of the process being monitored.

3.1 Precipitation

From July 2023 until the end of January 2024, a total of 442.05 mm of precipitation (with 69 events) was recorded. Figure 5 shows the time series of daily precipitation and daily temperature. Initially, the temperature gradually decreased, becoming more pronounced as the frequency of precipitation events increased. From mid-October, we observed a significant drop in temperature. In January, the measurements became more difficult because of frost and snow.

3.2 Effective and stand precipitation

The measurements of canopy and litter interception are related to the measurements of stand and effective precipitation. Based on the data from the paired plots in the botanical garden, precipitation is closely correlated with both stand (R^2=0.976) and effective precipitation (R^2=0.986) (Figure 6). According to collected results in the black pine stand, no precipitation below 1.18 mm reaches the litter surface, and precipitation less than 1.50 mm does not infiltrate into the soil through the litter. According to the aforementioned findings, infiltration through the litter begins almost immediately after the occurrence of throughfall precipitation, and the utilization of the litter's storage capacity is demonstrated by the differences in the slopes of the data (Figure 6).

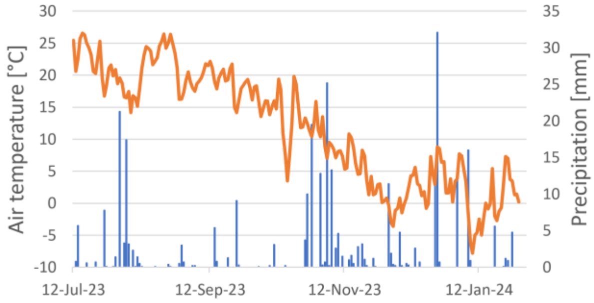

***Figure 5:** Time series plot of precipitation and air temperature.*

***Slika 5:** Padavine in temperature zraka v analiziranem obdobju.*

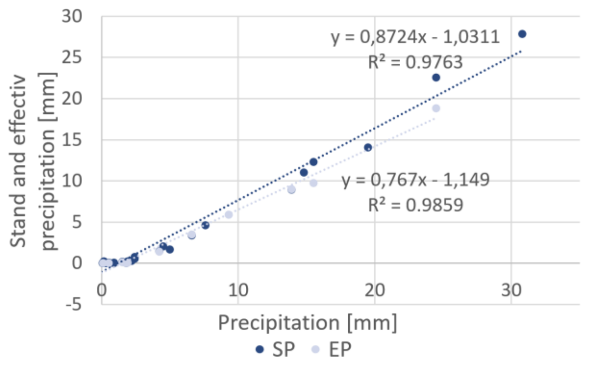

***Figure 6:** Relationship between stand precipitation (SP) and effective precipitation (EP) (for 37 events).*

***Slika 6:** Razmerje med prepuščenimi in efektivnimi padavinami (za 37 dogodkov).*

3.3 Groundwater

Forest stands can have different local effects on groundwater levels. Therefore, the background of the processes taking place can only be explored based on monitoring data from several elements of the hydrological system, rather than general observations (Szabó et al., 2022, 2024, 2025). Due to their large water reserves, forests generally exhibit better resistance to short-term droughts and provide a more favorable climate in their surroundings (Bolla et al., 2024). The influence of deep-rooted forests on groundwater dynamics even shows daily characteristics in addition to seasonal ones. The magnitude of daily fluctuations is closely related to groundwater uptake and evaporation, providing information on the vegetation's daily uptake of groundwater, its extent, and the extent of groundwater replenishment in an area, thereby aiding in estimating underground water resources (Szabó et al., 2023).

According to Fig. 7, the groundwater depth below the forest is closer to the surface than it is under grass cover, which is contrary to the common trends, as forests sink the groundwater better than herbaceous covers (Tóth et al., 2014; Gribovszki et al., 2019; Szabó et al., 2023). The explanation for this phenomenon, which contradicts the mentioned general rule, can be found in topography. In the examined paired plots, the grassland plot is located 1.5 meters higher above sea level (BSL) than the forested area.

In August, October, and at the end of December, a rise in groundwater levels was observed in both plots due to significant precipitation events. When the amount of precipitation does not exceed 20–25 mm, the groundwater level changes only slightly, while for less precipitation, the effect is negligible. The effects are more noticeable in the black pine plot, where the decline in groundwater levels is slower (Figure 7). It is important to note that the influence of the surrounding stand cannot be disregarded in the open area plot. Figure 8 shows that the open area responds more sensitively to precipitation and seasonal changes than the forested area, because trees have more buffering capacity against the precipitation (higher value of interception loss).

While the groundwater depth as measured from the surface is more important in the context of ecology due to its characterization of the groundwater supply’s availability, a water table expressed in elevation is rather useful in engineering, since it represents the direction of groundwater flow.

