

Interdisciplinary Approach in Current Hydrological Research

Book of peer-reviewed papers

Edited by
J. Vitková, L. Botyanszká

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Editors

Interdisciplinary Approach in Current Hydrological Research



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Preface

Climate change is mainly a water crisis. Scientific research must propose solutions that will have a positive impact not only on the state of water but also on the favorable status of plant and animal species. This book of papers provides an overview of current topics and research results to help us understand the implications of changes in natural systems, as well as to build the knowledge base for more effective adaptation.

Authors of presented studies from Slovakia, Czech Republic, Hungary, Slovenia, Georgia and Mongolia have focused mainly on analysis of hydrophysical parameters of the soil-atmosphere system, especially in agro- and forest ecosystems, but also on quantification of stream flow regime, modeling of hydrological balance of catchments, or on a broader context of land use change, climate change, occurrence of natural extremes and their general impact on human society and biodiversity.

The research papers are classified into three thematic chapters:

- Subsurface Hydrology;
- Surface Hydrology;
- Climate Change and Variability.

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Section I: Subsurface Hydrology

CHANGES IN SATURATED HYDRAULIC CONDUCTIVITY, EXTRACTABLE MACRONUTRIENT CONTENTS AND ORGANIC CARBON FRACTIONS OF A DRIP IRRIGATED SANDY SOIL UNDER WETTING AGENT APPLICATION

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ABSTRACT

The use of soil wetting agents has gained scientific attention for their prominent benefits particularly in sandy soils. These benefits are attributed to the increased soil water residence time in the root zone. Inherently, this fundamental change in water adsorption ability of soils can be expected to bring about changes in saturated hydraulic conductivity (K_s), extractable nutrient distribution, and consecutively the formation of organic carbon fractions (OCF's) due to the modified conditions of organic matter decomposition processes. In the current study, influence of a commercial wetting agent H2Flo (*ICL-SF, Inc.*) on K_s , together with water-soluble organic carbon (C_w), hot water-soluble organic carbon (C_{hw}), potassium permanganate-oxidizable organic carbon (POXC) and extractable nutrient contents ($\text{NH}_4^+ \text{-N}$, $\text{NO}_3^- \text{-N}$, K, Mg, Ca, P) were investigated in different depths (0-15 cm and 15-30 cm) of potato grown sandy soils irrigated with subsurface drip system. The treated soils presented decreased rates of K_s , and increased contents of extractable K, Ca and Mg in top-soil. OCF's were not influenced by the treatment considerably in quantitative manner, while representing significant correlations only in treated soils.

Keywords: soil wetting agent, saturated hydraulic conductivity, extractable nutrients, organic carbon fractions

INTRODUCTION

The commercially available wetting agents are commonly alkyl block polymer (ABP) or polyoxyalkylene polymer (PoAP) based surfactants; the effect-mechanisms and influences of these surfactants are well documented in terms of increased re-wettability and infiltration rate in water-repellent sandy soils (Barton et al., 2011; Hmielowski, 2018), and enhancement of soil hydration in managed urban lawns (Chang et al., 2020; Dekker et al., 2019). Wetting agent molecules are usually structured with a lipophilic/nonpolar head and a polar/hydrophilic tail. Briefly, surfactants that have a strong affinity for the hydrophobic surfaces of soil particles are adsorbed onto water-repellent surfaces; in other words, the polar and nonpolar side of wetting agent molecules will be bonded to water molecules and water-repellent soil, respectively (Karnok et al., 2004). Simultaneously, the process can increase the infiltration rate and regulate the redistribution of water throughout the soil profile (Gross et al., 2011), usually for a short time after a single application. It should be noted that the efficiency and influence-sustainability of these products may vary considerably in terms of the balance between water retention and infiltration (Song et al., 2014), consecutively bringing about the necessity of product-based examination.

However, the main scientific curiosity in surfactant studies has changed its perspective recently, due to emerging reports on surfactant-induced re-hydrophobicity (Song et al., 2021) and increased dissolved organic carbon (DOC) together with particulate organic carbon (POC) in treated soil leachates (Song et al., 2018; Song et al., 2021). In particular, PoAP-based surfactants were found to build hydrophobic organic coatings on sand surfaces after repeated applications, eventually establishing water repellency even in originally wettable sands. The reported increase in the POC content of soil leachates from surfactant-treated soils was considered as an indicator of the replacement of authentic organic coating of the sand particles by the surfactant. In the latter study, although the treatments of ABP-based products represented 1.3 times more organic carbon input quantitatively, they were not found to induce hydrophobicity in hydrophobic or non-hydrophobic soils. However, in another study, ABP-based products were also reported to reduce microbial activity due to effectively removed hydrophobic organic coatings of sand particles (Song et al., 2019). Supportively, a holistic study on the influence of different wetting agents (organosilicone wetting agent; methyl ester of rapeseed oil; mixture of methyl ester palmitic and oleic acids; isodecyl alcohol ethoxylate) on water stable aggregates (WSA) was carried out by Kintl et al. (2022), reporting an average decrease of 50% in WSA that was reported to be in significant positive correlation only with soil organic carbon (SOC).

Studies focusing on both water and nutrient retention dynamics are rather limited; a convenient example is presented by Chang et al. (2020), on the changes in the vegetated lawns of St. Augustine grass (*Stenotaphrum secundatum*) under surfactant applications; expectedly, the soil moisture content and turfgrass quality were found to increase while no significant changes were observed in soil leachates with respect to ammonium nitrogen ($\text{NH}_4^+ \text{-N}$), nitrate nitrogen ($\text{NO}_3^- \text{-N}$) and extractable phosphorus (P), or in the contents of DOC and total organic carbon (TOC). However, there are some reliable studies on the plant side of nutritional evaluations; Chaichi et al. (2017), for instance, reported improved nutrient uptake for tomato plants under a single type of surfactant application. Banks et al. (2015), on the other hand, tried three commercial surfactants (*Activator 90*, *Agri-Dex*, *Thrust*) and reported a decrease in the uptake of only potassium (K) by *Thrust* in clay loam soils, while the uptakes of K, phosphorus (P), calcium (Ca), sulfur (S), copper (Cu) and zinc (Zn) decreased by 30% in soils treated with two other surfactants. Despite the contrary results on the dynamics of fixation / release of nutrients in soils treated with surfactants, the removal of some organic pollutants such as polycyclic aromatic hydrocarbons (PAH) was assisted with the commercial surfactant *Tween 80* (density: 1.064 g cm⁻³; critical micelle concentration (CMC): 0.012 mM), in order to ease the desorption (Yang et al., 2017; Li et al., 2019; Mirzaee and Sartaj, 2022).

H2Flo (*ICL-SF, Inc.*) is another commercial soil surfactant that promises to improve irrigation efficiency and water distribution in the root zone; the company indicates that the product has a small organic share of so-called 'root activator' molecules and describes the product as a mixture of active ingredients of the highest concentration (88%) on the market. The current study builds its hypothesis on the results of a previous study, as the elaborative continuation; previously, H2Flo applications had increased the residence time of water in the root zone and decreased the unsaturated hydraulic conductivity of sandy non-hydrophobic soils irrigated with the subsurface drip system. These expected changes were evaluated with the initial findings on electrical conductivity (EC) and SOC, which had represented more homogeneous distributions compared to control soils. Hereby, the current study tries to reveal the changes in saturated hydraulic conductivity after applications of wetting agent, along with the changes in the quantity and mobility of chemically fractionated OCF and extractable nutrients. Magnesium (Mg), Ca, and K were analyzed for their susceptible nature against leaching and agronomical importance, together with P; $\text{NH}_4^+ \text{-N}$, $\text{NO}_3^- \text{-N}$ and their ratios were presented to

gain insight into possible changes in the nitrification rate of the soils. Hot water-soluble organic carbon (C_{hw}), water-soluble organic carbon (C_w), and potassium permanganate oxidizable organic carbon (POXC) were analyzed to investigate the possible changes in such organic matter decomposition products under modified moisture conditions. One of the fundamental objectives of the work was to determine whether well-defined chemical OCF's would tend to be easily leached to the subsoil with increased K_s , in surfactant treated soils, as previously reported by other studies. Therefore, the current study is expected to greatly contribute to our understanding of the dynamics of water / nutrients adsorption by soil mineral particles under wetting agent applications along with their relationships with OCF's, as one of the first integrative field studies.

METHODS AND DATA (STUDY AREA)

Description of the Study Area and Soil Sampling

The experimental field with loamy sand soils (81.2% sand, 13.3% silt, 5.5% clay) was in Benátky nad Jizerou district, in the Central Bohemian Region of the Czech Republic. The altitude is 220 m above sea level and the WGS84 coordinates are 50.2782878N, 14.8392344E. This area has a warm climate with mild and dry winters, with a long-term mean annual temperature of 8.4 °C and a mean annual precipitation of 560 mm year⁻¹. Some descriptive parameters on the experimental soil are available in Table 1. The area is formed in the alluvial plains of the Jizera River with varying soil types and high ratio of sand particles; see the soil map in Fig. 1.

Table 1. Main Physicochemical Characteristics of Soils with Statistical Differences

Treatment	pH	Electrical conductivity ($\mu\text{S cm}^{-1}$)	Organic matter (%)
After the second application of H2Flo			
0-15 cm	H2Flo	5.22**	384.75
	Control	4.67	492.75*
15-30 cm	H2Flo	5.39*	266.5
	Control	5.04	301.5

*Duncan's test *: $p < .05$; **: $p < .01$; [Adapted from Almaz et al. (2019)]*

Potatoes were planted on 1 April 2019, drip irrigation started on 1 June 2019. Organic fertilization was applied in spring (10 t ha⁻¹), NPK fertilizer was applied before planting on 1 April and then on 28 April before canopy cover involvement, in total 180 kg N ha⁻¹. H2Flo was applied three times using subsurface driplines, 3 May, 3 June, and in the first week of July, always 5 l diluted in 1000 l of water. Fungicides and insecticides began to be applied on 11 June repeatedly over an interval of 7-10 days. Disturbed soil samples were taken after the second application of H2Flo (5 June 2019) from depths of 0-15 cm and 15-30 cm; sampling scheme can be seen in Fig. 1.

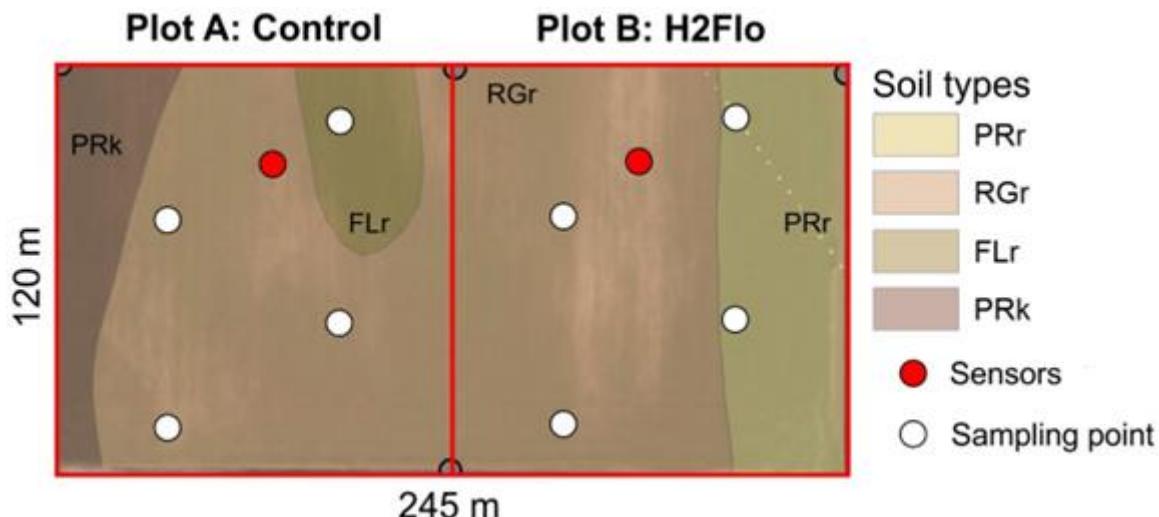


Fig. 1. Sampling scheme and soil map of the study area (soil map was adjusted according to the soil survey map produced by the Research Institute for Soil and Water Conservation), [Adapted from Almaz et al. (2019)].

