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Hydrology of the Carpathian Basin: Catchment Experiments and Modeling for Improved Description and Prediction of Hydrological Processes

Proceedings

Edited by Péter Kalicz, Kamila Hlavčová, Silvia Kohnová, Borbála Széles, Anna Liová, Zoltán Gribovszki

HydroCarpath International Conference

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Contents

Solicited Speaker

GROUNDWATER MONITORING IN FORESTS OF THE GREAT HUNGARIAN PLAIN

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In arid lowland areas, forests have a diverse ecological role, requiring significant water resources while also serving as important contributors to environmental cooling, soil moisture preservation, erosion control, and carbon storage. Consequently, significant efforts have been made over the past few decades to understand the complex interaction between forest vegetation and groundwater on the Great Hungarian Plain. With climate change altering meteorological conditions, the importance of drawing conclusions from measured data has increased.

The hydro-meteorological monitoring system operated by the Forest Research Institute, University of Sopron has provided a basis for new findings in recent years, particularly regarding subsurface salt accumulation, groundwater uptake, diurnal fluctuations, recharge, and soil moisture. Looking ahead, this monitoring system also presents an opportunity for collaboration among experts from various fields. This article was made in frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

INTRODUCTION

Since the early 1970s, a trend of groundwater level decline occurred in the Great Hungarian Plain. This phenomenon raised questions about the impact of afforested areas on groundwater. However, the scientific debate on the issue remained inconclusive due to a lack of adequate data. Due to the complex and high-resolution measurements of forestry hydro-meteorological monitoring system operated by the Forest Research Institute, University of Sopron, new findings have emerged in recent years on this subject.

METHODS

Each study site includes one or more forested point and a control point, covered with herbaceous vegetation. Groundwater level data is collected in every 15 minutes at the measurement points.

RESULTS

Móricz et al. (2016) found, that in discharge areas, the forest stands are capable of significantly higher rates of evaporation compared to potential evapotranspiration (Fig. 1.).

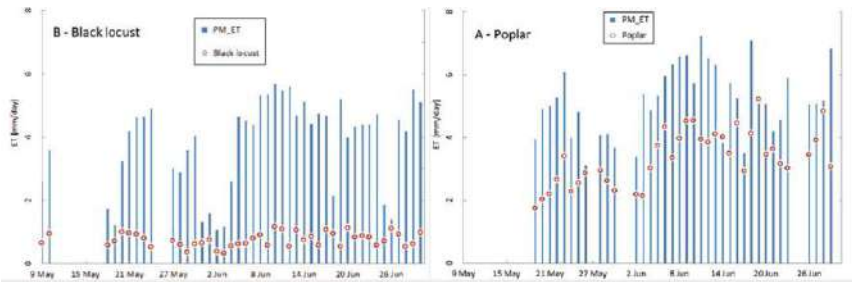

Figure 1. Daily evapotranspiration rates at the discharge (a) and recharge (b) zones in comparison with potential evapotranspiration (after Móricz et al. 2016).

Csáfordi et al. (2017) found that among meteorological factors, longer preceding dry periods (Fig. 2, a) increase, while higher relative humidity (Fig. 2, b) and precipitation events (Fig. 2, c) decrease the daily fluctuation of soil water level and thus the evapotranspiration from the groundwater.

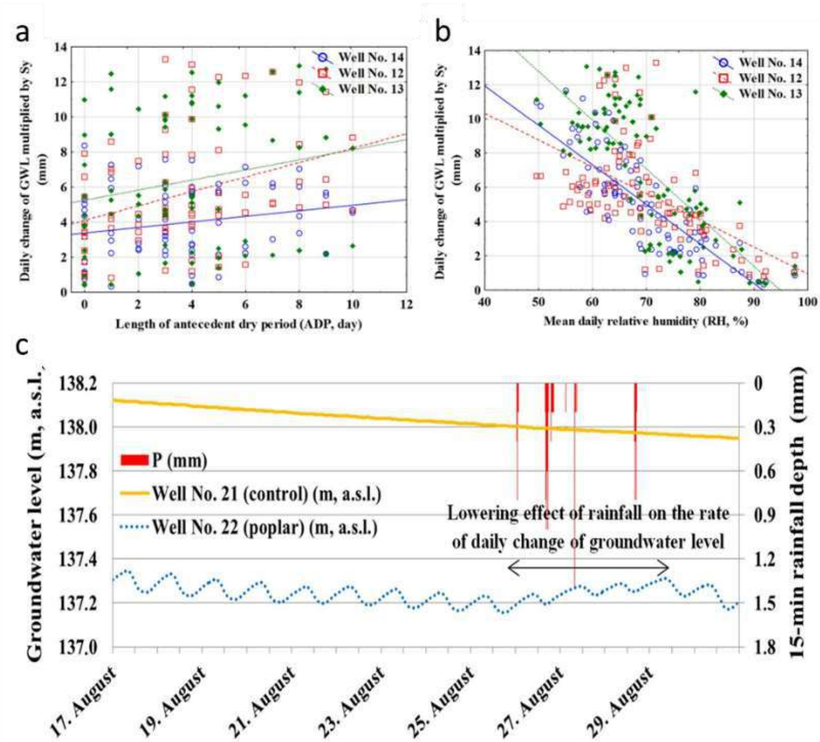

Figure 2. Effect of the length of antecedent dry period (a), relative humidity (b) and precipitatiuon events (c) on daily change in groundwater level (after Csáfordi et al. 2017)

Szabó et al. (2022) concluded that despite the detectable drying effect at 90 cm in the root zone of the forest vegetation (Fig. 3, a) at Kecskemét study site, the likelihood of deep infiltration (below 200 cm) is highest under the Black locust stand (Fig. 3, b), presumably due to the bypass-flow effect created by the roots.

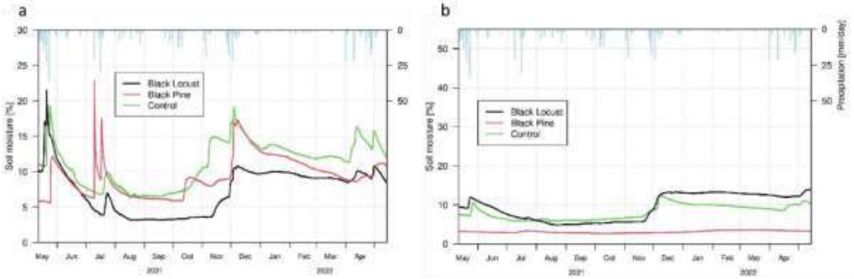

Figure 3. Soil moisture data in Kecskemét-Méntelek study site at a depth of 90 and 200 cm (after Szabó et al. 2022)

Based on the results of Szabó et al. (2023) a drying process observable during consecutive years lead to a rapid decrease of the surplus (precipitation independent) groundwater recharge (Fig. 4.). The observed process indicates a disruption in the connection between the root system of the forest stand and the soil water.

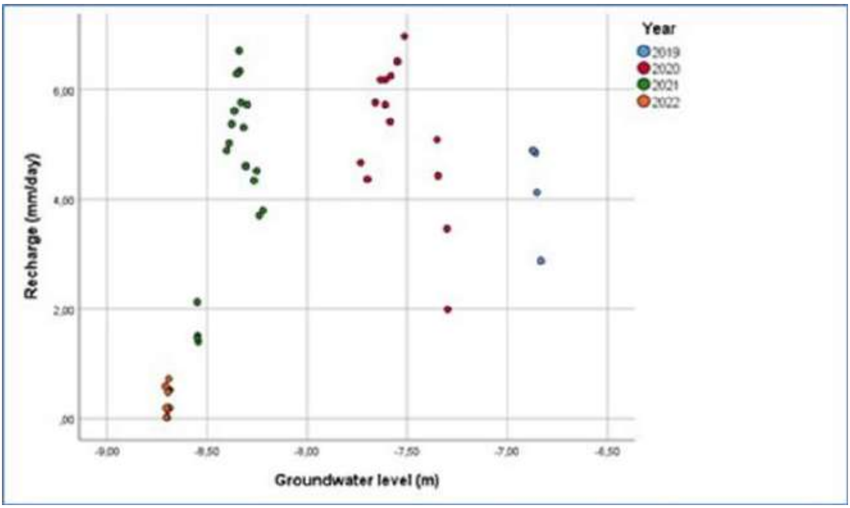

Figure 4. Relationship between the groundwater level recharge and groundwater level at the forested point at Püspökladány study site (after Szabó et al. 2023)

Conclusion

The represented groundwater monitoring system, especially due to the high temporal resolution data, enables more detailed analyses compared to previous ones, which can assist in better understanding the complex hydrological effects of the forest stands in the Great Hungarian Plain.

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Changes and trends in the climatic water balance of the Danube River basin based on meteorological, hydrological, and gravimetric data for the period 1961-2020

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ERA5-Land gridded meteorological data for the Danube watershed show a significant increasing trend with $p = 0.05$ for the annual mean net radiation and temperature and a significantly decreasing trend for the relative humidity. These forcing parameters have also led to an increase in evaporation with a significant trend of 1.7 mm yr^{-1}. The spatial distribution of the evaporation trends shows that lower-lying areas of central and eastern Europe are unable to meet the growing demand for evaporative water. Precipitation is decreasing in these areas.

The water loss in the Danube River basin, which is estimated as the annual decrease of the difference between the precipitation and evaporation trends, is about 1km^3 yr^{-1}. The magnitude is confirmed by the Terrestrial Water Storage Anomalies (TWSA) detected with gravimetry, which show a decreasing trend of 7 mm yr^{-1} in the equivalent water height.

In Hungary, both the evaporation trend estimated by the complementary relationship method and the Penman reference evaporation trend show a significantly increasing trend. The demand (reference evaporation) is increasing by 2.23 ± 0.3 mm yr^{-1}, while the supply (land evaporation) is increasing by 1.64 ± 0.2 mm yr^{-1}. The gap between them is widening, indicating increasing vulnerability to droughts.

Keywords: drought, evaporation trends, loss of water, climatic energy balance, gravimetry, mass anomaly

INTRODUCTION

Rising annual average temperatures due to global warming have serious physical consequences. Among others, the evaporative capacity of the air is increasing, inducing an increase in the water demand. This change requires more attention to better understand the processes of moisture transport and energy dissipation in our region at our climate. An analysis of two 30-year meteorological reference periods for the Danube River Basin was performed, which proved the increased demand for water. The watershed is losing 1 km^3 of water annually. The growing importance of evaporative cooling as a key environmental service has become more and more prominent.

METHODS

Meteorological data are from the ECMWF (European Centre for Midrange Weather Forecast) ERA5-Land reanalysis database (Muñoz, 2019) for the 60-year period of 1961-2020. Temporal resolution is monthly. Data were downloaded from the Copernicus CDC Data Store site for the following parameters: air temperature (ta), dew-point temperature (td), surface solar radiation (ssr), surface thermal radiation (str), total precipitation (tp), total run-off (ro). Surface net radiation was calculated as the total of shortwave and thermal radiation.

The selected area was from 8.0º E to 29.9º E and 42.0º to 50.3º N, respectively. The spatial resolution of the gridded data is 0.1º x 0.1º (approx. 9 km x 11 km cell size). This way, the area of the Danube River Basin is covered by an 84x220 grid matrix. Data were processed in MATLAB, including averaging, monthly and annual aggregation, and generation of graphs. Maps were visualized in QGIS. Linear trends were assessed for a subset of the grid matrix, masked out by the area of the Danube Basin. The existence of a linear trend in the data series was checked with the Mann-Kendall test at a 5% significance level.

RESULTS

The annual averages for the key forcing meteorological parameters driving evaporation (air temperature and net radiation) show increasing trend, and relative humidity shows decreasing trend. Air temperature and net radiation show statistically significant trends in the last 30-year reference period 1991-2020 (see Figure1a-c). The results of the Mann-Kendall test are shown in Table 1. The average change in net radiation over the 30-year study period is around 224 MJ/m^2 which is 89.6 mm in water equivalent of evaporation. Conversion was performed by a latent heat of evaporation value of 2.5 MJ/kg and water density of 1 kg/dm^3.

The trend in evaporation (see Figure1d-e) shows a statistically significant increase in the annual averages for the 1991-2020 thirty-year period. Note that the term evaporation used here includes all components where water changes phase from liquid to gaseous, like in the term evapotranspiration.

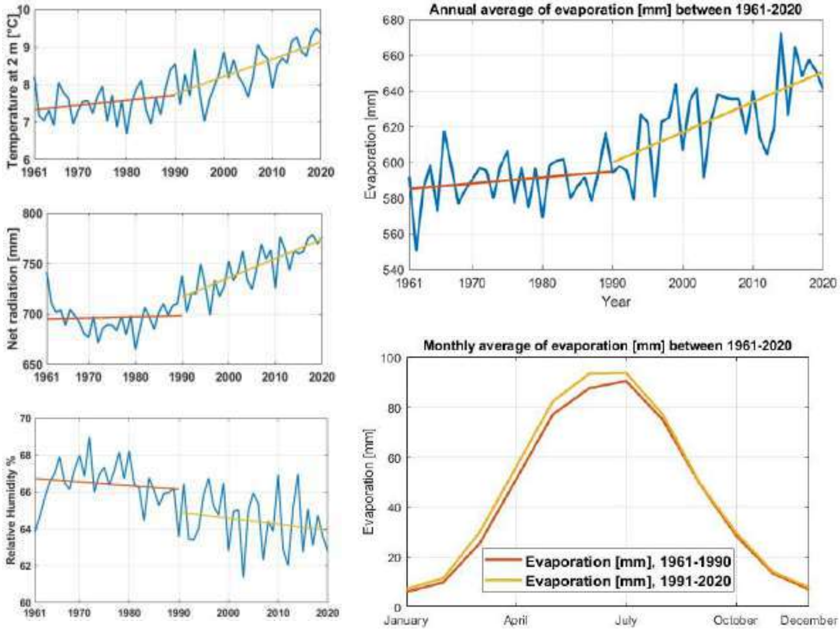

Figure 1. The forcing parameters of evaporation (left panel from top down): air temperature (℃), net radiation (mm) and relative humidity from 1961 to2020. Annual average evaporation (top right) and 30-year monthly averages (bottom right panel).

Monthly average evaporation in the last 30-year reference period 1991-2020 exceeds the evaporation in each month of the previous 30-year period.

Table 1. Trends of meteorological variables in the Danube River Basin during 1991-2020 calculated with the Mann-Kendall trend test.

ERA5 parameter	Name of the parameter	p	Trend significance	Probability of existing trend%
ssr+str	Net radiation	0.0001	significant	99.99
t2m	Air temperature (2m)	0.0001	significant	99.99
d2m	Dew point temp (2m)	0.0001	significant	99.99
e	Evaporation	0.0013	significant	99.87
ro	Run-off	0.4978	not significant	50.22
tp	Total Precipitation	0.7753	not significant	22.47

The spatial distribution of changes in evaporation was investigated by assessing the linear trend in each grid point, as well as showing the accrued change. Evaporation has increased in most parts of the Danube River Basin, except south and southeast (Figure 2.).

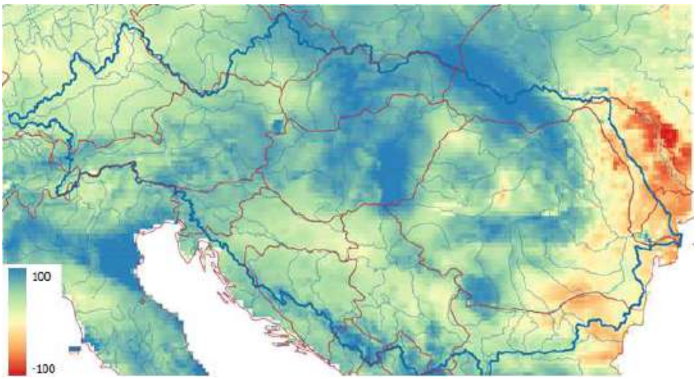

Figure 2. Spatial distribution of evaporation trends in the Danube River Basin. Accrued changes in evaporation during 1991-2020 (mm).

Evaporation trends were calculated grid point by grid point with the Mann-Kendall test. The test result identifies areas with significant and no or not significant trends (Figure 3.). Cells with significant trend in evaporation can be seen in areas where evaporation has increased. This is in line with our expectations. For the annual time series, we have seen that increasing trends in forcing factors determine the increase in evaporation. The distribution of cells with no significant trend in evaporation, however, raises further questions: what is the physical meaning of the scenario where the change in evaporation is negative (decreasing evaporation)? Does this mean that these areas are „running out of water" to evaporate and contribute less efficiently to the cooling of the surface? The gap may be opening between actual evaporation and potential evaporation, as confirmed for Hungary (Báder& Szilágyi, 2023).

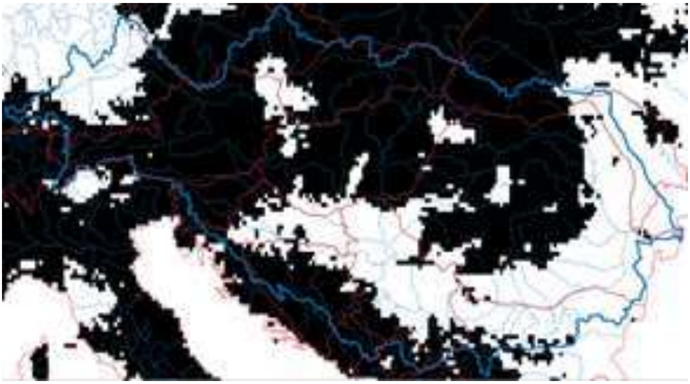

Figure 3. Spatial distributions of evaporation trends between 1991-2020. Significant trend (Mann-Kendall $p<0.05$) in a gridpoint is marked by black.

Spatial distribution of precipitation and the accrued changes during the period 1991-2020 are shown in Figure 4. Dry areas in the northeast receive less precipitation and southwest receive more, confirming that „ wet areas will get wetter and dry regions will become drier". (Putnam & Broecker, 2017).

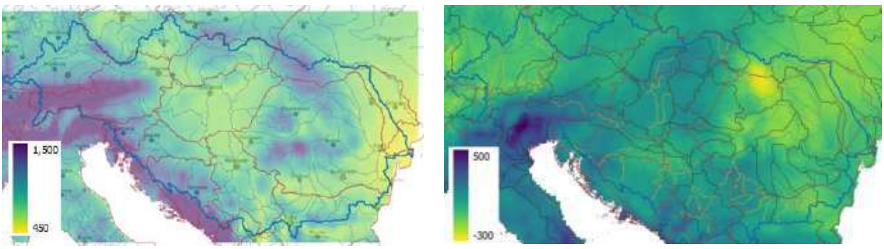

Figure 4. Spatial distribution of average annual precipitation between 1991 – 2020 in mm (left) and accrued change during the 30-year period (right).

Comparison of the monthly trends of net radiation, precipitation, and evaporation for the 30-year reference periods reveals further changes (Figure 5.). In the first 30-year period from 1961 to 1990, there was only one month (July), when average monthly evaporation exceeded precipitation (the black solid line is above the blue solid line in July). In the second 30-year period from 1991 to 2020, evaporation exceeds precipitation in all three summer months (the black dotted line is above the blue dotted line in June, July, and August).

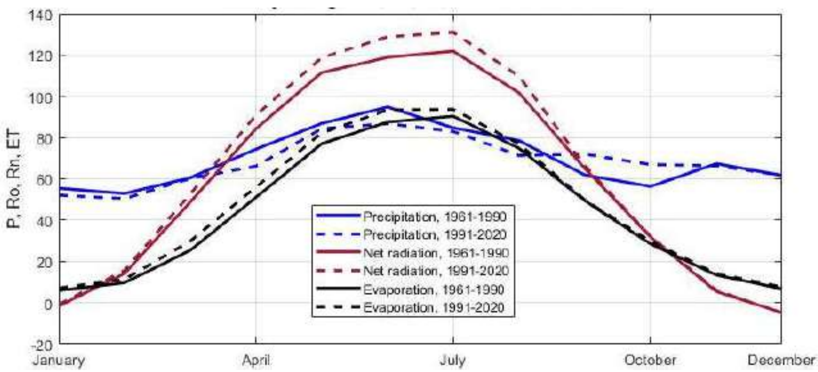

Figure 5. Changes in the monthly distribution of net radiation, precipitation, and evaporation from 1961-1990 (solid lines) to 1991-2020 (dotted lines).

The overall outcome of the changes is that the water balance of the Danube River Basin has become negative. Total average evaporation exceeds total average precipitation in the period 1991-2020 (Table 2.). The unfavorable trend and the magnitude of the change shown in this study are also confirmed by mass anomaly measurements using gravimetry (Boergens et al. 2020).

Table 2. The 30-year water balance of the Danube River Basin between 1991-2020.

Parameter	Annual change in the Danube River Basin		Accrued change in the last 30 years
	mm/year	million m^3 /year	km^3
ET (evaporation)	1.59	1302.29	39.07
P (precipitation)	0.37	302.77	9.08

Conclusion and discussion

Retaining water from the surplus precipitation in autumn to spring- and summertime of the next year becomes vital in the Danube River Basin. Conditions for the climatic energy dissipation process via evaporation (removal of latent heat from the surface) are getting more stressed!

Beyond technical and administrative measures, effective use of natural soil reservoirs at a regional scale could help to proactively prepare for climate change and underline the importance of Nature-based solutions (Sušnik et al., 2022). Further research is encouraged to estimate the short-term consequences and get ready for action to avoid extreme weather events such as more frequent droughts.

Acknowledgement:

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Can we calibrate a recursive baseflow separation filter relying on catchment response time parameters?

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The physically meaningful separation of a baseflow from an observed streamflow time series is still an unresolved problem in hydrology. This study provides a novel method that builds upon catchment response time to formulate an optimization criterion for calibrating the Lyne-Hollick filter. The catchment's response time parameters, including the time of concentration (T_c) and time to equilibrium (T_e), can be derived from the observed precipitation and discharge time series. A range for the ratio of these two has already been derived on a physical basis. In the approach presented, the parameter of the Lyne-Hollick filter was calibrated so that the ratio of T_c and T_e falls within a physically plausible range. The proposed method was tested in 25 Hungarian catchments, and the results were compared to those derived in a previous study. The Pearson correlation coefficient improved from 0.654 to 0.862 between T_c and the lag time when applying the proposed calibration procedure.

EXPLORING DROUGHT-RICH AND FLOOD-RICH PERIODS IN BRAZIL

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Streamflow exhibits persistent decadal variability; however, it is unclear if the magnitude and spatial extent of these variabilities are symmetrical for droughts and floods. Here, we examine drought-rich and flood-rich periods in 319 streamflow gauges in Brazil from 1940 to 2020. We contrast streamflow temporal clustering with rainfall, water abstraction, the Atlantic Multidecadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO). We found drought-rich periods in 61% of the basins, which were 11.5 times the false positive rate and 2.2 times the flood-rich periods (28%). The higher number of basins with drought-rich periods is linked with increased water abstractions since the 1990s, an interannual persistence of rainfall deficits, and a higher prevalence of rainfall-poor periods (44% of the gauges) compared to rainfall-rich periods (29% of the gauges). The drought-rich periods are aligned with the rainfall-poor periods, AMO, PDO, and increased water abstractions. These findings highlight the nonlinearity and asymmetry in changes in droughts and floods on decadal scales.

COUPLED SNOW-HYDROLOGICAL MODELLING FOR TWO HIGH ALPINE AUSTRIAN CATCHMENTS

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The timing and quantity of snow and ice melt in high-alpine regions is of great importance, especially for time-sensitive processes such as hydropower production. In most conceptual hydrological models, the simulations of these components are frequently only based on simple temperature index methods. Additionally, the estimation of precipitation inputs for areas with complex terrain is characterised by a high degree of uncertainty.

This contribution aims to improve the simulation of relevant components of the water balance by coupling the conceptual rainfall-runoff model COSERO with the physically-based snowpack model Alpine3D. Two high-alpine catchments with intense hydropower activity are used as a case study, with hourly data for the period 2003-2020. Snow and ice processes are modelled by Alpine3D, while runoff routing and subsurface flow are computed in COSERO. Additional information from local weather stations and topography is integrated into the gridded meteorological input data. An iterative process is used to find local optimized precipitation correction factors. The proposed detailed and coupled simulation of glaciers, snowpack and runoff together with complex interpolations of meteorological inputs shows an improved simulation of reservoir inflow and discharge, especially during the snowmelt period.

Acknowledgements: We thank the VERBUND Energy4Business GmbH for fruitful discussions and providing us with data. This work was carried out as part of the HyMELT-CC project.

FORECASTING KARST SPRING DISCHARGES USING AN INTERPRETABLE MACHINE LEARNING APPROACH

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Karst springs supply approximately 10% of the global population with drinking water; understanding them therefore plays a vital role in water resource management. This study is aimed at forecasting karst spring discharges using machine learning models. A secondary aim was to increase the transparency of the forecast by providing attributions of the input variables.

We have compared the performance of four machine learning models of varying complexities, a multivariate adaptive regression spline (MARS), a feed-forward neural network (ANN), a Long Short-Term Memory model (LSTM), and a Transformer (TF) to a Naïve baseline model for a highly dynamic Austrian alpine karst spring. Moreover, we have employed the DeepSHAP model explainability method to investigate the contributions of the input variables to each forecast and analyze the seasonal differences.

Our findings demonstrate that the complex models, i.e., the Transformer and LSTM, exhibit the best performances in forecasting the discharge, as quantified by the four evaluation metrics. The contributions of the input variables differ for each season. The input variables, discharge, UV-absorption, water temperature, air temperature and conductivity contributed most to the forecasts.

The spring discharge forecasts, together with the model explanations, enhance understanding of the karst systems and aid in short-term water supply management and decision-making in karst regions.

INVESTIGATING THE IMPACT OF POST-PROCESSING ENSEMBLE PRECIPITATION FORECASTS TO SIMULATE RESERVOIR INFLOW

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Flood forecasting mainly relies on the quality of precipitation forecasts. Numerical Weather Prediction (NWP) models play a crucial role in improving the reliability of precipitation forecasts. The direct application of ensemble precipitation forecasts derived from NWP models produces significant biases in hydrological modelling. Therefore, it is necessary to post-process ensemble precipitation forecasts. The aim of this research was post-processing the raw precipitation forecasts of three NWP models, i.e., UKMO, NCEP, and KMA, for six storm events that resulted in heavy floods in the Dez River basin, Iran, during 2013-2019. Post-processing of the ensemble precipitation forecasts was done in two steps. First, the regression models were used to correct the raw output of every individual NWP model. The second step developed a multi-model ensemble system using the Weighted Average–Weighted Least Square Regression (WA-WLSR) model and the Group Method of Data Handling (GMDH) model. Then, the HBV hydrological model was fed with the post-processed ensemble precipitation forecasts to simulate the reservoir inflow floods. Besides, in order to investigate the effects of post-processing the ensemble precipitation forecasts, the ensemble inflow forecasts were compared with the deterministic inflow forecasts. The results demonstrated that the forecasting skill of the NWP models was improved using both the GMDH and WA-WLSR models, but the WA-WLSR model provided better results. The results of the HBV model in producing ensemble inflow forecasts showed that the normalized root mean square error (NRMSE) index decreased by an average of 21.3%, compared to the deterministic inflow forecasts in the validation stage. This research methodology is practical in adopting more efficient strategies for the flood control management of reservoirs due to applying the uncertainty of inflow forecasts.

Keywords: Numerical weather prediction models; Multi-model ensemble system; Ensemble inflow forecasts; Deterministic inflow forecasts

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The impact of climate change on the aquatic habitat of the Hybica River

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The effects of climate change could affect the whole spectrum of the ecosystem. It disrupts the system of bonds, changes energy-material cycles, and thus disrupts the standard operation of a landscape, especially its components. Heavy rain and other frequent weather events are often repeated. They could lead to floods and reduced water quality, but also to a deterioration in the availability of water resources in some areas. One of the most determinative changes in weather extremes that we can expect is a protraction of drought seasons and the more frequent occurrence of minimum flows. This change in runoff conditions could have a direct impact on the ecosystem of a stream. Therefore, this study is aimed at determining the impact of climate change on an aquatic habitat in future decades. This problematic will be documented on the specific reach of the Hybica River.

The modelling of the quality of the aquatic habitat based on bio-indications was executed using IFIM methodology. Modelling based on bio-indications is a demanding procedure that is unavailable in design practice, so the results from dozens of streams were generalized. The analysis shows that generalized results can be used for mountain and piedmont streams.

The results of the modelling of the aquatic quality show that climate change may cause significant modifications in the ecosystem of watercourses. Based on these results, it is possible to design and evaluate restorative measures that could mitigate the impact of climate change on the in-stream areas of watercourses.

This study has been jointly supported by the Scientific Grant Agency under Contracts no. VEGA 1/0067/23.

Study of the functioning of the fish passage on the Hron River in Slovakia.

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River ecosystems can be considered the most diversified and productive ecosystems on the planet. Since the last century, the free flow of water, which ensures the basic functioning of lotic ecosystems and the constant dynamics of an environment, has been systematically disrupted by the construction of dams worldwide, thereby causing the massive loss of fish abundance and even biodiversity. Almost one in three freshwater species are globally threatened with extinction, with all taxonomic groups showing a higher risk of extinction in freshwater, compared to the terrestrial system.

On the way to their natural spawning habitats in the upper Hron River in southern Slovakia, from hundreds to thousands of fish, mostly barbels (Barbus barbus), have died in the turbines of the small hydro power plant of the Želiezovce reservoir, even though the weir has a implemented bio-corridor. Using 3-year ichthyological and hydraulic monitoring and robust 2D mathematical flow modelling, this study seeks to find the cause of this ecological disaster in order to prevent the recurrence of such events in the future.

Modelling and evaluation of the snow and ice melt in the Grossglockner Region

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The cryosphere in high alpine regions is dramatically affected by climate change. All over the world people are dependent on the melt water of the cryosphere as they use it for drinking water, hydropower and agriculture. It is an important task to simulate the processes in high alpine regions. This study features an adapted version of the GR4J model, which is a simple conceptual rainfall-runoff model, to simulate snow and ice. The aim of this thesis is to test this new adaptation in a glaciated catchment in Austria for the time period 1986–2022.

The results calibrated with the discharge show the best Nash-Sutcliffe Efficiency value (0.86), when dividing the catchment into elevation bands. The validation of the simulated snow extent with the snow detected and the georeferenced webcam pictures reveal an R^2 of 0.92. The results indicate that the yearly discharge consists on average of 37% ice melt and 33% snow melt. A focus on glacier melt reveals an increase in ice melt at higher elevations as well a reduction of ice melt in lower elevations due to glacier losses.

Quantifying projected effects of climate change on low-flows in the Salzach River, Austria: An approach for adapting stochastic weather generator outputs

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In the context of ongoing climate change, the use of climate model predictions plays a crucial role in preparing adaptation strategies that could reflect the expected changes in low-flow conditions within water systems. These predictions are often non-stationary and thus not very suitable for a comprehensive statistical analysis of extremes, mainly due to very short periods of quasi-stationary conditions. In this study, we address these problems by adapting a 10,000-year long dataset of synthetic meteorological outputs, representing the current climate conditions and produced by a large multi-site stochastic weather generator, to account for both spatial and temporal variability of the changing climate through a delta-change approach. We adapted this dataset to depict the mean climate conditions of the final three decades of the 21st century, as defined by four different scenarios (2xGCM, 2xRCP) incorporated into the high-resolution Austrian National Climate dataset (ÖKS15). We employed an HBV-distributed hydrological model to simulate synthetic river discharges for both the current and four future climate conditions in the Salzach River, Austria. Our subsequent analysis of the low-flows reveals that the more extreme climate conditions, as characterized by increased temperatures and rainfall amounts, also transfer into larger low-flows and shorter dry periods compared to the current climate. The results can be attributed to two factors: (1) the low-flow season in the Salzach River predominantly occurs during the winter, leading to reduced snow accumulation in the catchment due to rising temperatures, and (2) the adopted delta change approach reflects the changes in rainfall amounts but does not address the changes in rainfall frequencies. Future research should, therefore, prioritize the development of methods that can accommodate qualitative changes in rainfall distribution.

QUANTIFYING PROJECTED EFFECTS OF CLIMATE CHANGE ON LOW-FLOWS IN THE SALZACH RIVER, AUSTRIA: AN APPROACH FOR ADAPTING STOCHASTIC WEATHER GENERATOR OUTPUTS

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TECHNISCHE UNIVERSITÄT WIEN

MOTIVATION

In the context of ongoing climate change, the use of climate model predictions plays a crucial role in preparing adaptation strategies that could reflect the expected changes in low-flow conditions within water systems. However, their non-stationary nature and short quasi-stationary periods limit a comprehensive analysis of the extremes. One possible solution is establishing a stochastic weather generator, but **adjusting existing generator outputs may also be viable**.

Research questions:

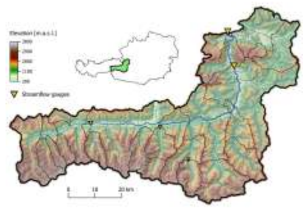
1) Can weather generator outputs for current climate be adapted for the future climate?
2) How do the projected meteorological variables change at the end of the 21st century?
3) How do these changes translate into the expected low-flow statistics in the Salzach River?

STUDY AREA

The analysis was conducted in the mountainous **Salzach River** catchment in Austria, with the outlet located in **Golling an der Salzach**.

Info:

- catchment area: 3555 km^2
- mean elevation: 1577 m.a.s.l.
- mean annual rainfall: 1242 mm/year
- mean annual runoff: 1201 mm/year
- mean annual temperature: 4.1 °C

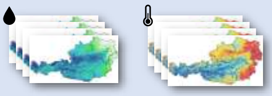


METHODS

CLIMATE CHANGE PROJECTIONS

- 4 different climate projections were selected from the Austrian National Climate datasets (ÖKS15).
- ÖKS15 – downscaled and bias-corrected simulations of EURO-CORDEX models in high resolution (1x1 km).