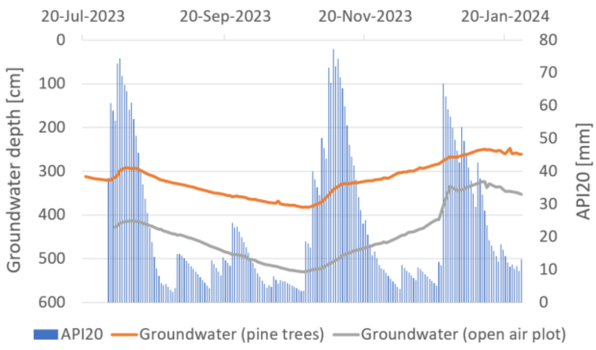

Figure 7: *Representation of groundwater depths illustrating the effects of antecedent precipitation (measured from the well rims).*

Slika 7: *Nivo gladine podzemne vode glede na vpliv predhodnih padavin (merjeno od roba vodnjaka).*

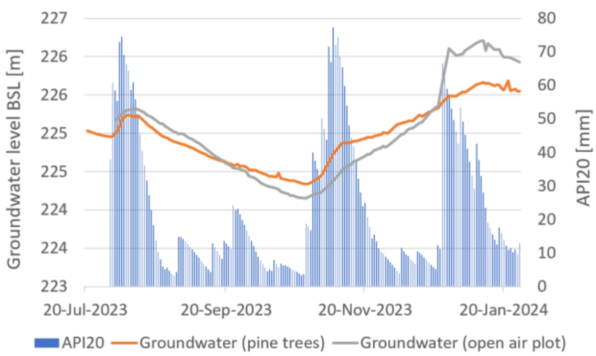

Figure 8: *Groundwater levels illustrating the effects of antecedent precipitation (BSL).*

Slika 8: *Nivo podzemne vode, ki kaže učinek predhodnih padavin (izraženo v m od nivoja površine).*

Szabó et al. (2019) have studied the effects of forests on groundwater levels and soil ion transport at 108 sites since 2012, employing one-time soil sampling, measurements of forest stands, and groundwater monitoring.

There is no direct link between the amount of water trees uptake from groundwater and the observed decline in groundwater levels. This shows that local factors—such as topography, hydrological conditions, soil type, and the different water uptake methods of various tree species—play a crucial role. Therefore, a single measurement of groundwater level changes caused by increased evapotranspiration from forest stands is not enough to accurately determine the groundwater usage of trees. Instead, continuous groundwater monitoring over several growing seasons is needed to draw more reliable conclusions.

3.4. Case study (examples) of the data use – API analysis

An important parameter calculated from precipitation can be the antecedent precipitation index, which can serve as an independent variable in the analysis of various relationships from a hydrological perspective.

The Antecedent Precipitation Index (API) is a hydrological index for the quantification of the soil moisture in a specific area or a catchment. The definition is based on the amount of precipitation that has occurred over a certain period of time, typically from a few days to a few weeks, before a specific event. Consequently, API is defined as a weighted summation of daily precipitation amounts. This index is particularly useful if soil moisture data are unavailable (Kontur et al. 2003). Higher values of API indicate more saturated soil, on which less precipitation tends to be absorbed (and thus this moisture contributes to the surface runoff). Therefore, this index can be applied to predict the possibility of flooding or landslides (Xie and Yang, 2013).

The calculation that was used to determine the X-day antecedent precipitation index, based on Kontur et al. (2003), is as follows:

$$API_x = \sum_{i=1}^{x} p_i * h_i = 1.00 * h_1 + 0.95 * h_2 + 0.90 * h_3 + 0.85 * h_4 + \cdots + p_x * h_x \quad (2),$$

...where h_1, h_2,..., h_x represent the precipitation that occurred on the first, second,... xth day preceding the precipitation event, multiplied by linearly decreasing weighting factors.

Using the antecedent precipitation index as a variable allows for the estimation of surface soil moisture conditions (Figure 9). The slopes are steeper for the open-air plot compared to those under the tree stand, which can be explained by the forest's significant interception that delays and reduces infiltration.

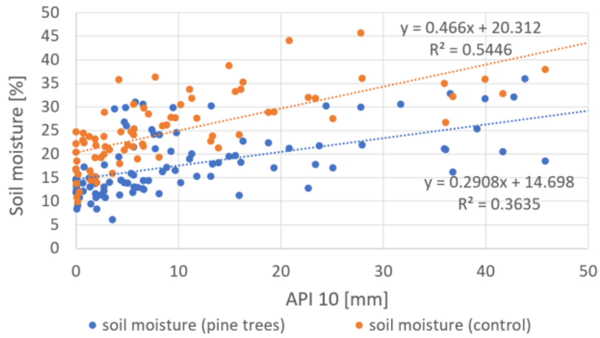

Figure 9: *Relationship between Soil Moisture and 10 days Antecedent Precipitation Index (API 10).*

Slika 9: *Razmerje med vlažnostjo v tleh in 10-dnevnim predhodnim padavinskim indeksom (API 10).*

The results suggest that smaller and medium precipitation events have a greater impact on soil moisture in the open grass plot compared to the forested plot. The evapotranspiration from grass reduced near-surface soil moisture more significantly in the open-air plot, while only slight reductions were observed in the forested plot.