Analytical procedures

K_s was measured in undisturbed core rings (250 cm^3) using a KSAT device (*Decagon Devices, Inc., Pullman, WA, USA*) with three replications. The core rings were saturated and placed in the KSAT device, then the falling head method was used to simulate the saturated flow; hydraulic conductivity was calculated using the Darcy equation (Eq. 1). The achieved rates of K_s (cm d^{-1} in 20°C) are logarithmically transformed before statistical evaluation:

$$K_s = (L - V)/(H - A - T) \quad (1)$$

where:

L is the length of the sample, cm

V is the percolated volume of water, ml

H is the height of the water column, cm

A is the area of probe, cm^2

T is the time, s

Concentrations of extractable Ca, K, Mg and P are determined in the extracts of Meclich III solution (Meclich et al., 1984) and measurements were realised in atomic absorption spectroscopy (AAS). NH_4^+ -N and NO_3^- -N concentrations were determined after 0.01 mol l^{-1} CaCl_2 extraction according to ISO 14255 (1998). The C_w and C_{hw} contents were determined using the internal method of modified Körschens (Körschens, 1980). POXC was determined according to the method of Weil et al. (2003), which is based on the observable colorimetric difference at the wavelength of 540 nm in soil extracts of 0.2 M KMnO_4 . Statistical analyzes were performed with STATISTICA 13 software (*Statsoft, USA*). One-way analysis of variance (ANOVA) tests were performed to examine differences between treatments and soil depths (*Duncan's test, the F test, or the Kruskal Wallis test*).

RESULTS AND DISCUSSION

K_s and OCF's

The K_s rates were found to decrease with H2Flo applications, and the decrease was much more significant after the second H2Flo application (Fig. 2a). Both treated and control soils presented decreasing rates with time; however, the difference between the mean K_s rates of

the sampling periods was not significant. The results were consistent with the decrease in *unsaturated* hydraulic conductivity values presented in the previous study (Almaz et al., 2019), performing infiltration tests under laboratory conditions using treated and untreated soils of the same locality. Numerous studies have reported similar findings on K_s over the past two decades, especially in non-hydrophobic soils (Allred and Brown, 1994; Lee and Cody, 2001; Mobbs et al., 2012; Bashir et al., 2018). Bashir et al. (2018) correlated the decrease in K_s with delayed vertical movement and enhanced lateral spread of water and surfactant.

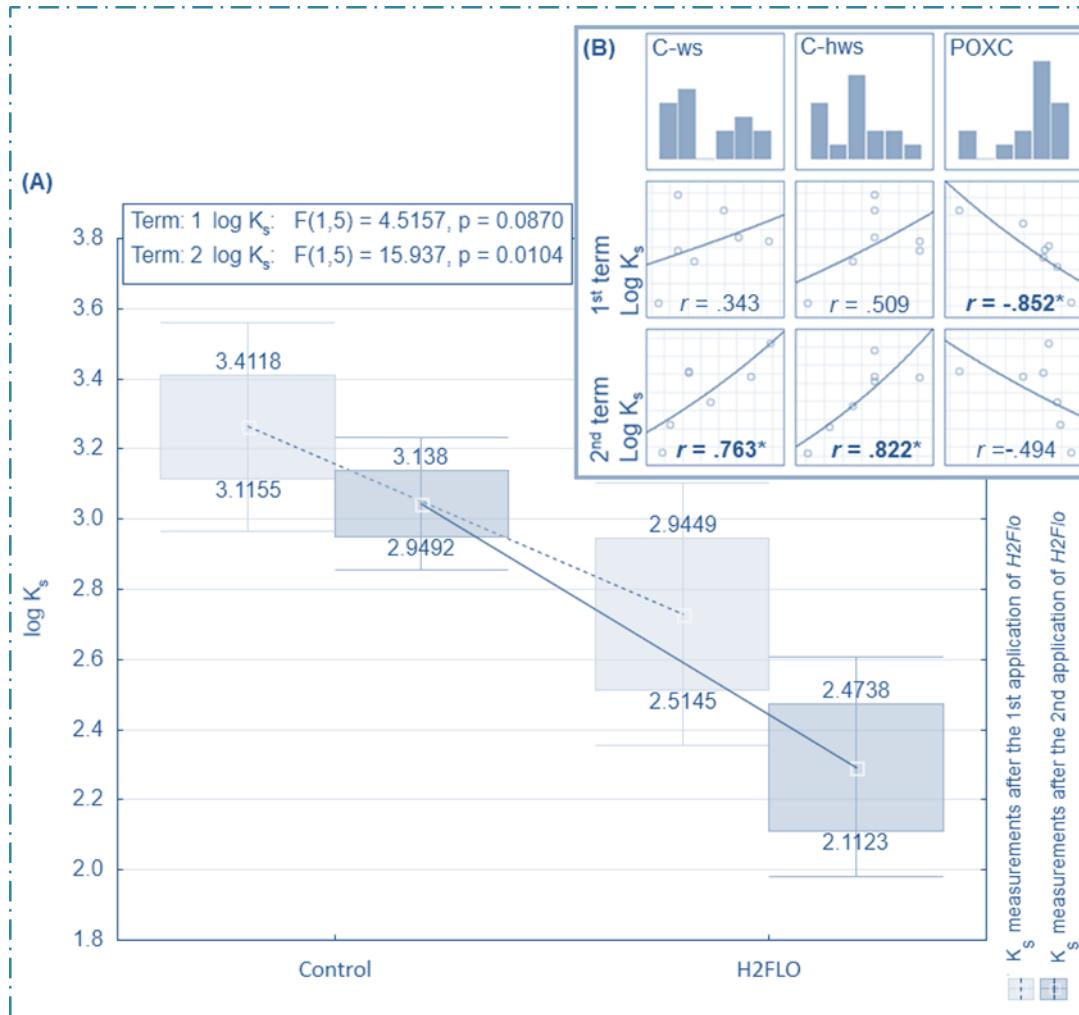


Fig. 2. (A) Changes in K_s rates (log-transformed values for cm d^{-1}) of top soils according to the treatments with F -test evaluation; (B) Pearson correlation coefficients of K_s and OCF in the scatterplots and histograms, *: $p < .05$; the inner whisker values were tagged to define the range of changes; whiskers represent mean $\pm 2 \times$ standard deviation.

POXC and C_{hw} fractions are known for their significant positive relationships with WSA, water retention capacity, and bulk density of arable soils (Bongiorno et al., 2019), as well as extractable nutrients such as N, P, and sulfur (S) (Verma et al., 2010). Unsaturated hydraulic conductivity and mean weight diameter of aggregates were also associated with increases in POXC by negative and positive correlations, respectively (Blair et al., 2006). When it comes to K_s , the current literature does not provide an example to elaborate on, mainly because of the design of the studies, including the *unsaturated* hydraulic conductivity along with the carbon fractions. However, our findings suggest strong correlative relationships between organic carbon fractions and K_s , as shown in Fig. 2b. When the data set was grouped by the

treatment, it was evident that the related correlations were stronger and more significant in the H2Flo treated soils; K_s were in positive correlation with C_w and C_{hw} , while POXC was in negative correlation. These findings may be a detailed support for the studies mentioned above, indicating that a small share of the increase in water-soluble carbon fractions can induce higher conductivity. However, POXC, as an indicator of the entire labile carbon pool consisting of various hydrophobic and hydrophilic substances (Duval et al., 2018), was in an opposite relationship to K_s .

The observed correlations were particularly important to indicate the importance of small changes, as the observed differences between treatments were not significant for C_w and C_{hw} ; however, the POXC content was significantly lower in top-soils of control treatment, with higher standard error (Fig. 3).

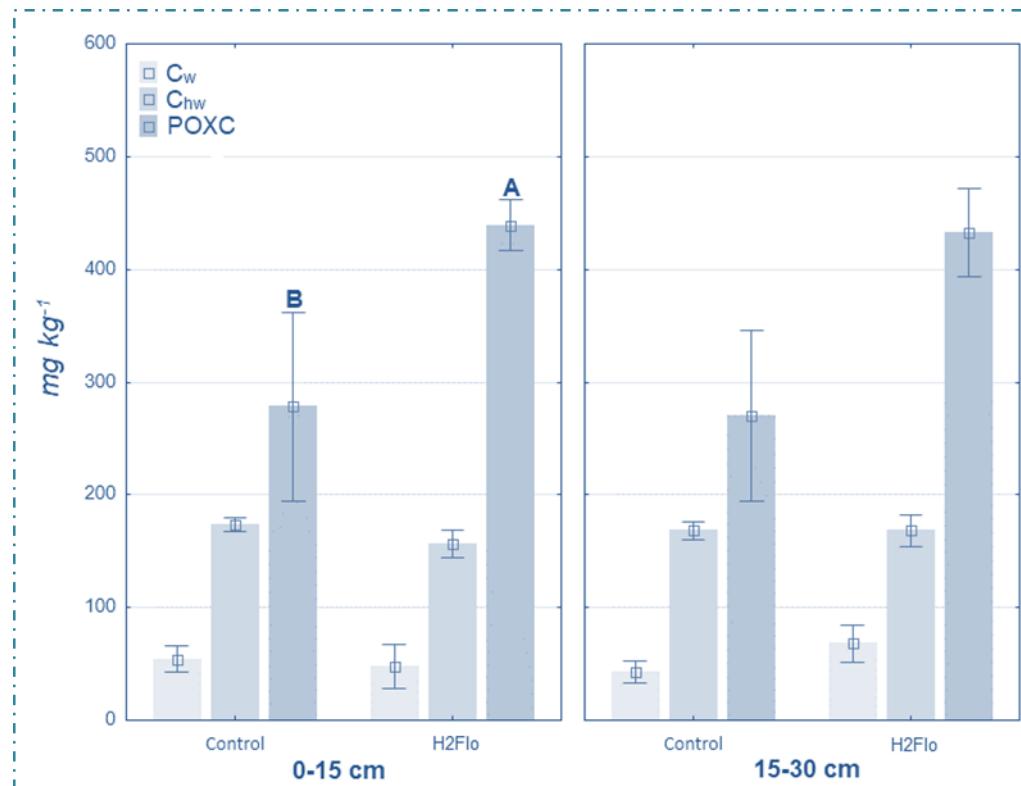


Fig. 3. Changes in organic carbon fractions depending on the treatment and sampling depth (significant statistical differences between treatments of the same sampling depth are represented with capital letters); whiskers represent mean \pm SE.