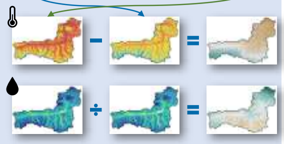
RCP 8.5: CNRM-CM5, MPI
RCP 4.5: CNRM-CM5, MPI



ANALYSIS OF CHANGES

- Each ÖKS15 dataset was split into 4 periods – 1 for current climate and 3 for future climates.
- The changes were evaluated only for the current and the latest future periods for each month separately.

current: 1981-2010
future: 2011-2040, 2041-2070, 2071-2100



ANALYSIS OF LOW-FLOWS

- The analysis of low-flows was carried out at the outlet from the catchment for the runoff simulations from 5 scenarios.
- The current climate scenario was used to calculate a low-flow threshold of Q_{80}.
- The following low-flow statistics were evaluated:

T-year low-flows | *longest low-flow runs in year* | *total low-flow days in year*

WEATHER GENERATOR

- A multi-site weather generator of daily rainfall and air temperature series utilizing weather pattern classification.
- Used to simulate 10000 years of synthetic outputs at 507 and 1732 rainfall stations.
- Spatial interpolation from station data to a 2x2 km raster.

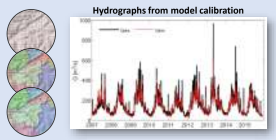
DELTA CHANGE ADJUSTMENT

- Synthetic outputs of the stochastic weather generator from the WETRAX+ project for the current climate were adjusted for each climate change scenario to represent climate at the end of the 21st century.
- Δ change adjustments – separately for each pixel and month

$$\left.\begin{aligned} P_{i,adj} &= P_{i,raw} \times \Delta P_i \\ T_{i,adj} &= T_{i,raw} + \Delta T_i \end{aligned}\right\}, i \in \text{Months}$$

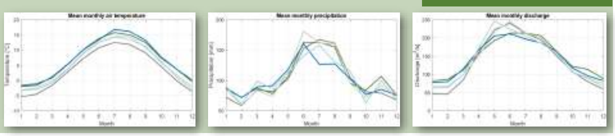
HYDROLOGICAL MODELLING

- HBV-type distributed rainfall-runoff model with a spatial resolution of 2x2 km.
- In calibration the model performance at the outlet from the catchment was KGE = 0.86 with a 5% underestimation of the water balance.
- Simulations for 5 synthetic scenarios – 1 for the current climate and 4 for the future climate



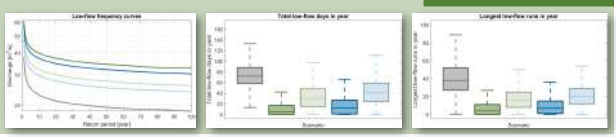
RESULTS

MONTHLY MEANS



CNRM_8.5 | MPI_8.5 | Current climate
CNRM_4.5 | MPI_4.5

LOW-FLOW STATISTICS



CONCLUSIONS

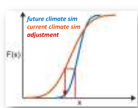
The low-flow analysis showed that the more extreme climate conditions transfer into **larger low-flows and shorter dry periods** compared to the current climate. The results can be attributed to two factors:

1) the low-flow season predominantly occurs during the winter, leading to reduced snow accumulation in the due to rising temperatures,
2) the adopted delta change approach reflects the changes in rainfall amounts but does not address the changes in rainfall frequencies.

FUTURE DIRECTIONS

Future efforts should primarily concentrate on rainfall adjustment methods.

1) Replace the delta change approach by a **quantile mapping** – use a separate model for each season and m-day rainfall.
2) Suggest a method to adjust the frequency of m-day rainfall events – for stations or grids.
3) Test different climate datasets to enable simulations for catchments outside of Austria.



HydroCarpath
Hydrology of the Carpathian Basin: catchment experiments and modeling for improved description and prediction of hydrological processes
9th November 2023, Karlsplatz 13/222, Vienna, Austria

download poster as pdf

Predicting water level changes in Lake Velence – an invitation to participate in a scientific challenge

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The prediction of lake water levels is becoming a crucial task of water resources management as changes in the climate and land use, coupled with increased water use, cause the water level of lakes and reservoirs to decrease progressively in many locations around the globe. Recently, an extreme drought caused record low water levels in Lake Velence, Hungary, that undermined recreational tourism around the lake, thereby triggering conflicts between water users within the catchment. Water managers' efforts to find solutions require reliable lake water level predictions.

This poster invites researchers, engineers, and enthusiasts to participate in a scientific challenge of predicting the water levels of Lake Velence at the beginning of each month during 2024. To participate in the challenge, one must estimate the daily water levels for the upcoming month.

Past data for the 2002-2022 period will be provided, including catchment characteristics and the operational rules of the hydraulic structures, stage and flow measurement in the catchment area, and the lake's current official water budget calculation method. Considering the known uncertainties of the current calculation method, participants are encouraged to develop their own unique method to determine lake water levels. Initial water levels and meteorological forecasts for the basin area will be given at the beginning of each month.

The monthly winner is the one whose prediction results in the lowest root mean squared error. The overall champion of the challenge is the one with the most monthly wins throughout the year.

INVITATION
TO PARTICIPATE IN A SCIENTIFIC CHALLENGE
predicting water level changes IN LAKE VELENCE

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SZÉCHENYI EGYETEM
UNIVERSITY OF GYŐR

The prediction of lake water levels (LWL) is becoming a crucial task of water resources management as changes in the climate and land use, coupled with increased water use, cause the water level of lakes and reservoirs to decrease progressively in many locations around the globe. (Ozdemir et. al. 2023)
Recently, an extreme drought caused record low water levels in Lake Velence, Hungary, that undermined recreational tourism around the lake, thereby triggering conflicts between water users within the catchment. Water managers' efforts to find solutions require reliable lake water level predictions.

1 WHY participate?

You can build and test your own prediction model on a well-measured catchment. You can get the excitement of the game. You can even win this challenge. There is a small but valuable prize for the champion as well.
Find out more in **#2 - #7**.

2 WHO can participate?

I thought this could be a good challenge for You! **Yes YOU!** You might be a hydrologist, a mathematician, a data scientist, a researcher or an engineer, but don't worry if you are none of those, you can still get involved!

Just look at **#3** to see What to do.

3 WHAT to do?

In a year-long competition, predict lake water levels for each day of a month at the beginning of each month. One LWL value for each day, as simple as that. You can even guess. Of course you can make it more complicated than that.

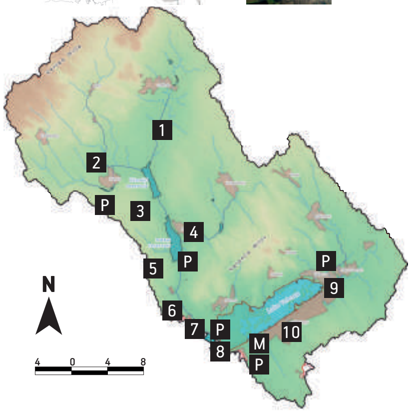
See **#4** on how to do that.

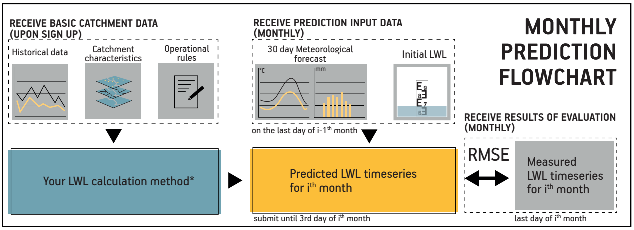
STEP 1 SIGN UP! **STEP 2** RECEIVE DATA **STEP 3** DEVELOP METHOD **STEP 4** PREDICT i^{TH} MONTH **STEP 5** CHECK RESULTS **STEP 6** REPEAT FROM STEP 3

4 HOW to predict?

You can use any method you want. Conceptual models, Hydrodynamic models, Statistical models, Regression models, AI or ML models, a combination of the above, or a completely new approach? You decide.
You will be equipped with past data for the 1998-2022 period, including catchment characteristics, stage and flow measurements, and the operational rules of main hydraulic structures.
Initial water levels and meteorological forecasts for the basin area will be given on the last day of each month. You need to hand in your predictions for the next month within the next 3 days.
Seems like you have some work to do... So when does this whole thing start?

See **#5** to find out.





* The lake's current official water budget calculation method will be given as well, however considering the known uncertainties of the current method (Chappon, Bene 2022, 2023), you are encouraged to develop your own model to determine future lake water levels.

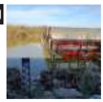
1 
Császár-stream upper
Q daily 1998-2022

5 
Pátkai reservoir
H monthly 1998-2022
elevation-area-capacity curve

9 
Vereb-Pázmándi creek
Q daily 1998-2022

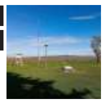
2 
Burján-creek
Q daily 1998-2022

6 
Császár-stream lower
Q daily 1998-2022

10 
Lake Velence
H daily 1998-2022
elevation-area-capacity curve

3 
Zámolyi reservoir
H monthly 1998-2022
elevation-area-capacity curve

7 
DIT - Water Outtake
Q monthly
1998-2022

M P 

4 
Rovákja creek
Q daily
1998-2022

8 
Dinnyés Outflow structure
Q monthly 1998-2022

Agárd Meteorological station:
T_{air}, T_{lake}, w, P°, pan evaporation
monthly: 1998-2022

Precipitation:
Zámoly, Pátka - monthly: 1998-2022
Dinnyés, Agárd, Velence -
daily: 1998-2022

5 WHEN does it start?

Predictions are first expected on **3rd January 2024.**

Initial water levels and meteorological predictions will be provided on 31st December 2023.
But don't worry if you miss the first months, you can still be the **OVERALL CHAMPION** at the end of the year.

See **#6** to find out how to become champion.

6 WHO wins?

At the end of each month, predicted and measured lake water levels will be compared and root mean squared error (RMSE) values will be calculated.
The monthly winner is the one whose prediction results in the lowest RMSE. The overall champion of the challenge is the one with the most monthly wins throughout the year.

Sounds like fun? Want to sign up? See **#7.**

7 WHERE do I sign up?

Just go to:
https://github.com/mate-chappon/LWL-prediction-challenge

to request access to all necessary data, comprehensive rules, and to join the discussion.

CHAMPION'S PRIZE: A hard cover book: "Conflict Resolution in Water Resources and Environmental Management" (Springer, 2015)
- or a scientific publication of your choice up to 150€.

Acknowledgements:
The research presented in this poster was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 project.

Literature:
Serkan Ozdemir, Muhammad Yaqub, Sevgi Ozkan Yildirim: A systematic literature review on lake water level prediction models 2023, https://doi.org/10.1016/j.envsoft.2023.105684
Máté Chappon, Katalin Bene: Uncertainties in the water budget calculation of Lake Velence, Hydrocarpath Conference 2022
Máté Chappon, Katalin Bene: Improving methods to calculate monthly water budget for Lake Velence EGU Conference 2023 https://doi.org/10.5194/egusphere-egu23-8334

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Land Use Land Change due to Wildfires: Impacts on Surface Runoff and Erosion. The Case Study of Mt. Pelion, Thessaly, Greece

Aris Psilovikos[1], Theodoros Papathanasiou[1], Georgios Mpouras[1], Dimitrios Malamataris[1], Thomas Psilovikos[3], Anthimos Spiridis[2]

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[2] HYETOS S.A. Consulting Company, Ippodromiou Sq. 7, 54622, Thessaloniki, Greece
[3] Laboratory of Forest Engineering and Topography, School of Forestry and Natural Environment, Aristotle University of Thessaloniki, P.O. Box 226, 54124, Thessaloniki, Greece.

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Wildfires can trigger dramatic increases in surface runoff and erosion, because of the burned vegetation and the appearance of a condition of soil-water repellence. Fire-enhanced surface runoff generation and soil erosion, constitute adverse effects of high concern for a long-term future period after a fire event occurrence.

The current study, investigates the increase on peak surface runoff and sediment loss as a result of a fire event that occurred in Mountain Pelion area in Greece on June 27th, 2007. Mountain Pelion is located in Magnesia Prefecture (Thessaly Region, Central Greece), between the Aegean Sea to the northeast and the Pagasitikos Gulf to the southwest and its capital is the city of Volos. The boundaries of the burned area were determined using both a satellite image, as well as, a relative map produced by the Regional Forest Protection Service and the total burned area was found to be almost 60 km^2.

The land cover of the area prior to fire event, mainly included forest, seminatural and agricultural areas as determined by the raster datasets produced by the Copernicus Land Cover program. The change of peak surface runoff discharge pre- and post- fire event, was estimated using the Natural Resources Conservation Service – CN (NRCS-CN) method, while the sediment loss was also estimated, using the Stiny – Herheulidze Method. The fire event was found to significantly increased peak surface runoff, which may cause the occurrence of flood events in the downstream area.

The results of the current study demonstrated that fire-induced alterations to the soil structure as reflected by the increase of the Curve Number parameter, cause an increase in runoff volume and sediment yield. Post-fire runoff and soil losses calculation, constitutes a crucial procedure for the better adaptation of burned areas to post – fire flood events.

Keywords: Wildfires; Land Use – Land Cover Change; Surface Runoff; NRCS-CN Method; Erosion, Stiny – Herheulidze Method, Sediment Yield.

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Laboratory of Ecohydrology & Inland Water Management (ECO–HYDRO Lab), Department of Ichthyology and Aquatic Environment, University of Thessaly, Fytoko Street, 38446, N. Ionia Magnisias, Greece

Land Use Land Change due to Wildfires: Impacts on Surface Runoff and Erosion. The Case Study of Mt. Pelion, Thessaly, Greece

Psilovikos A., Papathanasiou T., Mpouras G., Malamataris D., Psilovikos T. and Spiridis A.

Presented by Dr. Aris Psilovikos, Professor, Head of ECOHYDRO Lab, Sabbatical leave in Dept. of Land & Water Resources Management, STU (psiloviko@uth.gr)

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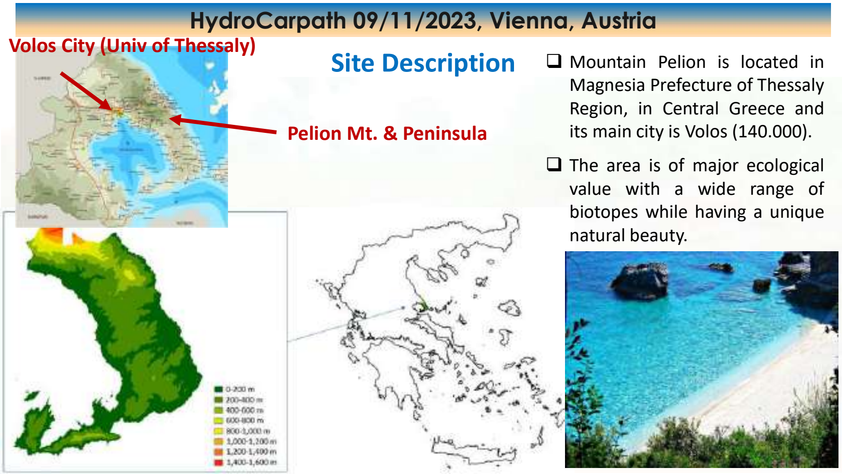
The Objectives of the study

(1) The determination of the burned area after a severe fire event in Mt. Pelion, using the **Natural Resources Conservation Service Curve Number (NRCS-CN) Method** (SCS, 1972) along with the **Stiny – Herheulidze Method** (Kotoulas, 1997), for the calculation of **surface runoff** and **sediment yields**, respectively

(2) The **comparison** of the peak runoff volumes and sediment yields **before** and **after** the event.


HydroCarpath 09/11/2023, Vienna, Austria
Volos City (Univ of Thessaly)
Site Description
Pelion Mt. & Peninsula
❑ Mountain Pelion is located in Magnesia Prefecture of Thessaly Region, in Central Greece and its main city is Volos (140.000).
❑ The area is of major ecological value with a wide range of biotopes while having a unique natural beauty.
0-200 m
200-400 m
400-600 m
600-800 m
800-1,000 m
1,000-1,200 m
1,200-1,400 m
1,400-1,600 m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…combination of coastal and mountainous environment in Pelion Mt. !!!

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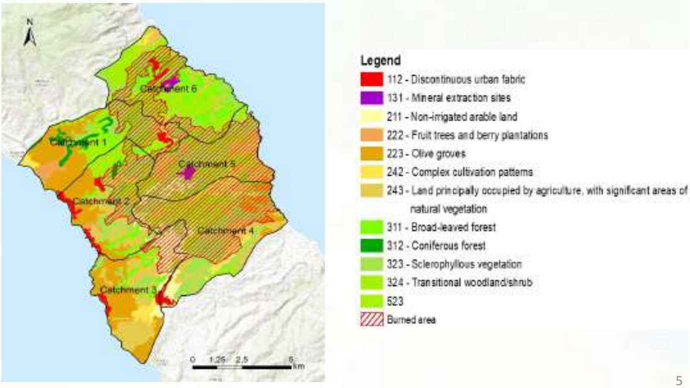
Determination of Burned Area

- A fire event occurred on June 27th, 2007.
- The total burned area was delineated using satellite images and was found equal to 58.11 km^2.



5

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Geographic characteristics and burned areas

Table 1. Geographical characteristics of the catchments affected by the fire event

Catchments name	Area (km^2)	Maximum elevation (m)	Average elevation (m)	Average slope (%)	Main channel length (km)
Catchment 1	19.77	625.64	235.38	14.06	9.49
Catchment 2	19.64	419.45	224.15	9.45	5.49
Catchment 3	19.36	340.12	177.72	7.73	6.05
Catchment 4	27.82	392.85	238.45	7.43	8.65
Catchment 5	17.33	624.12	315.54	14.99	6.44
Catchment 6	23.80	701.32	400.51	14.35	3.86

Table 2. Burned area (%) per each catchment and land cover

Land Cover	Catch. 1	Catch. 2	Catch. 3	Catch. 4	Catch. 5	Catch. 6
112	13.16	1.94	0.00	0.00	0.00	55.56
131	0.00	0.00	0.00	0.00	97.22	39.53
211	0.00	51.52	75.18	60.00	100.00	0.00
222	0.00	0.00	0.00	0.00	0.00	0.00
223	0.00	0.00	0.00	70.56	90.00	0.00
242	0.00	98.00	0.00	65.43	100.00	0.00
243	78.13	16.91	7.35	56.29	99.52	18.07
311	58.86	22.45	8.33	100.00	100.00	18.53
312	0.00	60.71	0.00	0.00	0.00	0.00
323	64.16	62.88	35.48	66.41	96.42	55.27
324	26.61	44.41	0.00	92.29	93.82	34.73
Total	25.90	31.62	16.74	68.15	96.65	33.49

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Impacts on Runoff and Sediment Yield

Catchment	Runoff volume (m^3/s)	
	Pre-fire	Post-fire
1	112.18	130.14 (+16.01%)
2	149.29	174.52 (+16.90%)
3	138.40	142.68 (+3.09%)
4	144.74	197.15 (+36.21%)
5	93.46	131.83 (+41.05%)
6	146.12	167.29 (+14.49%)
Weighted average		**+21.70%**

Catchment	Sediment yield (m^3/s)	
	Pre-fire	Post-fire
1	12.75	14.79 (+16.00%)
2	16.96	19.83 (+16.92%)
3	15.73	16.21 (+3.05%)
4	16.45	22.40 (+36.17%)
5	10.62	14.98 (+41.05%)
6	16.60	19.01 (+14.52%)
Weighted average		**+21.69%**

7

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Thank you for your attention !!!

8

Land Use Land Change due to Wildfires: Impacts on Surface Runoff and Erosion. The Case Study of Mt. Pelion, Thessaly, Greece

HydroCarpath 2023

09 November 2023
Vienna, Austria

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Abstract

Land Wildfires can trigger dramatic increases in surface runoff and erosion, because of the burned vegetation and the appearance of a condition of soil-water repellence. Fire-enhanced surface runoff generation and soil erosion, constitute adverse effects of high concern for a long-term future period after a fire event occurrence. The current study, Investigates the increase on peak surface runoff and sediment loss as a result of a fire event that occurred in Mountain Pelion area in Greece on June 27th, 2007.Mountain Pelion is located in Magnesia Prefecture (Thessaly Region, Central Greece), between the Aegean Sea to the northeast and the Pagasitikos Gulf to the southwest and its capital is the city of Volos. The boundaries of the burned area were determined using both a satellite image as well as, a relative map produced by the Regional Forest Protection Service and the total burned area was found to be almost 60 km2. The land cover of the area prior to fire event, mainly included forest, semi natural and agricultural areas as determined by the raster datasets produced by the Copernicus Land Cover program. The change of peak surface runoff discharge pre- and post- fire event, was estimated using the Natural Resources Conservation Service – CN (NRCS-CN) method, while the sediment loss was also estimated, using the Stiny–Herheulidze Method. The fire event was found to significantly increased peak surface runoff, which may cause the occurrence of flood events in the downstream area. The results of the current study demonstrated that fire-induced alterations to the soil structure as reflected by the increase of the Curve Number parameter, cause an increase in runoff volume and sediment yield. Post-fire runoff and soil losses calculation, constitutes a crucial procedure for the better adaptation of burned areas to post – fire flood events.

01 Introduction

Land use and climate change is expected to increase the magnitude and frequency of fires in many wildland environments, including the European region (Wu et al., 2021). Wildfires are of particular concern since they promote the reduction or elimination of ground cover and alteration of soil characteristics, exposing the mineral soil to raindrop impact and significantly affecting hydrological processes, including surface runoff and soil erosion (Wang et al., 2020). Hydrologic regime modification and soil degradation promotion depend on several factors such as pre-fire land cover, soil properties, soil water repellency, slope, rainfall intensity and amount, and the spatial distribution of the burned areas (Wilson et al., 2021).
The negative post-fire consequences cover not only the on-fire sites but also the downstream flood zone area and the associated human infrastructures. Fire-enhanced generation of runoff and soil erosion are maximal immediately after the fire event while the necessary time period for the situation to become similar to pre-fire one could be difficulty quantified since it depends on fire severity and post-fire climatic conditions.

Table 1. Geographical characteristics of the catchments affected by the fire event

Catchments name	Area (km²)	Maximum elevation (m)	Average elevation (m)	Average slope (%)	Main channel length (km)
Catchment 1	19.77	625.64	235.38	14.06	9.49
Catchment 2	19.64	419.45	224.15	9.45	5.49
Catchment 3	19.36	340.12	177.72	7.73	6.05
Catchment 4	27.82	392.85	238.45	7.43	8.65
Catchment 5	17.33	624.12	315.54	14.99	6.44
Catchment 6	23.80	701.32	400.51	14.35	3.86

Table 2. Burned area (%) per each catchment and land cover

Land Cover	Catch. 1	Catch. 2	Catch. 3	Catch. 4	Catch. 5	Catch. 6
112	13.16	1.94	0.00	0.00	0.00	55.56
131	0.00	0.00	0.00	0.00	97.22	39.53
211	0.00	51.52	75.18	60.00	100.00	0.00
222	0.00	0.00	0.00	0.00	0.00	0.00
223	0.00	0.00	0.00	70.56	90.00	0.00
242	0.00	98.00	0.00	65.43	100.00	0.00
243	78.13	16.91	7.35	56.29	99.52	18.07
311	58.86	22.45	8.33	100.00	100.00	18.53
312	0.00	60.71	0.00	0.00	0.00	0.00
323	64.16	62.88	35.48	66.41	96.42	55.27
324	26.61	44.41	0.00	92.29	93.82	34.73
Total	25.90	31.62	16.74	68.15	96.65	33.49

iii). Impacts of fire event on runoff and sediment yield

The Natural Resources Conservation Service Curve Number (NRCS-CN) method (SCS, 1972) along with the Stiny – Herheulidze method (Kotoulas, 1997) were used for the calculation of surface runoff and sediment yield, respectively. The runoff is mainly based on the Curve Number (CN) parameter which is related to soil type and land use. Considering the high severity of the fire event (Mpouras, 2009),the post-fire CN values are taken equal to 95 for the artificial surfaces, and 92 for the agricultural, forest and seminatural areas (Livingston et al., 2005).

The CN parameter was calculated equal to 82.16, 82.81, 85.72, 84.28, 84.75 and 82.99 for the pre-fire conditions, and was found to increase at 85.00 (+3.46%), 86.12 (+4.00%), 86.37 (+0.76%), 89.95 (+6.73%), 92.47 (+9.11%) and 86.50 (+4.23%) for the post-fire ones, for the catchments numbered as 1, 2, 3, 4, 5 and 6, respectively.
The calculated 50-years peak runoff volume and the relevant sediment yield are presented in Table 3.

Table 3. 50-years peak runoff volume and sediment yield for pre- and post-fire conditions

Catchments name	Peak runoff volume (m³/s)		Peak sediment yield (m³/s)	
	Pre-fire	Post-fire	Pre-fire	Post-fire
Catchment 1	112.18	130.14 (+16.01%)	12.75	14.79 (+16.00%)
Catchment 2	149.29	174.52 (+16.90%)	16.96	19.83 (+16.92%)
Catchment 3	138.40	142.68 (+3.09%)	15.73	16.21 (+3.05%)
Catchment 4	144.74	197.15 (+36.21%)	16.45	22.40 (+36.17%)
Catchment 5	93.46	131.83 (+41.05%)	10.62	14.98 (+41.05%)
Catchment 6	146.12	167.29 (+14.49%)	16.60	19.01 (+14.52%)

03 Discussion

The results of the current study demonstrated that fire-induced alterations to the soil structure as reflected by the increase of the Curve Number parameter, cause an increase in runoff volume and sediment yield. Post-fire runoff and soil losses calculation constitutes a crucial procedure for the better adaptation of burned areas to post-fire flood events.

02 Methods and Results

i). Site description

Mountain Pelion is located in Magnesia Prefecture of Thessaly Region, between the Aegean Sea to the northeast and the Pagasitikos Gulf to the southwest, in Central Greece (Fig. 1). The region is of major ecological value with a wide range of biotopes while having a unique natural beauty due to the harmonization of the natural environment with the traditional local building style.
The climate in the study area is hot-summer Mediterranean (Csa, Köppen classification system) with moderate temperatures, changeable rainy weather, and hot and dry summers. The average annual rainfall is 885.40 mm/year and the rainfall amount that Mountain Pelion receives is enough to support abundant vegetation with a plenty of different plant species.

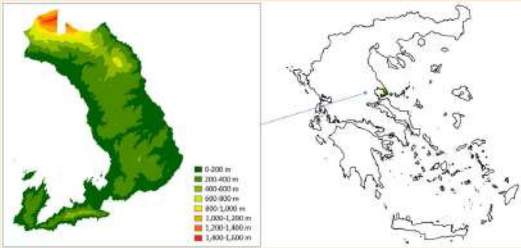

Fig. 1. Mt. Pelion Peninsula in Thessaly, Central Greece

ii). Determination of the burned area

The total burned area was delineated, using the appropriate satellite images, and analyzed using Esri ArcGIS pro software. The soil in the whole study area has very high runoff potential and low infiltration rates.
The DEM was utilized in the framework of the surface hydrological analysis of the study area which includes the surface water flow direction and accumulation, resulting in the delineation of the boundaries of 6 catchments (Fig. 2). The main geographical characteristics of the 6 catchments are presented in Table 1.
In terms of land cover in the pre-fire area, this included mainly forest and agricultural areas, as determined by the raster datasets generated by the Copernicus land cover program (Fig. 2). After the wildfire, the form of the total area revealed an area that has lost vegetation as a whole, and exposed its soil to the risk of erosion. The total and post-fire area per each catchment and land cover are presented in Table 2.

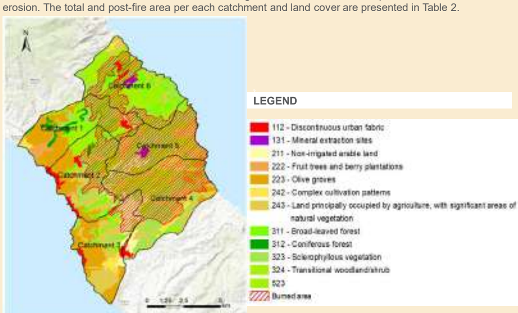

Fig. 2. Land cover of the study area and the extent of the burned area

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THE EFFECT OF MULTIPLE RESERVOIRS ON FLOOD PEAK REDUCTION: THE CASE OF TWO AUSTRIAN CATCHMENTS

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In Austria there are 78 large reservoirs, and in most cases, they are located in nested catchments. The presence of a reservoir generally produces an attenuation effect on flood peaks downstream; however, the combined effect of multiple reservoirs in a catchment remains unclear.

The aim of this work is to analyze the combined effect of multiple dams on flood peaks along the river network on a regional scale. Its evolution can be studied in space, considering how the effect changes along the river segments and as a function of the return period of the flood event.

The method used consists of two steps: (i) the design hydrographs are evaluated at several locations along the river network for 30, 100 and 300 year return periods, based on interpolated flood quantiles in ungauged catchments; (ii) the peak reduction is estimated based on the information on dams in the catchment (i.e., the number, position, storage capacity, and drainage area) and, using the concept of an equivalent reservoir, the protection ratio and the filling discharge.

The effect of the reservoirs is evaluated here as a percentage of the reduction of the flood wave peak. Preliminary results have been obtained for the Salzach and the Austrian parts of the Drau catchments that show that the relative peak reduction is highest near the reservoirs and rapidly diminishes downstream for each return period and different combinations of the dams.

Evaluation of precipitation corrections to improve reservoir inflow predictions by a conceptual hydrological model in the Malta Valley, Austria

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Conceptual hydrological models are widely used for the prediction of high-alpine runoff, which is essential for efficient reservoir management in hydropower production. The performance of these models is, however, strongly linked to the quality of the meteorological forcing data. The inherent uncertainties of distributed meteorological datasets in high-alpine areas are especially pronounced for precipitation. We evaluated different precipitation corrections to downscaled INCA data serving as inputs for hydrological modelling. The physically-based Alpine3D snowpack model, in combination with satellite-based snow depth maps, was used to derive quantitatively and spatially distributed precipitation scaling for the winter period; and a stepwise linear correction model was applied for the correction of the summer precipitation. Using the corrected precipitation, the Kölnbrein reservoir inflow (Malta Valley, Austria) was simulated with the COSERO precipitation-runoff model on an hourly timescale for the period 2015 – 2023. Different combinations of the winter and summer corrections were evaluated according to their potential to improve hydrological modelling. The preliminary results show that the combined correction of the winter and summer precipitation leads to the greatest improvements overall and during the snowmelt season.

Acknowledgements: We thank the VERBUND Energy4Business GmbH for fruitful discussions and providing us with data.

RAINFALL-RUNOFF MODELING BASED ON AN ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM IN HUNGARY

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Artificial neural networks (ANNs) have become one of the most promising tools to simulate complex phenomena in various fields. In hydrology, the first ANN-based rainfall-runoff models appeared in the 1990s. Since then, the ANN-based models have shown results comparable to conceptual models. According to the most recent publications, the Adaptive Neuro-Fuzzy Inference System (ANFIS) is one of the best-performing hydrological data-driven models. It can model nonlinear functions and identify nonlinear components while combining the flexibility of fuzzy modeling with the learning capability of neural networks. The present study is the first step of our detailed research. It reviews the international literature to identify the possibilities of rainfall-runoff modeling using ANFIS. Furthermore, an analysis of its applicability through model simulations was performed in MATLAB for the Hungarian catchments. The available datasets and the best input data combinations were examined. The results provide an insight into the limitations and potential of applying ANFIS-based rainfall-runoff models in Hungary.

Sparse runoff observations ample enough to improve multiple-objective calibration of satellite data of snow cover and soil moisture (preliminary results)

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Remote sensing has great potential for setting hydrological models and hence predicting runoff hydrographs in regions with sparse ground observations. The aim of this study was to analyze the annual and seasonal patterns of agreement between the model simulations and observations and to propose and evaluate strategies using only irregular runoff observations to constrain a conceptual hydrological model. In the first step, the model was calibrated to satellite images of the snow cover and soil moisture (without using runoff data). In the second step, the seasonal and annual agreement between the runoff model simulations and observations is analyzed in a large number of Austrian catchments. Identification of the spatial and temporal patterns of the agreement serves for the development of different scenarios of adding sparse (irregular) runoff observations into the multiple-objective calibration. The preliminary result of this study derives the patterns in the agreement and disagreement of the observed and simulated runoff, i.e., when and where the satellite data allows setting the hydrological model and where and when some additional runoff data are needed along with a comparison of different strategies to constrain the conceptual hydrological model.

Changes of the balance evapotranspiration trends in Austria

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Evapotranspiration plays an essential role in the hydrological cycle; however, this water cycle component is difficult to quantify. Changes in evapotranspiration are a consequence of climate change, and their magnitude is affected by changes in the available water and energy. Describing changes in evapotranspiration provides an important tool for decision-making processes in water resource management. This paper seeks to investigate how the water balance evapotranspiration trends have changed over time. We calculated evapotranspiration from the SPARTACUS database of daily runoff and precipitation totals for 140 watersheds in Austria. Trend analyses were realized with the Mann-Kendall test of trends and modifications of the Man-Kendall test of trends and Sen's slope in two periods, i.e., 1981–2020 and 2001-2020. The results show changes in the water balance evapotranspiration trends between the two examined periods. In the last years (2001–2020), the occurrence of increasing trend in water balance evapotranspiration of many watersheds decreased, there were also detected increasing occurrence of watersheds with decreasing trend in this period. Significant trends were mostly detected in watersheds with mean altitude lower than 500 m a.s.l. for both periods.

POOLING OF THE LONG-TERM AVERAGE MONTHLY RUNOFF USING THE PCA METHOD AND K-MEANS CLUSTERING IN SLOVAKIA

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This study is aimed at creating a new pooling scheme for the long-term average monthly runoff regime on the territory of Slovakia. For the analysis, the data of the long-term average monthly discharges from 57 gauging stations of the whole territory of Slovakia, which was provided by the Slovak Hydrometeorological Institute, were used. The selected basin areas range from 7.25 km^2 (5130 – the Spariská gauging station on the Vydrica stream) to 11474.30 km^2 (9670 – the Streda nad Bodrogom gauging station on the Bodrog stream). The monthly discharge data available were from gauging stations for the new reference period from 1991 to 2020 according to the World Meteorological Organization (WMO). The input data were processed as normalised long-term average monthly discharge data. The appropriate number of clusters was determined according to the statistical analysis using the average Silhouette Width and the Elbow method. Subsequently, the PCA method and K-means clustering were performed to pool the catchments into groups.