The sensitivity of the antecedent precipitation index (API) can vary depending on the length of the observation period. When examining surface soil moisture, the 10-day antecedent precipitation index showed the closest correlation in the case of the open-air plot, while for the forest plot it was the 40-day index (Figure 8).

The weighing factors can also take into account real moisture depleting processes (Jakeman & Hornberger, 1993).

According to Kontur et al. (2003), the 20-day API is recommended in Hungary for small catchments. However, in our study, we applied API_{10}, due to the highest R^2 value for it in the open plot, while for the forest plot R^2 is constantly increasing with API values.

Measured throughfall in the urban black pine forest accounted for 87% of open field precipitation. Basically, we could compare our results with pines due to the lack of available studies about exactly black pine. Lishman et al. (2015) found a similar value of 87.7 % for throughfall compared to open field precipitation (associated with 38 rainfall events, from May to October 2010) for 9 juvenile lodgepole pine trees at the Mayson Lake hydrological research area (Canada). Llorens et al. (2018) studied the hydrological processes in the Vallcebre Research Catchments from 1988 to 2018 and found a 75% ratio of throughfall of open field precipitation for Scots pine. Wei et al. (2017) focus on the factors that control throughfall from 36 rainfall events in *Pinus tabulaeformis* plantations at the Mulan Forestry Management Bureau in the Hebei Province (China). The throughfall rate increased with increasing rainfall, but the rate of increase gradually decreased, with the average ratio of throughfall/precipitation at 79%. Zabret and Šraj (2018) investigated throughfall in an open plot under a single black pine tree, with results of 56% of the rainfall for 30 analyzed events. In order to compare the data precisely, the precipitation distribution and the LAI must be known.

De Moraes et al. (2024) calculated API in estimating soil moisture in order to determine thresholds based on landslide occurrences in Serra da Mantiqueira (Brazil). The moisture sensors are EnviroScanTM type capacitive sensors distributed along three meters inserted into the soil. The correlation coefficient reached a value of 0.89 at a depth of 50 cm, with API_{28}, while in our case, at the top soil (0–7 cm depth), the highest value was 0.74 for the open-air plot of API_{10}, but 0.84 for API_{40} at the pine plot.

Zabret et al. (2025) used API to analyze how long the preceding rainfall period best estimates the soil moisture values in the open and under the pine trees in the urban park in Ljubljana. They reported 10 to 20 days of API values to correlate the best with soil moisture values under the trees, while in the open site, shorter periods between 5 and 10 days were the most relevant.

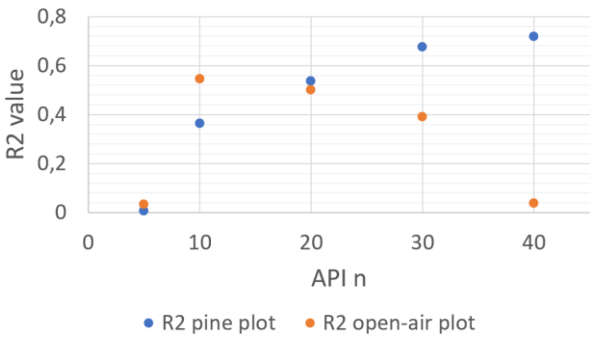

Figure 10: *R^2 values of the relationships between surface soil moisture and API_n.*

Slika 10: *Koeficient determinacije med vlago v tleh in indeksom API.*

Regarding the results due to the water retention by interception, soil moistening begins later from the onset of precipitation events. Surface wetting, followed by soil saturation, lasts longer in forest soil compared to a grass-covered open-air plot. On the other hand, the amount of captured water can vary greatly depending on the characteristics of the tree stand (Hewlett, 1982).

4. Conclusion

Hydrological measurements based on paired plots have been shown to be useful in comparing the water balance of various surface cover types. However, the results of this study can only be used to illustrate the variability of the processes without the ambition to arrive at conclusive statements on the regime and its changes, considering the short (only two years long) observation period. Our research has demonstrated that the tree canopy, through the process of rainfall interception may significantly influence the distribution of precipitation both spatially and temporally, as well influence the dynamics of the soil moisture and groundwater level. Nevertheless, this experiment serves educational and demonstrative purposes. The future potential work (besides database extension) is the automation of measurements for litter interception. During the writing of this article, the automation of the throughfall is in progress, while for the groundwater measurements, it has already been completed. Applying longer observational periods in a future study, the results may offer a deeper understanding of urban forests' (as nature-based solutions) hydrology (with the contribution to urban water management) and may provide a basis for sustainable urban and green infrastructure planning efforts.

CRediT authorship contribution statement

András Herceg – Writing – original draft; Kamilla Orosz – Writing – original draft; Péter Kalicz – Conceptualization; Katalin Anita Zagyvai-Kiss – Conceptualization; Géza Király – Methodology**;** Katarina Zabret – Writing – review & editing; Mark Bryan Alivio – Formal analysis; Gábor Keve – Formal analysis; Dániel Koch – Formal analysis; Lili Muraközy – Writing – original draft; Zoltán Gribovszki – Writing – review & editing

Data availability

The data presented in this paper are available from the corresponding author upon request.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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