The nearly mutual increase in both depths of the soil profile indicates that this could be the result of significantly different degradation conditions (increased moisture, decreased temperature, and matric potential) previously documented (Almaz et al., 2019), with a small share of organic input mentioned above by the H2Flo treatment *itself*, sourced from the organic *root activator* molecules available in the chemical composition of the product. Unfortunately, the exact amount of these organic molecules is unknown, while the approximations based on the treatment dose of 5 l of H2Flo ha^{-1} could only indicate that the cumulative input of the H2Flo treatment is far from the capacity to be a cause of the observed increase. Furthermore, the previously reported significant increase in total organic matter content of treated soils (in 15-30 cm, see Table 1 in Section *Materials and Methods*) may confirm that a fraction of POXC might have the largest support in the observed increase.

No significant differences were observed between soil depths in terms of OCF concentrations; however, it can be said that all OCF's showed a slight decrease by depth in control treatment, but a slight increase in H2Flo treated soils.

Extractable Macronutrients

Extractable Ca, K and Mg concentrations were clearly higher in H2Flo treated top-soils (Fig. 4). Ca and Mg were higher in the treated soils also at the depths of 15-30 cm, however, K concentrations were not significantly different at this depth. The reason behind this is the only depth-based difference in nutrient concentrations observed in control soils, revealing significantly higher concentrations in 15-30 cm ($p < .05$), compared to the top-soil.

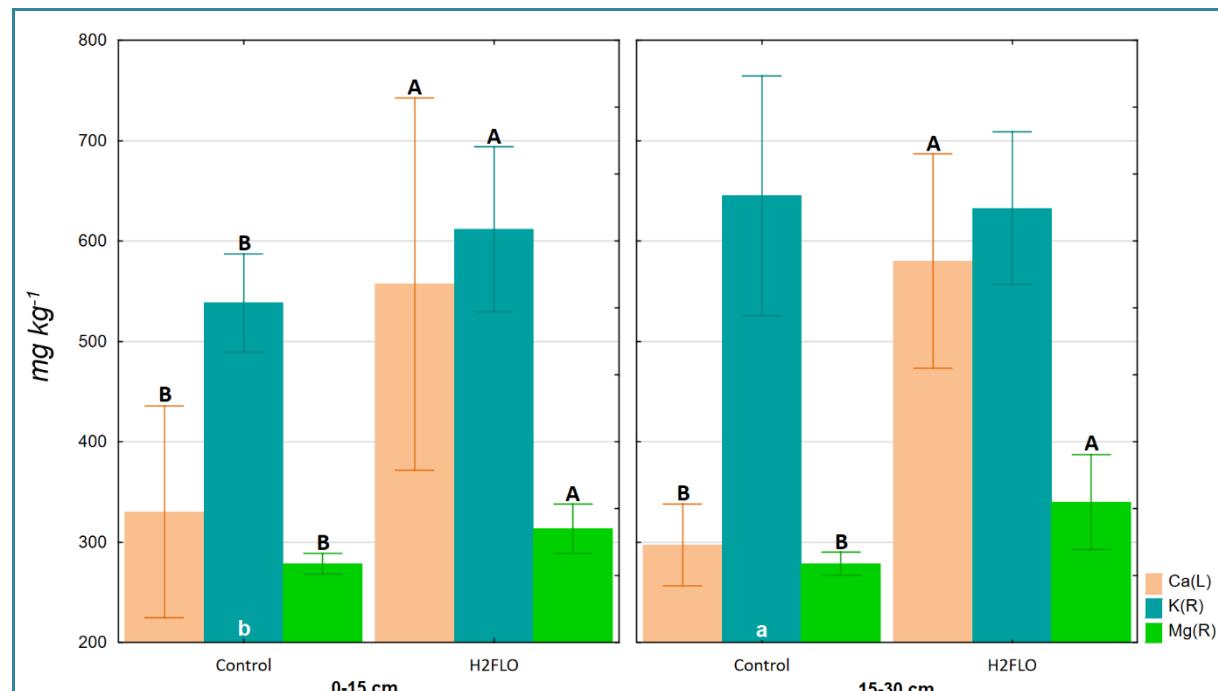


Fig. 4. Changes in extractable Ca, K and Mg concentrations depending on treatment and soil depth (significant statistical differences between treatments of the same sampling depth were represented in capital letters; differences between the sampling depth of nutrients were represented in lowercase letters on the related columns; $p < 0.05$); whiskers represent mean $\pm 2^{\ast}$ standard deviation.

In the recent and one of the rare studies on the topic, Ogunmokun and Wallach (2021) applied increasing doses (5, 10 and 20 g l⁻¹) of a commercial nonionic surfactant blend (*Aquatrols*) to a grapefruit grown sandy loam soil, together with treated wastewater. Expectedly, soil moisture content and saturation degree was found to be increased, while it was reported that the surfactant treatments may cause in significantly lower extractable K and exchangeable Ca+Mg in depths of 0-20 and 20-40 cm of the soil. These drops also reflected on the decreased electrical conductivity values of the soils. However, it should be taken into account that the researchers received a higher yield outcome from the treated soils compared to the untreated soils, which might lead a relative decrease in the observed concentrations due to the increased nutrient uptake by plants. Contrary findings may confirm the implications of the previously mentioned work of Banks et al. (2015), which had underlined the product-specific influences of wetting agents on the nutrient availability of soils.

The increase in extractable nutrients may also be related to the previous findings of Almaz et al. (2019) on pH values; the treated soils showed a significant and considerable increase in

both depths (from 4.67 to 5.22 in 0-15 cm, from 5.04 to 5.39 in 15-30 cm), which could improve the availability of nutrients. Considering that EC values were also reported to be decreased by the treatments, the supporting share of the pH increase in the observed higher concentrations should be critical. As an additional factor, C_{hw} concentrations were found to have a strong correlation with Mg concentrations in H2Flo treated soils ($r = .773$, $p = .025$); control soils did not have such relationships between OCF and extractable cations.

N sources and Meclich-P

NH_4^+ -N was found to be considerably decreased in both soil depths following the H2Flo applications, and NO_3^- -N was proportionally increased (Fig. 5), indicating induced conditions of nitrification. Therefore, the most significant difference between treatments was observed in the ratio of these N sources ($p = .03$ in the nonparametric *Kruskal Wallis test*; $p = .08$ in *F-test*).

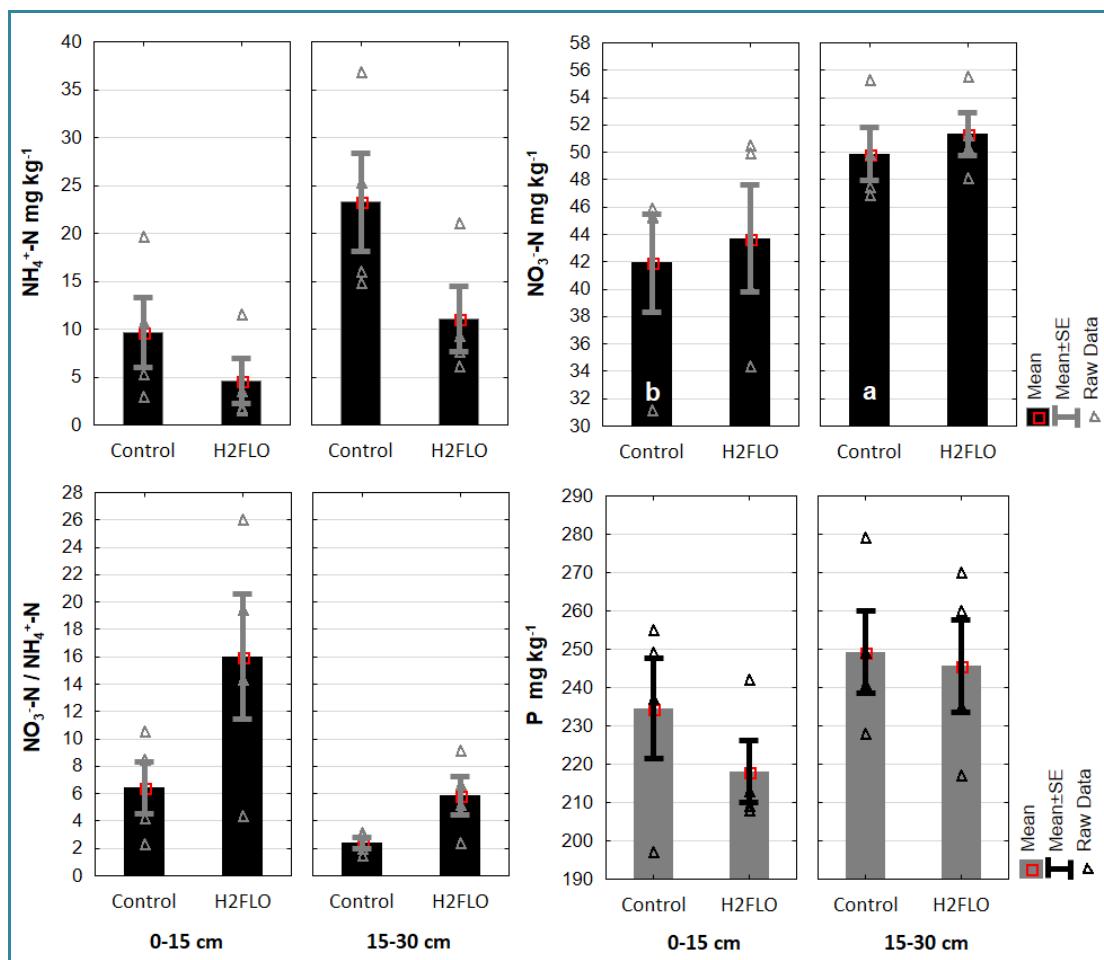


Fig. 5. Changes in nitrogen sources, nitrogen source ratio, and extractable Meclich-P, depending on the treatment and the sampling depth (differences between the sampling depths were represented with low-case letters on the related columns; $p < 0.05$).

The results of Chang et al. (2020) on N sources were consistent with the low significance of the present results; however, Ogunmokun and Wallach (2021) reported significant decreases in total N at different depths of soils. Although the changes were found to be small in the current study, the POXC values that were significantly higher in the treated soils had a strong negative correlation with NH_4^+ -N in the control soils ($r = -.983$, $p = .017$), while it had a strong positive correlation with NO_3^- -N / NH_4^+ -N in the treated soils, at depths of 15-30 cm (r

$= .993$, $p = .007$). The performed principal component analysis (PCA) indicated that the changes in nitrogen sources were the most important contributors to the first component which explains 37.5% of the total variance, along with Ca concentrations (Fig. 6a). The observed vegetative growth of potato plants may also suggest a NO_3^- -N rich uptake mechanism, due to the vigorous growth of aboveground biomass compared to the control soils (Fig. 6b).