The results present the outputs of the particular runoff regime in the selected gauging stations divided into five clusters. Cluster 1 is characterised by south-central Slovakia and central Slovakia; Cluster 2 by the northwest and northeast of the country; Cluster 3 for the centre of northern Slovakia; Cluster 4 for central Slovakia, and Cluster 5 for the east, south and west of Slovakia.

These results were compared with previous studies of monthly runoff regionalisation in Slovakia for the previous reference period of 1961-2000. Using the R Studio program, the most important characteristic features of the individual clusters of gauging stations created were also analysed, which could help incorporate other catchments into appropriate regional types in the future. The methodological procedure developed could also be used in further studies to predict future flow regime changes on the territory of Slovakia.

Key words: pooling types, K-means clustering, PCA, R Studio

Acknowledgements This study was supported by the Slovak Research and Development Agency under Contract No. APVV-20-0374 and VEGA Grant Agency No 1/0782/21. The authors thank the agencies for their research support.

POOLING OF THE LONG-TERM AVERAGE MONTHLY RUNOFF USING THE PCA METHOD AND K-MEANS CLUSTERING IN SLOVAKIA

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ABSTRACT

This study is aimed at creating a new pooling scheme for the long-term average monthly runoff regime on the territory of Slovakia. For the analysis, the data of the long-term average monthly discharges from 57 gauging stations of the whole territory of Slovakia, which was provided by the Slovak Hydrometeorological Institute, were used. The selected basin areas range from 7.25 km2 (5130 – the Spariská gauging station on the Vydrica stream) to 11474.30 km2 (9670 – the Streda nad Bodrogom gauging station on the Bodrog stream). The monthly discharge data available were from gauging stations for the new reference period from 1991 to 2020 according to the World Meteorological Organization (WMO). The input data were processed as normalized long-term average monthly discharge data. The appropriate number of clusters was determined according to the statistical analysis using the average Silhouette Width and the Elbow method. Subsequently, the PCA method and K-means clustering were performed to pool the catchments into groups.

The results present the outputs of the particular runoff regime in the selected gauging stations divided into five clusters. Cluster 1 is characterized by south-central Slovakia and central Slovakia; Cluster 2 by the northwest and northeast of the country; Cluster 3 for the centre of northern Slovakia; Cluster 4 for central Slovakia, and Cluster 5 for the east, south and west of Slovakia.

1 RESEARCH AREA AND MATERIAL

***Fig. 1:** 1 Location of the selected gauging stations in Slovakia*

The input data consisted of the long-term average monthly discharges for 57 gauging stations (Fig. 1) in Slovakia in period 1991-2020, provided by the Slovak Hydrometeorological Institute.

The selected basin areas ranged from 7.25 km^2 (5130 – the Spariská gauging station on the Vydrica stream) to 11474.30 km^2 (9670 – the Streda nad Bodrogom gauging station on the Bodrog stream). The data from the gauging stations were normalized using standard normalization, and then processed using the PCA method and K-means clustering. QGIS (version 3.26.3) and R Studio (version 2022.12.0) created outputs.

2 METHODS

PCA method

Based on the PCA method (Principal Component Analysis), the main components were selected, which performed as input to the K-means clustering analysis. The Cumulative Proportion was determined at 0.98 (or 98 %) and based on it, seven main components were used.

The number of clusters

When deciding the number of clusters in the analyses, the following statistical methods were used, e.g., Average Silhouette Width, and Total within the Sum of Squares. When evaluating these results, using the "elbow" method, we set a suitable number of clusters to 5.

K-means clustering

The K-means clustering was used finally to create homogeneous pooling groups of the runoff regime in Slovakia for the period analysed.

SVM model and Permutation feature importance

Support Vector Machine (SVM model)

- Was used to determine the boundaries that separate individual clusters.
- The SVM model was trained with normalized data of the long-term average monthly discharges.
- The results were used to calculate the importance of cluster characteristics.

3 RESULTS

Based on the statistical methods used, the final division of catchments formed 5 clusters (Fig. 2). The number of clusters was chosen based on the Average Silhouette Width method and Total Within of Square tests.

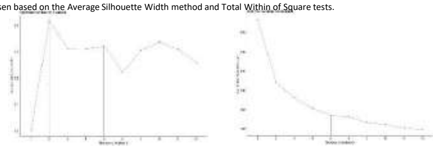
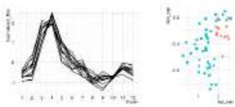


***Fig. 2** Results of statistical methods when calculating the number of clusters for PCA method and K-means clustering*

The results of the analysis with the boundaries of the clusters according to the most significant months are shown together with the indicated limit values of normalised data of the long-term average monthly discharges. To better evaluate the results of the analysis, a spatial visualisation of the basins was also created. The final runoff regime typical for each cluster is visualised with a graph of the dependence between the two most important months that decided the splitting in the clusters.

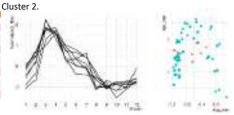
The first group of gauging stations (Cluster 1) are stations characterized by maximum values of the long-term average monthly discharges in March and April. Low values of the long-term average monthly discharges occur in September. Cluster 1 includes basins located in the south of Slovakia and central Slovakia. The most significant months for Cluster 1 are April and November.

Cluster	ID	
1	5740	7015
	5790	7045
	5800	7160
	5810	7730
	5820	7820
	6130	7860
	6150	
Month	**Min.**	**Max.**
April	1.75	2.51
October	-0.70	-0.84



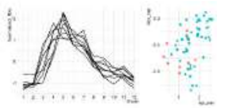
The second group of gauging stations (Cluster 2) is represented by the maximum long-term average monthly discharges in March and April and a minimum in autumn. The boundary of this cluster was determined by February and March. Basins in the north-west and north-east of Slovakia represent Cluster 2.

Cluster	ID	
2	5100	8930
	5880	9290
	6480	9500
	8870	9650
Month	**Min.**	**Max.**
February	-0.66	0.71
March	1.01	2.25



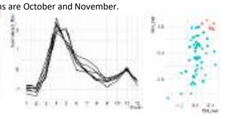
The following group of gauging stations is Cluster 3, mainly located in the northern part of central Slovakia. The maximum values of the long-term average monthly discharges are reached in May, and the lowest values in December, January and February. April and November are the most important months for Cluster 3. These basins represent part of the High Tatras, where the snowmelt affects the runoff regime.

Cluster	ID	
3	5330	5840
	5400	7930
	5550	8320
	5730	8690
	5780	
Month	**Min.**	**Max.**
April	0.24	1.80
November	-0.83	-0.19



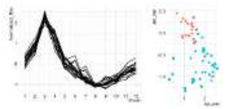
Gauging stations located in central Slovakia are located in Cluster 4. They reach the highest values of the long-term average monthly discharges in April and May. They show the lowest long-term average monthly discharges in January and February. The decisive months for this group of gauging stations are October and November.

Cluster	ID	
4	5310	7070
	6950	7660
	7060	8530
	7065	
Month	**Min.**	**Max.**
October	-0.62	-0.31
November	-0.06	0.09



The last group of catchment forms Cluster 5, in which the highest values of the long-term average monthly discharges are reached in March, and the lowest values of the long-term average monthly discharges are in August and September. Cluster 5 has the most of gauging stations.

Cluster	ID		
5	5130	6400	7440
	5250	6450	7480
	5260	6470	7600
	6180	6540	9410
	6200	6620	9620
	6360	6640	9670
	6390	6730	
Month	**Min.**	**Max.**	
January	-0.24	0.45	
April	0.62	1.61	



4 CONCLUSION

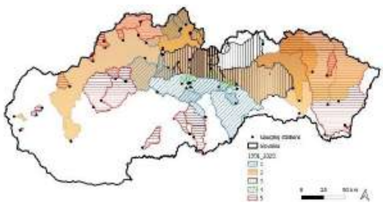


***Fig. 3** Spatial representation of the runoff regime clustering for selected Slovakia's basins.*

The presented study aimed to create a new pooling groups of the long-term average monthly discharge regime in Slovakia. The analyses used data from 57 selected gauging stations from the period 1991-2020. Based on the PCA method, the main principal components were selected, which performed as input to the K-means clustering analysis. The data, modified by standard normalization, were divided into 5 clusters. Using the R Studio program, the most important characteristic features of the created individual clusters of gauging stations were also analyzed, which can help to classify other gauging stations into derived pooling groups.

The results (Fig. 3) consists of the division of selected basins into five groups, which have a typical runoff regime on the territory of Slovakia. Cluster 1 represents catchments of the south of central Slovakia. The lowest long-term average monthly discharges are observed in September and the highest in April. Cluster 2 is in the northwest and northeast Slovakia. The long-term average monthly discharges reach their maximum in March and their minimum in autumn. Cluster 3, for centre-north Slovakia, and Cluster 4 are form for catchments mostly in central Slovakia. Both clusters 3 and 4 have the highest long-term average monthly discharges in May and the lowest in winter months. Cluster 5 is formed in the east, south and west of Slovakia. This cluster is characterised by an increase in the long-term average monthly discharges in March and a decrease in the long-term average monthly discharges in August and September.

Acknowledgement

This study was supported by the Slovak Research and Development Agency under Contract No. APVV-20-0374 and VEGA Grant Agency No 1/0782/21. The authors thank the agencies for their research support.

Comparison of two hydrograph separation methods in the Hydrological Open Air Laboratory using stable isotopes

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Exploring the isotopic composition of precipitation and streamflow in small catchments and the event and pre-event components of precipitation events using two-component and ensemble isotopic hydrograph separation may better explain overall catchment behaviour, more specifically, the origin of water. The aim of this study was to investigate the variability in the isotopic composition of precipitation and runoff in the 66 ha agricultural catchment in Austria known as the Hydrological Open Air Laboratory (HOAL) in order to compare two isotope hydrograph separation methods. Two-component (IHS) and ensemble (EIHS) isotopic hydrograph separations (for both 18O and 2H) were conducted for the catchment outlet for multiple events during the warm periods of 2013–2018. The results showed that the isotopic composition of the discharge in the HOAL remained nearly constant between the events which can be explained by the large diffuse groundwater discharge into the stream in the catchment. It was found that EIHS provided average new water fractions that were close to the averages obtained by IHS. Even though EIHS could not provide the ranges of the new water fractions during peak flows, this study proved that the results obtained by EIHS were close to the ones by IHS.

Evaluating flood events caused by Medicane "Daniel" of the Thessaly district (Central Greece) using remote sensing data and techniques

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On September 4, 2023, Thessaly, Greece, witnessed a catastrophic flood due to Medicane Daniel. Extreme rainfall, ranging from 305 mm to 1096 mm between 4 and 12 September, caused extensive damage to the infrastructure, agriculture and houses. Seventeen casualties were recorded. This study is aimed at utilizing radar data from earth observation satellites to detect the inundated areas and evaluate the flood impacts. Sentinel images were acquired from https://scihub.copernicus.eu/ for 7, 10, 13, and 19 September, 2023, along with a CORINE Land use/Land cover map. Processing the satellite images involved several steps, including their calibration, noise removal, filtering, and polarization adjustment. Flooded areas were quantified for the specified dates, thereby revealing substantial coverage. The damage assessment focused on irrigated and non-irrigated land as well as pasture areas, highlighting the severity of the impact on them. The second phase incorporated the Flood Water Depth Estimation Tool (FwDET) to estimate the floodwater depths and revealed maximum depths near riverbanks. In conclusion, this study employed advanced remote sensing and GIS techniques to rapidly estimate flood characteristics and assess Medicane Daniel's damage to the Thessaly prefecture from September 4 to 12, 2023.

Evaluating flood events caused by Medicane “Daniel” of the Thessaly district (Central Greece) using remote sensing data and techniques

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ABSTRACT Severe floods cause extensive damage, affecting lives, agriculture, and infrastructure. Accurate mapping of flooded areas is crucial for assessing impacts and guiding response efforts. The Floodwater Depth Assessment Tool (FwDET), a key GIS algorithm, calculates water depths in inundated regions. A study in Thessaly, Greece, utilized Sentinel imagery and FwDET to assess flooding caused by Medicane "Daniel". The impacted area, including the Pinios River basin, showed significant inundation and damage to irrigated land, emphasizing the need for adequate flood response and mitigation.

1 DATA

The study area, spanning from 39°11' N to 39°58' N latitude and 21°52' E to 22°45' E longitude, includes the Pinios river basin with an area of 12.200 km2 and significant agricultural productivity (49.5% of Thessaly Water District). The region, encompassing Mount Olympus and a fertile Thessaly plain, contributes about 14.2% of Greece's primary products, and the Pinios River flows from the Pindus Sierra to the Aegean Sea.

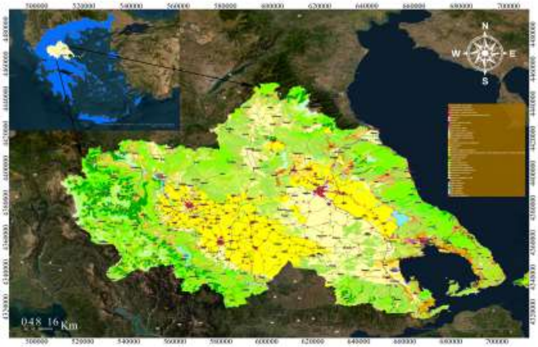

Figure 1. Land use / Land cover map of Thessaly district (Greece)

2 METHODS

The materials and methodology employed to fulfil the objectives of this study can be categorized into two main sections. The initial section encompasses inundation mapping utilizing SAR images, while the subsequent section focuses on flood depth calculation using the FwDET tool and damage assessment. SNAP software is used for pre-processing Sentinel images, including calibration, noise removal, speckle filter, and terrain correction. Corine Land use/Land cover map and ALOS PALSAR DEM were used to assess flood damage and calculate water depth, respectively.

3 RESULTS

The flood event progression from western to eastern Thessaly.

- September 07, 2023, inundated areas covered a total of 223.34 Km^2
- September 10, 2023, inundated areas covered a total of 516.52 Km^2
- September 13, 2023, inundated areas covered a total of 169.70 Km^2
- September 19, 2023, inundated areas covered a total of 109.43 Km^2

Figure 2. Flood covered maps of Thessaly, September 7th, 10th, 13th, 19th, (from left to right)

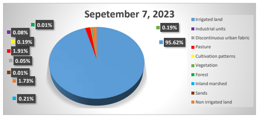

Figure 3. Land use / Land cover damage distribution, 7th of September

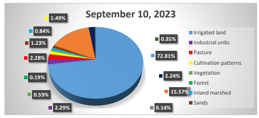

Figure 4. Land use / Land cover damage distribution, 10th of September

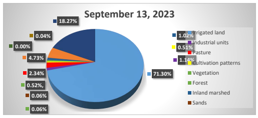

Figure 5. Land use / Land cover damage distribution, 13th of September

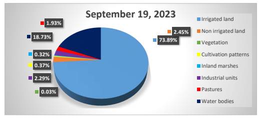

Figure 6. Land use / Land cover damage distribution, 19th of September

- Irrigated land is the most affected class, with inundated areas covering 96.52% to 73.89% of the total extent from the 7th to the 19th of September.
- Non-irrigated land damage accounts for 15.98% to 2.45% of total area cover.
- Inundated areas cover 1.91% to 2.34% of pasture areas.

Figure 6. Distribution of flood water depth estimated by the FwDET tool

- Areas within the red circles present the highest observed depth. Maximum depths are located near the river banks.
- Depth is increased from 7th to 10th of September and decreased from 13th to 19th

4 CONCLUSION

- Floods have extensive and devastating impacts, causing loss of life, agricultural damage, and infrastructure destruction.
- On 10th of September maximum flooded area observed (516.52 Km^2) along with maximum flood depth.
- Irrigated land was the most affected area, with flooded areas covering 95.62% of the total cover on the 10th of September.
- Accurate flood mapping is crucial. Remote sensing techniques and tools like FwDET are essential for damage assessment.

Acknowledgement
This work was supported by the the VEGA Commission for Earth Sciences, Enviromental Sciences (and Earth Resources). VEGA 1/0782/21

Selection of the peak runoff coefficient estimation method for the Horné Orešany – Parná case study (Slovakia)

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The research presents the results of the peak runoff coefficient estimated for the small Horné Orešany – Parná basin in Slovakia. The study aims to estimate the design peak runoff coefficient, which was determined by direct and indirect methods.

The first part of the study was devoted to calculating the design peak runoff coefficient according to the indirect method, which is based on the basic parameters for calculating runoff based on a rational formula. Three different critical durations of rain were used according to the calculation methods given by Nash (1960), Kirpich (1940) and Hrádek (1989). The critical rainfall was estimated for the nearest rain gauge station, i.e., Smolenice.

The second part of the study was devoted to the direct estimation of the design peak runoff coefficient. The analysis is based on the hourly flow measurements in the Horné Orešany – Parná basin for the 1989 – 2021 case study. For the analysis, we divided the annual maximal flows in the winter and summer. We separated and estimated the runoff volume and the time of rising and falling limbs from the selected peak flood waves. This was used to calculate the direct peak runoff coefficient and was subsequently subjected to statistical analysis according to the Johnson probability distribution. The results of the model are estimated peak runoff coefficient for a recurrence period of a hundred years.

The study results show that the direct method leads to lower estimates of the peak runoff coefficient in a small watershed (0.20 for the summer and 0.21 for the winter). On the other hand, the values determined by the indirect method are 0.18 – 0.39 in the winter months, but in the summer months, the estimated values are close to double, and in some cases, up to three times (0.42 – 0.90) those values, pointing to significant differences in the estimation of the peak runoff coefficient, which should be taken into account in future calculations.

The study was supported by the VEGA Grant No. 1/0782/21. The authors are very grateful for their research support.

Keywords: peak runoff coefficient; small basins; drain; rational formula

SELECTION OF THE PEAK RUNOFF COEFFICIENT ESTIMATION METHOD FOR THE HORNÉ OREŠANY – PARNÁ CASE STUDY (SLOVAKIA)

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INTRODUCTION

The aim of the project is the analysis of peak runoff coefficients (φN) in small watersheds using two calculation methods.

The first method deals with indirectly determining peak runoff coefficients based on predetermined data and relationships established on rational formulas for calculating the runoff from the basin.

The second method is based on direct flow observations. These flows were obtained from direct measurements of total precipitation and hourly monitored flows for an investigated period from 1989 to 2021 in the selected small watershed Parná - Horné Orešany. In each year were estimated maximal flood for winter and summer seasons. The resulting values are used for mutual comparison and evaluation of the individual methods for their application in practice.

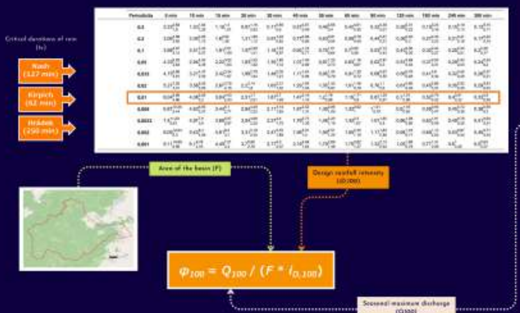
STUDY AREA

The research subject was the Horné Orešany - Parná basin, located in west Slovakia.

It is a small basin of 4,559 ha, primarily flat in nature.

METHODS

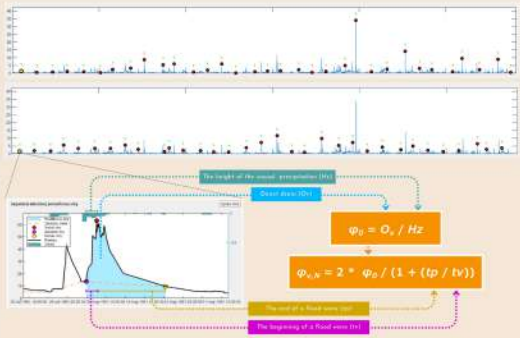
CALCULATING THE PEAK RUNOFF COEFICIENT



This method is based on the basic parameters of runoff formation in the watershed. The input data consists of three forms of calculation of time concentration, according to the authors Nash (1960), Kirpich (1940) and Hródek (1989). The result of the first part of the study is three indirect calculations of the peak runoff coefficient based on different procedures for calculating tc given by the named authors.

Data from the National Climate Program of the Slovak Republic NKP 17/22 subsequently determined the intensity of the design rainfall intensity.

DIRECT ESTIMATION OF THE PEAK RUNOFF COEFICIENT



The second part of the study is devoted to calculating the peak runoff coefficient by the direct method.

The calculation is based on actual observations of seasonal flood waves in the Parná basin and precipitation observed over thirty-three years. The investigated period was divided into two seasons: winter (I – V and XI-XII) and summer (VI - X). At the same time, these data were used to estimate Q100.

To determine $\varphi 100$, the resulting values were subjected to statistical analysis using Johnson's distribution.

RESULTS

The results showed differences in estimating peak runoff coefficients using the direct (Johnson's distribution) and indirect methods. The most significant differences were in the summer season between the direct and indirect estimates of the peak coefficient. The values determined by the indirect method for summer are 0.42 - 0.90. These numbers are double and, in some cases, triple the estimated peak runoff coefficients calculated with the direct method. During the winter, there are no significant differences between the estimates of peak runoff coefficients. The values determined by the indirect method are 0.18 - 0.39 in the winter months. The study results show that the direct method leads to lower estimates of the peak runoff coefficient in a small watershed (0.20 for the summer and 0.21 for the winter). One reason may be that many of the selected summer flood waves did not represent extremes during the thirty years of drainage from the basin.

The study was supported by the VEGA Grant No. 1/0782/21. The authors are very grateful for their research support.

CONSTRUCTING OF CONTROL FLOOD WAVE USING A VINE COPULA-BASED APPROACH

ANNA LIOVÁ[1], ROMAN VÝLETA[1], KAMILA HLAVČOVÁ[1], SILVIA KOHNOVÁ[1], TOMÁŠ BACIGÁL[2], JÁN SZOLGAY[1]

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To assess secure hydraulic structures we need to correctly estimate design values. In Slovakia in the framework of the safety assessment of dams during a flood load, each dam is required to be assessed for the critical load represented by a control flood wave. The control flood wave can sufficiently describe the impacts of flood events in many cases. In this study is proposed a methodology based on using empirical and statistical approaches for constructing synthetic design flood hydrographs. The method consists of a seasonal analysis of floods; the sampling of seasonal flood hydrographs; the dependence modelling of peaks, volumes, and durations using vine copulas; and determining the joint conditional return period of the flood wave.

The resulting set of hydrographs can further serve as the basis for simulations of the transmission of a control wave through a reservoir for different load conditions, the long-term loading of water structures by high-volume waves, or surge loads induced by flood waves with large peak discharges. This method allows the designer to select a hydrograph of different shapes, volumes, and durations for a selected design discharge with a known joint conditional probability of exceeding the volumes and durations for the flood risk analysis. The case study was carried out on the Parná river catchment in Slovakia.

STU SvF
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
FACULTY OF CIVIL ENGINEERING

TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

BOKU | HyWa Institute of Hydrology and Water Management

HYDROLOGY OF THE CARPATHIAN BASIN: CATCHMENT EXPERIMENTS AND MODELING FOR IMPROVED DESCRIPTION AND PREDICTION OF HYDROLOGICAL PROCESSES

12TH HYDROCARPATH INTERNATIONAL CONFERENCE, 9 NOVEMBER 2023

CONSTRUCTING OF CONTROL FLOOD WAVE USING A VINE COPULA-BASED APPROACH

ANNA LIOVÁ, ROMAN VÝLETA, KAMILA HLAVČOVÁ, SILVIA KOHNOVÁ, *TOMÁŠ BACIGÁL*, JÁN SZOLGAY

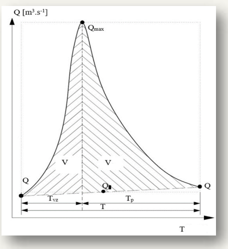
DEPARTMENT OF LAND AND WATER RESOURCES MANAGEMENT

DEPARTMENT OF MATHEMATICS AND DESCRIPTIVE GEOMETRY

FACULTY OF CIVIL ENGINEERING, SLOVAK UNIVERSITY OF TECHNOLOGY

MAIN AIM

- Secure hydraulic structures ► need to correctly estimate design values



Methodology for constructing nonparametric synthetic design flood hydrographs

Dependence modelling of peaks, volumes and durations using the vine copulas

Determine the joint conditional probability of non-exceedance of the flood volume and the duration conditioned on the flood peak for each synthetic hydrograph

STUDY AREA & DATA

- Horné Orešany reservoir, built on the Parná river
- Located in western Slovakia, in The Little Carpathians
- Catchment area in the profile of the dam is 45.59 km2

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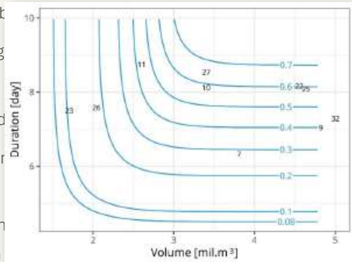
Data:

- from gauging station 5250 Horné Orešany:
- hourly discharges Qh [$m^3.s^{-1}$]
- period 1988-2021

METHODS & RESULTS

- Selection of waves occuring from June to Oktob
- Separation of discharge waves – for each hydrog V, duration D, observed shape
- Dependence modelling of peaks, volumes and d
- Rescaling of observed waves to hydrograph fragr
  - Q_{100}, fixed duration, estimated volume
- Determining the joint conditional probability of n duration conditioned on the flood peak for each



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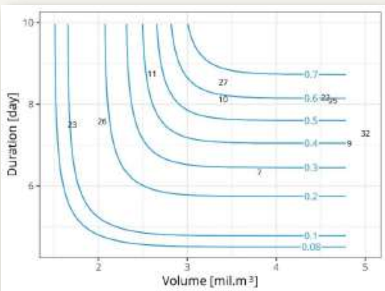
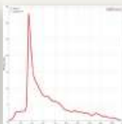
METHODS & RESULTS





Nr.10

- Known joint conditional probability of non-exceedance of the flood volume and the duration conditioned on the flood peak

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CONSTRUCTING OF CONTROL FLOOD WAVE USING A VINE COPULA-BASED APPROACH

Anna LIOVÁ[1], Roman VÝLETA[1], Kamila HLAVČOVÁ[1], Silvia KOHNOVÁ[1], Tomáš BACIGÁL[2], Ján SZOLGAY[1]

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Corresponding author: anna.liova@stuba.sk

ABSTRACT

To assess secure hydraulic structures, we need to correctly estimate design values. In Slovakia in the framework of the safety assessment of dams during a flood load, each dam is required to be assessed for the critical load represented by a control flood wave. The control flood wave can sufficiently describe the impacts of flood events in many cases. In this study is proposed a methodology based on using empirical and statistical approaches for constructing synthetic design flood hydrographs. The method consists of a seasonal analysis of floods; the sampling of seasonal flood hydrographs; the dependence modelling of peaks, volumes, and durations using vine copulas; and determining the joint conditional return period of the flood wave. The resulting set of hydrographs can further serve as the basis for simulations of the transmission of a control wave through a reservoir for different load conditions, the long-term loading of water structures by high-volume waves, or surge loads induced by flood waves with large peak discharges. This method allows the designer to select a hydrograph of different shapes, volumes, and durations for a selected design discharge with a known joint conditional probability of exceeding the volumes and durations for the flood risk analysis. The case study was carried out on the Parná river catchment in Slovakia.

1 DATA

Study area :

- Horné Orešany reservoir, built on the Parná river
- Located in western Slovakia, in The Little Carpathians
- Catchment area in the profile of the dam is 45.59 km^2

The catchment area of the river Parná with the water reservoir Horné Orešany

Data:

- from gauging station 5250 Horné Orešany:
- hourly discharges Q_h [m^3.s^{-1}]
- period 1988-2021

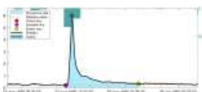
2 METHODS

- Selection of discharge waves based on their occurrence in year
  - Processed the waves occuring from June to Oktober – 33 summer waves

Identified waves from discharge time series

- Separation of discharge waves – for each hydrograph get characteristics: discharge Q, volume V, duration D, observed shape
  - FloodSep software

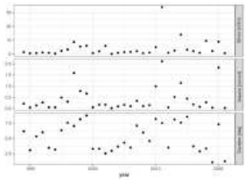
Example of separation ▶

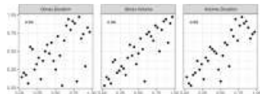


- Dependence modelling of peaks, volumes and durations using the vine copulas
- Rescaling of hydrograph fragments with the appropriate design flood into synthetic design hydrographs
  - synthetic hydrographs are constructed using the fixed T-year peak discharge and the shapes of the fragments; the durations of the floods is fixed, and their respective volumes are then calculated
  - y-values of the fragment calculate by interpolation
- Determining the joint conditional *probability of non-exceedance* of the flood volume and the duration conditioned on the flood peak for each synthetic hydrograph

3 RESULTS

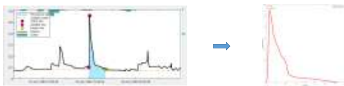
Results of the separation – hydrograph characteristic





Dependence analysis between the annual maximum peak discharges and the volumes and durations of the selected summer floods

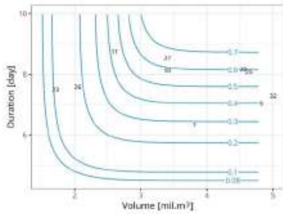
Rescaling of hydrograph fragments



Observed flood hydrograph
- Q= 0,559 m^3/s
- V = 0,215 mil. m^3
- T = 73 hours

Synthetic flood hydrograph
- Q= 32,76 m^3/s
- V = 1,566 mil. m^3
- T = 73 hours

Nr.	pQmax [-]	Volume [mil.m^3]	Duration [days]	Joined CDF conditioned by Q100
7	0,99	3.81	6.33	0.28
9		4.82	7.04	0.40
10		3.40	8.13	0.59
11		2.60	8.75	0.44
22		2.60	8.75	0.44
23		1.71	7.50	0.11
25		4.63	8.08	0.59
26		2.04	7.58	0.18
27		3.40	8.54	0.65
32		5.00	7.29	0.45



Isolines of joint conditional probability of non-exceedance of duration and volume on the 100-years flood peak

4 CONCLUSION

The method presented here is based on rescaling normalized observed seasonal flood hydrographs called fragments into synthetic flood hydrographs.

This analysis assumes that the hydrological risk of the failure of the hydraulic structure is determined by a joint probability of non-exceedance of the synthetic design flood duration and volume conditioned on the design flood peak.

Each synthetic hydrograph is described by a joint probability of non-exceedance of volume and duration conditioned on the flood peak with a given return period derived by vine copulas.

The designer is provided with the possibility of selecting design flood hydrographs of various shapes, volumes, and durations for a selected design discharge with a known joint conditional probability of non-exceedance of the volumes and durations for risk analysis.

Acknowledgement

This work was supported by the VEGA Grant No. 1/0782/21 and No. 1/0577/23. The authors are grateful for the support.

3D MODELLING OF THE HYDROLOGICAL OBSERVATION SITE IN THE HIDEGVÍZ-VALLEY FROM TERRESTRIAL LASER SCANS

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This study outlines the data acquisition and modelling of a hydro-meteorological observation site in the Hidegvíz Valley experimental catchment in West Hungary. The main goal is to record the spatial arrangement of the trees, site utilities, and the measuring equipment. A terrestrial laser scanner was applied to record high density point clouds from four station positions. Following the georeferencing of the individual scans and creation of a digital terrain model, the point measurements were classified into thematic categories by visual interpretation. The classified point cloud segments were used to create 3D surface and solid object models of the observation equipment as well as trees up to 2 meters in height. The resulting 3D models are appropriate for spatial documentation, and visualization, and they have potential to support the engineering design on the upgrade of the measuring equipment.

This presentation was made within the frame of the project TKP2021-NKTA-43 supported by the Ministry of Innovation and Technology of Hungary; National Research, Development and Innovation Fund.

INTRODUCTION

The hydrological observation site provides space for long-term studies to understand the relationship of water resources and forest vegetation. It is located in a mountainous forest in west Hungary, 15 km from Sopron, in the experimental catchment of Hidegvíz Valley. Researchers with the University of Sopron use this site to collect data over meteorological parameters, soil moisture, canopy interception, litter interception, leaf area, water consumption of trees, run-off water (Gribovszki et al. 2006, Kalicz et al. 2011, Zagyvainé et al. 2019). The site is surrounded by the Rák-stream, and covered by a mature alder (Alnus glutinosa L.) stand. The area is flat and rectangle shaped with side length of approximately 15 × 20 meter. Special attention has been paid during the maintenance of the site to preserve natural stand conditions. Hydro-meteorological observations carried out here have been contributed to numerous scientific results (Gribovszki et al. 2008, Gribovszki et al. 2011, Gribovszki 2018).

Upgrade plans of the site contain installation of additional manually-operated measuring devices, and electronic sensors with digital data recording. Setup, operation and maintenance of the equipment require detailed map over the site containing the following entities:

- fence and posts along the site boundary,
- iron tower on which hydro-meteorological sensors are mounted at various height,
- ground-fixed, wooden storage of meteorological sensors
- equipment for hydro-meteorological observation (barrels, tanks)
- plastic pipes for probing ground water level,
- tree stems within the site

The map is supposed not only to display the layout of objects, but model them in 3-Dimensional domain. Extension of 2D maps to 3D models requires additional measurement of object coordinates in consecutive height levels, but offer the possibility to view objects from arbitrary directions. Since the equipment used for observations is located on the ground or close to the ground level, the vertical extent of the model space is limited to 2 meter height, except for the tower. This limitation excludes tree crowns, which simplifies the subsequent work significantly. Models are created based on terrestrial laser scans comprising point measurements of high spatial density.

METHOD

The laser scanning is performed in March 2022 in leaf-less state of trees. The instrument is a Leica BLK360 terrestrial laser scanner which emits laser in the infra-red band with capacity of ranging up to 60 m. The scanning results in a radial point pattern with point spacing of 5 mm at 10 meter distance. In addition to the 3D coordinates, each point measurement has intensity data that enhance the visual classification of objects in the point cloud.