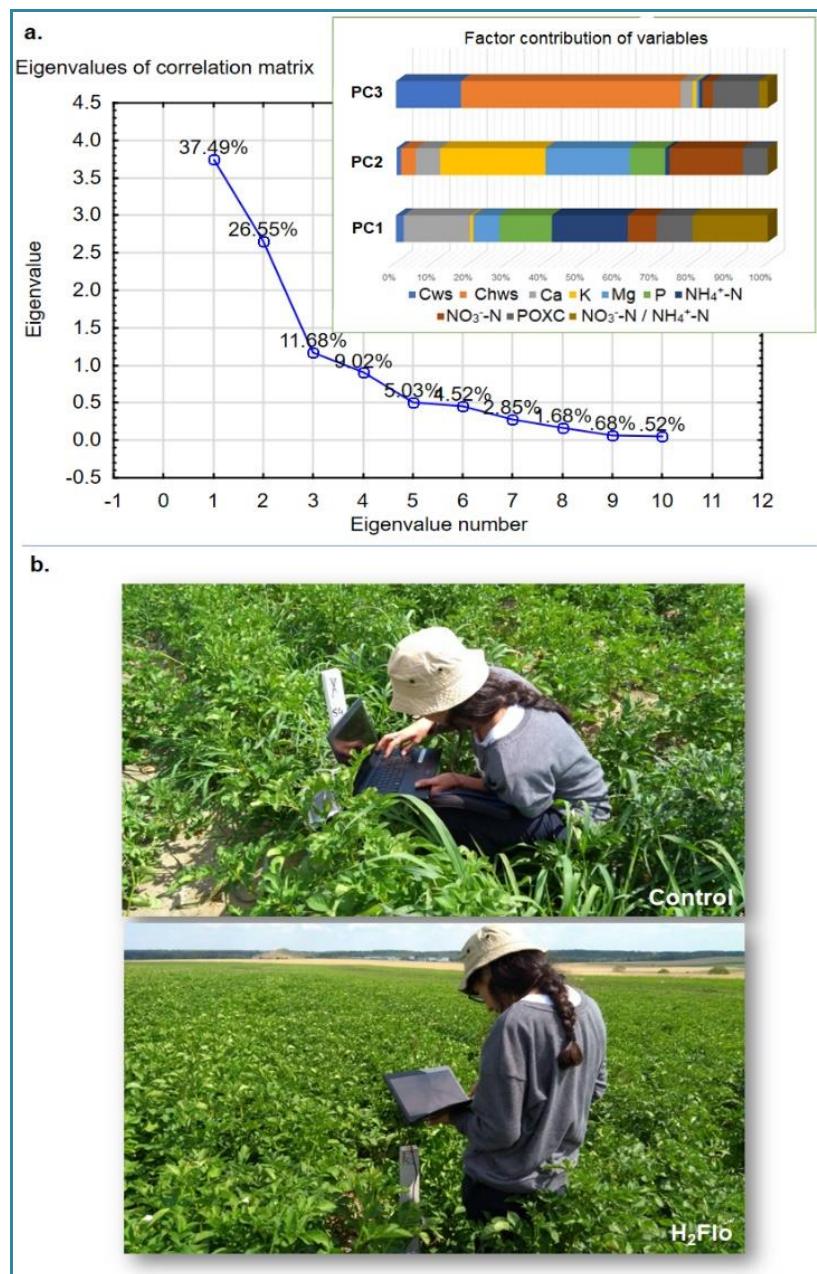


Fig. 6. (a) Scree-plotted eigenvalues of the extracted principal components with the percent contributions of the factors, PC: *principal component*; (b) observed vegetative growth of potato plants in treated and control soils – photography by Miháliková, M (DWR, CULS Prague).

There were no significant differences between treatments or depths in terms of extractable P concentrations. However, they were slightly lower in treated soils (Fig. 5). The findings were consistent with the results of Ogunmokun and Wallach (2021), as well as the results of Chang et al. (2020), and it should be noted that the latter study only investigated the top soils.

CONCLUSIONS

H2Flo applications were influential on a wide set of soil characteristics, modifying the physical, chemical, and possibly biological characteristics of the soil. The saturated hydraulic conductivity was found to decrease with time and H2Flo treatment; the initial mean K_s rate of the control soils decreased to 195 cm d^{-1} from the mean K_s rate of 1821 cm d^{-1} after the second application of H2Flo. These crucially modified hydraulic conductivity rates were in positive correlation with C_w and C_{hw} , while in negative correlation with POXC values that were significantly higher in treated soils. This change, which may require a re-evaluation of the routine duration of irrigation, may also have resulted in a decrease in potassium mobility compared to control soils, which contain significantly more potassium in the subsoil.

The extractable concentrations of Ca, Mg and K were positively influenced by the H2Flo treatment in the top and subsoils; These findings should be in partial relation to the slightly increased pH of the treated soils. These soils also represented higher concentrations of NO_3^- -N and lower concentrations of NH_4^+ -N compared to the control, similar to the favorably induced conditions of nitrification. The related parameters had a strong linear relationship with the POXC concentrations.

However, appropriate precautions should be taken in the event of repeated applications, considering the pattern drawn by the trend of a temporal decrease in K_s and the positive correlations observed between K_s and soluble OCF's in the top soil. These findings may be consistent with the main implication of the current literature mentioned above, in terms of increased leaching of soluble OCF's after repeated applications of wetting agent, associated with the re-hydrophobicity of the soils.

Acknowledgements

Analyzes of K, Ca, Mg, P, NH_4^+ -N, NO_3^- -N C_w and C_{wh} were carried out at the Research Institute for Soil and Water Conservation (Praha 5 – Zbraslav, CZ) through service procurement. This study was partly supported by project of the National Agency for Agricultural Research No. QK22020032 titled “Analysis and modifications of compost application schemes aimed at strengthening of the soil protection system within the stabilization of production capability”.

REFERENCES

- Allred, B., & Brown, G. O. (1994). Surfactant-induced reductions in soil hydraulic conductivity. *Groundwater Monitoring & Remediation*, 14(2), 174-184.
- Almaz, C., Kara, R.S., Miháliková, M., Matula, S., Duffková, R., Fučík, P. & Revuelta, M.S. (2019). An Influence of the H2Flo Wetting Agent to the Soil Hydrophysical and Chemical Properties in the Drip Irrigated Field. *26th International Poster Day Proceedings*, Institute of Hydrology SAS.
- Banks, M. L. L., Kremer, R. J., Eivazi, F., Motavalli, P. P., & Nelson, K. A. (2015). Effects of selected surfactants on nutrient uptake in corn (*Zea mays* L.). *Journal of Plant Nutrition*, 38(7), 1036-1049.
- Barton, L., & Colmer, T. D. (2011). Granular wetting agents ameliorate water repellency in turfgrass of contrasting soil organic matter content. *Plant and Soil*, 348(1), 411-424.
- Bashir, R., Smith, J. E., & Stolle, D. F. (2018). Surfactant flow and transport in the vadose zone: a numerical experiment. *Environmental Geotechnics*, 7(5), 361-372.
- Blair, N., Faulkner, R. D., Till, A. R., & Poulton, P. R. (2006). Long-term management impacts on soil C, N and physical fertility: Part I: Broadbalk experiment. *Soil and Tillage Research*, 91(1-2), 30-38.
- Bongiorno, G., Bünenmann, E. K., Oguejiofor, C. U., Meier, J., Gort, G., Comans, R., ... & de Goede, R. (2019). Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. *Ecological Indicators*, 99, 38-50.

- Chaichi, M. R., Keshavarz-Afshar, R., Lu, B., & Rostamza, M. (2017). Growth and nutrient uptake of tomato in response to application of saline water, biological fertilizer, and surfactant. *Journal of Plant Nutrition*, 40(4), 457-466.
- Chang, B., Wherley, B., Aitkenhead-Peterson, J., Ojeda, N., Fontanier, C., & Dwyer, P. (2020). Effect of wetting agent on nutrient and water retention and runoff from simulated Urban Lawns. *HortScience*, 55(7), 1005-1013.
- Dekker, L. W., Ritsema, C. J., Oostindie, K., Wesseling, J. G., & Geissen, V. (2019). Effects of a soil surfactant on grass performance and soil wetting of a fairway prone to water repellency. *Geoderma*, 338, 481-492.
- Duval, M. E., Galantini, J. A., Martínez, J. M., & Limbozzi, F. (2018). Labile soil organic carbon for assessing soil quality: influence of management practices and edaphic conditions. *Catena*, 171, 316-326.
- Gross, A., Mohamed, R., Anda, M., & Ho, G. (2011). Effectiveness of wetting agents for irrigating sandy soils. *Water*, 38(2).
- Hmielowski, T. (2018). Differences in Mechanisms of Soil Wetting Agents. *CSA News*, 63(11), 4-5.
- ISO 14255 (1998). Soil Quality — Determination of Nitrate Nitrogen, Ammonium Nitrogen and Total Soluble Nitrogen in Air-dry Soils Using Calcium Chloride Solution as Extractant
- Karnok, K. J., Xia, K., & Tucker, K. A. (2004). Wetting agents: What are they, and how do they work. *Golf Course Management*, 72(6), 84-86.
- Kintl, A., Vlček, V., Brtnický, M., Nedělník, J., & Elbl, J. (2022). Potential effect of wetting agents added to agricultural sprays on the stability of soil aggregates. *Soil*, 8(1), 349-372.
- Körschens, M. (1980). Beziehung zwischen Feinanteil, C " t – und Nt – Gehalt des Bodens. *Arch. Acker- Pfl. Boden.*, Berlin, 24 (9), 585–592, (1980)
- Lee, D. H., & Cody, R. D. (2001). Variation of soil hydraulic conductivity by anionic surfactants in soil column. *Geosciences Journal*, 5(4), 287-291.
- Li, Z., Wang, W., & Zhu, L. (2019). Effects of mixed surfactants on the bioaccumulation of polycyclic aromatic hydrocarbons (PAHs) in crops and the bioremediation of contaminated farmlands. *Science of the Total Environment*, 646, 1211-1218.
- Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in soil science and plant analysis*, 15(12), 1409-1416.
- Mirzaee, E., & Sartaj, M. (2022). The application of surfactant-enhanced soil washing process combined with adsorption using a recoverable magnetic granular activated carbon for remediation of PAH-contaminated soil. *Environmental Advances*, 9, 100274.
- Mobbs, T. L., Peters, R. T., Davenport, J. R., Evans, M. A., & Wu, J. Q. (2012). Effects of four soil surfactants on four soil-water properties in sand and silt loam. *Journal of soil and water conservation*, 67(4), 275-283.
- Ogunmokun, F. A., & Wallach, R. (2021). Remediating the adverse effects of treated wastewater irrigation by repeated on-surface surfactant application. *Water Resources Research*, 57(6), e2020WR029429.
- Song, E., Goyne, K. W., Kremer, R. J., Anderson, S. H., & Xiong, X. (2018). Surfactant chemistry effects on organic matter removal from water repellent sand. *Soil Science Society of America Journal*, 82(5), 1252-1258.
- Song, E., Goyne, K. W., Kremer, R. J., Anderson, S. H., & Xiong, X. (2021). Certain Soil Surfactants Could Become a Source of Soil Water Repellency after Repeated Application. *Nanomaterials*, 11(10), 2577.
- Song, E., Pan, X., Kremer, R. J., Goyne, K. W., Anderson, S. H., & Xiong, X. (2019). Influence of repeated application of wetting agents on soil water repellency and microbial community. *Sustainability*, 11(16), 4505.
- Song, E., Schneider, J. G., Anderson, S. H., Goyne, K. W., & Xiong, X. (2014). Wetting agent influence on water infiltration into hydrophobic sand: I. Rewettability. *Agronomy Journal*, 106(5), 1873-1878.
- Verma, B. C., Datta, S. P., Rattan, R. K., & Singh, A. K. (2010). Monitoring changes in soil organic carbon pools, nitrogen, phosphorus, and sulfur under different agricultural management practices in the tropics. *Environmental monitoring and assessment*, 171(1), 579-593.
- Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B., & Samson-Liebig, S. E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, 18(1), 3-17.
- Yang, S., Li, J., & Song, Y. (2017). Application of surfactant Tween 80 to enhance Fenton oxidation of polycyclic aromatic hydrocarbons (PAHs) in soil pre-treated with Fenton reagents. *Geology, Ecology, and Landscapes*, 1(3), 197-204.