Despite the leaf-less state of vegetation, the abundant shrub layer reduces the range of measurements, so scanning from four positions were needed to capture all objects. Single scans are transformed from the sensor's body frame (i.e. local reference system) to a mapping reference system. This process, known as georeferencing, requires control points with coordinates measured in both reference systems. A network of eight control points was established using a Leica Flexline TS03 total station and a Leica Viva GS16 surveying-grade GNSS antenna. To identify control points in the laser scans, retro reflecting target was set on each point before performing the laser scanning. The spatial arrangement of the control points ensures that minimum three targets can be identified in each scan. To ensure the consistent georeferencing among multiple scans, targets are mounted on tripods, which firmly keeps the vertical axis stationary, thus reduces the discrepancy in target centre coordinates measured from varying positions. Leica Cyclone (https://leica-geosystems.com/) and CloudCompare (https://cloudcompare.org/) software packages were used for georeferencing, which resulted in a spatially consistent point cloud of the scans captured from the four station positions.

To create the model of the terrain surface, we need point measurements having been measured from the ground. The point cloud is subdivided into a grid of 0.5 meter, and the lowest measurement is selected as ground point in each cell. A digital terrain model (DTM) is created on the ground points by using TIN interpolation. The DTM is used to compute the elevation of points relative to the ground, so the resulting Z-coordinates refer to height of the point above the ground.

Figure 1. The merged point cloud of four terrestrial laser scans following the georeferencing. Point measurements from the ground level and from above 2 meter height are removed for better visualization. Remarkable that the majority of the points are recorded from the vegetation.

The point cloud is submitted to visual interpretation, when each point is classified into one of the following categories: fence post; tree stem; tower; tanks and barrels for recording precipitation; sensor storage box; pipe. In case of objects with simple geometry, a simple model (geometric primitive) is fit directly to the object points. At objects with complicated shape, the main dimensions are measured in the point cloud manually, and the models are created upon these dimensions using the AutoCAD software package. The tower, an instance of the precipitation tank, and the sensor storage box is created with this two-staged procedure. Since the tower had been assembled by fixing uniform elements one over the other, it is reasonable to create the model solely of the lowermost element, then copy-and-move this element up to reaching the top of the tower. Tree stems, fence poles, and the tower are modelled as solid objects, while the rest are modelled with set of surfaces.

RESULTS AND DISCUSSION

The first outcome of the data processing is the georeferenced point cloud compounding four scans captured from different positions. The projection system of the horizontal coordinates is the Hungarian National Grid (EOV, EPSG:23700), while the primary elevation coordinates are referenced to the Baltic sea level (EOMA) which were subsequently normalized to ground level. The maximum residual of the georeferencing is below 5 mm, so the scans spatially match well enough for object modelling.

Cylindrical models represent tree stems up to 2 meters in height in terms of position, leaning, and diameter. However, the actual shape of deciduous trees may additionally feature taper and curvature, both of which remain obscured at cylindric approximation. Models of the fence poles reveal that some of them are leaning and need affirmation. The highest object in the site is the tower that emerges above the canopy. Moving up along the tower, data gaps increasingly encounter in the point cloud due to obstruction of the canopy. Since the tower is modelled with replication of the lowest element, these data gaps hardly impact the modelling.

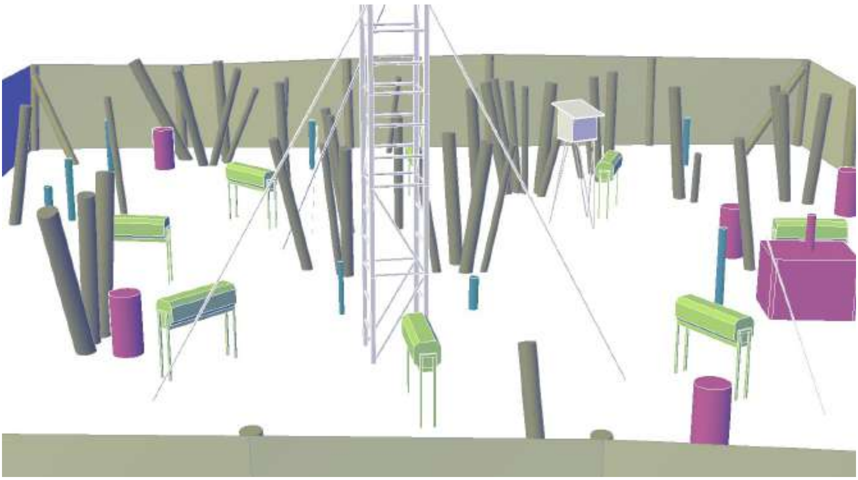

Figure 2. The completed 3D model of the observation site

Comparing to classic topographic surveying, laser scanning is regarded more generic in data collection as the sensor captures any kind of reflecting surfaces within its operating range, including ones that are irrelevant in the current mapping project. Consequently, as sort of manual or automatic filtering procedures are required to classify the point data by relevance. For a different purpose, the point data that have just been classified as irrelevant may contain valuable information. For instance, tree metrics have not been estimated in this study, but the normalized point cloud allows for tree height estimation following tree segmentation (Brolly et al. 2022).

In this study, the main objective is to record the 3D spatial arrangement of the observation equipment. There are some advantages of three-dimensional modelling over conventional map projections. Beyond giving insight into the site characteristics for visualization purpose, 3D models are convenient for checking whether two objects intersect each other, or whether the extent of free space is enough when the location of an object is searched. It is difficult in a map to display the variation in height below the cables of the tower, while it is straightforward in a model (Figure 2.). A similar possibility is to identifying trees that affect the appropriate operation of an observation device or pose threat to the infrastructure, like an inclined tree weighing on the fence as it depicted in Figure 3.

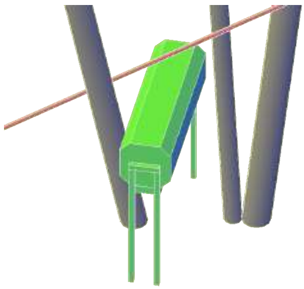

Figure 3. Test of the available space for setting up a water tank below the cable and between the trees

Our model omits the objects that are too small to be detected in the point cloud; thermometers for soil temperature monitoring, and nets on the ground for collecting litter, just to mention a few. The complement of the model with fine details requires a total station survey, which can benefit from using the control points established in this study.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Culture and Innovation project TKP2021-NKTA-43 with the National Research Development and Innovation Fund TKP2021-NKTA program.

This research was supported by the project "Assessment of wooden biomass production" (GINOP-2.3.3-15-2016-00039).

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3D MODELLING OF THE HYDROLOGICAL OBSERVATION SITE IN THE HIDEGVÍZ-VALLEY FROM TERRESTRIAL LASER SCANS

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This study outlines the data acquisition and modelling of a hydro-meteorological observation site in the Hidegvíz-Valley experimental catchment in West Hungary. The main goal was to record the spatial arrangement of the trees, site utilities, and the measuring equipment. Terrestrial laser scanner was applied to record high density point clouds from four station positions. Following the georeferencing of the individual scans and the creation of a digital terrain model, point measurements were classified into thematic categories by visual interpretation. Classified point cloud segments were used to create 3D surface and solid object models of the observation equipment as well as trees up to 2 meters in height. The resulting 3D models are appropriate for spatial documentation, visualization, and they have potential to support the engineering design on the upgrade of the measuring equipment.

Data acquisition

The laser scanning was performed in March 2022 in leaf-less state of trees using a Leica BLK360 instrument in high point density mode (5 mm spacing at 10 m distance). Four scan positions were used to ensure evenly distributed point cover in multiple directions for all observation objects. A network of eight control points was established using a Leica Flexline TS03 total station and a Leica Viva GS16 surveying-grade GNSS antenna. To identify control points in the laser scans, a retro reflecting target was set on each point (Figure 1.).

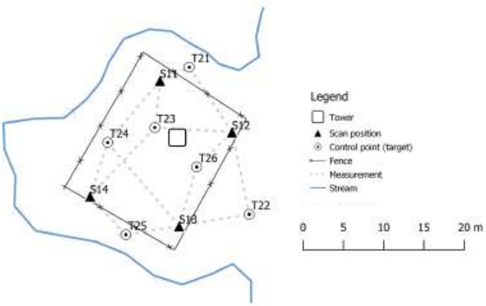

Figure 1. The location of the observation site, the control points, and the scan positions. The arrangement of the scan positions enables minimum three control points to be identified in the corresponding point cloud.

Processing

The individual point clouds were merged and transformed into the national map coordinate reference system. Terrain points were filtered automatically by selecting the point measurements with the lowest elevation coordinate in a grid of 0.5 × 0.5 meter, and applying a TIN interpolation. Point measurements above two meter from the ground were removed temporally to enhance the identification of the objects of interest (Figure 2.).

Figure 2. Point cloud merged of the four individual scans. For better visualization, point measurements on the ground and above two meters height were removed. The abundance of vegetation is notable.

Thematic classification and modelling

The point cloud was submitted to visual interpretation to classify point measurements into one of the following thematic categories:

- Fence and posts along the site boundary
- Iron tower as the platform of hydro-meteorological sensors
- Ground-fixed, wooden storage of meteorological sensors
- Equipment for hydro-meteorological observation (various barrels and tanks)
- Plastic pipes for probing ground water level
- Tree stems with diameter exceeding 5 cm

In case of objects with simple shape, a geometric primitive (e.g. a cylinder) was directly fitted to the object points using the software package Leica Cyclone. For objects with complicated geometry (e.g. tower, precipitation tank), the main dimensions are measured in the point cloud manually, then the models were created upon these dimensions using the AutoCAD software package (Figure 3.).

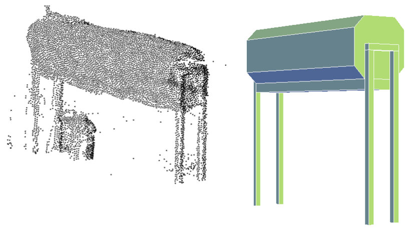

Figure 3. A precipitation tank in the laser scanned point cloud, and the resulting surface model.

Outlook

Terrestrial laser scanning provided effective way to obtain spatially explicit data of the observation site. The created 3D model allows for the display of the site in its current state from arbitrary viewpoints (Figure 4). However, the complement of the model with fine details (such as water probing pipes), that are too small to be detected in the point, cloud still requires a total station survey.

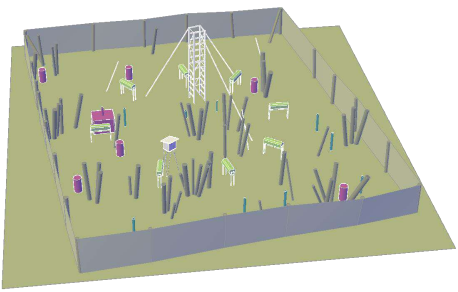

Figure 4. Visualization of the hydro-meteorological observation site in the model space.

Acknowledgement: This research was made within the frame of the TKP2021-NKTA-43 project, which has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

This research was supported by the project "Assessment of wooden biomass production" (GINOP-2.3.3-15-2016-00039).

DATA INTEGRATION AND ERROR ANALYSIS OF THE BOTANICAL GARDEN'S HYDROMETEOROLOGICAL STATION IN SOPRON

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The monitoring of hydrometeorological processes has been for centuries crucial for analysing the water balance of long-lived plant communities such as forests. In contrast, long-term measurements are crucial for evaluations of the impact of climate change. Meteorological records (which were the first regular examinations in Hungary) began in 1711 in Sopron. The Botanical Garden's meteorological station at the University of Sopron operated from 1925.06.01. to 1974.04.24. and was the official station in Sopron at that time. The official station was moved to the Observatory of Kuruc Hill in 1974. The instruments that remained in the Botanical Garden continued to operate. The presentation reviews the integration of the station's data, the error analysis, and the simple data processing for hydrometeorological purposes.

The following joint projects (143972SNN project and the TKP2021-NKTA-43 project) supported the preparation of this paper. TKP2021-NKTA-43 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

Supported by the ÚNKP-23-2-III-SOE-176 New National Excellence Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund.

Introduction

The monitoring of hydro-meteorological processes for centuries is crucial for analysing the water balance of long-lived plant communities such as forests. In contrast, long-term measurements are crucial for evaluations of the impact of climate change. Meteorological records (which were the first regular examinations in Hungary) began in 1711 in Sopron. The Botanical Garden's meteorological station at the University of Sopron operated from 1925.06.01. to 1974.04.24. and was the official station in Sopron at that time. The official station was moved to the Observatory of Kuruc Hill in 1974. The instruments that remained in the Botanical Garden continued to operate. (Pődör, 1985) The presentation reviews the integration of the station's data, the error analysis, and the simple data processing for hydro-meteorological purposes.

Methods

Processing of precipitation and temperature measurement data (with trend lines, correlation, graphic representation), then their evaluation (with diagrams, FAI) We focused on error correction. (Sevruk, 1982)

Results

For comparison, we made a representation of the temporal evolution of the yearly average temperature and precipitation sum between 1870-2021 for the homogenized data of Kuruc Hill station. (Karl, 1986)

Precipitation trend: 79mm/150 year. Temperature trend: 1,61°C/150 year (more significant rise since 1990, Figure 1.)

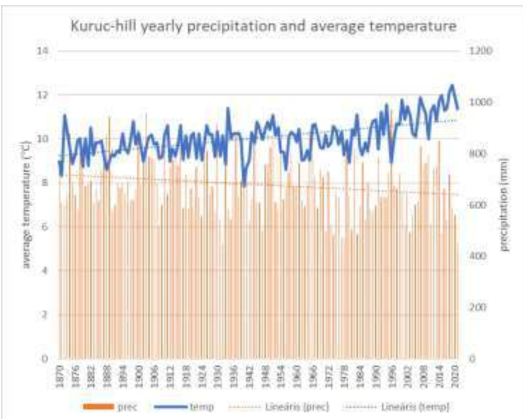

Figure 1. Kuruc-hill yearly precipitation and average temperature

Comparison of the last 30-year average temperature of Kuruc Hill and Botanical Garden station with raw data, with corrected gross error, and with corrected data (Figure 2, 3, 4):

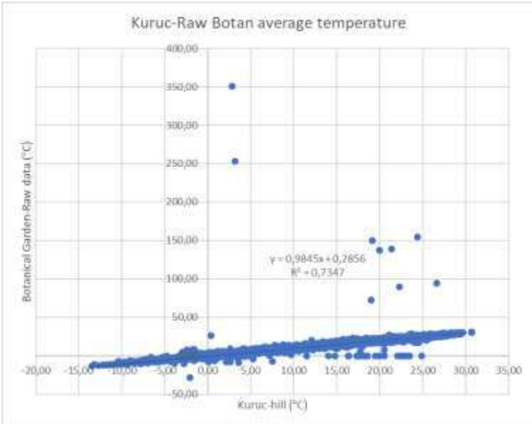

Figure 2. Comparison of Kuruc-hill's and raw Botanical garden's temperature

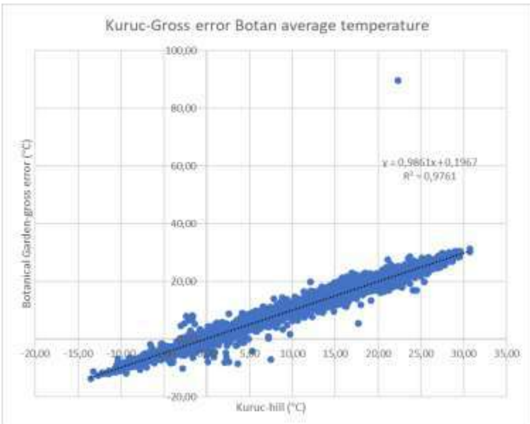

Figure 3. Comparison of Kuruc-hill's and gross error Botanical garden's temperature

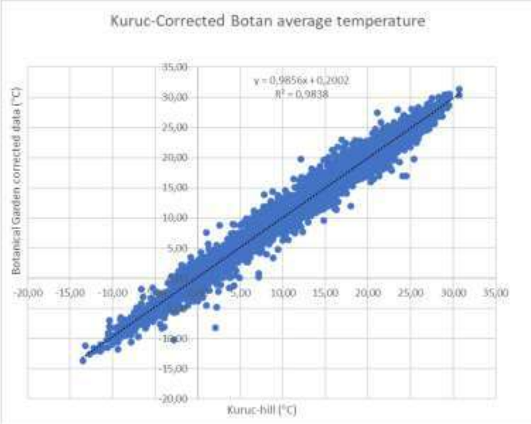

Figure 4: Comparison of Kuruc-hill's and corrected Botanical garden's temperature

We compared the precipitation distribution of the Botanical Garden's corrected daily data. We categorised the number of the precipitation and summarised the individual categories to get the precipitation amounts per category. The current 30 years has 370 mm more precipitation. The most significant difference related to high rainfall category (Figure 5, 6).

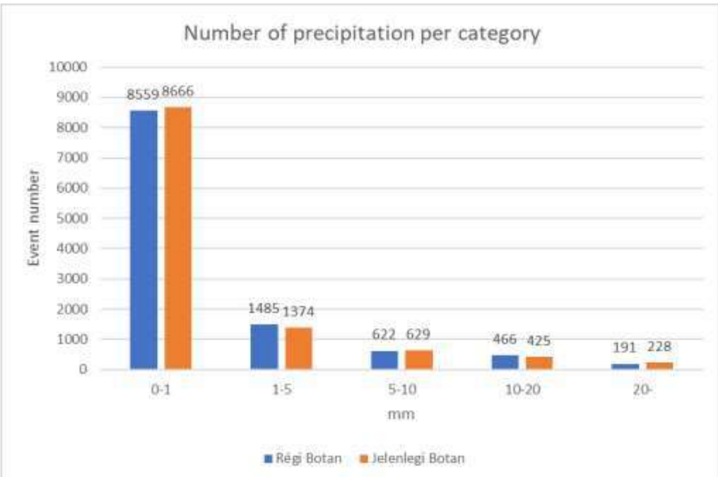

Figure 5: Comparison of 1930-1960 (blue) and 1989-2019 (orange) precipitation by category

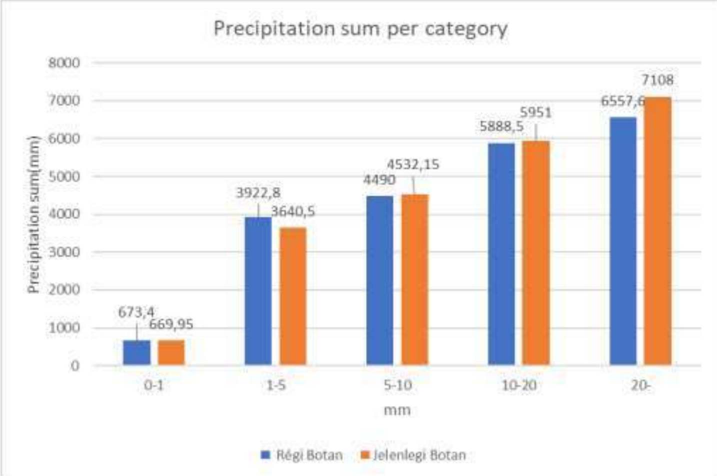

Figure 6: Comparison of precipitation amounts for 1930-1960 (blue) and 1989-2019 (orange) by category

We compared the precipitation during the last 30 years between two stations (Figure 7, 8). The results showed that the Botanical Garden's station has a bit more rainfall (13-14 mm/year).

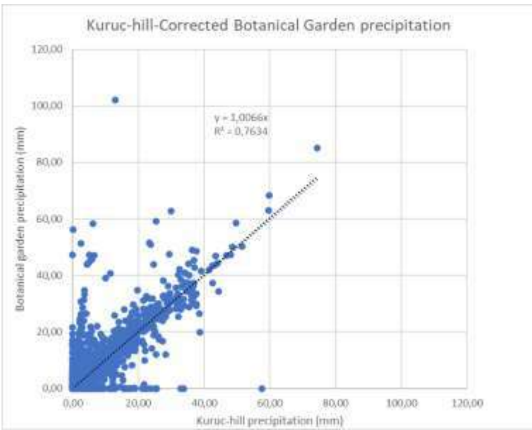

Figure 7: Comparison of the precipitation of Kuruc Hill and Botanical Garden

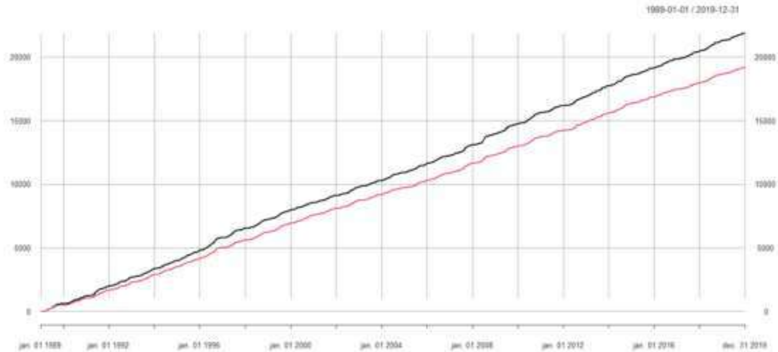

Figure 7. Comparison of the precipitation amounts of the Kuruc hill (red) and the Botanical Garden (black).

CONCLUSION

We have created an improved database that can be used to create complex hydro-meteorological analyses such as FAI, interception, evapotranspiration, snow development, water balance analyses from a forestry perspective (e.g.: in connection with afforestation, tree species exchange during plant planning negotiations) We made simple analyses to test the database.

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Data integration and error analysis of the Botanical Garden’s hydrometeorological station in Sopron

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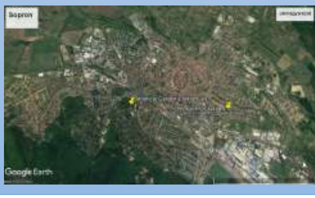
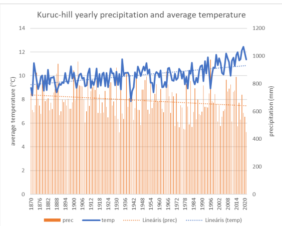
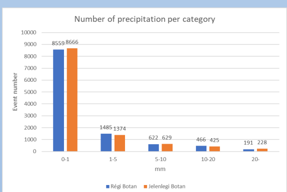
The monitoring of hydrometeorological processes for centuries is crucial for analysing the water balance of long-lived plant communities such as forests. In contrast, long-term measurements are crucial for evaluations of the impact of climate change. Meteorological records (which were the first regular examinations in Hungary) began in 1711 in Sopron. The Botanical Garden’s meteorological station at the University of Sopron operated from 1925.06.01. to 1974.04.24. and was the official station in Sopron at that time. The official station was moved to the Observatory of Kuruc Hill in 1974. The instruments that remained in the Botanical Garden continued to operate.

The presentation reviews the integration of the station's data, the error analysis, and the simple data processing for hydrometeorological purposes.

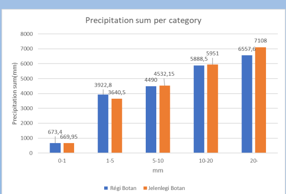




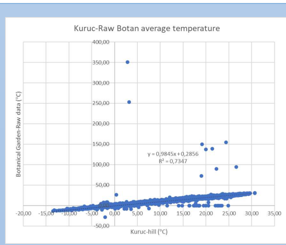
For comparison, we made a representation of the temporal evolution of the yearly average temperature and precipitation sum between 1870-2021 for the homogenised data of Kuruc Hill station.
Precipitation trend: 79mm/150 year
Temperature trend: 1,61°C/150 year
(More significant rise since 1990)

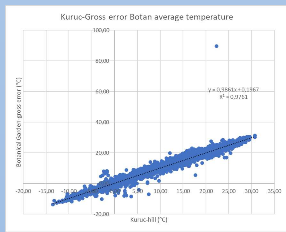


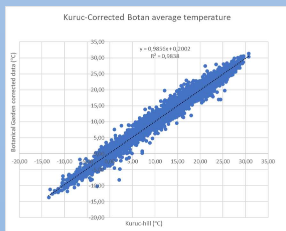
We compared the precipitation distribution of the Botanical Garden’s corrected daily data.
We categorised the number of the precipitation.
Blue: Data of 1930-1960
Orange: Data of 1989-2019



Then we summarised the individual categories to get the precipitation amounts per category
Blue: Data of 1930-1960
Orange: Data of 1989-2019
The current 30 years has 370 mm more precipitation

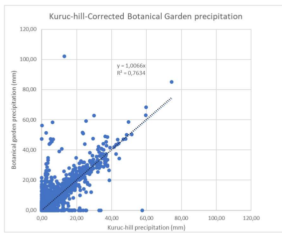




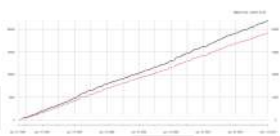


Comparison of the last 30-year average temperature of Kuruc Hill and Botanical Garden station with raw data, with corrected gross error, and with corrected data.

We compared the precipitation of the last 30 years between Kuruc Hill and Botanical Garden.



We compared the precipitation sum of 30 years between the two station.
(black line: Botanical Garden, red line: Kuruc Hill)
The results show that the Botanical Garden’s station is a little more rainy. (13-14 mm/year)



Acknowledgement:
The following joint projects (143972SNN project and the TKP2021-NKTA-43 project) supported the preparation of this paper. TKP2021-NKTA-43 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.
SUPPORTED BY THE ÚNKP-23-2-III-SOE-176 NEW NATIONAL EXCELLENCE PROGRAM OF THE MINISTRY FOR CULTURE AND INNOVATION FROM THE SOURCE OF THE NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION FUND.

Paired plot water balance experiment setup in the botanic garden of the University of Sopron

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Paired plot-based hydrological measurements present good opportunities for water balance comparisons of different surface covers. Hydro-meteorological measurements have been carried out in the Botanical Garden of the University of Sopron since 1925. Conducting long-term measurements presents an excellent opportunity to establish studies on forest water balance. The proximity of educational facilities provides ample opportunities for frequent measurements, routine equipment checks, and student involvement. A paired-plot (clearing, black pine forest") hydrological experiment was set up within the framework of an international Slovenian-Hungarian project. The first set of experiments are suitable for analysing rainfall distribution in a forest (crown and litter interception), but they are also suitable for comparing the soil moisture and groundwater dynamics of grass and forest plots. The process of installing automated equipment in the experimental area is currently in progress. Beyond its primary research character, the experiment also serves educational and demonstration purposes.

The following joint projects (143972SNN, N2-0313 projects and the TKP2021-NKTA-43 project) supported the preparation of this paper. TKP2021-NKTA-43 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme. This contribution is also part of ongoing research entitled “Microscale influence on runoff” supported by the Slovenian Research and Innovation Agency (N2-0313).

INTRODUCTION

Hydrological measurements, particularly those conducted on paired plots, provide valuable tools for comparing the water balance of different surface covers. Hydro-meteorological measurements have been carried out in the University of Sopron Botanical Garden since 1925. Conducting long-term measurements provides a significant opportunity for studying the water balance in forested areas. The proximity of educational facilities allows for frequent measurements, regular equipment inspections, and student participation. A hydrological paired-plot experiment site was established in the botanical garden as part of an international Slovenian-Hungarian project. We set up the research site under black pine trees near the main building. For comparative purposes, we designated an open-air plot as a control site, positioned approximately 100 meters away from the pine trees. The focus of the research was to gain a better understanding of the complex water dynamics within the research site under the black pine tree canopy. The first set of experiments is suitable for analysing rainfall distribution in a forest, and for comparing the soil moisture and groundwater dynamics of grass and forest plots.

Figure1. Location of the research site

METHODS

The focus of our research was to gain a better understanding of the complex water dynamics within the research site under the black pine tree canopy (Figure 2). The primary goal was to quantify water volumes at various stages of precipitation to establish a water balance model for this ecosystem (Hewlett 1982).

Precipitation was measured on the open-air plot, and on the forest plot, the amount of precipitation falling through the canopy, the stemflow (Kucsara 1996), as well as the amount of precipitation retained by and seeped through the forest litter (Zagyvai-Kiss et al. 2019).

We also monitored the surface soil moisture, and the fluctuations in water table and analysed how precipitation events and vegetation influenced the water balance of the plot.

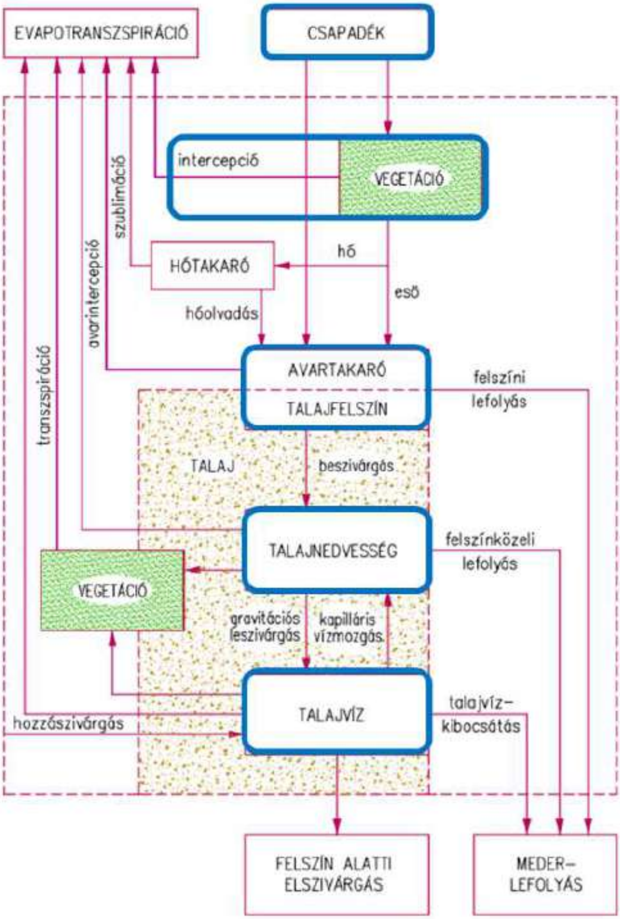

Figure 2. Water balance in forested catchment area (Kucsara 1996)

Figure 3. Instruments used for measurements and their arrangement in the field

RESULTS

A total of 223.19 mm of precipitation fell during the period under analysis; mainly in early August 2023. After major precipitation events, temperature values dropped (Figure 4.).

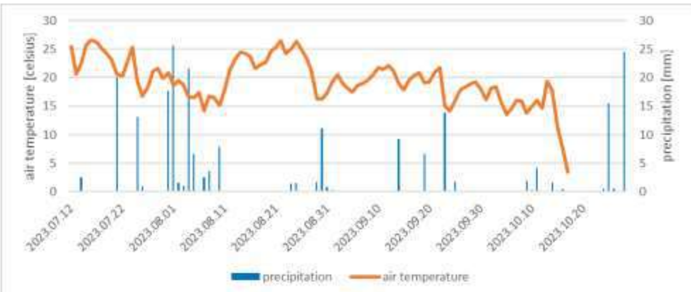

Figure 4. Precipitation and air temperature time series

Based on the data of the botanical garden paired plot, open air precipitation is closely related to stand precipitation (SP) and effective precipitation (EP) as well. According to preliminary results, on the black pine plot, nothing below 2.1 mm of precipitation reaches the forest litter surface, and precipitation less than 2.2 mm does not seep through the forest litter (Figure 5).

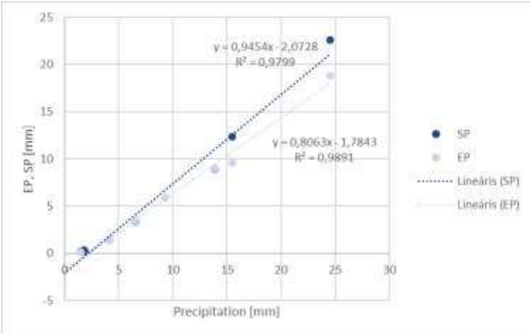

Figure 5. Relationship between effective (EP) and stand precipitation (SP).

We used antecedent precipitation index (API) for 20 days (Kontur 2003) as a proxy to evaluate soil moisture and water table data. Comparison of API and surface soil moisture showed that interception of the forest causes a delay and decrease in infiltration (Figure 6).

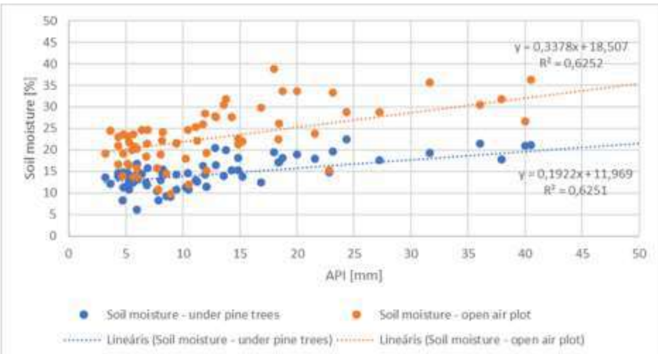

Figure 6. Relationship between near-surface soil moisture and API.

Regarding groundwater we found that major rainfall events in early August raise the water table in case of both plots. Below 20-25 mm of API value, there was no significant change in the groundwater levels. On the black pine plot, the effects of major rainfall events are more noticeable, but the groundwater recession is slower (Figure 7).This is an unexpected result, which is why we need to analyse the effects of the surrounding large trees in the case of an open air plot piezometer in more detail.

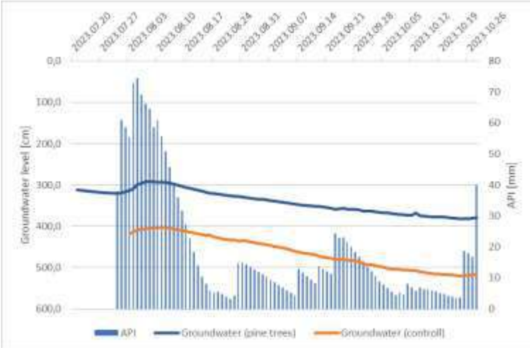

Figure 7. Groundwater levels and the effects of API.

CONCLUSION

The tree canopy plays a crucial role in altering both the spatial and temporal distribution of precipitation. To comprehensively understand these modifying effects of vegetation, we need to eliminate measurement errors and use higher frequency data collection. The process of installing automated equipment in the experimental area is currently in progress.

Beyond its primary research character, the experiment also serves educational and demonstration purposes. It provides an excellent opportunity for students at various educational levels, including university, high school, and primary education to deepen their knowledge through practical experience.

ACKNOWLEDGEMENT

This contribution is part of ongoing research entitled “Microscale influence on runoff” supported by the Slovenian Research and Innovation Agency (N2-0313) and National Research, Development, and Innovation Office (OTKA project grant number SNN143972). The following joint project TKP2021-NKTA-43 project was also supported the preparation of this paper. TKP2021-NKTA-43 has been implemented with the support provided by the Ministry of

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FACULTY OF FORESTRY

Paired plot water balance experiment setup in the Botanic garden of the University of Sopron

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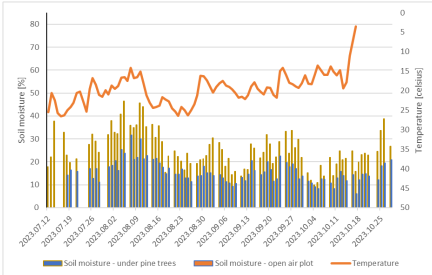
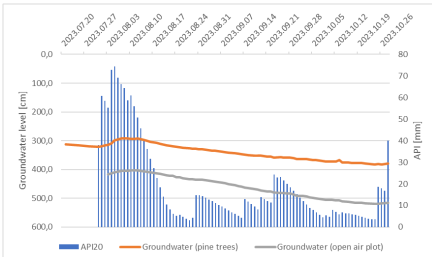
Paired plot-based hydrological measurements present good opportunities for water balance comparisons of different surface covers. Hydro-meteorological measurements have been carried out in the Botanical Garden of the University of Sopron since 1925. Conducting long-term measurements presents an excellent opportunity to establish studies on forest water balance. The proximity of educational facilities provides ample opportunities for frequent measurements, routine equipment checks, and student involvement. A paired-plot (clearing, black pine forest") based hydrological experiment was set up within the framework of an international Slovenian-Hungarian project. The first set of experiments are suitable for analysing rainfall distribution in a forest (crown and litter interception), but they are also suitable for comparing the soil moisture and groundwater dynamics of grass and forest plots. The process of installing automated equipment in the experimental area is currently in progress. Beyond its primary research character, the experiment also serves educational and demonstration purposes.

Location of the research site

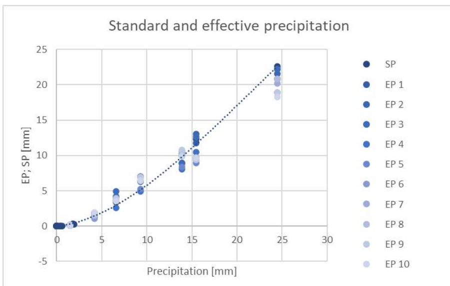

Paired plot sites



Comparison of volumetric water content under pine trees and an open-air plot over a specific period. Temperature values are also represented on the diagram.



Temporal changes of actual precipitation index and groundwater levels over the 2 experimental plots.



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Impact of climate variability on a crown interception of a beech forest

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The role of tree canopies is crucial in forest hydrology, as they intercept significant amounts of precipitation, which is evaporated back into the atmosphere during and after rainfall events. This process determines the net intake of forest soil and is an important factor in a site potential. The average amount of interception loss heavily depend on the storage capacity of tree canopies and the rainfall distribution.

In this study a site-based interception estimation based on the Meriam model was developed for two characteristic years at a beech forest plot in the Sopron Hills area (near the Hidegvíz Valley experimental catchment of Hungary). Ground-based observations and MODIS LAI datasets were applied to model the seasonal variations in the canopy storage.

There was 1.5 times difference between the two years in the context of the precipitation sums. The main finding was that the average yearly interception ratios were significantly less (29%) in one year, when a lower number of precipitation events occurred compared to the year with a higher number of events (39%). On the other hand, the absolute values of the interception (mm) were nearly the same.

The 143972SNN, N2-0313 and the TKP2021-NKTA-43 joint projects supported the preparation of this paper. TKP2021-NKTA-43 was implemented with support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, which is financed under the TKP2021-NKTA funding scheme. This contribution is also part of ongoing research entitled “Microscale influence on runoff” supported by the Slovenian Research and Innovation Agency (N2-0313).

Keywords: interception, precipitation distribution, beech, water balance

INTRODUCTION

Interception is a very important concept in the water balance of forests and accounts for 15-50 % of the total amount of precipitation (Gerrits et al. 2010) however it is not always considered as a significant process in hydrological models (De Groen and Savenije, 2006). Although interception can be negligible during large rainfall events, which induce big floods, it can strongly influence antecedent soil moisture, which is a very important factor for the generation of floods (Savenije, 2004).

Upon reaching forest stands, rainfall initially interacts with the canopy level, where tree crowns retain differing amounts of precipitation. A limited portion of this rainfall, referred to as 'stand precipitation,' eventually makes its way to the forest litter layer. In this layer, substantial amounts of water can be stored and evaporated. The rain that permeates the litter does so at various speeds, influenced by the morphology of the litter itself. While the canopy primarily wets the surfaces of leaves, the forest litter, composed of decomposed organic matter, has the capacity to store water not only on its surface but also within the tissues of dead leaves. The speed at which rainfall infiltrates through the litter plays a pivotal role in regulating the quantity of water retained by the forest litter (Zagyvai-Kiss et al. 2019).

DATA AND METHOD

STUDY AREA

A middle age beech (*Fagus sylvatica* L., 1753) dominated forest ecosystem was selected for the present study (located in Hidegvíz Valley Experimental Watershed) (Figure 1., Figure 2.). Northern latitudes 47°35’08’’ – 47°39’06’’ and eastern longitudes 16°25’31’’ – 16°28’15’’ above WGS 84 datum in Hungary in the Sopron Hills of the eastern foothills of the Alps. The area enjoys a sub-alpine climate with daily mean temperatures of 19 °C in July, and -2 °C in January, and with an annual precipitation of 750 mm. Late spring and early summer are the wettest and fall is the driest season (Dövényi 2010, Gribovszki et al. 2006).

Figure 1. Location of the study area.


Figure 2. Interception measurements at the study area.

METHOD

For the analysis of precipitation-interception relationship the so-called Merriam model (Merriam, 1960) was used.

$$E_{su} = S * \left(1 - e^{-\frac{P}{S}}\right) + K * P \qquad \text{(eq. 1)}$$

where:

P - precipitation amount [mm]

S - forest canopy storage capacity [mm]

K - evaporation parameter , valid for evaporation process during the rainfall event (-)

E_{su} - interception [mm]

The parameters (S: 2.1 mm and K: 0.1) of the interception model (Figure 3) were determined using the measured interception data (collected in growing season) in the beech forest plot of Hidegvíz-valley experimental catchment (Kucsara, 1998).

Canopy storage capacity (S) changes during the year especially in the case of deciduous forests. Consequently, static 2.1 mm storage capacity value is only an approximately maximum value.

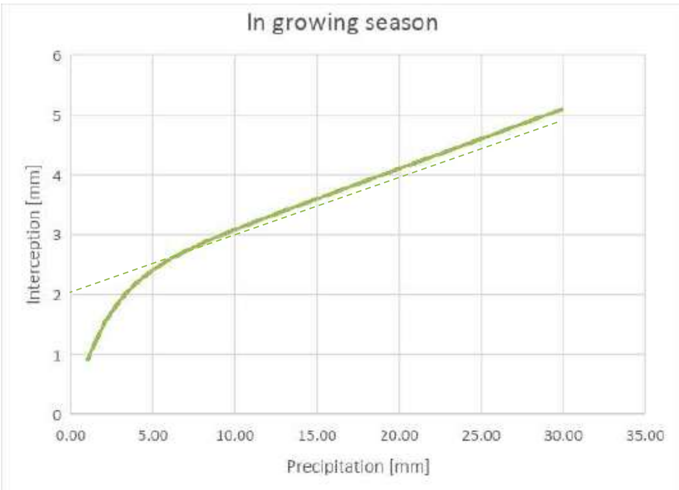

Figure 3. Precipitation vs i nterception applying the parametrized Meriam equation.

The change of S shows strong correlation with the leaf area index (LAI).

$$S = C_{int} \cdot (LAI + SAI) \quad \text{(Eq. 3)}$$

where: C_{int} - maximum storage capacity for unit surface (mm/m^2), LAI - projected leaf area surface, SAI - projected stem area surface

While SAI - which is the projected surface of stems, branches and twigs is constant through seasons, 0.7 m^2/m^2 is calculated for the approx. 20 m height stand, but LAI shows significant variability in temporal scale.

In this study MODIS sensor based LAI time series (Myneni et al. 2015) are used to estimate changes of the storage capacity. A yearly average curve (Figure 4) was calculated from the smoothed MODIS LAI dataset of the research plot. The averaged curve data was used for determination of dynamic *S*.

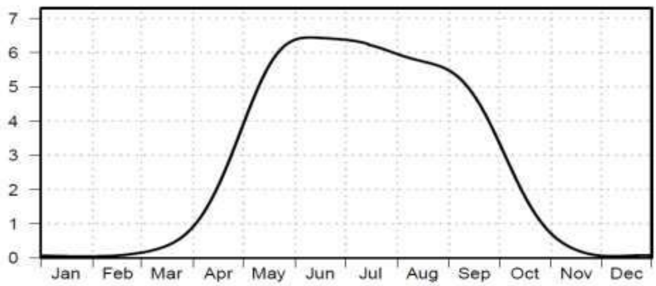

Figure 4. Annual average LAI curve for the forest plot.

RESULTS

Table 1 shows the number of rainy days and interception loss of each rainfall category for two selected years with different rainfall distribution. Annual rainfall sum in 2001 (606 mm) (a "dry" year) was only two-thirds of that in 2007 (900 mm) (a "wet" year). The number of precipitation events (139, which is a typical event number in a normal year) was larger in the drier year (2001). In 2001 the minor precipitation events were more common, while in 2007 the major ones were representative.

Interception losses of these years were similar (237 mm in 2001 and 257 mm in 2007), but if we calculate the interception ratio (interception loss/yearly rainfall) significantly higher value was found in 2001.

As a consequence, stand precipitation (open air precipitation minus interception loss, which reaches the forest litter layer surface) was almost twofold in 2007 (643 mm) than in 2001 (369 mm). In other words, twice as much water is available for mostly transpiration and runoff in 2007.

Table 1. Interception loss in each category and ratio of yearly averages.

Precipitation categories	Number of rainy days		Interception loss in each category	
	2001	2007	2001	2007
(mm)	(day/year)		(mm)	
0.1-0.5	28	12	7	3
0.5-1.0	24	12	16.9	8.4
1.0-2.0	14	13	17.1	15.9
2.0-5.0	34	25	69.7	51.3
5.0-10.0	23	17	64.2	47.4
10.0-20.0	13	18	46.8	64.8
20.0<	3	13	15.3	66.3
Sum	139	110	237	257.1
Yearly rainfall sum. P (mm)			605.6	899.9
Yearly average interception ratio. E_{su} (%)			39.1	28.6

ACKNOWLEDGMENT

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UNIVERSITY of SOPRON

FACULTY OF FORESTRY

Impact of Climate variability on a crown interception of a beech forest

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[2] Faculty of Civil and Geodetic Engineering. University of Ljubljana. Slovenia

Abstract

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Keywords: interception. precipitation distribution. beech. water balance

Study area

Figure 2. Location of the study area

Figure 2. Interception measurements devices at the study area

A middle age beech (*Fagus sylvatica* L., 1753) dominated forest ecosystem was selected for the present study (located in Hidegvíz Valley Experimental Watershed). Northern latitudes 47°35'08'' – 47°39'06'' and eastern longitudes 16°25'31'' – 16°28'15'' above WGS 84 datum in Hungary in the Sopron Hills of the eastern foothills of the Alps. The area enjoys a sub-alpine climate with daily mean temperatures of 19 °C in July, and -2 °C in January, and with an annual precipitation of 750 mm. Late spring and early summer are the wettest and fall is the driest season (Dövényi 2010, Gribovszki et al. 2006).

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where:

- **P. precipitation amount (mm)**
- S. forest canopy storage capacity (mm)
- K. evaporation parameter. valid for evaporation process **during** the rainfall event (-)
- E_{su}. interception (mm)

The parameters (S: 2.1 mm and K: 0.1) of the interception model were determined using the measured interception data (collected in growing season) in the beech forest plot of Hidegvíz-valley experimental catchment (Kucsara 1998).

$$E_{su} = S * \left(1 - e^{-\frac{P}{S}}\right) + K * P$$

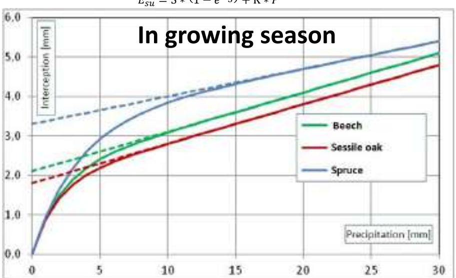

Figure 3. Interception precipitation functions for different species in growing season

Canopy storage capacity (S) changes during the year especially in the case of deciduous forests. → static 2.1 mm storage capacity value only an approximately maximum value.

The change of S shows strong correlation with the leaf area index (LAI).

$$S = C_{int} * (LAI + SAI)$$

where:

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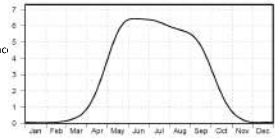
- LAI projected leaf area surface
- SAI projected stem area surface



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While **SAI** - which is the projected surface of stems. branches and twigs. is constant through seasons. **0.7 m²/m²** is calculated for the aprox. 20 m height stand. LAI shows significant variability in temporal scale.

In this study MODIS sensor based LAI time series (Myneni et al.. 2015) are used to estimate changes of the storage capacity**.** A yearly average curve was calculated from the smoothed MODIS LAI dateset of the research plot. The averaged curve data was used for determination of dynamic ***S***.

Results

Table 1. Interception loss in each categories and ratio of yearly averages

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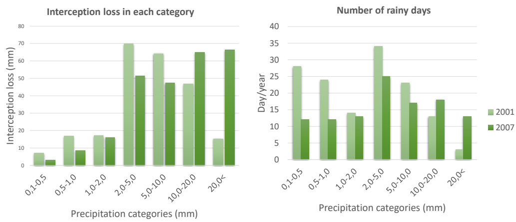

Figure 5. Interception loss in each categories and ratio of yearly averages

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DIURNAL STREAMFLOW PATTERNS IN SMALL URBAN MIXED FOREST CATCHMENT IN LJUBLJANA, SLOVENIA

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The present study aims to analyze the diurnal streamflow patterns of a small catchment nourished by an urban mixed forest in the city of Ljubljana, Slovenia, with an outlet joining the city's drainage system. The diurnal patterns of streamflow remain pertinent in understanding the eco-hydrological processes occurring in an urban forest and its intricate response to environmental drivers, which is essential in harnessing their role as an element of nature-based solutions in urban water management strategies. The water level data in the creek, including the stream water temperature, were measured at 10-min intervals (HOBO Fresh Water Level Data Logger), which were converted to discharge data via a rating curve. The stage–discharge relationship was established by performing sporadic discharge measurements during low- and high-flow events. A visual analysis of the 2-year time series data demonstrated a clear diurnal rhythm in streamflows from May to September, particularly during periods of low flows and no precipitation. This pattern is characterized by a gradual rise and sharp decline, often with noticeable amplitudes. From late spring to summer, streamflow maxima generally occurred in the early morning, and the minima were observed in the afternoon, whereas during the winter, this timing is either reversed or the diurnal pattern is less pronounced. Notably, an inverse synchronization between the streamflow and diurnal temperature (air and stream water) cycles, including solar radiation, was apparent from May to September. The temperature (air/stream) maxima correspond to the streamflow minima, and vice versa, with some lag time. Additionally, the streamflow fluctuations were paralleled by fluctuations of the temperature-dependent streamwater's viscosity, potentially inducing diurnal variations in the hydraulic conductivity. Thus, we hypothesized that the viscosity effect is a relevant process contributing to the diurnal streamflow pattern in this catchment, even when it is overlain by the stronger influence of evapotranspiration. The interplay of the diurnal fluctuations of the different elements could potentially account for the diurnal patterns in the streamflow.

Keywords: diurnal pattern, streamflow, urban forest, viscosity

Acknowledgment: This contribution is part of ongoing research entitled "Microscale influence on runoff" supported by the Slovenian Research and Innovation Agency (N2-0313) and National Research, Development, and Innovation Office (OTKA project grant number SNN143972).

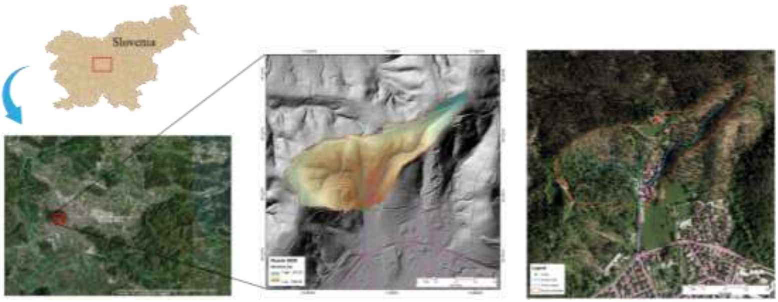
INTRODUCTION

Urbanization and climate change have been recognized to have a profound influence on the hydrological cycle, altering the natural processes, functions, behaviors, and responses of catchment ecosystems (McGrane, 2016). The confluence of these factors introduces complexities to urban hydrological systems and processes, necessitating a more advanced understanding of the complex interaction of natural and built environments within the urban catchments by delving into the soil properties, land use patterns, local topography, and other factors characterizing the local catchment area. Improving our knowledge of urban hydrological processes continues to be a priority within the field of hydrological science (Niemczynowicz, 1999, Vörösmarty et al., 2000). Among the crucial aspects of analyzing how the changing climatic conditions and land use affect the catchment response lies in their streamflow behaviors. The diurnal patterns of streamflow play a crucial role in the overall variability of many rivers around the world. It provides valuable insights into the dominant processes influencing the water balance within a specific river basin (Deutscher et al., 2016; Lundquist & Cayan, 2002).

In the context of urban stormwater management strategies, urban forests have increasingly gained recognition as nature-based solutions in cities. In addition to their microclimatic amelioration benefits, they can increase the hydrological losses in the catchment via canopy interception, evapotranspiration, and improved infiltration, thus reducing the quantity of rainfall that will potentially become a surface runoff (Berland et al., 2017; FAO, 2016). The present study aims to analyze the diurnal streamflow patterns of a small catchment in an urban mixed forest in the city of Ljubljana, Slovenia. This remains pertinent in understanding the eco-hydrological processes occurring in an urban forest and its intricate response to environmental drivers, which is essential in harnessing their role as an element of nature-based solutions. Furthermore, given that the catchment outlet is connected to the city's drainage system, it is essential to reduce runoff discharge during wet periods and promote water retention during dry periods, making this analysis particularly relevant. This paper is meant to contribute to the understanding of diurnal streamflow patterns in a small urban mixed forest catchment in response to the driving forces such as evapotranspiration, stream water viscosity, and temperatures (water and air) by focusing on the identification of their trends and dynamics.

STUDY AREA

The investigated urban mixed forest (Fig. 1) is part of the Tivoli, Rožnik, and Šiška Hill landscape park adjacent to Ljubljana's city center, which provides multiple ecosystem services to city dwellers, such as recreation, tourism, climate regulation, stormwater management, habitat, among others. The delineated catchment (0.24 km^2) in this study is fed by Rožnik Hill and its outlet joins the city's drainage system. Dominant land use is forests from the mixed canopies of sessile oak (*Quercus petraea (Mattuschka) Liebl.*), sweet chestnut (*Castanea sativa (Mill.)*) and Norway spruce (*Picea abies (L.) Karst.*) (Kermavnar & Vilhar, 2017). The study area experiences a temperate continental climate with an average annual rainfall of 1371 mm and an average annual temperature of 11°C, according to long-term meteorological data (1970-2022) of the Ljubljana-Bežigrad synoptic station.



MEASUREMENTS

Water level was measured at a 10-minute interval in a narrow creek at the outlet of the catchment using the HOBO Fresh Water Level Data Logger (Fig. 2a). This data was then converted to discharge data using the rating curve. The data loggers measure the hydrostatic and barometric pressure above the sensor in the logger, which is known as absolute pressure. To account for the barometric pressure, water level data recorded by a logger installed 10 cm below the bed of the channel are adjusted using barometric pressure measurements from an additional logger installed approximately 1 m above the top of the creek. Barometric compensation was carried out in HOBOware Pro version 3.7.22 software and for a comprehensive description of this process, refer to the manual

(Onset Computer Corporation, 2018) and the publication of do Amaral et al. (2023). Furthermore, a stage-discharge relationship (rating curve) was established by conducting sporadic discharge measurements under different hydrological conditions, such as low and high flows, using a tracer dilution method (Fig. 2b).

The meteorological station at the location is managed by the Slovenian Forestry Institute (Gozdarski inštitut Slovenije). Thus, the meteorological data from the station is available in the online system by request. The potential evapotranspiration data used in the analysis was derived using the temperature-based model by Oudin et al. (2005). On the other hand, streamwater viscosity was calculated as a function of water temperature (in Kelvin) according to Vogel equation as described by Schwab et al. (2016).

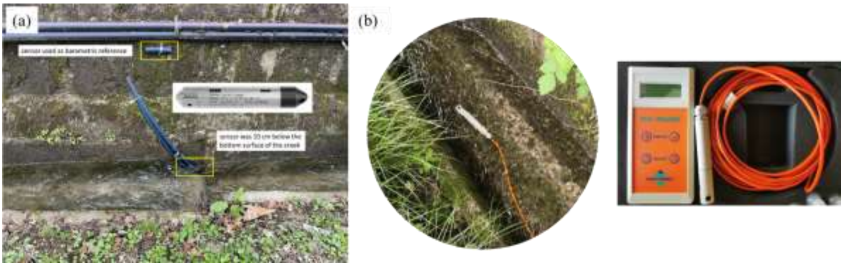


Fig. 2. HOBO water level logger (a), discharge measurement FLO-TRACER (b)

Results

The diurnal cycle is a recognizable component of streamflow variation (Lundquist & Cayan, 2002). In the urban mixed forest catchment, a clear diurnal pattern in streamflows is evident during spring, summer, autumn, and winter as shown in Fig. 3, particularly during periods of low flows and no precipitation. However, it is worth mentioning that the diurnal cycles in streamflow gradually disappear in late autumn, which continues to winter until early spring, depending on the amount of precipitation. Over the course of the observation period, the creek begins to yield distinct diurnal streamflow signals in late spring when the trees are transitioning from leafless to leafing and are most prevalent during summer. Summer diurnal pattern of streamflow is characterized by moderate gradual rise and sharp decline, which also includes spring. Whereas, during winter, when the diurnal variations are present (like in January 2022), it is characterized by a sharp rise and gradual decline.

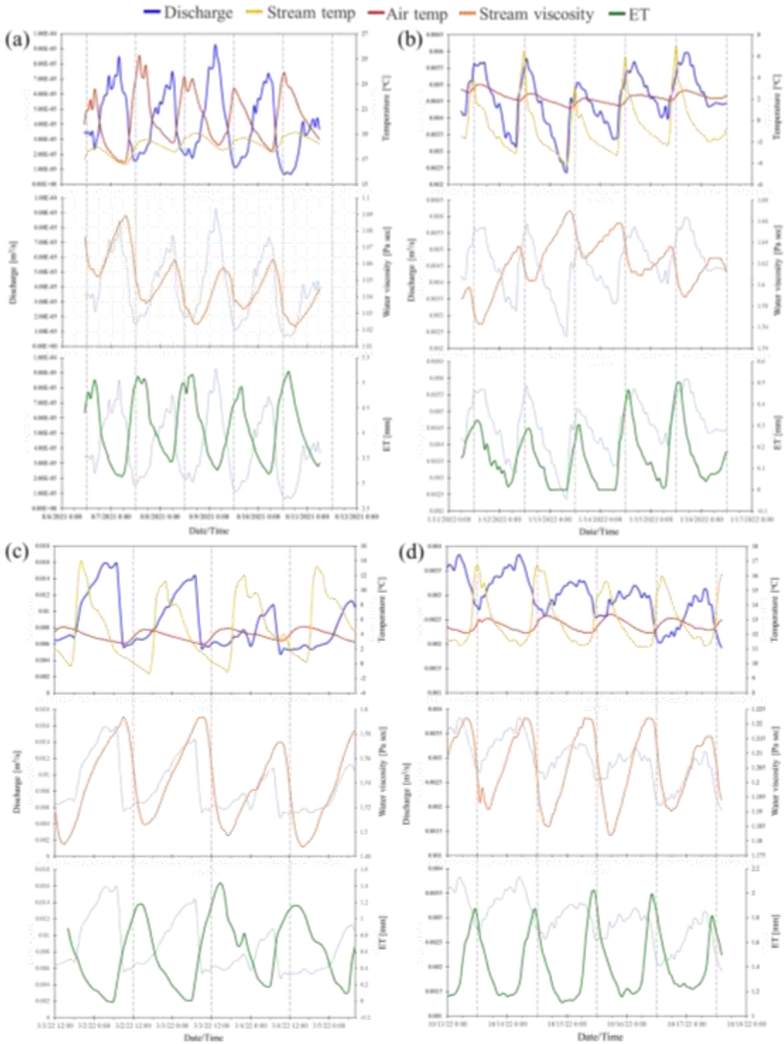


Fig. 3. Diurnal cycles of streamflow, air/water temperatures, ET, and water viscosity during (a) winter – January; (b) summer – August; (c) spring – March; (d) autumn – October. Broken vertical lines in each plot indicate 12:00 noon (mid-day) and the minor tick in the x-axis is by 6-hr interval.

As depicted in Fig. 3, several meteorological variables were used to explain and understand the characteristics of the diurnal streamflow patterns in the catchment. Notably, an inverse synchronization in the diurnal patterns of streamflow and temperature (air and stream water) cycles, including evapotranspiration, was apparent in summer and autumn, particularly from May to September. The temperature (air/stream) and evapotranspiration maxima correspond to the streamflow minima, and vice versa, with some lag time. Additionally, the streamflow fluctuations were paralleled by fluctuations of the temperature-dependent streamwater's viscosity, potentially inducing diurnal variations in the hydraulic conductivity.

Furthermore, the hourly timing of diurnal streamflow maxima and minima differs seasonally (Tabel 1). Diurnal streamflow patterns with maxima in the early morning were clearly discernable during summer months and the minima were observed in the afternoon. This timing reflects water loss from the system by evapotranspiration or streambed infiltration during daylight hours, when the temperatures and solar radiation are at maximum, causing a decrease in streamflow in the afternoon. Whereas winter diurnal patterns in streamflow showed a maxima in the afternoon and a minima in the morning.

Our analysis suggests that the viscosity effect is a relevant process contributing to the observed diurnal streamflow pattern in this catchment, even when it is overlain by the stronger influence of evapotranspiration, particularly during summer. Like evapotranspiration, their relative diurnal trends are changing seasonally. The interplay of the diurnal fluctuations of the different elements could potentially account for the diurnal patterns in the streamflow.

Table 1. Diurnal amplitudes and timing to maxima/minima

Summer (August)	Diurnal amplitude				
	Q*	Air Temp	ET	Stream Temp	Viscosity
Mean	6.88×10^{-5}	6.03	1.5	1.2	0.032
Range	$(5.74\text{-}8.14) \times 10^{-5}$	4.3-8.4	1.1-1.7	0.76-1.9	0.02-0.05
Timing to maxima	early morning (3-6)	afternoon (13-16)	late afternoon (15-17)	late afternoon	morning (7-9)
Timing to minima	afternoon (13-16)	early morning (2-6)	early morning (2-6)	early morning (2-6)	late afternoon (17-19)
Winter (January)	**Diurnal amplitude**				
	Q	Air Temp	ET	Stream Temp	Viscosity
Mean	0.00215	7.87	0.19	0.78	0.038
Range	0.00154-0.00263	5.5-9.4	0.08-0.03	0.6-0.9	0.03-0.05
Timing to maxima	afternoon (14-17)	Noon (12)	late afternoon (15-17)	afternoon (15-17)	late morning (10-11)
Timing to minima	morning (7-8)	morning (7-9)	early morning (2-6)	late morning (10-11)	afternoon (15-17)

*Q – m^3/s; Temperature - °C; ET – mm; Viscosity – Pa sec

Acknowledgement

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Surface water-groundwater interaction analysis in a forested riparian zone

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Riparian forests are valuable from a nature conservation viewpoint, but a drying climate can threaten them. The groundwater dynamics of these areas provide essential information for a more accurate quantification of the elements of the water balance, as this surplus form of water is usually a prerequisite for the survival of the communities there. This study investigates the surface water-groundwater interaction in a forested riparian zone.

Our study area is a streamside alder forest ecosystem in an experimental catchment of the Hidegvíz Valley in Hungary. Spatial groundwater level dynamics were assessed using data from seven manually (and, in the case of one well, automatically as well) detected groundwater wells during the period 2017-2022. The associated meteorological parameters were collected on an open-air site nearby.

The estimated groundwater transpiration of the alder forest ecosystem was significant during hot periods without any precipitation. Due to the spatial analyses of the streamside zone's groundwater level, we found that in dry summer periods, the water table can significantly fall below the streambed.

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Introduction

Riparian forests are valuable from a nature conservation viewpoint, but a drying climate can threaten them. The groundwater dynamics of these areas provide essential information for more accurate quantification of the elements of the water balance, as this surplus form of water is usually a prerequisite for the survival of the communities there. This study investigates the surface water-groundwater interaction in a forested riparian zone.

Method

Our study area is a streamside alder forest ecosystem in an experimental catchment of the Hidegvíz Valley in Hungary (Figure 1). The area enjoys a sub-alpine climate with an average annual temperature of 9.2 °C and annual precipitation of 750 mm. Tertiary fluvial sediments were deposited in the area. The depths of the groundwater monitoring wells are 1-2 m. The characteristics of the examined alder forest stand are as follows: its leaf area index is 7 m2/m2, its average height is 22 m, and its average diameter at breast height (measured at a height of 1.3 m of the trunk) is 18-20 cm. In addition to the gummy alder (Alnus glutinosa), which forms a stand in the area, the mountain maple (Acer pseudoplatanus) and the mountain elm (Ulmus glabra) appear. In the shrub level, the black elder (Sambucus nigra) and common hazel (Corylus avellana) dominate.

Figure 1. Location of the research area.

The associated meteorological parameters were collected on an open-air site nearby. Spatial groundwater level dynamics were assessed using data from seven groundwater wells during the period 2017-2022. Six wells in the alder-dominated forest ecosystem and one well in the border of the forest stand and the meadow. The groundwater level is measured manually on average weekly and in well 4+, the groundwater level is recorded both manually and automatically.

The topographic model of the area, the longitudinal section and cross sections of the Rák brook along the line of the wells have been prepared (Figure 2, Figure 3, Figure 4).

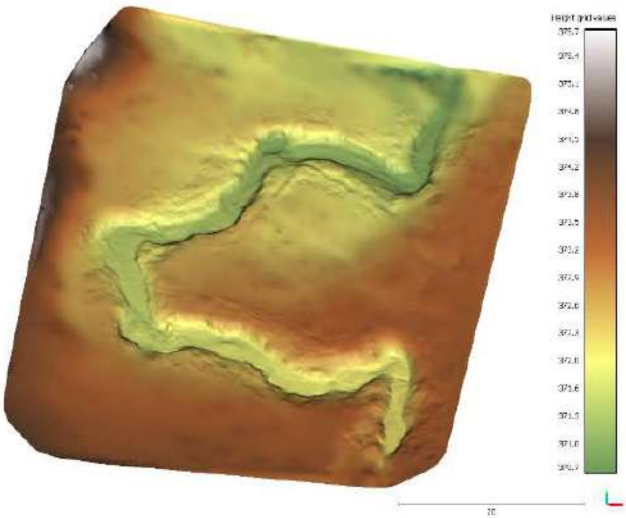

Figure 2. Typical topography model based on a laser scanner survey of the area.

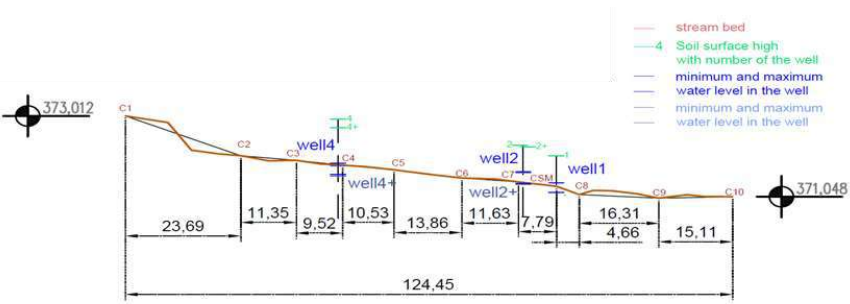

Figure 3. Longitudinal section of the Rák brook (after Figure 1).

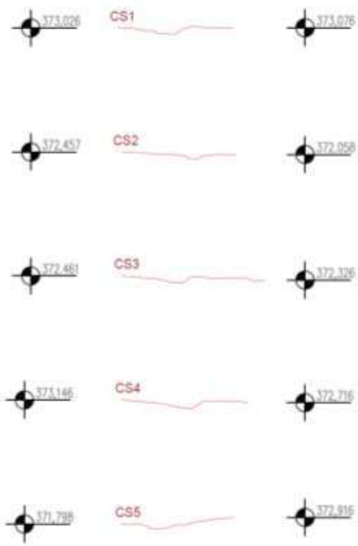

Figure 4. Cross sections of Rák brook in lines of wells (after Figure 1.).

RESULTS

We examined the hydrometeorological data of the sample area between 2017-2022. Monthly temperature averages and monthly precipitation amounts were presented (Figure 5).

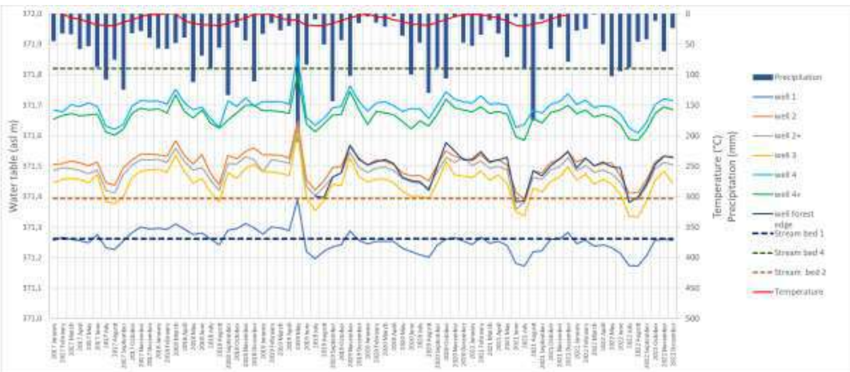

Figure 5. Monthly time series of groundwater levels.