DEVIATION OF SOIL MOISTURE CONTENT IN A PERMACULTURE FARM, KÓSPALLAG, HUNGARY

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ABSTRACT

The energy crisis, COVID pandemic and the war fastened the process of finding alternative, cheaper and most effective ways for food production. Permaculture farms were found to be the areas where the most food can be produced on a unit area. One of the reasons is the basic philosophy of this farming system that includes not only the use but excessive use of organic fertilizers and organic matter (such as mulch) in general. This “extra” organic matter means better surface cover that also leads to less evaporation, compared to an intensive farm with bare soil surface and also, a better water holding capacity. In the recent paper soil moisture content data is provided to better understand the overall situation, and also, the deviation of the soil moisture content of the upper 5 cm of the materials used for food production. The smallest soil moisture content was 15.4%, the highest was 33.6%. Two samples were collected from a “cold frame” where the crops were under irrigation. These data could be used for comparison of open-air plots but there were similarities. Soil organic matter and clay contents were also used as a possible explanatory factor of the soil moisture content deviation.

Keywords: water holding, water retention, horticulture, sustainable agriculture

INTRODUCTION

While the Earth’s population keeps growing, the availability of natural resources keeps decreasing. Future planning started to deal with recent issues, such as achieving zero emission for decreasing the effects of climate change, etc. Still, resources are used too fast, a reorganization of our crop production is at the gate. Intensive agriculture is proposed everywhere, announcing that this is the form of agriculture where the biggest yield can be achieved on a unit area. However, calculations were made and permaculture was found to be better. Besides being better, it is also important that permaculture can be practiced at home, even if people have only a few square meters of a garden or inner yard, or only a terrace on the seventh floor. The road towards reaching self-sufficiency is important, even if there is little or no chance to fully realize it, for multiple reason. On the one hand, people are far away from nature, the majority of knowledge related to natural processes, including food production is lost. On the other hand, the percentage of lost food is tremendous, so people should take part in the process of food production, even if this part is very little, so they can value the food much better. This way the amount of waste could be reduced. On the third hand, planning a diverse garden with vegetables and combining it with some animal husbandry (any poultry or rabbits, etc.) can further decrease the amount of waste at home in general, and the amount of organic waste also.

In the recent study a permaculture farm is analysed in Hungary. There is some soil related data published from various parts of the world (Pulleman et al., 2003; Hathaway, 2015; Tombeaur et al 2018) but we have to admit that thorough investigations are still missing, so any related data can be valuable and add information to help understanding the processes on a

permaculture farm. On the other hand, since the products are considered healthy and better than those produced on the intensive farms with excess fertilizer and pesticide use, it is of high importance to provide information on the soils that are the very core of the vegetable production. In the recent study the soil moisture deviation is examined on a small-scale farm in a municipality area. Soil moisture is crucial for horticultural production. 2022 was an extremely dry year, so the importance is even more highlighted. Besides, horticultural production needs irrigation, and this also raises the question of the ecological footprint of such productions/farming type.

METHODS AND DATA

Soil analyses

Soil samples were taken from 12 plots, based on local knowledge and also, on local interest in the examination of the farm. Two samples were taken from underneath of a greenhouse (plastic tunnel with irrigation). The upper 10 centimeters were examined. The soils were analysed by using the NIR (Near InfraRed) device (Figure 1.) of the Soil cares/Agrocares Company and its mobile application.



Fig. 1. The Near Infrared (NIR) AgroCares Scanner in use (1300–2600 nm). The scanner has one button for switch on and off and for starting the scanning process. There is also a reset option on the side of the device. A white and a yellow puck is used for calibration. There is a brush for cleaning the scanner surface.

The data is automatically transferred to the Netherlands, evaluation is done in the center of the company and results arrive to the users' mobile application, so the evaluated data can be seen and used immediately. The original database can be downloaded from the server of AgroCares, and the excel can be the basis of further analyses.

A short description of the analysed farm

The study area is in Kóspallag, Hungary. Kóspallag is situated in the heart of the Börzsöny Mountain (Figure 2).



Fig. 2. The situation of the examined horticultural permaculture farm in Hungary and the location of the sampling points.

It can be characterized by brown forest soils whose clay content is normally high. This high clay content makes the infiltration of the water difficult, so hand tools are used for loosening the soil. On the other hand, a lot of organic matter, straw, organic manure, etc. are used for improving the upper layer of the soil for the main purpose which is horticultural production. Some crops, e.g. potato is growing in this, artificially created growing medium that also raises some questions related to the technology (e.g. filling up the plants' stems is difficult or not possible).

The area is sloping, from northeast to southwest (so from the upper right corner to the lower left corner). Sampling started at the bottom of the slope and finished in the upper third of the

slope. The farm has small plots that is favorable from the point of view of protection against soil erosion (Figure 3).



Fig. 3. The location of the plots on the horticultural permaculture farm, Kóspallag Hungary
(Photo: Gábor Lévai, 2022).

The farm is also surrounded by some forested area to the north-north-west and a tree line can also be found at the east-south-east edge of the plots. The forested part also required of building a fence to avoid the entrance of wildlife that could cause damage in the crops.

RESULTS AND DISCUSSION

The soil moisture content (m/m %) was reaching a minimum of 15.4% in Sample No. 1. that is situated at the lowest part of the farm, also close to the trees and some grassy area. The highest soil moisture content (m/m %) was 33.6%, measured in one of the polytunnel (Table 1.).

Numerous parameters were measured with the NIR device but only those that might affect the soil moisture content or interrelation between the parameter and the soil moisture can be assumed, are published here (Table 1.). These parameters are the pH (H_2O), soil organic matter and the clay content.

Table 2. The measured soil parameters with the Near Infrared (NIR) device, Kóspallag, Hungary (24th of August 2022)

Crop Name	Field Name	pH (H ₂ O)	Soil Organic Matter	Clay content (m/m %)	Soil moisture (m/m %)
empty bed, pea was previous crop	kpallag1	6.8	2.3 %	21 %	15.4 %
potato	kpallag2	6.7	3.5 %	21 %	17.1 %
cucumber (after sweet pea)	kpallag3	7.0	5.1 %	21 %	33.6 %
cucumber	kpallag4	6.9	5.4 %	16 %	32.5 %
carrot	kpallag5	7.4	6.5 %	18 %	31.6 %
sorrel	kpallag6	6.9	2.6 %	18 %	24.4 %
potato	kpallag7	6.9	6.6 %	20 %	27.2 %
leek	kpallag8	6.9	2.4 %	17 %	28.4 %
beetroot	kpallag9	7.3	3.6 %	17 %	29.8 %
aubergine	kpallag10	7.0	17.7 %	17 %	31.2 %
tomato	kpallag11	7.5	5.2 %	24 %	26 %
compost	kpallag12	7.7	12 %	19 %	23 %

For a better understanding of the trend between the sampling sites, we present Figure 4 where the sampling sites are in the order of their magnitude, starting from the smallest and ends with the highest soil moisture content. The magnitude of the R²-values shows the strength of the trends, in this case towards the higher soil moisture content (Figure 4).

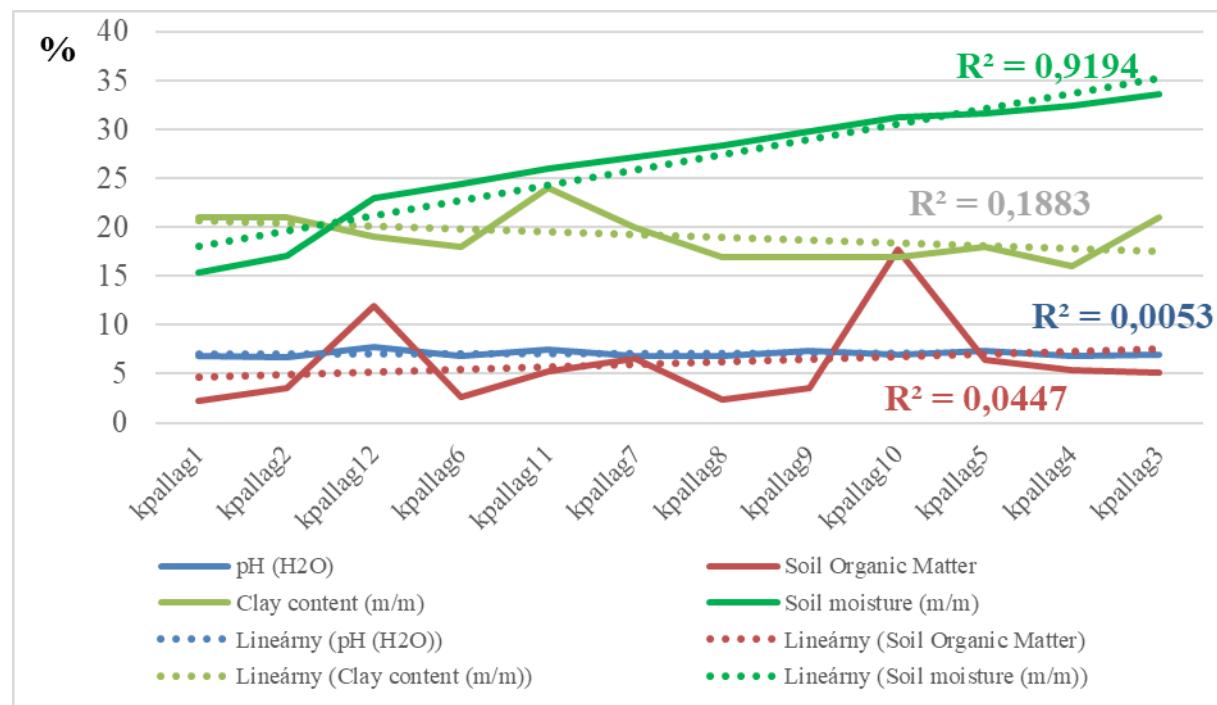


Fig. 4. The magnitude of the pH (H₂O), Soil Organic Matter, clay content and soil moisture in the order of the soil moisture, and the trendlines with the R² values.

The only parameter that seems increasing (as its R² value is 0.9194 between the sites) is the soil moisture content. The other parameters (pH, clay and SOM) do not seem to change along the soil moisture, at least their R² values are quite small. The best R² value belongs to the clay content however, it is a decreasing trend.

CONCLUSIONS

There are obvious differences between the soil moisture content of the examined sampling points and we could find an increasing trend but this trend is only occurring in case of the soil moisture content. This can be due to the soil type that is very similar all over the farm, has a high clay content, high compactness and thus, little infiltration capacity.

REFERENCES

- Hathaway, M. (2015): Agroecology and permaculture: addressing key ecological problems by rethinking and redesigning agricultural systems. *J. Environmental Studies Sci.*, 6, 2, 239–250. <https://doi.org/10.1007/s13412-015-0254-8>
- Pulleman, M., Jongmans, A., Marinissen, J., Bouma, J. (2003): Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in the Netherlands, *Soil Use Manag.*, 19, 157–165. <https://doi.org/10.1079/SUM2003186>
- Tombeur, F., Sohy, V., Chenu, C., Colinet, G., Cornelis, J.T. (2018): Effects of permaculture practices on soil physicochemical properties and organic matter distribution in aggregates: a case study of the Bec-Hellouin Farm (France). *Front. in Env. Sci.*, 6, article 116 <https://doi.org/10.3389/fenvs.2018.00116>

DYNAMIKA PÔDNEHO VODNÉHO POTENCIÁLU V BANSKOU ČINNOSŤOU NARUŠENEJ LESNEJ KRAJINE

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ABSTRACT

Anthropogenic disturbance of geological structures has recorded a considerable extent in Slovakia in recent decades. The reason was the need for mining sources for the national economy. One of the essential was also brown coal, which was mined in the Upper Nitra coal basin area in the district of Prievidza (Slovakia). Brown coal was mined around the town of Handlová, the village of Koš, and the villages of Cígel' and Sebedražie. Cígel' coal mine (near the village of Cígel' and Sebedražie) caused several geological defects, which have the character of large cracks and local landslides, which disrupt the hydrogeological conditions, resulting in significant impacts on soil water regime stability of forest ecosystems growing in such a damaged area. This paper aims to point out the variability and dynamics of soil water potential at the mining-damaged locality (Račkov laz) and intact reference area (Čertove chodníky) during the period 2020-2022. The results showed that mining activity probably significantly impacts the soil water regime and thus the ecological stability of forest ecosystems.

Keywords: soil water potential, anthropogenic disturbance, forest ecosystems, water regime, undermining, ecological stability

ÚVOD

Antropogénne narušenie geologických štruktúr zaznamenávalo v minulých desaťročiach na Slovensku značný rozsah (Halmo et al. 2010). Dôvodom bola logická potreba dobývania a získavania nerastných surovín pre národné hospodárstvo. Jedným z najdôležitejších nerastných surovín bolo aj hnedé uhlie, ktoré sa v najväčšej miere dobývalo hlbinným, ale aj povrchovým spôsobom v oblasti Hornonitrianskej uhoľnej panvy v okrese Prievidza. Hlbinným spôsobom sa dobývalo hnedé uhlie najmä v okolí mesta Handlová, obce Koš, a obce Cígel' a Sebedražie. Práve v bezprostrednej blízkosti poslednej spomenutej obce sa nachádza baňa Cígel', ktorej činnosť spôsobila množstvo geologických porúch, ktoré majú charakter rozsiahlych trhliín, miestnych zosuvov a prepadov, ktoré narušujú geologické kontinuum, poškodzujú hydrogeologické pomery územia (Kučera et Novotná 2015), čo môže mať za následok zásadné dopady na vodný režim pôdy a tým aj ekologickú stabilitu lesných ekosystémov rastúcich v takto poškodenom území v prípade výskytu epizód sucha (Vido et Nalevanková. 2021). Z dôvodu potreby zistenia možných dopadov vyššie uvedených antropogénnych destrukčných faktorov na edifikátor miestnych ekosystémov - bukové porasty, boli v dopredu vytypovanej lokalite poškodené poddolovaním nainštalované senzory pôdneho vodného potenciálu s dataloggerom (EMS SP3 so seznromi GB1, EMS Brno, Czech republic). Na tejto lokalite vznikla následkom ťažby v sedemdesiatych rokoch terénna depresia, prieplavek s viacerými trhlinami v bezprostrednom okolí. Táto lokalita s miestnym názvom Račkov laz sa nachádza na území Horského komposesorátu Prievidza, pozemkového spoločenstva. Lokalizovaná je severovýchodne od obce Cígel'. Z dôvodu potreby porovnania vodného režimu resp. režimu pôdneho vodného potenciálu na banskou činnosťou nepoškodenej lokalite, bola ako referenčná plocha vybraná lokalita s miestnym názvom

Čertove chodníky, nachádzajúca sa juhovýchodne od obce Kamenec pod Vtáčnikom. Cieľom uvedeného príspevku je poukázať na variabilitu a dynamiku pôdneho vodného potenciálu na banskou činnosťou poškodenej lokalite (Račkov laz) a intaktnej referenčnej ploche (Čertove chodníky) na výsledkoch meraní v období rokov 2020, 2021 a 2022. A tým poukázať na banskú činnosť ako antropogénny disturbánčny faktor potenciálne znižujúci ekologickú stabilitu lesných ekosystémov prostredníctvom zvýšenia stresového faktora sucha.

METODIKA

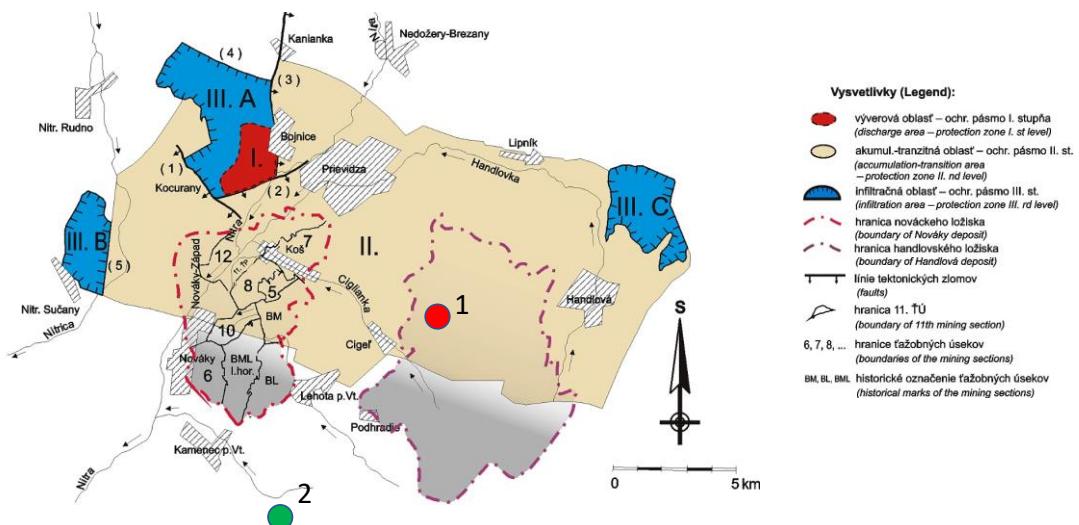
Založený experiment pozostáva z kontinuálneho sledovania a zaznamenávania pôdneho vodného potenciálu v hĺbke 30 cm. V tejto hĺbke sa podľa predbežného pôdneho prieskumu identifikovala hlavná zóna prekorenenia. Za týmto účelom boli aplikované senzory pôdneho vodného potenciálu od výrobcu Delmhorst (U.S.A) s typovým označením GB 1, merajúcim potenciál do maximálneho tlaku -15 barov. Tieto boli pripojené k dataloggerom SP3 výrobcu Environmental Measuring Systems s.r.o. (Brno, Czech republic), ktorý je vybavený taktiež integrovaným senzorom pre meranie teploty prostredia. Z uvedeného dôvodu bol datalogger osadený do pôdy do hĺbky 5 cm a zabezpečoval okrem kontinuálneho záznamu hodnôt vodného potenciálu aj meranie teploty pôdneho prostredia. Zariadenie je zhotovené z odolných nekorozívnych materiálov so celkovým stupňom krycia IP 68, čo zabezpečuje jeho spoľahlivú prevádzku aj v podmienkach úplného zakopania do pôdneho prostredia. Každý datalogger je vybavený troma senzormi GB 1, takže je zabezpečené opakovanie meraní v troch meracích bodoch. Hodnoty pôdneho potenciálu boli vyhodnotené ako priemerná hodnota údajov nameraných jednotlivými senzormi pripojenými k dataloggeru.

Atmosférické zrážky boli merané na voľnej ploche v lokalite rekreačného strediska Púšť - Prievidza, rovnako ako teplota vzduchu. Tieto merania boli realizované prostredníctvom automatickej meteorologickej stanice s kontinuálnym prenosom údajov prostredníctvom siete IoT (RainSet 02, Environmental Measuring Systems s.r.o., Brno, Czech republic).

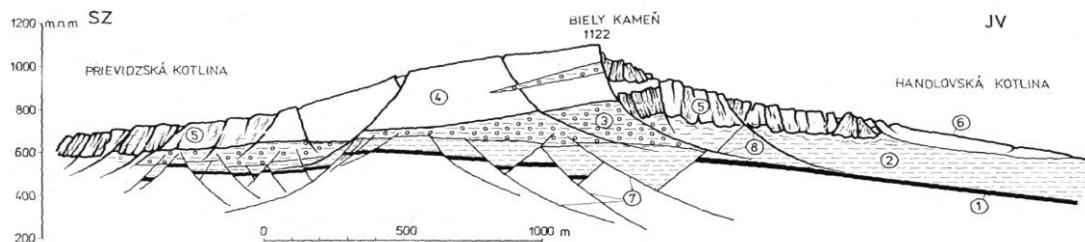
Všetky merané údaje o poveternostných podmienkach ako aj hodnoty pôdneho vodného potenciálu boli spracované a použité ako denné priemery s výnimkou atmosférických zrážok, ktoré boli vyhodnotené ako denné úhrny.

CHARAKTERISTIKA ÚZEMIA

Študijné plochy sú situované v severozápadnej časti orografického celku Vtáčnik v okrese Prievidza. Banskou činnosťou poškodená lokalita Račkov laz (619 m n.m.) je lokalizovaná v oblasti banských aktivít dnes už uzavretej bane Cígel' v ťažobnej oblasti handlovského uholného ložiska (Obr. 1). Príčiny a dôvody hydrogeologických poškodení v tejto lokalite, možno definovať nasledovne. Geologická stavba územia (Obr. 2) znázorňuje, že na mechanicky mäkkých a plastických ílovcoch, prachovcoch a zlepencoch ležia polohy rigidných andezitov a tufov, v dôsledku čoho došlo k rozlámaniu celého pohoria Vtáčnik na systém blokových polí, ktorých pohyb bol následne akcelerovaný aj procesmi podpovrchovej ťažby Bane Cígel' handlovského uholného ložiska (Halmo et al. 2010). Záujmové územie v oblasti lokality Račkov laz je tak porušené viacerými tektonickými poruchami poklesového charakteru so zložitým systémom priekopových prepadlín a hrastí.

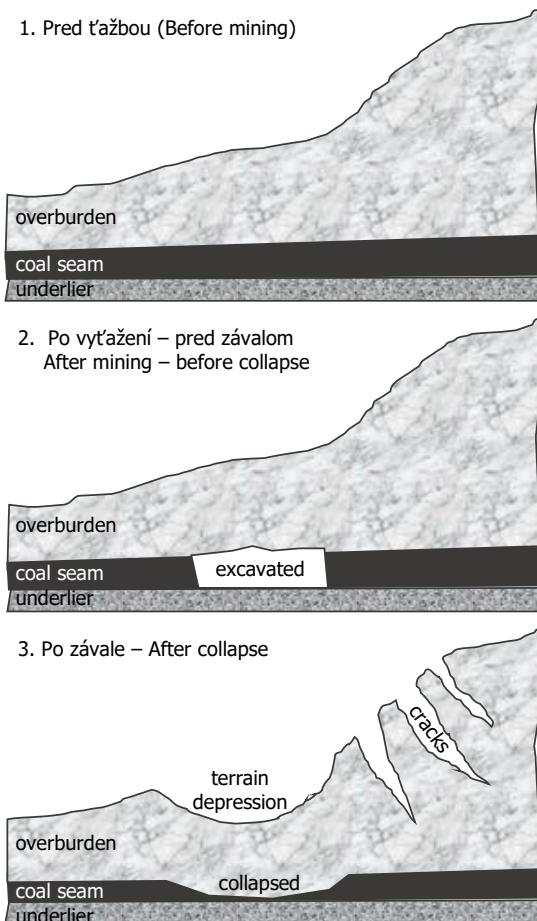


Obr. 1. Situačná mapa oblasti Nováčkej a Handlovskej uholnej panvy (Zdroj: Halmo et al. 2010). Červeným terčíkom s číslicou 1 označená lokalizácia poddolované výskumnej lokality Račkov laz a zeleným terčíkom s číslicou 2 označená lokalizácia referenčnej výkumnej lokality Čertove chodníky.