The groundwater level is usually at its maximum in winter or spring, and at its minimum in mid-to-late summer. The groundwater level-raising effect of months with precipitation above 100 mm is clear, and monthly precipitation above 150 mm can significantly raise groundwater levels even during the vegetation period. Overall, it can be concluded that the wettest year was 2018, and the driest was 2022. During drier periods, there is a decrease in the groundwater table of the alder stand to the extent that the stream turns from effluent to influent (in this section). In the long term, the process could result in intermittent streamflow.

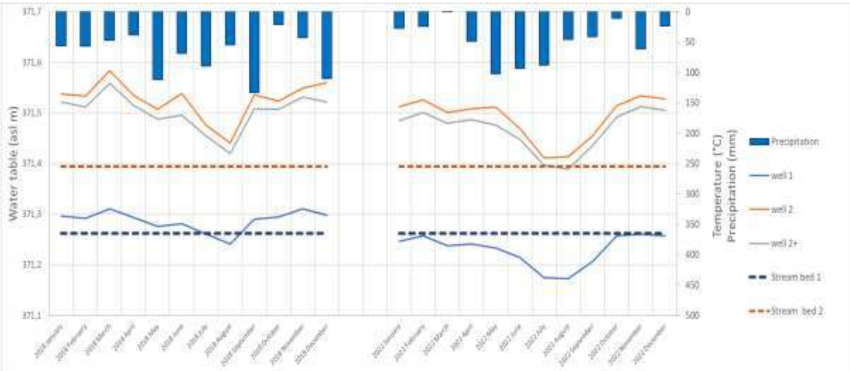

Figure 6. Groundwater level of a dry and a wet year in relation to the streambed.

As an example, we have highlighted groundwater dynamics in the driest and wettest years to provide a more in-depth look at the relationship to the streambed level (Figure 6).

The mean annual diameter growth at breast height (over bark) for alder trees was also measured between 2017 and 2022 because there is a close relationship between the diameter at breast height and the wood volume growth (Figure 7).

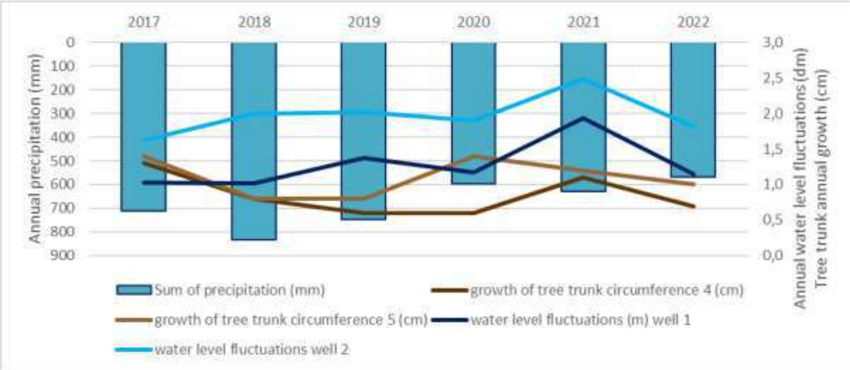

Figure 7. Precipitation, annual groundwater fluctuations and tree growth.

Forest stand growth dynamics in Central Europe have accelerated since 1870 (Pretzsch et al 2018). Grote and Pretzsch (2002) suggested that mainly the temperature rise and extended growing seasons contribute to the growth acceleration, but the drought events may temporarily cut down the growth rates (Pretzsch and Dieler, 2011, Rötzer et al., 2013).

However the results of Pretzsch et al indicate that current increased wood volume growth rates must not be straightforwardly converted into sequestrated C and biomass harvest potentials, because the wood density decreased (by 8–12% since 1900).

SUMMARY

The estimated groundwater transpiration of the alder forest ecosystem was significant during hot periods without any precipitation. Due to the spatial analyses of the streamside zone's groundwater level, we found that the water table can significantly fall below the streambed in dry summer periods. There is not a strong correlation between the change in the groundwater level and the diameter at breast height. It would be worth examining the correlation with temperature. The weakness of the correlation allows us to conclude that the groundwater depth did not reach a critical level for the forest stand.

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FACULTY OF FORESTRY

Surface Water Groundwater Interaction Analysis in a Forested Riparian Zone

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Our study area is a streamside alder forest ecosystem in an experimental catchment of the Hidegvíz Valley in Hungary. Spatial groundwater level dynamics were assessed using data from seven manually (and, in the case of one well, automatically as well) detected groundwater wells during the period 2017-2022. The associated meteorological parameters were collected on an open-air site nearby.

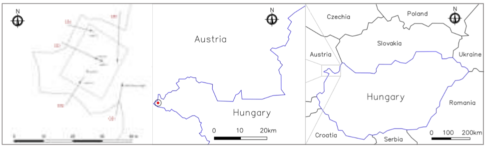
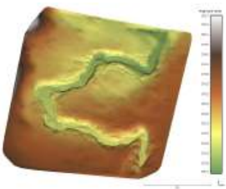


Figure 1. Location of the research area.

Seven monitoring points are in this area, i.e., six wells in the alder dominated forest ecosystem and one well in the border of the forest stand and the meadow. The groundwater level is measured manually on average weekly and in well 4+, groundwater level is recorded both manually and automatically. The climatic parameters such as the precipitation, air temperature and relative humidity are continuously recorded at a nearby meteorological station. Temperature and relative humidity are also recorded in the alder research plot too.
The area enjoys sub-alpine climate with an average annual temperature of 9.2 °C and annual precipitation of 750 mm. Tertiary fluvial sediments (mostly of sandy type) were deposited in the area. The depth of the groundwater monitoring system is 1-2 m.



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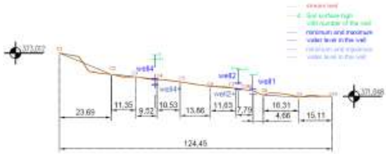


Figure 3. Longitudinal section of the Rák brook (after Figure 1.).

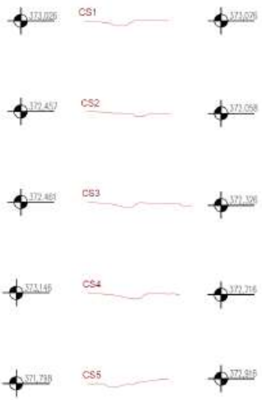
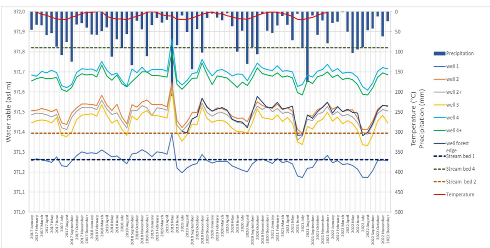


Figure 4. Cross sections of the Rák Brook in the lines of the wells (after Figure 1.).



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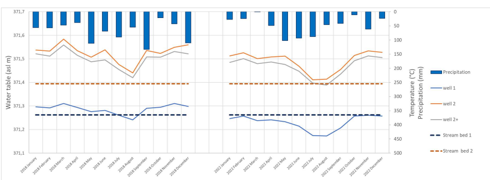

Figure 6. Groundwater dynamics of a dry and a wet year in relation to the streambed level.

	growth of tree trunk circumference 4 (cm)	growth of tree trunk circumference 5 (cm)	annual average groundwater table height (asl m) well 1	annual average groundwater table height (asl m) well 2	Sum of precipitation (mm)	annual minimum groundwater table height (asl m) well 1	annual maximum groundwater table height (asl m) well 1	water level fluctuations (m) well 1	annual minimum groundwater table height (asl m) well 2	annual maximum groundwater table height (asl m) well 2	water level fluctuations (m) well 2
2017	1,3	1,4	371,264	371,507	710,6	371,204	371,307	0,103	371,414	371,576	0,162
2018	0,8	0,8	371,287	371,526	831,2	371,238	371,340	0,102	371,435	371,634	0,199
2019	0,6	0,8	371,259	371,518	745,9	371,184	371,322	0,138	371,410	371,612	0,202
2020	0,6	1,4	371,240	371,502	596,5	371,174	371,291	0,117	371,400	371,590	0,190
2021	1,1	1,2	371,236	371,493	629,4	371,132	371,326	0,194	371,317	371,566	0,249
2022	0,7	1	371,230	371,489	566,3	371,157	371,272	0,115	371,370	371,552	0,182

Table 1. Statistics on annual groundwater levels and tree growth in alder stand.

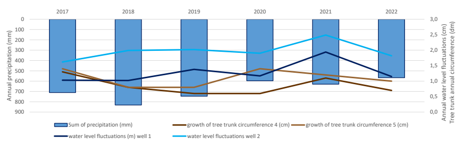

Figure 7. Relationship between annual groundwater level fluctuations and tree growth in alder stand.

The estimated groundwater transpiration of the alder forest ecosystem was significant during hot periods without any precipitation. Due to the spatial analyses of the streamside zone's groundwater level, we found that in dry summer periods, the water table can significantly fall below the streambed.

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INVESTIGATION OF THE GROUNDWATER TURNOVER IN A SALT STEPPIC OAK FOREST IN THE LOWLANDS

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As groundwater levels continue to sink, it is vital to understand what is happening in the groundwater beneath a forest, how much it is taking up, and how much it is taking away from its environment. The oak forest of Ohat is a relict area along the Tisza, so it is also important from a conservation point of view to explore what is happening there.

In 2021, two groundwater wells were installed in the area, and automatic measuring devices were installed in them to record the daily fluctuations of groundwater. We will use the White method to calculate the groundwater recharge during periods of no precipitation, which will allow us to estimate the groundwater abstraction from the forest. We will also examine how the conditions in the area have changed in the light of long-term meteorological data series for the region.

The multi-year data series will allow us to compare the soil water recharge in different years.

The following joint projects (143972SNN project and the TKP2021-NKTA-43 project) supported the preparation of this paper. TKP2021-NKTA-43 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021- NKTA funding scheme.

INTRODUCTION

Lowland forests in Hungary use a significant amount of groundwater, and this is especially true in Hungarian Great Plain (Ijjász 1939). Groundwater table is sinking deeper and deeper every year for a number of reasons. It is important to understand the role of forests in this process and the extent to which they actually use the water in their environment. The situation of forests is deteriorating due to climate change, and in many places, their existence could be threatened by the sinking of groundwater levels. It is therefore essential to be aware of the impact of forests on groundwater and therefore on the ecosystem as a whole.

METHOD

This paper focuses groundwater recharge dynamic from below in a salt steppic oak forest near river Tisza (Figure 1). The oak forest of Ohat is a relict area along the Tisza, so it is also important from a conservation point of view to explore what is happening there.

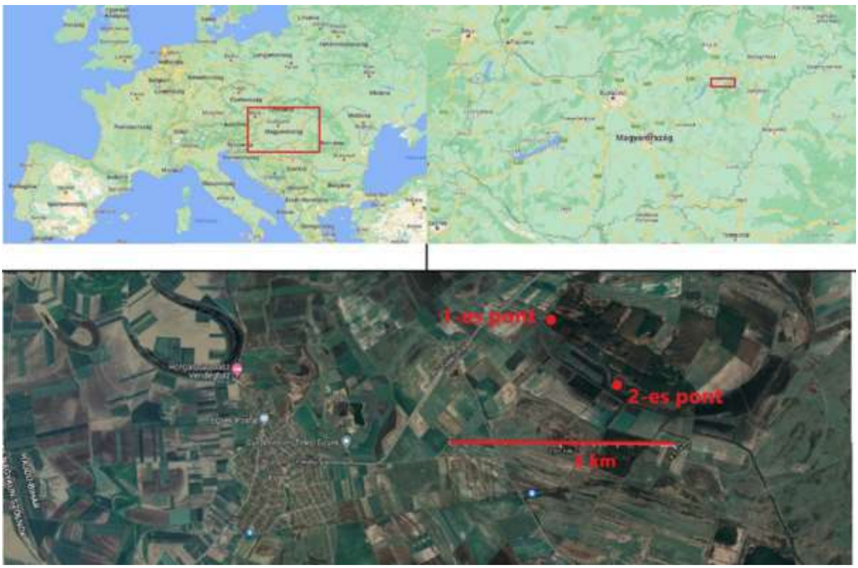

Figure 1. The location of the study site

In 2021, two groundwater wells were installed in the area, and automatic measuring devices were installed in them to record groundwater level (Figure 2).

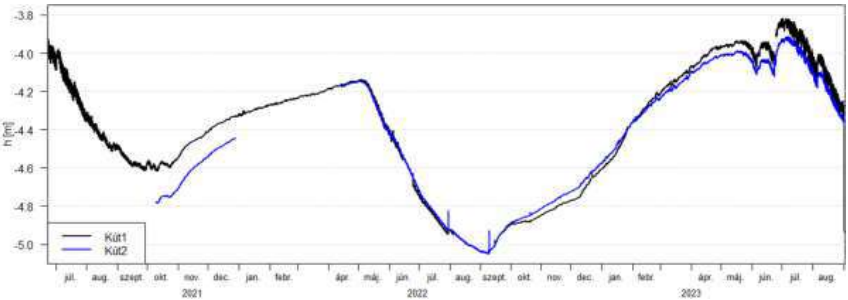

Figure 2. The measured water table time series

Diurnal fluctuation of water table was used for recharge estimation. Recharge related part of the White method (White 1932) was applied to calculate the groundwater replenishment during dry periods (Figure 3., Eq 1.)

Recharge=Sy*24*r (Eq 1.)

Recharge, daily groundwater replenishment from below (mm/day)

Sy, specific yield of the aquifer (-)

r, hourly recharge in late night period (mm/hour)

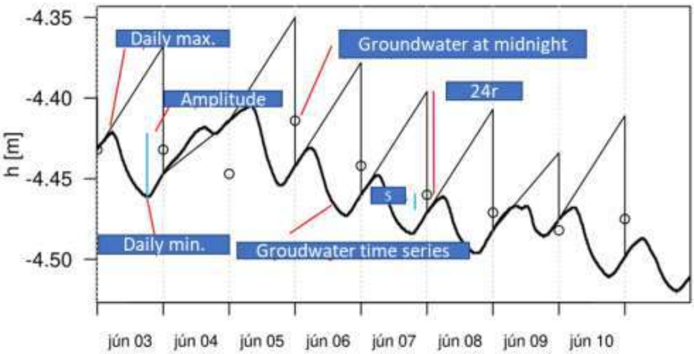

Figure 3. Characteristic values related to recharge estimation.

RESULTS

The calculated daily recharge was significantly different in the summer period of 2022 and 2023 (Figure 4 a and b). In the growing season of 2023 was more rainfall and as a consequence the groundwater level was closer to the surface than the previous year. The water table was shallower (in July, it was 3.9 m) so the recharge was 5-8 times higher than during the summer of 2022. In the beginning of the vegetation period in 2022, the recharge was started to grow, but when groundwater depth reached 4.8-5 m, the replenishment was significantly reduced because of limiting groundwater resources (the root system lost the contact with the water table). In contrast, in 2023 the recharge has continuously grown until August.

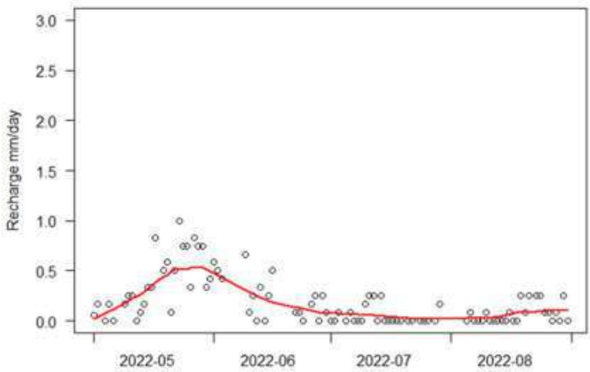

Figure 4 a. Recharge in 2022 growing season

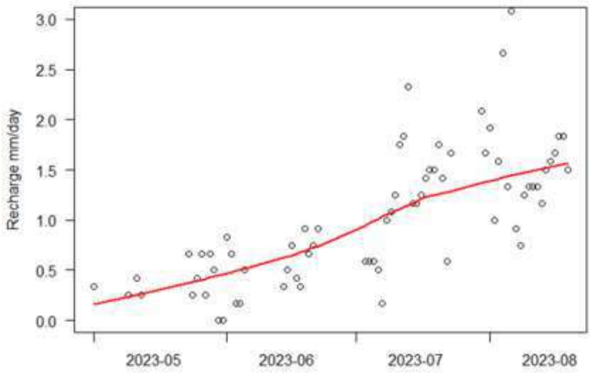

Figure 4 b. Recharge in 2023 growing season

SUMMARY

In the case of the Ohati forest, there is a risk that the forest will be significantly damaged by groundwater shortages during long dry periods similar to the case in 2022. If the rainfall is well distributed and abundant in a given year, the forest stand will do quite well, but if the water table continues to sink there could be serious problems. Groundwater time series data showed that in this area if the groundwater sink below 5m, it is difficult for the forest to survive in the long term. Similar characteristics of groundwater recharge decrease under oak forest was found in other part of the Hungarian Great Plain in 2022 by Szabó et al. (2023).

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UNIVERSITY of SOPRON

FACULTY OF FORESTRY

Investigation of the groundwater turnover in a salt steppic oak forest in the lowlands

Zsombor Kele, Péter Kalicz, Zoltán Gribovszki

As groundwater levels continue to sink, it is vital to understand what is happening in the groundwater beneath a forest, how much it is taking up, and how much it is taking away from its environment. The oak forest of Ohat is a relict area along the Tisza, so it is also important from a conservation point of view to explore what is happening there.

In 2021, two groundwater wells were installed in the area, and automatic measuring devices were installed in them to record the daily fluctuations of groundwater. We will use the White method to calculate the groundwater recharge during periods of no precipitation, which will allow us to estimate the groundwater abstraction from the forest. We will also examine how the conditions in the area have changed in the light of long-term meteorological data series for the region.

The multi-year data series will allow us to compare the soil water recharge in different years.

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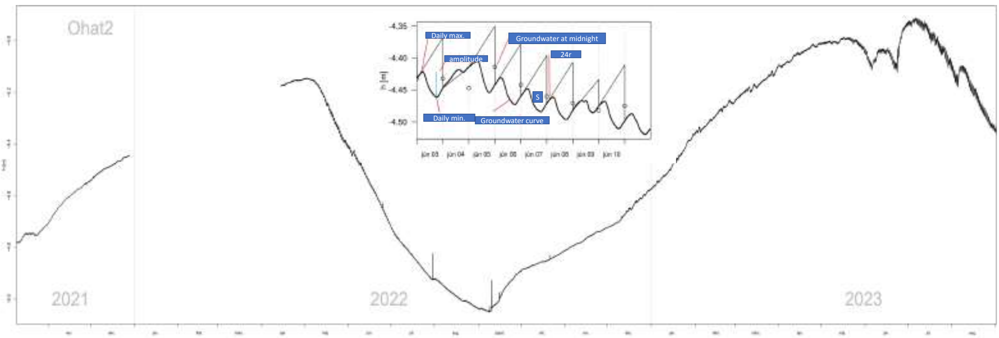
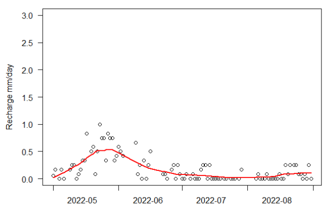
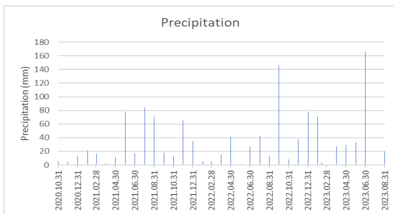


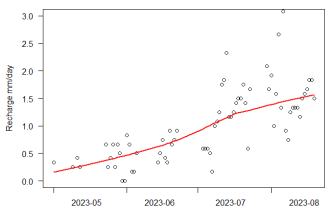
The groundwater altitude of the second well from July of 2021 to September of 2023. There is a small figure of the White-method.



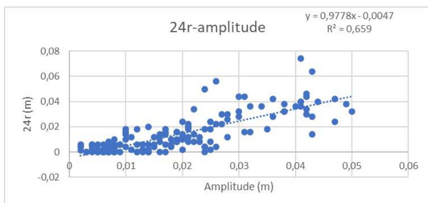
Recharge in 2022



The precipitation from 2020 october to 2023 august



Recharge in 2023



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DROUGHT SENSITIVITY AND WATER-HOLDING CAPACITY OF LOWLAND SOILS UNDER FORESTS IN THE CARPATHIAN BASIN

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The changing climate is bringing more extreme weather and the uneven distribution of rainfall events. These effects are already being observed, and although the average of the many annual precipitation totals has not been changing significantly, the length and frequency of periods of no precipitation and drought have significantly increased. These changes are also being felt by forest stands, and their sensitivity to drought is a crucial factor in their management. During our study, we looked for stands with more extreme site conditions and which are more exposed to the effects of drought. Therefore, we wanted to address the water-holding capacity of lowland soils under forests with more extreme weather conditions and investigate the drought sensitivity of these soils.

We have recently investigated the water-holding capacity of the soils of two stands of the "Tilos" forest in Kunpeszér and two stands of a forest near the Peitsik watercourse in Szentkirály, Hungary. The soils were sampled to a depth of 110 cm using a motorized soil sampler.

In the two areas selected, we recorded albic arenosol (calcaric) and petrocalcic chernozem genetic soil types under the pedunculated oak stands; the climatic characteristics indicated a forest-steppe climate. The texture of the soils was sand and loamy sand. The pH, lime content, organic matter content, texture, and bulk density of the soil fractures were measured at a 10 cm resolution under laboratory conditions, from which the potential available water for plants (PAW) was calculated using pedotransfer functions. In addition, using the climatic data of the area and the results obtained, its sensitivity to drought was investigated using the Thornthwaite-type model.

The changing climate is bringing more extreme weather and the uneven distribution of rainfall events. These effects are already being observed, and although the average of the many annual precipitation totals has not been changing significantly, the length and frequency of periods of no precipitation and drought have significantly increased (Szilágyi & Józsa, 2008). These changes are also being felt by forest stands, and their sensitivity to drought is a crucial factor in their management. (Führer, 2018). Because of climate change, the importance of individual soil properties increases. Regarding the water retention capacity of the soil, only forests with adequate water supplies are able to survive longer periods without precipitation. In periods of drought without precipitation, the water retention capacity of soils is of particular importance, which can be described with the metric potential of the given soil (pF-curves) and the physical characteristics of the soils (Rajkai & Kabos, 1999). The latter is determined by the grain size distribution of the soil (Stefanovits, 1992). Secondary factors further modify this, which must also be taken into account during the survey (Tóth et al., 2014). The measured properties of the soils can be used for further investigations, by pedotransfer functions. These functions can replace the pF-measurements, but the results they only infer the real values. The field capacity and the potential available water content for plants could be derived from the pF-values. For the water balance of the area, several models have been prepared to describe it, including the Thornthwaite-type (1955) water balance model with a monthly time scale, which is also suitable for forestry applications (Herceg et al., 2018).

We have recently investigated the water-holding capacity of the soils of two stands of the "Tilos" forest in Kunpeszér and two stands of a forest near the Peitsik watercourse in Szentkirály, Hungary. The two sites are just 40 km apart and the climatic conditions are really close to each other and the composition of the tree species are also similar. The average annual temperature varies between 10.3-10.5°C, the annual precipitation amount is between 510-550 mm, of which 290-320 mm are included for the vegetation period (Dövényi, 2010). The difference is in the parent material, which is sand in Kunpeszér and loess in Szentkirály. The soils were sampled to a depth of 110 cm using a motorized soil sampler. Undisturbed soil samples were collected with metal cylinders to save the structure of the soil, and disturbed samples were used for the chemical and physical analysis.

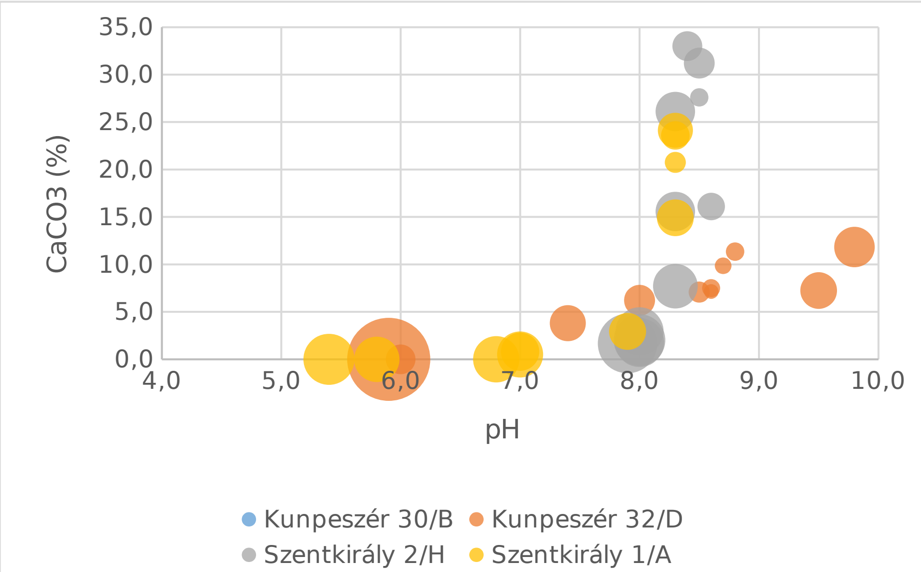

Figure 1. Chemical characteristics of the samples (pH, CaCO3 (%), organic carbon (%))

In the two areas selected, we recorded albic arenosol (calcaric) and petrocalcic luvic kastanozem (greyic) genetic soil types under the pedunculated oak stands; the climatic characteristics indicated a forest-steppe climate. The pH, lime content, organic matter content, texture, and bulk density of the soil fractures were measured at a 10 cm resolution under laboratory conditions. We found neutral pH (pH=7,4-8,3), with moderate lime content ($CaCO_3$%=8,0-15,1%), and moderate humus content (C%=0,81-0,93%). The texture of the soils was sand and loamy sand. The soils were not compacted (ρ_b=1,52-1,41 g/cm^3).

From the laboratory results, the potential available water for plants (PAW) was calculated. The texture of the soils indicated the estimation from pF=2. Two pedotransfer function were used, one method with the Brooks and Corey (1964) and Campbell (1974) formulas with Clapp and Hornberger's (1978) empirical equations to the PAW for the 10 cm resolution and method 2 by van Genuchten (1980) formula and complex pedotransfer functions (Szabó et al. 2019) for the whole profile. The upper levels had the highest potential water resources (16-20%), but this is not the same as the real water resources, because evaporation is also the most significant here. The water resources of the additional layers moved together with the loam and clay content, but showed a relative decrease in the deepest levels of the profile (11-16%).

We created water balance models, according to Thornthwaite (1955), from the second method data, the field capacity (θ_{fc}), and the local climate data (OMSZ, 2023). We also calculated the relative extractable water (REW) based on Granier (1999) recommendation. The periods with REW<40% gives us the aridity index of the area. Examining the examined period in three scales (1972-2002, 1982-2012, 1992-2022), we found that the number of drought days increased for each site, even though the precipitation amounts did not follow these trends.

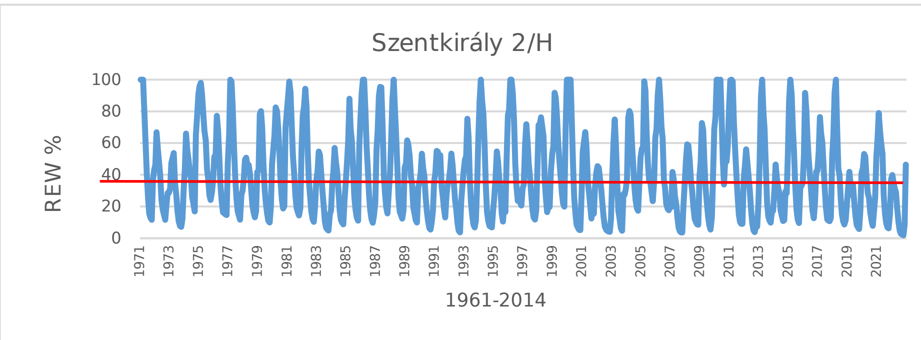

Figure 2. Water balance model of the area (Szentkirály 2/H)

The areas we examined served as good examples for characterizing the natural climate-zonal forest areas of the Great Hungarian Plain. The available water resources of the soils were mainly determined by the sandy texture, however, the soil tests clarified these with additional secondary factors. The soil properties and the local environment has a major factor to the water management of these areas and the basic soil parameters can help to improve these models. The weak water retention capacity has resulted in extreme site conditions, to which the forest population must adapt. However, changing trends predict further drying, which could decide the fate of these forest stands.

Acknowledgment

This publication was realized with the support of the Ministry of Innovation and Technology (successor Ministry of Culture and Innovation) from the National Research Development and Innovation Fund within the framework of the TKP 2021 NKTA project with the identification number 43, financed by the TKP 2021 NKTA tender program and by the New National Excellence Programme of the Ministry of Culture and Innovation, code number ÚNKP-23-3-I-SOE-172, funded by the National Research, Development and Innovation Fund. The authors would like to thank the KEFAG Kiskunsági Forestry and Wood Industry Zrt. and forestry director Sándor Madácsi for supporting works.

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INFILTRATION AND SOIL MOISTURE MEASUREMENTS IN AN EXPERIMENTAL PARCEL

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With changing weather conditions, understanding the infiltration process is increasingly important. The Faculty of Water Sciences of the University of Public Service in Hungary created an experimental catchment area in the East Mecsek Hill along the Völgységi stream to measure the elements of the rainfall-runoff process. An infiltration experiment was recently carried out in the irrigation parcel to determine the infiltration curve and better understand the infiltration process. During the infiltration experiment, measurements were combined with multi-level soil moisture probes to determine the water content in different soil layers. Throughout the infiltration measurements, two multi-level soil moisture meters were placed within the experimental plot to collect soil moisture data at 10, 20, 30, 40, 60, and 100 cm depths. The results show that the top soil layer has the highest moisture content. There is a clay layer at a depth of about 30–40 cm a with better water-holding capacity and lower water conductivity. Between 60 and 100 cm, the sandy soil-forming rock still receives a small water recharge when intense rainfall occurs, but this layer is slow to respond to surface inputs. In situ and laboratory samples were taken to determine the soil hydraulic parameters.

The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 project.

INTRODUCTION

With the increasing negative impact of climate change, there is a significant need for more accurate determination of the water flow in mountain and hilly catchments to protect against water damage and our water resources. (Werners, S., E., et al. 2016) The spatial and temporal variability of precipitation, different soil parameters eg. soil moisture and infiltration characteristics have a significant influence on the runoff conditions in natural catchments and thus on the water flow in watercourses.

LOCATION

The experimental site is located on the hilly watersheds of the Faculty of Water Sciences of the University of Public Service in the headwaters of the Völgységi creek. The Völgységi Creek catchment is in the central Mecsek mountains in the southern part of Hungary. The experimental catchment covers 32 km^2 of the Völgységi catchment, roughly 6 % of the area. In the Várvölgy catchment an infiltration experiment was carried out with soil moisture measurement. The purpose of the ongoing experiments is to determine the seepage processes taking place in the upper soil layer. (Koch, D., et al. 2019)

SOIL EXPLORATION

The soil profile is located approx. 20 meters from the stream, 5-7 m higher than the riverbed level, on a straight slope. It is covered with cypress and beech vegetation.

There is a very thin 1-2 cm humic A level, a significant part of which is raw humus, undecomposed, very young material.

From 2 to 50/55 cm there is a deep leaching level; it has a layer of darker color up to 30 cm, a very fine loam physical type, with sand and dust. This profile was formed on loess (this loess can also be seen on the surface in several places in the valley). From 30 to 50 cm, the color starts to lighten and fade, with very small spots of iron and manganese, indicating that the water already exists. The iron starts to go into the solution and sits on top of soil level B.

Soil level B is a degraded clay accumulation level, full of spots, gray streaks, and long cracks, and the material of these cracks is filled by the material falling from above. These cracks could even be old root canals, water flows down through them and is stuck in them for a long time, like in stagnant soils. Between 90-100/110 cm one can see the entire spotted pattern. It has a clay membrane, its clay content has increased, it can be identified as clay loam, its weaker type, but still has a very good water-retention capacity.

In summary: (1) stagnant brown forest floor, which is almost always present in the lower part of the slopes. It was formed on loess, so it is basically a clay loam physical type, with a lightened part with stagnant water, and (2) a color pattern with stagnant water in soil level B. (Dobos, E., et al. 2023)

Soil moisture and infiltration measurements

In the experimental irrigation parcel (infiltration measurement) with multi-level soil moisture probes were installed to observe the wetting process of different soil layers. We placed 2 soil moisture meters inside the parcel, which collected data at depths of 10, 20, 30, 40, 60, and 100 cm. The frequency of the measurements was from 2 hours to 1 minute to clearly see the development of soil moisture in the initial phase, later it was necessary to measure every 1 hour or every 2 hours. (Fig. 1, a)

The experiment was done by delimiting a 25 m^2 plot (parcel) on the hillside with an edge and a weir at outflow to measure water discharge. Within the plot, sprinkler heads were placed and fed with water from a nearby stream using a pump, simulating rainfall on the plot. The amount of rainfall applied was measured using rain gauges. (Fig. 1, b) (Majer, F., et al. 2020)

A significant amount of water continuously infiltrated into the soil over time. Infiltration was calculated by subtracting the water measured at the runoff point from the precipitation to obtain the exponential infiltration curve. In addition, we found that runoff still occurred 2 hours after the start of rainfall and that roughly 100 mm of precipitation infiltrated the plot during this time, indicating a severe drought in the area.