Obr. 2. Geologický rez pohorí Vtáčnik (Zdroj: Halmo et al. 2010). Vysvetlivky: (1) uholné sloje, (2) ilovce a prachovce Bádenského veku, (3) štrky (Sarmatského veku), 4) andezity, aglomerátové tufy (Sarmatského veku), (5) blokové rify, blokové polia, (6) zosuvy.

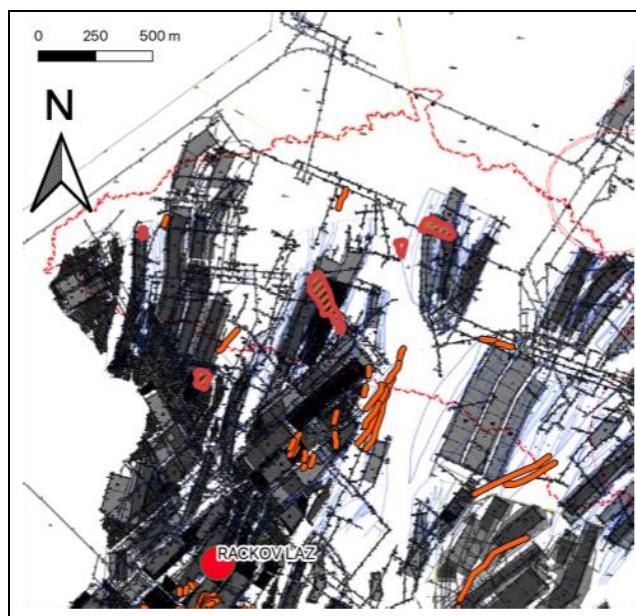
Antropogénne narušenie geoekosystému (krajiny) prebiehalo v oblasti lokality Račkov laz v istej postupnosti a nadväznosti. Najskôr dochádzalo k odťaženiu časti geologickeho podložia (odťaženie uholného sloja). Následne sa po zavalení zosunulo nadložie do prázdnego vytvoreného priestoru a dochádzalo k posúvaniu jeho jednotlivých vrstiev, zmene jeho hustoty a narušeniu kontinuity. Vo svahu boli dôsledky ťažby podstatne výraznejšie ako na rovine (Obr. 3). Nasledovali zmeny hydričkého režimu na povrchu (zmeny odtokových pomerov, riečnych sietí) a zmeny hydričkého prostredia pod zemským povrhom. Územie musí byť pri ťažbe kompletne odvodnené a procesy, ktorými sa odvodnenie dosiahne, môžu byť dočasné, ale aj trvalé, a môžu tak mať širšie dôsledky na okolité ekosystémy. So zmenami a narušením geologickeho prostredia nadložia totiž súvisia aj možné a pravdepodobné zmeny a narušenie vodných kolektorov podzemnej vody, ktoré môžu mať dôsledky na širšom území (Kučera et Novotná, 2015).



Obr. 3. Schematický rez terénom v prípade hlbinej tŕažby závalom vo svažitom teréne (ilustrácia: Vido J.).

Ukážka plošného priemetu banskej hlbinej tŕažby hnedého uhlia v okolí lokality Račkov laz do mapy zobrazujúcej zmapované rozsiahle trhliny a zosuvy na povrchu terénu je znázornené v obrázku č. 4. Tmavé polia v obrázku zobrazujú vytážené hnedouhoľné polia. Oranžové línie zobrazujú rozsiahle trhliny na povrchu terénu, plošné šrafované plochy reprezentujú zosuvy a červený terčík zobrazuje lokalizáciu výskumnej plochy Račkov laz v rámci banskou činnosťou postihnutej oblasti.

Na základe uvedených skutočností bola ako referenčná, banskou činnosťou nepoškodená lokalita vybratá oblasť východne od obce Kamenc pod Vtáčnikom s miestnym názvom Čertove chodníky (590 m n.m.). Táto leží vo vzdialosti 15 km od banskou činnosťou postihnutej oblasti. Obe lokality sú z hľadiska geologického podložia resp. pôdneho prostredia identické (kambizeme na pyroxenických a amfibolicko-pyroxenických andezitoch) s rovnakou južnou resp. juho-západnou expozíciou. Obe patria do bukového lesného vegetačného stupňa a do klimatického okrsku M6 (mierne teplý, vlhký, vrchovinový) podľa Bochníček et al. (2015).

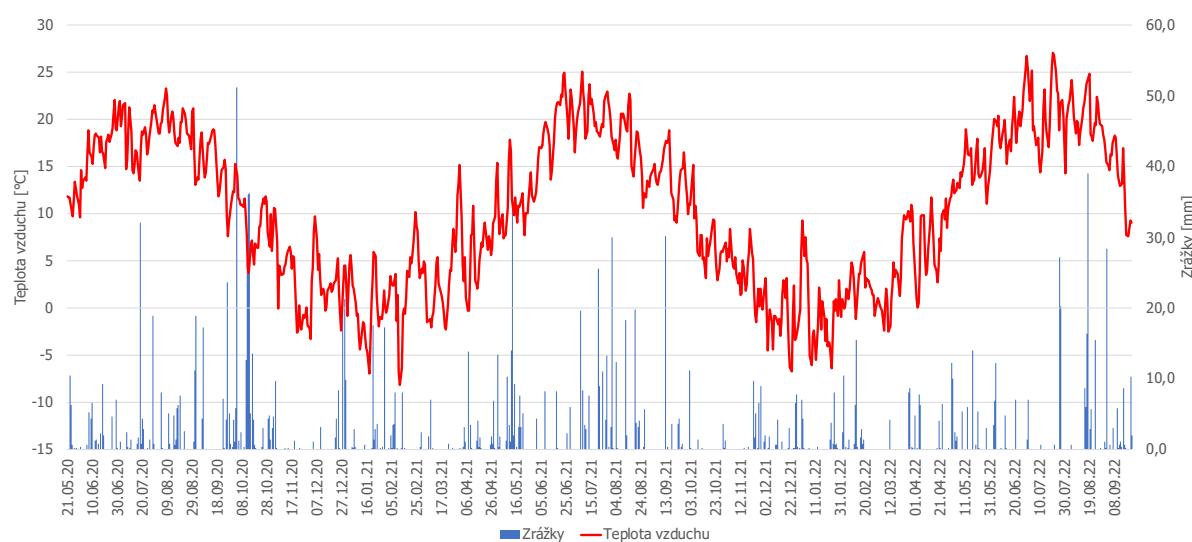


Obr. 4. Povrchový priemet vyťažených hnedouhoľných ložísk Bane Cígel' so zobrazením lokalizácie výskumnej plochy Račkov laz. Oranžové línie zobrazujú rozsiahle povrchové trhliny, šrafované plochy reprezentujú v zosuvy pôdy aktivované banskou činnosťou. Červený terčík je lokalita s inštalovanými meračmi pôdneho potenciálu SP3. Údaje o plošnom priemete boli získané od HBP Prievidza a.s., ostatné podkladové zdrojové údaje boli získané z ÚGKK SR a spracované prostredníctvom systému QGIS.

VÝSLEDKY A DISKUSIA

POVETERNOSTNÉ PODMIENKY V SLEDOVANOM OBDOBÍ

Poveternostné podmienky prostredia sme sledovali kontinuálne v celom sledovanom období od 21.5.2020 do 22.9.2022. V uvedenom období bola najvyššia priemerná teplota vzduchu nameraná dňa 20.7.2022, naopak najnižšia priemerná denná teplota vzduchu bola nameraná dňa 12.2.2021. Priebeh poveternostných podmienok podľa meraní meteorologickej stanice RS Púšť-Prievidza (350 m n.m.) uvádzame na obrázku č. 5.



Obr. 5. Zobrazenie dynamiky priemernej dennnej teploty vzduchu a denného úhrnu zrážok na stanici v lokalite RS-Púšť Prievidza v období od 21.5.2020 do 22.9.2022.

V roku 2020 boli najvyššie denné zrážkové namerané dňa 4.10.2020 (51,2 mm). Druhý najvyšší denný úhrn bol zaznamenaný 14.10.2020 (36,2 mm) a tretí najvyšší 13.10.2020 (36 mm). Možno konštatovať, že zrážkovo najvýdatnejšie obdobie bolo zaznamenané v roku 2020 od 10.10 do 19.10. s úhrnom 135,2 mm, zatiaľ čo za takmer celé vegetačné obdobie od 1.6 do 30.9. bol celkový úhrn 269,4 mm. Najdlhším súvislým bezzážkovým bolo obdobie od 8.9.-23.9.2020 (15 dní). Avšak veľmi suchým obdobím bolo aj obdobie od 12.11.2020 do 21.12.2020 kedy bolo toto štyridsať dňové obdobie prerušené iba troma dňmi so zrážkami od 1 do 3,2 mm. Z pohľadu teplotného bolo vegetačné obdobie roku 2020 zo všetkých sledovaných priemerne najchladnejšie. Treba poznamenať, že najchladnejšie mesiace (január a február) neboli odsledované, nakoľko došlo k inštalácii meracích zariadení až 21.5.2020. Priemerná denná teplota v období od 1.6. do 30.9.2020 bola 17,9 °C, absolútne maximum bolo zaznamenané 7.8.2020 (28,7°C), absolútne minimum pripadalo na 27.12.2020 (-7,8°C). Rok 2021 je charakteristický dvoma výraznými obdobiami zrážok v jarnom období (8.5.-21.5.) s úhrnom 96,8 mm a letnom období (21.7.-5.8.) s úhrnom 109,4 mm a dvoma suchými epizódami. Prvé v predjarnom období od 16.2. do 30.4. (79 dní s úhrnom 52,6 mm) a jesenná epizóda sucha v trvaní 70 dní (od 15.9. do 20.11) s celkovým úhrnom 31,8 mm. Zrážkovo bolo obdobie od 1.6.2021 do 30.9.2021 lepšie zásobené (280,8 mm) v porovnaní s rovnakým obdobím v roku 2020 (269,4 mm), avšak je potrebné zvýrazniť horšiu časovú distribúciu v súvislosti s vyššie uvedeným jarným resp. jesenným suchým obdobím.

Z teplotného hľadiska bol rok 2021 oproti predchádzajúcemu roku teplejší, pričom priemerná denná teplota vzduchu v období od 1.6. do 30.9. bola 18,2 °C (+0,4° oproti roku 2020). Prejavilo sa to aj na výrazne vyššej nameranej absolútnej teplote vzduchu (35°C - 24.6.2021). Absolútne minimum bolo zaznamenané dňa 23.12.2021 (-9,6°C).

Rok 2022 bol zrážkovo v období od 1.6. do 30.9. najlepšie zásobený spomedzi hodnotených rokov (295,5 mm). Avšak je potrebné v tejto súvislosti poznamenať viacero skutočností. V prvom rade to bol výskyt veľmi dlhá letná epizóda sucha (55 dní) v období od 1.6. do 25.7. s veľmi nízkym úhrnom zrážok (44,2 mm). V druhom rade je potrebné zvýrazniť, že tento veľmi nízky úhrn zrážok sa vyskytol v období s najvyššími teplotami vzduchu (dve vlny horúčav vrcholiace priemernou dennou teplotou 26,7°C - 30.6. a 26,8°C - 22.7. a absolútne najvyššou nameranou teplotou na úrovni 36,5°C dňa 21.7. Evaporačné požiadavky atmosféry tak nedokázali byť saturované vyššie popísaným minimálnym úhrnom zrážok počas prakticky polovice letného obdobia. K výraznejšiemu uvoľneniu sucha došlo až od 16.8., kedy nastúpilo obdobie zrážok (trvajúce až do konca hodnoteného obdobia (30.9.), ktoré doplnili meteorologický deficit a posunuli hodnotenie roka 2022 z pohľadu zrážkového paradoxne na najlepšiu úroveň spomedzi hodnotených rokov. Môžeme však konštatovať, že pri komplexnom pohľade bol rok 2022 práve naopak najsuchším, ak hodnotíme kumulačný efekt teploty vzduchu a zrážok. To sa prejavilo aj na priebehu a dynamike pôdneho vodného potenciálu čo uvedieme v ďalšej kapitole.