Figure 1. Multi-level soil moisture probes and the experimental irrigation parcel

RESULTS

The experiment aimed to measure the water flow between the sensors, which has not yet been achieved yet.

The experiment was repeated three times during an arid, almost rain-free period: August 28, September 8, and October 17, 2023. The results support the soil exploration observation. The upper layer (level A) was uniformly moistened, but the increase in moisture content was not so intense in the lower layers; the water was stuck in the B level. (Fig. 2.)

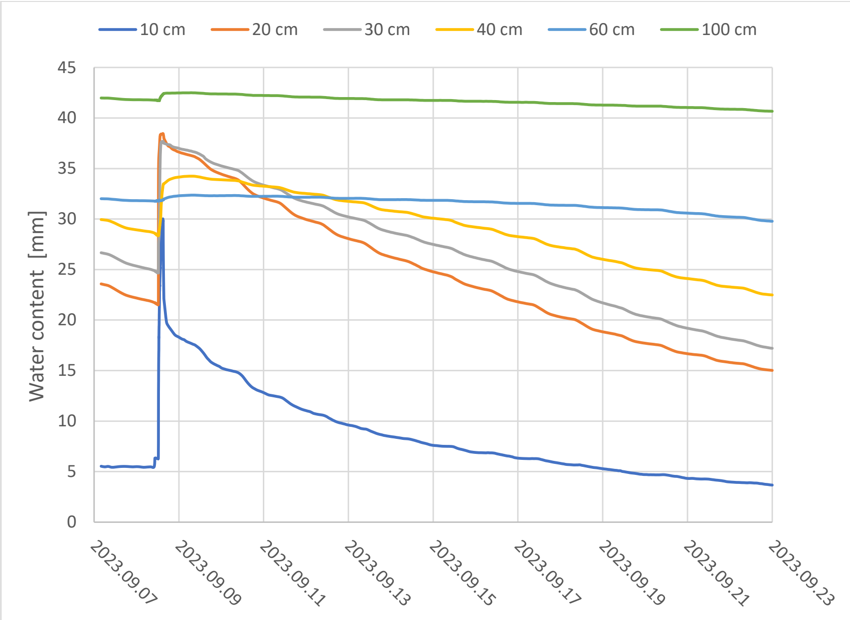

Figure 2. Soil moisture curves in different soil layers

Conclusion

Soil layers and parameters of seepage and wetting processes cannot be simplified by averaging.

Different soils formed on different bedrock with different water management properties.

Our goal is to perform these experiments on soils developed on sandstone, limestone, and basalt in the experimental area. Our current initial results also support that soil exploration should be part of watershed exploration, helping rainfall runoff modeling.

The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 project.

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IRISE: Impact of rainfall interception on soil erosion

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Rainfall interception by vegetation is an essential part of the hydrological water cycle. Part of the intercepted rainfall evaporates into the atmosphere, and throughfall and stemflow contribute to surface runoff, affect soil erosion and infiltration processes, and control soil moisture and runoff connectivity patterns. The impact of changing climate and land cover on the rainfall interception, structure, velocity and erosive power is, however, still not well understood.

This contribution presents the objectives of a bilateral research project between TU Wien and the University of Ljubljana that aims to understand the effect of meteorological and vegetation characteristics on changes in a raindrop microstructure and, therefore, on the erosive power of rainfall. The main research focus is to investigate and compare the mechanisms of the rainfall interception process in different climate conditions in terms of the throughfall microstructure below different vegetation types, i.e., trees and crops on the experimental urban plots in Slovenia and a small agricultural basin in Austria and to evaluate the impact of the changed raindrop microstructure on the erosive power of the rainfall as well as to sediment transport in the streams.

Acknowledgment: This contribution is part of the ongoing research project entitled “Evaluation of the impact of rainfall interception on soil erosion” supported by the Slovenian Research and Innovation Agency (J2-4489) and it was funded in part by the Austrian Science Fund (FWF) I 6254-N.

IRISE: Impact of rainfall interception on soil erosion

Juraj Parajka , Borbala Szeles, Urša Vilhar, Nejc Bezak, Mojca Šraj

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TECHNISCHE UNIVERSITÄT WIEN

Abstract

Rainfall interception by vegetation is an essential part of the hydrological water cycle. Part of the intercepted rainfall evaporates into the atmosphere, and throughfall and stemflow contribute to surface runoff, affect soil erosion and infiltration processes, and control soil moisture and runoff connectivity patterns. The impact of changing climate and land cover on the rainfall interception, structure, velocity and erosive power is, however, still not well understood.

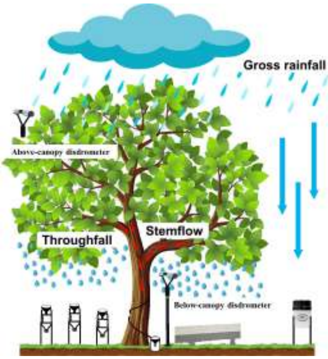
This contribution presents the objectives of a bilateral research project between TU Wien and the University of Ljubljana, that **aims to understand the effect of meteorological and vegetation characteristics on changes in raindrop microstructure and, therefore on the erosive power of rainfall.** The main research focus is to investigate and compare the mechanisms of the rainfall interception process in different climate conditions in terms of the throughfall microstructure below different vegetation types, i.e., trees and crops on the experimental urban plots in Slovenia and a small agricultural basin in Austria and to evaluate the impact of the changed raindrop microstructure on the erosive power of rainfall as well as to sediment transport in the streams.

Research objectives

1) Identifying the influence of several meteorological characteristics (e.g. rainfall amount, intensity and duration, wind speed and direction, air temperature, air humidity) on rainfall and throughfall DSD in different climates.

2) Identifying the influence of rainfall interception by different types of vegetation, namely several types of trees and crops on throughfall DSD in different seasons (i.e. phenophases).

3) Identifying the impact of rainfall interception process on the erosive power of raindrops (i.e. rainfall erosivity) as one of the most important factors of soil erosion.

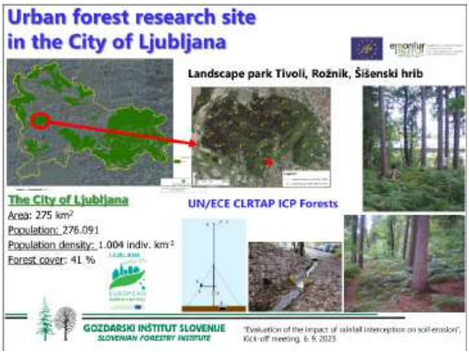


Urban park in Ljubljana

Roof

Birch

Pine



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Investigation of erosion in the Hydrological Open Air Laboratory – The HOAL 2.0 Project

Leon Hohenstein[1], Günter Blöschl[1], Peter Strauss[2], Elmar Schmaltz[2], Jürgen Komma[1], Juraj Parajka[1], Borbála Széles[1], Peter Valent[1], Carmen Krammer[2], Thomas Brunner[2]

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Pluvial floods can lead to soil erosion, soil loss and increased sediment loads in streams and can result in increased risks and economic losses. In many regions, the likelihood of such events is growing due to climate change.

The Hydrological Open Air Laboratory (HOAL) in Petzenkirchen in Lower Austria is an experimental catchment that has offered long-term observations of hydro-meteorological variables since 1945 that enable the investigation of the drivers and factors which control erosion processes. Additionally, its geographical and agricultural characteristics are representative of regions all over the world. The HOAL 2.0 project aims to answer the following questions: (1) To what extent can optimal and integrative agricultural land management contribute to the effective water retention of landscapes and therefore reduce the risk of pluvial extreme discharges in agricultural catchments? (2) To which way can an integrative and participatory implementation of optimized land-management practices be realized for achieving maximal protection as well as maximal acceptance by farmers, mayors, residents and other stakeholders?

In a first step, the potential of different on and off-site land-management practices are evaluated. The hydro-meteorological monitoring network in HOAL captures all the components of the water cycle in a high spatio-temporal resolution, which enables answering the research issues of the project. The measurements can then provide a solid basis for developing models for the generalization of the results. Finally, a comprehensive communication and outreach campaign can allow for a public exchange about the findings and encourage further discussion with farmers, stakeholders and residents. This will ensure that the best practices for land management are realistic and economically feasible.

THE EXPERIMENTAL MEASUREMENTS OF THE EFFECTIVENESS OF ROOF SUBSTRATE IN TERMS OF A REDUCTION IN RUNOFF FROM VEGETATED ROOFS

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The primary focus of the experiment is to investigate the substrate material by examining its composition and properties. Its main objective is to investigate and compare how different intensities of short-term extreme rainfall events affect the ability of the substrate to retain water under different conditions.

Specifically, the efficiency of a pure substrate is compared with substrates enriched with 5% and 10% of the biochar components. The results achieved from this experiment reveal differences in the adsorption capacity of the three different samples. The addition of biochar shows an especially significant effect on the delay of runoff from the substrate, which was mainly observed during a 15-minute of low-intensity rainfall. The most significant differences in water retention were observed during a 15-minute rainfall with an intensity of 3 mm/min. In contrast, the differences in retention appear less significant at more moderate rainfall intensities (4 mm/min) and even at extreme rainfall intensities (5 mm/min).

Based on the observations from the experimental measurements, the use of biochar as an alternative method to improve the retention capacity of a substrate proves to be a reasonable option for reducing rainfall runoff.

Keywords: roof substrate, biochar, runoff, water retention, rainfall intensity

Acknowledgements: The study was supported by the VEGA grant project No. 1/4021/07.

The experimental measurements of the effectiveness of roof substrate in terms of a reduction in runoff from vegetated roofs

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ABSTRACT

The primary focus of the experiment is to investigate the substrate material by examining its composition and properties. Its main objective is to investigate and compare how different intensities of short-term extreme rainfall events affect the ability of the substrate to retain water under different conditions.

Specifically, the efficiency of a pure substrate is compared with substrates enriched with 5 % and 10 % of the biochar components. The results achieved from this experiment reveal differences in the adsorption capacity of the three different samples. The addition of biochar shows an especially significant effect on the delay of runoff from the substrate, which was mainly observed during a 15-minute of low-intensity rainfall. The most significant differences in water retention were observed during a 15-minute rainfall with an intensity of 3 mm/min. In contrast, the differences in retention appear less significant at more moderate rainfall intensities (4 mm/min) and even at extreme rainfall intensities (5 mm/min).

Based on the observations from the experimental measurements, the use of biochar as an alternative method to improve the retention capacity of a substrate proves to be a reasonable option for reducing rainfall runoff.

1 MOTIVATION

The project will present the results from the experimental measurements. The aim of the experiment is to analyze the effect of rain intensity on the retention capacity of the roof substrate under laboratory conditions. And also to compare the results of adding biochar to the substrate to enhance water retention and subsequent water release for vegetation cover. Which should demonstrate the difference in reducing stormwater runoff on the experimental roof substrate mixtures.

2 METHODS

ROOF SUBSTRATE

The most common substrate components are brick rubble, lava, and compost (Fig. 1). In the construction of vegetated roofs, it is used with a layer thickness of 6 cm. The high water absorption of the substrate has several advantages. It helps the vegetation to create optimal conditions for growth.

In the case of the tested roof substrate, the material consists of 90 % skeleton and approximately 80 % brick rubble (Figure 2).

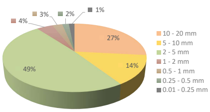


Fig. 2 – Grain size analysis

Fig. 1 - Substrate

BIOCHAR

It is an organic material consisting mainly of wood. It is prepared by a process called pyrolysis. This is a thermal process in which the structure of the wood is chemically altered. The material is burned at high temperatures with low air content.

Fig. 3 - Biochar

Pyrolysis combustion results in almost pure carbon (charcoal) (Fig.3). Charcoal has a porous structure. Due to the cavities and pores, it has a significantly positive effect on the properties of the soil.

EXPERIMENT

- Rainfall simulations were performed at intensities of 3, 4, and 5 mm/min (Fig. 5).
- It was an intermittent 15 minutes rain of constant intensity.
- The rain interruption and the measurement itself took place at times (3, 6, 9, 12, 15 minutes).
- Simultaneously with the start of the rain simulator, the subsurface runoff time was measured by using a stopwatch.
- After 3 minutes, the simulation was stopped and the runoff, and substrate moisture were measured in the shortest time possible (Fig. 6, 7).

Fig. 4 - Tools

- The runoff from the bottom container was measured with a graduated cylinder in which the amount of un-infiltrated water was accurately read.

Fig. 5 - Experimental setup

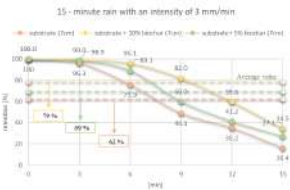
Fig. 6 – Un-infiltrated water

Fig. 7 - Moisture measurement

3 RESULTS

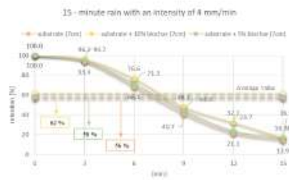
The result of the experimental measurements is a comparison of samples of Bratislava roof substrate and samples of Bratislava roof substrate mixed with biochar (5%, 10%).

The aim was to show the effect of the intensity of short-term extreme rain on the retention capacity of the substrate.



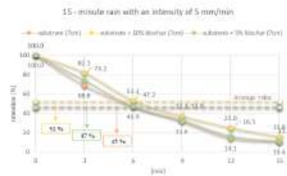
- **100 % Substrate**
  Total rainfall 45 mm
  Runoff 17 mm (38 %)
- **95 % Substrate + 5 % biochar**
  Total rainfall 45 mm
  Runoff 14 mm (31 %)
- **90 % Substrate + 10 % biochar**
  Total rainfall 45 mm
  Runoff 10 mm (21 %)

Fig. 8 – 15 minute rain with an intensity of 3 mm/min



- **100 % Substrate**
  Total rainfall 60 mm
  Runoff 26 mm (44 %)
- **95 % Substrate + 5 % biochar**
  Total rainfall 60 mm
  Runoff 25 mm (42 %)
- **90 % Substrate + 10 % biochar**
  Total rain 60 mm
  Runoff 23 mm (38 %)

Fig. 9 – 15 minute rain with an intensity of 4 mm/min



- **100 % Substrate**
  Total rainfall 75 mm
  Runoff 41 mm (55 %)
- **95 % Substrate + 5 % biochar**
  Total rainfall 75 mm
  Runoff 40 mm (53 %)
- **90 % Substrate + 10 % biochar**
  Total rainfall 75 mm
  Runoff 36 mm (48 %)

Fig. 10 – 15 minute rain with an intensity of 5 mm/min

The experimental measurements were performed to determine the retention capacity of the roof substrate by simulating short-term extreme rainfall (duration of 15 minutes and intensities of 3, 4, and 5 mm/min). In the results part, the retention performance of the tested roof substrate is expressed in percentage of the runoff (Fig. 8, 9, 10).

Overall, it can be assessed that the addition of biochar helped to reduce the runoff from rain.

4 CONCLUSION

The experiment showed that the intensity of rain can affect the retention capacity of the substrate. The addition of biochar was shown to reduce runoff at all measured rain intensities. These types of experiments help us to understand the hydrological processes on the vegetation roof along with the application of biochar.

The mentioned measurements can also be used to obtain an infiltration curve to model the water regime in the soil/substrate.

Acknowledgement
This work was supported by the VEGA grant project 1/0577/23.

A COMPARISON OF THE SURFACE TEMPERATURE OF TYPICAL URBAN MATERIALS IN RELATION TO THE STREET ORIENTATION

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[1] Slovak University of Technology in Bratislava, Department of Land and Water Resource Management

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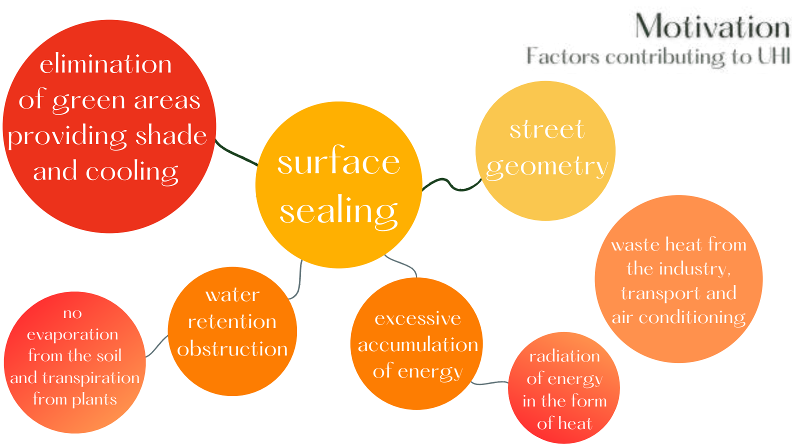
The overheating of cities is mainly caused by sealing formerly permeable surfaces and eliminating vegetation. Even though greenery is a valuable asset for mitigating extreme heat conditions and has proved to be the most efficient, it is vital to comprehend the urban conditions to create effective strategies with positive microclimatic and economic merit. The inappropriate use of trees can result in unnecessary expenses, but more importantly, it can worsen urban climate conditions by obstructing the airflow and subsequent entrapment of the overheated air. Therefore, it is essential to examine the local conditions and determine the most irradiated and overheated parts of streets suitable for tree planting. Subsequently, combining these measures with the existing building geometry and using building shading could be a suitable tool for overheating mitigation. When applied correctly, this combination has proved to be the most effective by creating shade and enabling airflow. In our pilot case study, we measured the surface temperature of the five most typical materials in Old Town district of Bratislava, Slovakia, in relation to their cardinal directions. We chose the representative streets in each direction and divided them into two groups i.e., narrow and wide. Consequently, we compared the temperature progression of each material in relation to their orientation, geometry, and the time of day. The results could serve as a basis for our further studies of urban conditions and provide a general key to effective blue-green infrastructure strategies.

This study has been supported by the Scientific Grant Agency under Contracts no. VEGA 1/0067/23.


A comparison of the surface temperature
of typical urban materials
in relation to the street orientation
Miriam Zaťovičová, Martina Majorošová


Motivation
Factors contributing to UHI
elimination of green areas providing shade and cooling
surface sealing
street geometry
waste heat from the industry, transport and air conditioning
no evaporation from the soil and transpiration from plants
water retention obstruction
excessive accumulation of energy
radiation of energy in the form of heat

Impact of street orientation on urban microclimate

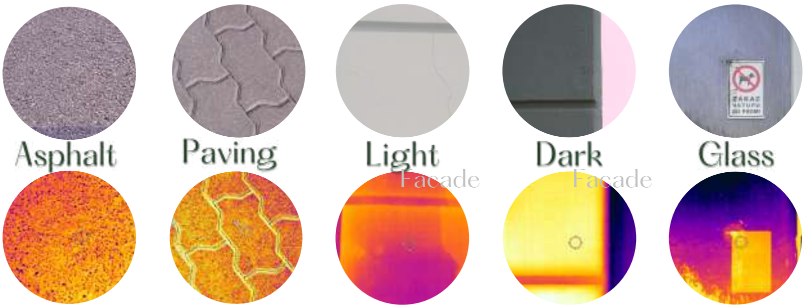
•Buildings obstruct fresh air flow
•Hot air is trapped in the street corridor

•Trees are the best UHI-mitigating measure for their shading and cooling abilities

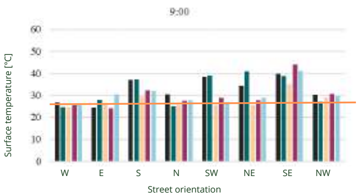
•The inappropriate use of trees can lead to further obstruction of airflow and heat entrapment

Methods

- We divided the representative streets of the Old Town into **narrow** and **wide** to assess the impact of H/W ratio on the temperature
- Measurements were conducted in the summer at **9:00, 14:00** and **23:00**
- We measured on both sides of the streets of every cardinal direction to assess the importance of building shading on surface temperature

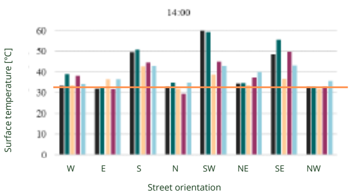


Typical surface materials



Results

- The **warmest** are **S, SW, SE** orientations at both 9:00 and 14:00
- E, W – facing streets did not show significant deviations from air temperature throughout the day
- Asphalt and pavement temperatures on the **NE-facing** street **dropped** by the afternoon
- **E, W, N** and **NW** showed the **lowest temperatures** and the differences between materials were not significant either
- Nighttime temperatures were more even across all orientations and materials, with S, SW and SE orientations slightly warmer



A comparison of the surface temperature of typical urban materials in relation to the street orientation

Miriam Zaťovičová, Martina Majorošová

Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, 810 05 Bratislava, Slovakia **miriam.zatovicova@stuba.sk**

ABSTRACT

The overheating of cities is mainly caused by sealing formerly permeable surfaces and eliminating vegetation. Even though greenery is a valuable asset for mitigating extreme heat conditions and has proved to be the most efficient, it is vital to comprehend the urban conditions to create effective strategies with positive microclimatic and economic merit. The inappropriate use of trees can result in unnecessary expenses, but more importantly, it can worsen urban climate conditions by obstructing the airflow and subsequent entrapment of the overheated air. Therefore, it is essential to examine the local conditions and determine the most irradiated and overheated parts of streets suitable for tree planting. Subsequently, combining these measures with the existing building geometry and using building shading could be a suitable tool for overheating mitigation. When applied correctly, this combination has proved to be the most effective by creating shade and enabling airflow. In our pilot case study, we measured the surface temperature of the five most typical materials in Old Town district of Bratislava, Slovakia, in relation to their cardinal directions. We chose the representative streets in each direction and divided them into two groups i.e., narrow and wide. Consequently, we compared the temperature progression of each material in relation to their orientation, geometry, and the time of day. The results could serve as a basis for our further studies of urban conditions and provide a general key to effective blue-green infrastructure strategies.

1 MOTIVATION

Climate change is becoming a significant threat that affects every aspect of our lives. Intensive urbanization contributes to global warming by eradication of green spaces resulting in the "urban heat island effect". This means that sealed urban surfaces are prone to overheating and subsequently increase temperature of the cities by over 10°C compared to rural areas.

Fig. 1 Factors contributing to UHI

- Buildings obstruct fresh air flow
- Hot air is trapped in the street corridor
- Trees are the best UHI-mitigating measure for their shading and cooling abilities
- However, the inappropriate use of trees can lead to further obstruction of airflow and heat entrapment

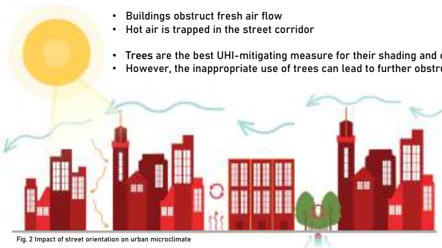


Fig. 2 Impact of street orientation on urban microclimate

BLUE - GREEN INFRASTRUCTURE DESIGN HAS TO BE BASED ON AREA ANALYSIS TO ENSURE MICROCLIMATIC AND ECONOMIC EFFECTIVITY

2 METHODS

Fig. 3 The area of interest

- The Old Town district is one of the most overheated parts of Bratislava
- In this part, we focused on **narrow streets** and studied **surface temperature** of five typical materials used in this area(Fig. 4)
- Measurements were conducted in the summer at **9:00, 14:00** and **23:00**
- We measured on both sides of the streets to assess the importance of building shading on surface temperature
- Results of this study will help determine problematic parts of streets which require implementation of blue-green infrastructure measures

Typical materials

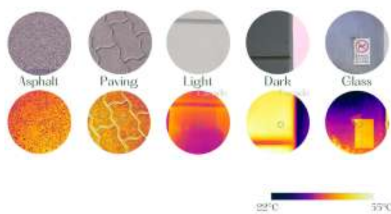


Fig. 4 Typical materials in the Old Town district of Bratislava and their surface temperatures

3 RESULTS

- The warmest are S, SW, SE orientations at both 9:00 and 14:00
- E, W – facing streets did not show significant deviations from air temperature throughout the day
- Asphalt and pavement temperatures on the NE-facing street dropped by the afternoon
- E, W, N and NW showed the lowest temperatures and the differences between materials were not significant either
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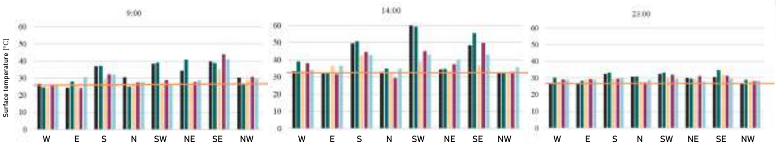

Fig. 5 Surface temperature measurements at 9:00, 14:00 and 23:00 on 19.7.2023

Fig. 6 Most overheated streets that require the design of blue-green infrastructure adaptation measures

4 CONCLUSION

- It is vital to know the conditions of the territory to develop a functional and effective methodology for climate change adaptation.
- In the first part of the measurement, we focused on narrow streets, where we measured the surface temperatures of five typical materials depending on their orientation to the cardinal directions
- The results show that the warmest parts of the streets are oriented to the South, South-East, South-West
- It is necessary to focus the design of the adaptation measures of blue-green infrastructure in these areas
- In the next phases of measurements, we will focus on wide streets, and measuring the surface temperature of other materials in the most exposed parts of the city, based on which a practical methodology will be proposed

STU SvF

SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA FACULTY OF CIVIL ENGINEERING

The surface temperature comparison of typical urban materials in relation to the street orientation

This study has been supported by the Scientific Grant Agency under Contracts no. VEGA 1/0067/23

9 November 2023 Vienna, Austria; Bratislava, Slovakia; Sopron, Hungary

THE POTENTIAL ECONOMIC BENEFITS OF RAINWATER IN THE "GREEN CITY DEVELOPMENT" PROGRAM

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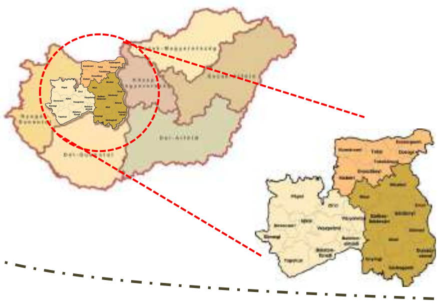
The adverse effects of climate change impact our daily lives and challenge decision-makers to address it. The primary focus of recent decades was mitigation, but recently, researchers and stakeholders have prioritized adaptation measures instead of mitigation efforts. To achieve effective adaptation measures, it is important to economically evaluate natural resources and possible scenarios with or without interventions. A comparison of potential damage and lost profits with achievable benefits is necessary for effective decision-making. Governments and municipalities have started to recognize the importance of adaptation actions, which have boosted various "green city, green settlement" type funded programs.

Hundreds of blue-green infrastructure developments have been completed in Hungary's most extensive regional development program, known as "green city development". This study focuses on the potential rainwater retention and the economically achievable benefits of these infrastructures. A part of the Central Transdanubian region was selected from these developments for evaluation. The maximum retainable rainwater and the theoretically attainable economic benefits were determined. The best methods were collected based on these criteria, and applicable nature-based solutions were proposed for using the stored (retained) water.

keywords: blue-green infrastructure, nature-based solutions, water retention, climate adaptation, water value, economic benefits

The potential economic benefits of rainwater in the "green city development" program

SZÉCHENYI EGYETEM
UNIVERSITY OF GYŐR



Problem statement

The adverse effects of climate change need adaptation measures by Hungarian settlements. Mayors have recognized the importance of adaptation actions, which have boosted the "green city, green settlement" type, state funded programs.

*Area involved in the research: **The Central Trans-danubian region***

Consists of 3 counties: Fejér (17 cities, 108 settlements)
Veszprém (15 cities, 217 settlements)
Komárom-Esztergom (12 cities, 76 settlements),
Natural and social geography: 11,086,47 km^2 (pop.1,058,236)

„Green city" program

Main aims: Biodiversity, green infrastructure, climate adaptation (storm, drought, erosion), social awareness, water related and water management issues, air quality, urban/rural developments.
Submission date: 2016-2017-(2020) ; End date: (2018)-2021-2023

High participation nationwide

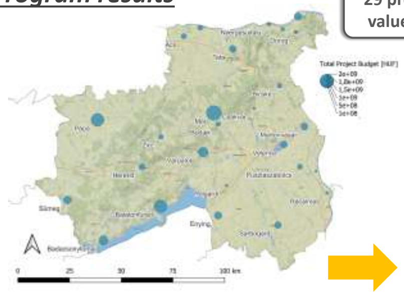
Complex projects with multiple areas

Number of cities in Hungary:
346
Cities participating in program:
198 → **57,2%**

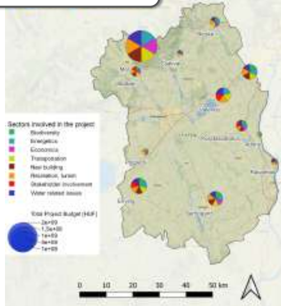
Classification by sectors:

- biodiversity, green infrastructure
- energy investment, energy efficiency improvement
- improving economic utility, income-generating capacity
- real estate development, new building construction
- transport development, transportation investment
- recreation, tourism, child-friendly and sport developments
- stakeholder involvement, increase of social awareness
- water management, water related issues (8 sub-categories)

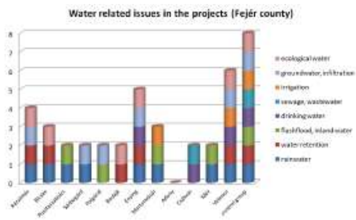
Program results



29 projects in 26 cities
value: 150k – 5.9M euro



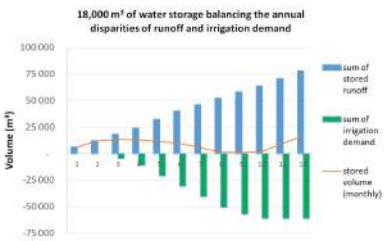
The 8 sub-categories of water related issues.



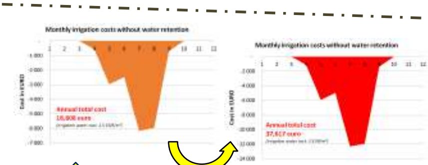
Green city programs only partially covered water related issues.
Irrigation was rarely included in the projects.

Possible economic benefits

Water retention measures using blue-green infrastructures can have financial and ecological benefits.



** figure: possible water retention volumes in cities participated on the „Green city program" from Fejer county (sum of the 11 cities)*



Present situation:
- without water retention;
- With (future) irrigation bill

Future plans:

- Extending investigation area to Hungary
- Comparing present and future green city programs with above projects
- Setting up indicators and methods

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IMPLEMENTATION OF A MONITORING PROGRAM TO TRACK POLLUTANT TRANSPORT PROCESSES IN A PILOT CATCHMENT IN HUNGARY

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To validate catchment-scale emission models, a targeted measurement program was implemented in the Koppány catchment (660 km^2). Samples were collected from stream water (the Koppány and its tributaries and shallow groundwater along the riverbed. Monthly bulk precipitation was collected. In addition to the water chemistry, stable and radioactive isotopes were measured as natural tracers to investigate hydrological pathways and residence times. Seasonal variations of water stable isotopes in the precipitation and stream water were observed to estimate the stream residence time. Tritium measurements were performed in the shallow groundwater zone to estimate the age of the groundwater. Preliminary results suggest that although the dominant land use in the watershed is arable land, during dry periods, the effect of the wastewater load determines the water quality of the Koppány-creek. Agricultural nitrate pollution is conveyed by the tributaries, and the nitrogen load contribution of the groundwater is negligible. The primary source of the particle-bound pollutants is the soil washed away during high-flow events. With the study, excess information can be obtained for a better understanding of pollutant transport via surface runoff and subsurface pathways.

The research is supported by the National Research Development and Innovation Office (NKFIH) through the OTKA Grant SNN 143868.

INTRODUCTION

Catchment scale emission models are widely used to quantify riverine load, which can be verified with flow and water quality measurements usually available at the catchment outlets. The results of the model are accepted if predicted flow and material flux values are in good agreement with measurement data. Riverine measurements, however, do not provide information either on the origin of runoff and substances nor on their temporal and spatial changes during transport. Consequently, they do not allow process-level verification of the model results.

The research aims to implement a targeted monitoring program combining methodologies of traditional hydrological and water chemistry observations with isotopic measurements to improve a deeper understanding of the sources and individual pathways of contaminants (mainly nutrients) on the catchment scale. Specific goals were (i) to identify the magnitude of particulate transport processes and (ii) to determine the contribution of surface and subsurface pathways to the nitrogen fluxes.

MATERIALS AND METHODS

The study area is the Koppány catchment in Hungary, spanning 660 km^2, which typifies the country's hilly regions, blending natural geography and human influences. Agriculture reigns as the primary land use, notably on erosion-prone hillsides (Szabó et al, 2013). Additionally, tributaries of the Koppány host reservoir-like fish ponds. Notably, the headwater area of the Koppány contends with substantial wastewater discharge, originating from Balatonlelle (Figure 1).

The sampling programme covered (i) regular stream water sampling (automatic samplers were installed in existing river gauges to sample high flow events); (ii) monitoring campaigns were executed for surveying the longitudinal profile of the main branch and the tributaries; (iii) shallow groundwater wells were drilled along the riverbed; (iv) monthly bulk precipitation was collected; (v) composite sample was collected from the direct wastewater discharge. In addition to the water chemistry (ions, total suspended solids (TSS), nutrients and potentially toxic elements (PTE)), stable and radioactive isotopes were measured as natural tracers to investigate hydrological pathways and residence times.

Lab measurements were shared within the participating institutions: BME (general water chemistry), Joseph Stephan Institute (stable isotopes and PTE), Institute for Nuclear Research (tritium) and Research Centre for Astronomy and Earth Sciences (water stable isotopes).

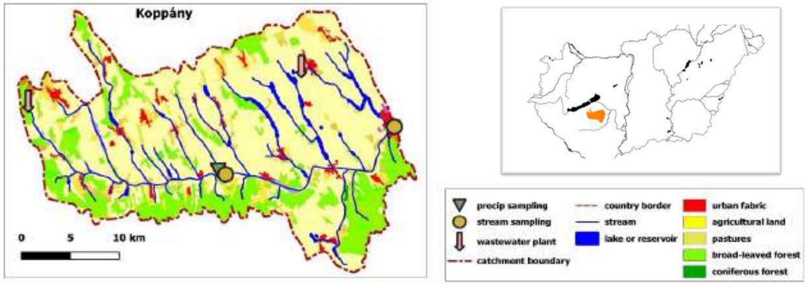

Figure1. The research catchment Koppány and the location of the sampling sites (left panel) and the location of the study area in Hungary (right panel)

RESULTS

The comparison of low-flow and high-flow periods shows significant differences in the substance concentrations. In general, TSS, particulate P and almost all soil-bound contaminants increase at high-flow events, while dissolved substances (e.g. phosphate and other ions) are higher in dry periods due to the lack of dilution. Inorganic N forms in general indicate high variability independent of any specific different hydrological condition (Figure 2).

Discharge and substance yields were measured in the frame of a winter survey, which was carried out in a dry period representing baseflow conditions. Based on the riverine load estimation, the contribution of the main transport pathways to the total catchment outflow was calculated. The surplus resulting in the water balance provides the estimate for the groundwater inflow along the Koppány Creek. In the case of the substance loads, the summation resulted in a loss, which can be approximated by the retention in the river system. Results highlighted the significant contribution of wastewater discharge (15 and 40% of the flow and N load, respectively, Figure 3.).

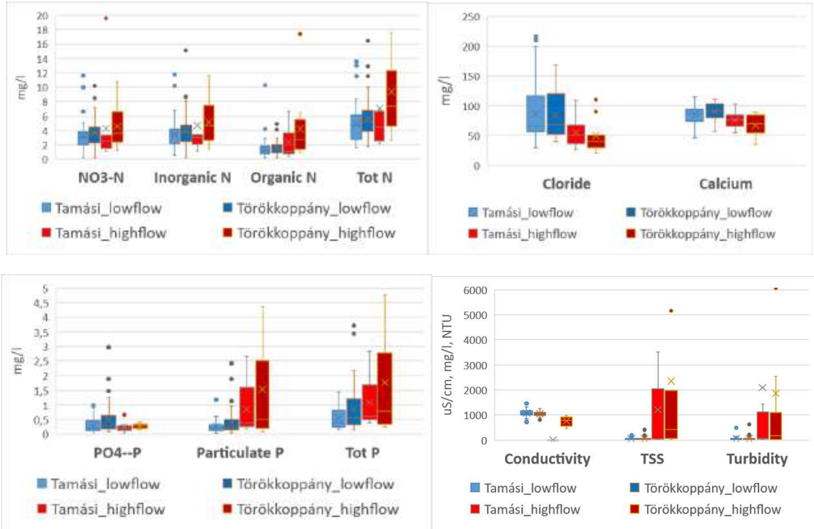

Figure 2. Effect of the flow regime on the concentrations (which are shown as box-whisker-plots). The boxes indicate the interquartile intervals. Two upright lines represent the data within the 1.5 interquartile range, the horizontal line inside the box represents the median, X the mean and the values outside 1.5-times the interquartile interval are indicated by a circle

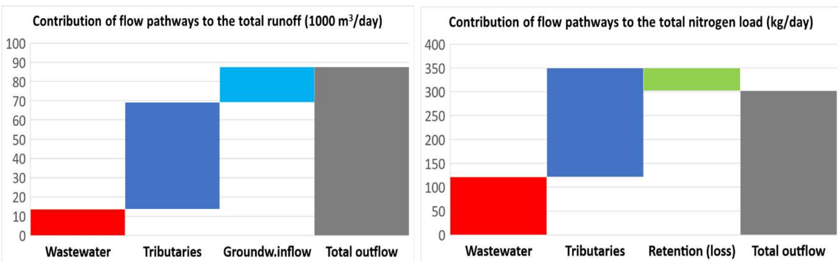

Figure 3. Distribution of the total outflow among various flow pathways

Isotopic measurements were conducted to estimate groundwater age. Groundwater sampling wells were drilled 10 - 50 m from the Koppány creak. The average value of the ^{3}H content measured in groundwater wells was 1.8 TU (9 samples), which is less than the country average (3.9 TU, 154 samples), and significantly less than the annual average value (9.3 TU) of precipitation in Hungary (Deák et al., 2023). This suggests a slow infiltration of around 60-70 years (< 3 TU). A model-based estimate of recent (2015-2017) mean annual precipitation ^{3}H is ~7 TU (Kern et al. 2020).

The tritium values were lower in the wells drilled closer to the riverbed, and the nitrate concentration was also very low there. Furthermore, a weak relationship was observed between the nitrate content of the wells and tritium, suggesting that groundwater with lower nitrate is older.

The stable isotope ratios of water (WSI: δ^2H and $\delta^{18}O$) in precipitation, surface water and groundwater, together with their seasonality, provide information on the origin of water, and are, therefore powerful tools to monitor hydrological processes and better understand their interrelationships (Gat, 1996). The measurement of WSI reveals that some wells in the Koppány Valley indicate the presence of water of Ice Age origin (Figure 4.), which supports the hypothesis, that groundwater is mixing with upwelling, causing dilution in the Koppány Creek.

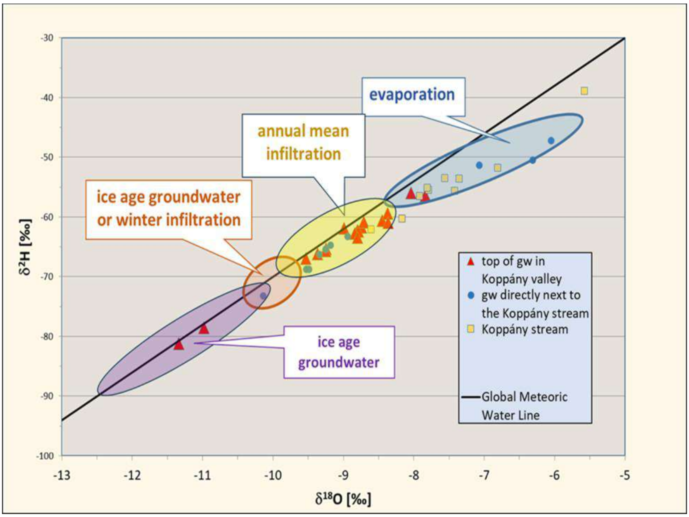

Figure 4. The ratio of water stable isotopes (WSI) in different water matrices measured in the Koppány catchment (ellipses indicate the presumed origin)

The preliminary estimations of residence time based on the seasonal amplitude of precipitation and streamwater (Rodgers et al., 2005), revealed a mean stream residence time of 170-180 days (Figure 5.). This indicates the effect of the reservoirs and the presence of waters of different origins.

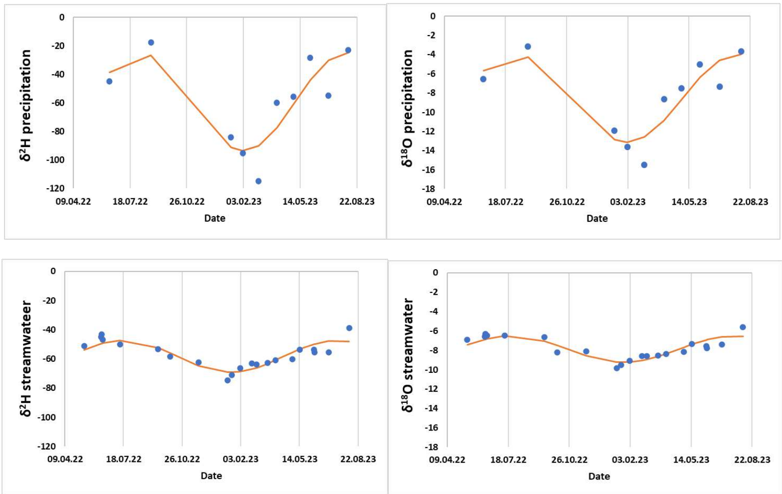

Figure 5. Seasonal pattern of the WSI (in per mil) in the precipitation and the streamwater. Dots are the WSI measurements, the orange line is a fitted sinusoid curve.

CONCLUSIONS

The study reveals that despite the watershed being primarily arable land, wastewater load becomes the dominant factor influencing Koppány Creek's water quality during dry periods. Agricultural nitrate pollution is conveyed by the tributaries, while direct groundwater's contribution to nitrogen load in the stream appears negligible, a hypothesis supported by the groundwater's extended age. The primary source of particle-bound pollutants is soil erosion during floods, impacting sediment transport and pollutant levels.

This study yields essential data to comprehend pollutant transport through runoff and subsurface routes, informing a catchment-scale contaminant emission model as the next research phase.

ACKNOWLEDGEMENT

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Implementation of a monitoring program to track pollutant transport processes in a pilot catchment in Hungary

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1. Introduction: background and objectives

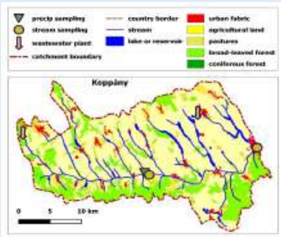
Catchment scale emission models are widely used to quantify riverine load, which can be verified with flow and water quality measurements usually available at the catchment outlets. However, these data do not provide direct information about the pollutant sources and the emission pathways and, therefore, do not allow process-level verification of the model results.

In our research, a targeted monitoring program was implemented, which combines methodologies of isotopic/hydrologic/hydraulic/chemical measurements to improve a deeper understanding of the sources and individual pathways of contaminants (mainly nutrients) on the catchment scale. Specific goals were (i) to identify the magnitude of particulate transport processes and (ii) to determine the contribution of surface and subsurface pathways to the nitrogen fluxes.

2. Materials and methods

2.1 Pilot area

The Koppány catchment, spanning 660 km^2, typifies Hungary's hilly regions, blending natural geography typifies Hungary's hilly and human influences. Agriculture reigns as the primary land use, notably on erosion-prone hillsides. Additionally, tributaries of the Koppány host reservoir-like fish ponds. Notably, the headwater area of the Koppány contends with substantial wastewater discharge, originating from Balatonlelle.



2.1 Sampling programme

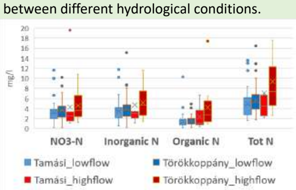
The sampling programme covered (i) regular stream water sampling (automatic samplers were installed in existing river gauges to sample high flow events); (ii) monitoring campaigns were executed for surveying the longitudinal profile of the main river and the tributaries; (iii) shallow groundwater wells were drilled along the riverbed; (iv) monthly bulk precipitation was collected; (v) composite sample was collected from the direct wastewater discharge.

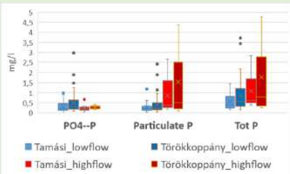
In addition to the water chemistry (ions, TSS, nutrients and PTE), stable and radioactive isotopes were measured as natural tracers to investigate hydrological pathways and residence times. Lab measurements were shared within the participating institutions: BME (general water chemistry), IJS (stable isotopes and PTE), tritium (ATOMKI), water stable isotopes (CsFK).

3. Results

3.1 Effect of the flow regime on the concentrations

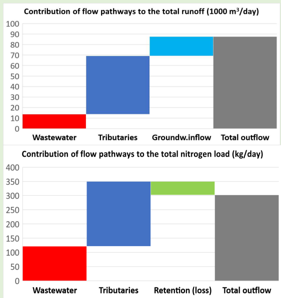
The comparison of low-flow and high-flow periods shows significant differences in the substance concentrations. In general, TSS, particulate P and almost all PTEs increase at high-flow events, while dissolved substances (e.g. phosphate and other ions) are higher in dry periods due to the lack of dilution. Inorganic N forms indicate high variability but are not capable of differentiating between different hydrological conditions.





3.2 Riverine load estimation

Discharge and substance yields were measured during the winter survey, carried out in a dry period and represented baseflow conditions. Water and substance balances allowed us to calculate the contribution of the main transport pathways to the total catchment outflow.

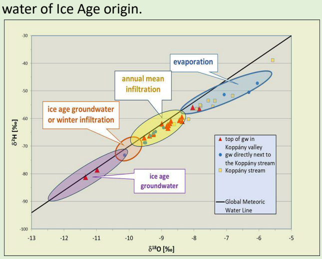


3.3 Isotopic measurements to approximate groundwater age

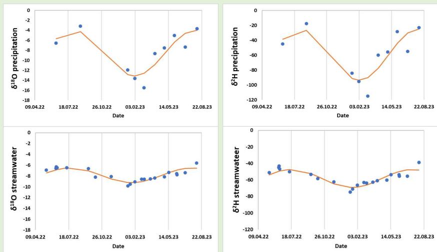
Groundwater sampling wells were drilled 10 - 50 m from the stream (Koppány). The average value of the tritium content measured in groundwater wells (drilled in the Koppány-valley) was 1.8 TU (9 samples), which is less than the country average (3.9 TU, 154 samples), and significantly less than the annual average value (9.3 TU) of precipitation in Hungary. This suggests a slow infiltration of around 60-70 years (< 3 TU).

The tritium values were lower in the wells drilled closer to the riverbed, and the nitrate concentration was also very low there. A weak relationship can be observed between the nitrate content of the wells and tritium.

Water stable isotopes ($\delta^{18}O$ and δ^2H) were measured from several matrixes. In the case of some wells, the results indicate the presence of water of Ice Age origin.



Preliminary estimations based on the seasonal amplitude of stable water isotope composition in precipitation and stream water suggest a mean stream residence time of 170-180 days. This indicates the effect of the reservoirs and the presence of waters of different origins.



4. Conclusions and outlook

The study reveals that despite the watershed being primarily arable land, wastewater load becomes the dominant factor influencing Koppány Creek's water quality during dry periods (contribution to the total N load is ~ 35%). Agricultural nitrate pollution is conveyed by the tributaries, while groundwater's contribution to nitrogen load appears negligible, a hypothesis supported by the groundwater's extended age.

The primary source of particle-bound pollutants is soil erosion during floods, impacting sediment transport and pollutant levels. This study yields essential data to comprehend pollutant transport through runoff and subsurface routes, informing a catchment-scale contaminant emission model as the next research phase.

Acknowledgement

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BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

Riverbed incision on the upper Hungarian Danube and Raab rivers in the Moson-Danube confluence area

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The phenomenon of river bed subsidence on our channelized rivers has been a well-known fact for a long time. In the upper reaches of the River Danube in Hungary this process seems to have accelerated in recent decades due to the construction of hydroelectric power plants on the German, Austrian, and Slovakian sections of the river and other anthropogenic effects. As a result, similar processes have also occurred on the lower reaches of the Moson-Danube and Raab rivers, which are significantly hydromorphologically influenced by the Danube. In our research, we measured the magnitude and temporal changes of this phenomenon by examining the hydrological time series for the Danube between the gauging stations of Dévény and Komárom and that of the Raab between Sárvár and Győr.

We pointed out that the phenomenon of bed erosion is still measurable in the upper reaches of the Danube in Hungary. In 2022, the Moson-Danube dam was inaugurated to restore low and medium water levels in the Moson-Danube and Rába estuaries, rehabilitate wetlands, ensure navigation, and enhance flood protection. After the first year of the dam's operation, there was a visible increase in the water level at the confluence of the Moson-Danube and Raab rivers, which solved the primary problem but generated additional known problems, such as handling the settling surplus of suspended sediment from the River Raab and difficulties with sewage disposal in the city of Győr. The dam is evidently unable to deal with issues in the ongoing process of the Danube riverbed incision. The settling of suspended sediment could reduce the magnitude of the erosion on the lower part of the Raab and Moson-Danube rivers but may have harmful side effects for river navigation over the long term. Furthermore, the floodgate function of the estuary structure in the event of a major Danube flood eliminates

any backwater effect on the Moson-Danube, which could have a negative impact on the culminating discharges of the Danube on the Gönyű-Komárom stretch. The previous effect of the reservoir on the lower reaches of the Moson-Danube and the Raab will be eliminated by the operation of the Moson-Danube estuary dam; thus higher peak discharges will occur on the Danube below the mouth of the Moson-Danube. This higher discharge could establish higher water velocities and water levels, which may speed up the erosion of the riverbed. This phenomenon should be evaluated during the next flood event as it occurs.

Keywords: hydrology, hydromorphology, trend analysis, flood protection, navigation, river basin, Danube, Raab, riverbed incision

Introduction

In the upper reaches of the River Danube in Hungary river bed subsidence seems to have accelerated in recent decades due to the construction of hydroelectric power plants on the German, Austrian, and Slovakian sections of the river and other anthropogenic effects. As a result, similar processes have also occurred on the lower reaches of the Moson-Danube and Raab rivers, which are significantly hydromorphologically influenced by the Danube.

Methods

In our research, we measured the magnitude and temporal changes of river bed subsidence by examining the hydrological time series (OVF, 2019) for the Danube between the gauging stations of Dévény (1875 rkm) and Komárom (1768.30 rkm) and that of the Raab between Sárvár and Győr.

Results

We pointed out that the phenomenon of bed erosion is still measurable in the upper reaches of the Danube in Hungary. Figures 1. and 2. show the variation of annual minimum water levels at each GS on the Danube and the Raab over the past 70 years, based on 10-year intervals averaging as in Tamás et al. 2021. As suggested by Kalocsa & Zsuffa in their publication (1997), the decrease is shown compared to the 1st year of investigation, i.e., the minimum water level observed in 1950 is zero on the vertical axis. The decrease concluded in 1997 continued at Komárom, Nagybajcs and Gönyű stations. The increase reported for the period between 1901−1990 for the Dunaremete GS has reversed and now this station shows a decrease, too. However, in the case of Dunaremete, it is not certain that the drop in the water levels is caused by the erosion of the riverbed. Establishing this would require a bivariate correlation, as water yields are also significantly lower at this stage of the riverbed.

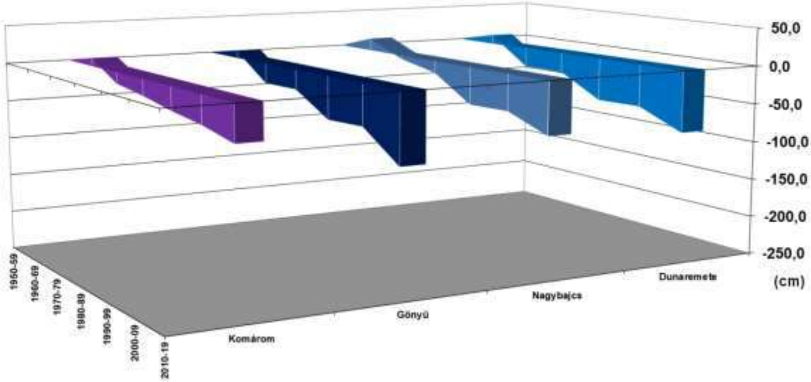

Figure 1. Integrated effect of riverbed incision and long-term changes of low water discharges on the Danube between 1950 and 2019 (ÉDUVIZIG, 2023)

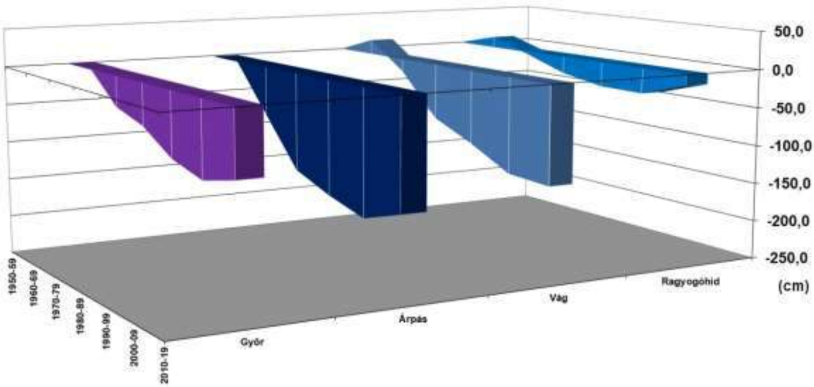

Figure 2. Integrated effect of riverbed incision and long-term changes of low water discharges on the Raab between 1950 and 2019 (ÉDUVIZIG, 2023)

A secondary consequence of the deepening of the riverbed is the depression of groundwater levels in the area. In the section of the Danube between Szap (where the tailrace of the Gabcikovo HPP joins the Danube) and Gönyű, where the incision of the bed is most significant, groundwater levels have also shown a significant trend decreasing in the decades since the measurements started. In the Győr area, this has been more than 1 m over the last 60 years.

The phenomenon is confirmed by linear trend graphs (Figure 3) of some monitoring wells in the area (ÉDUVIZIG, 2023). Along the estuary of the Raab, the groundwater level is decreasing by more than 1.5 m due to the Danube's incision. At Komárom, at the lower part of the analyzed Danube section, there is a slight but detectable decrease in groundwater levels.

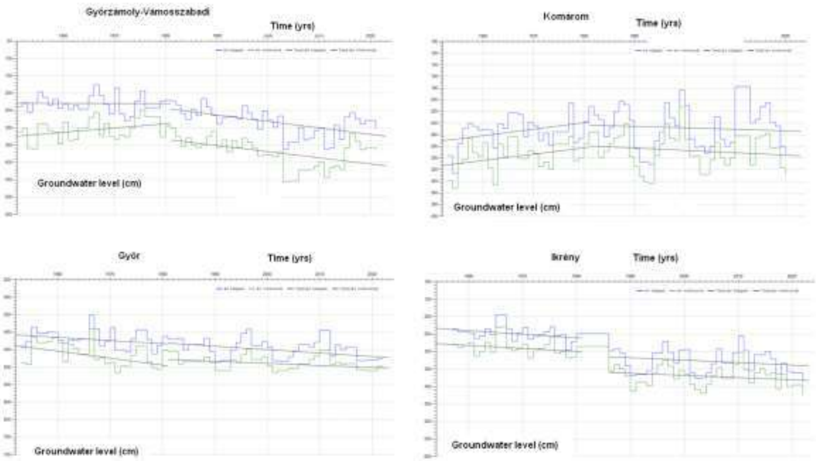

Figure 3. Groundwater trend analysis, 1953−2022 (ÉDUVIZIG, 2023)

CONCLUSION

The phenomenon of bed erosion is still measurable in the upper reaches of the Danube in Hungary. In 2022, the Moson-Danube dam was inaugurated to restore low and medium water levels in the Moson-Danube and Rába estuaries, rehabilitate wetlands, ensure navigation, and enhance flood protection. In 2023, after the first year of the Moson-Danube dam's operation, there was a visible increase in the water level at the confluence of the Moson-Danube and Raab rivers, which solved the primary problem but generated additional known issues, such as handling the settling surplus of suspended sediment from the River Raab and difficulties with sewage disposal in the city of Győr. Our conclusion is that the dam can only partly be used to counteract the issues originating from the ongoing process of the Danube riverbed incision.

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ÉDUVIZIG

ÉSZAK-DUNÁNTÚLI
VÍZÜGYI IGAZGATÓSÁG
GYŐR

RIVERBED INCISION ON THE UPPER HUNGARIAN DANUBE AND RAAB RIVERS IN THE MOSON-DANUBE CONFLUENCE AREA

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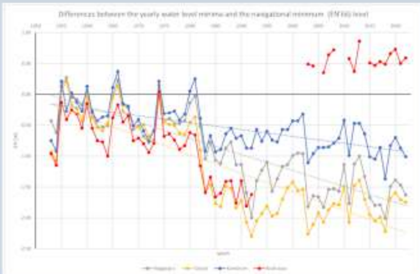
NEMZETI KÖZSZOLGÁLATI EGYETEM
VÍZTUDOMÁNYI KAR

ABSTRACT

The phenomenon of river bed subsidence on our channelized rivers has been a well-known fact for a long time. In the upper reaches of the River Danube in Hungary this process seems to have accelerated in recent decades due to the construction of hydroelectric power plants on the German, Austrian, and Slovakian sections of the river and other anthropogenic effects. As a result, similar processes have also occurred on the lower reaches of the Moson-Danube and Raab rivers, which are significantly hydromorphologically influenced by the Danube. In our research, we measured the magnitude and temporal changes of this phenomenon by examining the hydrological time series for the Danube between the gauging stations of Dévény and Komárom and that of the Raab between Sárvár and Győr. We pointed out that the phenomenon of bed erosion is still measurable in the upper reaches of the Danube in Hungary. In 2022, the Moson-Danube dam was inaugurated to restore low and medium water levels in the Moson-Danube and Rába estuaries, rehabilitate wetlands, ensure navigation, and enhance flood protection. After the first year of the dam's operation, there was a visible increase in the water level at the confluence of the Moson-Danube and Raab rivers, which solved the primary problem but generated additional known problems, such as handling the settling surplus of suspended sediment from the River Raab and difficulties with sewage disposal in the city of Győr. The dam is evidently unable to deal with issues in the ongoing process of the Danube riverbed incision. The settling of suspended sediment could reduce the magnitude of the erosion on the lower part of the Raab and Moson-Danube rivers but may have harmful side effects for river navigation over the long term. Furthermore, the floodgate function of the estuary structure in the event of a major Danube flood eliminates any backwater effect on the Moson-Danube, which could have a negative impact on the culminating discharges of the Danube on the Gönyű-Komárom stretch. The previous effect of the reservoir on the lower reaches of the Moson-Danube and the Raab will be eliminated by the operation of the Moson-Danube estuary dam; thus higher peak discharges will occur on the Danube below the mouth of the Moson-Danube. This higher discharge could establish higher water velocities and water levels, which may speed up the erosion of the riverbed.

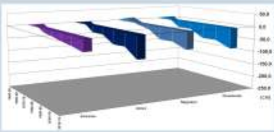
Overview map of the examination area (ÉDUVIZIG, 2023)



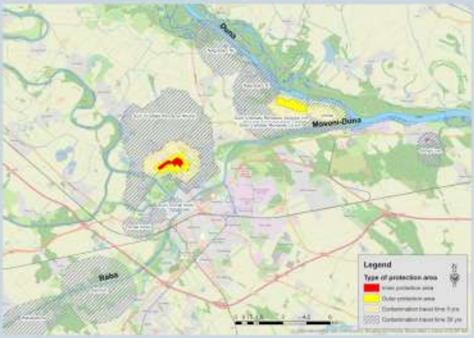
NAGYBAJCS
GÖNYŰ
KOMÁROM
BRATISLAVA

Water level differences compared to EN'66

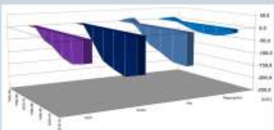
1953–2022 (ÉDUVIZIG, 2023)



Integrated effect of riverbed incision and long-term changes of low water discharges on the Danube between 1950 and 2019 (ÉDUVIZIG, 2023)



The city of Győr is indirectly supplied with drinking water from the Danube, by using a bank filtration water supply. The water supply wells are located on the right bank of the Danube, in the area of Szőgye. The Szőgye aquifer has a protection area granted by authorization. Its extent is shown on the map (ÉDUVIZIG, 2023).



Integrated effect of riverbed incision and long-term changes of low water discharges on the Raab between 1950 and 2019 (ÉDUVIZIG, 2023)

The Mosoni-Danube estuary structure (left), water level rehabilitation in the city of Győr (centre, right)

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Hydrology of the Carpathian Basin: catchment experiments and modelling for improved description and prediction of hydrological processes

12th HydroCarpath International conference, 9 November 2023

ORGANIZERS:
Slovak University of Technology in Bratislava, Slovakia (SUT)
University of Sopron, Hungary (UoS)
Vienna University of Technology, Austria (TUW)
University of Natural Resources and Life Sciences, Vienna, Austria (BOKU)

VENUE:
Gußhausstraße 27-29, 1040, Vienna
Kontaktraum, 6th floor
https://tuw-maps.tuwien.ac.at/?q=CD0603

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Call for abstracts 28th August 2023
Abstract submission deadline: 20th October 2023
Abstract acceptance: 27th October 2023
Conference: 09th November 2023

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PROGRAMME OVERVIEW:

Gußhausstraße 27-29, 1040 Wien, Kontaktraum, 6th floor

Date	Time	Programme
09 November 2023	08:30-09:15	Registration
	09:15-09:30	Opening: Günter Blöschl, Jan Szolgay, Zoltán Gribovszki
	09:30-10:45	1st Oral Block (4 lectures) Chairman: Kamila Hlavčová and Péter Kalicz
	10:45-11:00	Coffee Break
	11:00-12:15	2nd Oral Block (5 lectures) Chairman: Zoltán Gribovszki and Hubert Holzmann
	12:15-13:00	Lunch break
	13:00-14:30	Poster presentations (2 - 3 minute time slot/per poster) Chairman: Silvia Kohnová and Gábor Keve
	14:30-15:30	Poster Session with coffee
	15:30	Closure

Detailed Programme, 9 November 2023

Gußhausstraße 27-29, 1040 Wien, 6th floor

9:30-10:45 1st Oral Block

Chairman: Kamila Hlavčová and Péter Kalicz

Nr.	*Author*	*Title*
1	András Szabó (UoS) (30 min)	Groundwater monitoring in forests of the Great Hungarian Plain
2	László Báder (BME) (15 min)	Changes and trends in the climatic water balance of the Danube River basin based on meteorological, hydrological, and gravimetric data for the period 1961-2020
3	Eszter D. Nagy (BME) (15 min)	Can we calibrate a recursive baseflow separation filter relying on catchment response time parameters?
4	Vinícius B. P. Chagas (TUW) (15 min)	Exploring drought-rich and flood-rich periods in Brazil

10:45-11:00 Coffee break

11:00-12:15 2nd Oral Block

Chairman: Zoltán Gribovszki and Hubert Holzmann

Nr.	*Author*	*Title*
5	Caroline Ehrendorfer (BOKU) (15 min)	Coupled snow-hydrological modelling for two high alpine Austrian catchments
6	Anna Pölz (TUW) (15 min)	Forecasting karst spring discharges using an interpretable machine learning approach
7	Mitra Tanhapour (SUT) (15 min)	Investigating the impact of post-processing ensemble precipitation forecasts to simulate reservoir inflow
8	Zuzana Štefunková (SUT) (15 min)	The impact of climate change on the aquatic habitat of the Hybica River
9	Andrej Škrinár (SUT) (15 min)	Study of the functioning of the fish passage on the Hron River in Slovakia

12:15-13:00 Sandwich lunch

Detailed Programme, 9 November 2023
Gußhausstraße 27-29, 1040 Wien, 6th floor

13:00-14:30 Poster presentations (2 - 3 minute time slot/per poster)
Chairman: Silvia Kohnová and Gábor Keve

Nr.	Author	Title
P1	Sophie Lücking (BOKU)	Modelling and evaluation of the snow and ice melt in the Großglockner Region
P2	Peter Valent (TUW)	Quantifying projected effects of climate change on low-flows in the Salzach River, Austria: An approach for adapting stochastic weather generator outputs
P3	Máté Chappon (SZE)	Predicting water level changes in Lake Velence – an invitation to participate in a scientific challenge
P4	Aris Psilovikos (UTH)	Land use land change due to wildfires: Impacts on surface runoff and erosion. The case study of Mt. Pelion, Thessaly, Greece
P5	Anna Basso (TUW)	The effect of multiple reservoirs on flood peak reduction: the case of two Austrian catchments
P6	Thomas Pulka (BOKU)	Evaluation of precipitation corrections to improve reservoir inflow predictions by a conceptual hydrological model in the Malta Valley, Austria
P7	Klaudia Négyesi (BME)	Rainfall-runoff modeling based on an Adaptive Neuro-Fuzzy Inference System in Hungary
P8	Asma Khalil (TUW)	Sparse runoff observations ample enough to improve multiple-objective calibration of satellite data of snow cover and soil moisture (preliminary results)
P9	Viera Rattayová (SUT)	Changes of the balance evapotranspiration trends in Austria
P10	Zuzana Sabová (SUT)	Pooling of the long-term average monthly runoff using the PCA method and K-means clustering in Slovakia
P11	Borbala Szeles (TUW)	Comparison of two hydrograph separation methods in the Hydrological Open Air Laboratory using stable isotopes
P12	Evangelos Leivadiotis (SUT)	Evaluating flood events caused by Medicane “Daniel” of the Thessaly district (Central Greece) using remote sensing data and techniques
P13	Lynda Paulíková (SUT)	Selection of the peak runoff coefficient estimation method for the Horné Orešany – Parná case study (Slovakia)

P14	Anna Liová (SUT)	Constructing of control flood wave using a vine copula-based approach
P15	Gábor Brolly (UoS)	3D modelling of the hydrological observation site in the Hidegvíz-Valley from terrestrial laser scans
P16	Lili Muraközy (UoS)	Data integration and error analysis of the Botanical Garden’s hydrometeorological station in Sopron
P17	Kamilla Orosz (UoS)	Paired plot water balance experiment setup in the botanic garden of the University of Sopron
P18	András Herceg (UoS)	Impact of climate variability on a crown interception of a beech forest
P19	Mark Bryan Alivio (UoL)	Diurnal streamflow patterns in small urban mixed forest catchment in Ljubljana, Slovenia
P20	Katalin Anita Zagyvai-Kiss (UoS)	Surface water-groundwater interaction analysis in a forested riparian zone
P21	Zsombor Kele (UoS)	Investigation of the groundwater turnover in a salt steppic oak forest in the lowlands
P22	Máté Katona (UoS)	Drought sensitivity and water-holding capacity of lowland soils under forests in the Carpathian Basin
P23	Dániel Koch (UPS)	Infiltration and soil moisture measurements in an experimental parcel
P24	Juraj Parajka (TUW)	IRISE: Impact of rainfall interception on soil erosion
P25	Leon Hohenstein (TUW)	Investigation of erosion in the Hydrological Open Air Laboratory – The HOAL 2.0 Project
P26	Jana Grečnárová (SUT)	The experimental measurements of the effectiveness of roof substrate in terms of a reduction in runoff from vegetated roofs
P27	Miriam Zaťovičová (SUT)	The surface temperature comparison of typical urban materials in relation to the street orientation
P28	Attila Kálmán (SZE)	The potential economic benefits of rainwater in the "green city development" program
P29	Adrienne Clement (BME)	Implementation of a monitoring program to track pollutant transport processes in a pilot catchment in Hungary

P30	Dorottya Szám (UPS)	Riverbed incision on the upper Hungarian Danube and Raab rivers in the Moson-Danube confluence area

14:30-15:30 **Poster Session with coffee**

15:30 **Closure**