V tabuľke 1 uvádzame sumárne hodnotenie dynamiky poveternosti v sledovaných rokoch.

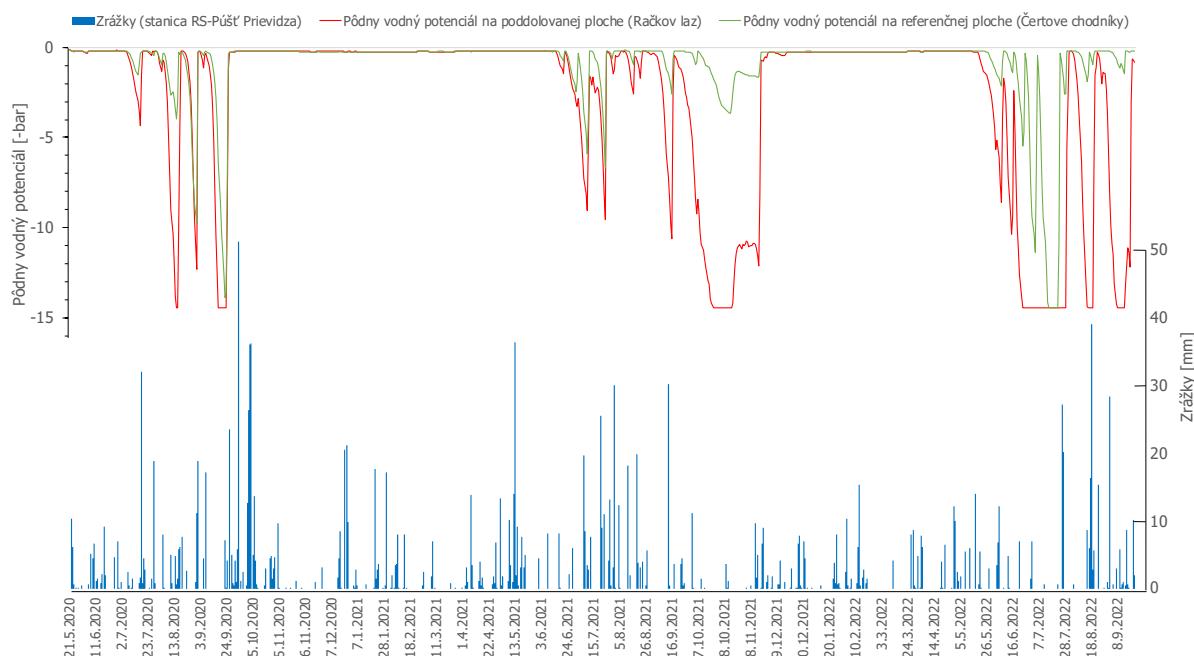
DYNAMIKA PÔDNEHO VODNÉHO POTENCIÁLU

Priebeh a charakter poveternostných podmienok sa v sledovaných rokoch prejavoval zásadne odlišne na lokalite poškodenej banskou činnosťou a na referenčnej lokalite. Pri celkovom pohľade na priebeh pôdneho vodného potenciálu v priebehu všetkých troch sledovaných rokov, je zrejmá skutočnosť, že existujú veľmi výrazné rozdiely medzi priebehom a dynamikou vodného potenciálu medzi poškodenou (poddolovanou) a referenčnou plochou. Názorný pohľad na variabilitu priebehu vodného potenciálu poskytuje obrázok č. 6.

Tabuľka 1. Vybrané ukazovatele meteorologických podmienok v sledovaných rokoch 2020 až 2022 na základe meraní meteorologickej stanice na lokalite RS-Púšť Prievidza

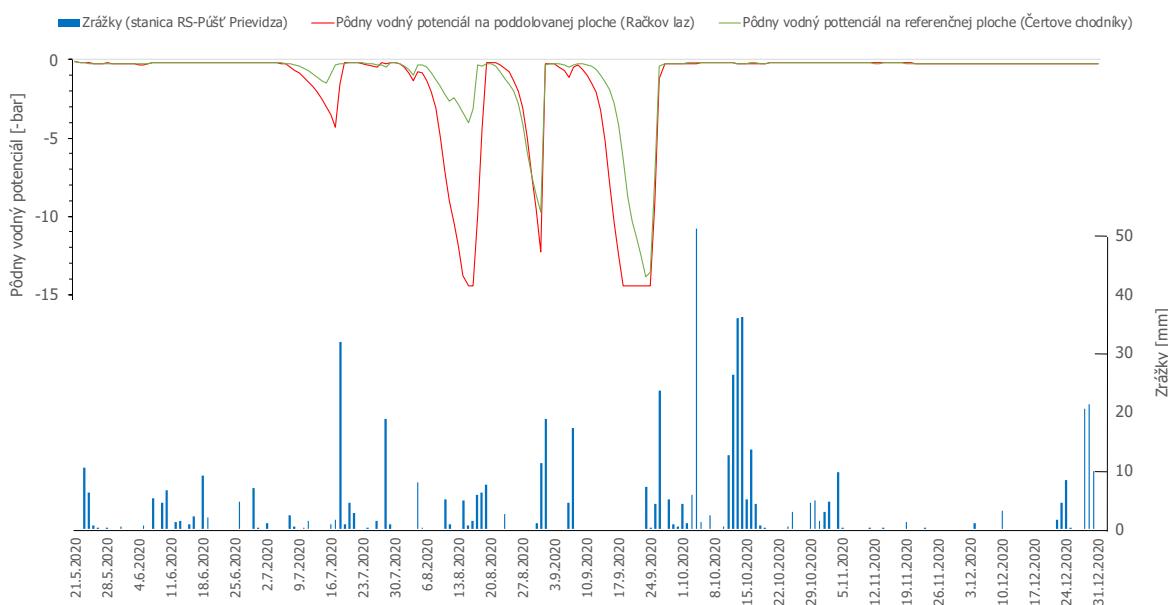
2020					
Zrážky	dátum	[mm]	Teplota vzduchu	dátum	[°C]
úhrn	1.6.-30.9.2020	269,4	absolútne min.*	27.12.2020	-7,8
max	4.10.2020	51,2	absolútne max.	7.8.2020	28,7
najdlhšie bezzážkové obdobie	8.9.-22.9.2020	15 dní	priemerná teplota	1.6.-30.9.2020	17,9
2021					
Zrážky	dátum	[mm]	Teplota vzduchu	dátum	[°C]
úhrn	1.6.-30.9.2021	280,8	absolútne min.	23.12.2021	-9,6
max	13.5.2021	36,4	absolútne max.	24.6.2021	35
najdlhšie bezzážkové obdobie	13.10.-28.10.2021	16 dní	priemerná teplota	1.6.-30.9.2021	18,2
2022					
Zrážky	dátum	[mm]	Teplota vzduchu	dátum	[°C]
úhrn	1.6.-30.9.2022	295,5	absolútne min.	24.1.2022	-11,7
max	18.8.2022	39	absolútne max.	21.7.2022	36,5
najdlhšie bezzážkové obdobie	20.2.-11.3.2022	20 dní	priemerná teplota	1.6.-30.9.2021	18,4

* rok 2020 meranie až od 21.5.2020



Obr. 6. Rozdielna dynamika pôdneho vodného potenciálu v priebehu sledovaných rokov (2020 až 2022) na poddolovanej (Račkov laz) a referenčnej ploche (Čertove chodníky).

V roku 2020 bola dynamika pôdneho vodného potenciálu ovplnená najmä výskytom krátkodobých bezzážkových epizód. Priebeh dynamiky vodného potenciálu v roku 2020 je detailne zobrazený na obrázku 7.

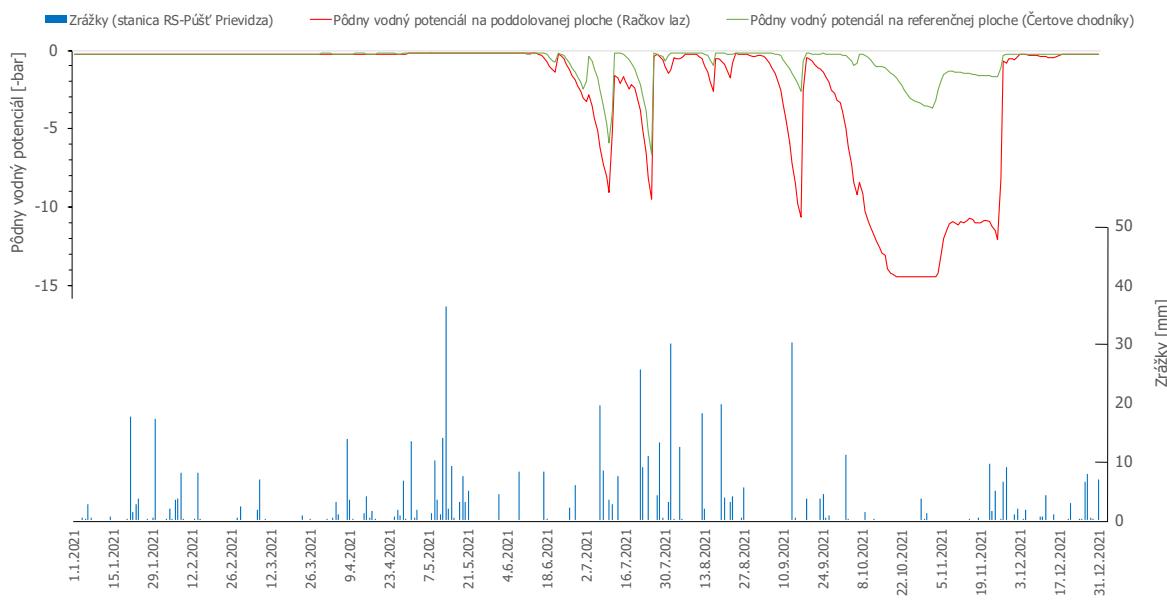


Obr. 7. Pôdny vodný potenciál v roku 2020. Z dôvodu neskoršej inštalácie začína hodnotenie roka 2020 až 21.5.

Detailnejší pohľad na obrázku 7 dokumentuje výrazne rozdielny chod vodného potenciálu na banskou činnosťou poškodenej ploche a na referenčnej ploche. Pri krátkodobých epizódach sucha ako napríklad v prvej a druhej dekáde júla 2020, došlo iba k miernemu poklesu vodného potenciálu na hodnoty -1,4 bar na referenčnej ploche (15.7.) a -4,4 bar na poškodenej lokalite (17.7.). Vyšia zásoba pôdnej vody resp. vyššia retenčná kapacita je dokumentovateľná aj skutočnosťou, že na referenčnej ploche sa už po veľmi miernych zrážkach dňa 16.7. (0,8 mm) a dňa 17.7. (1,6 mm) zvýšila hodnota pôdneho potenciálu na hodnotu -0,3 bar, zatiaľ čo v tej dobe bola na poškodenej lokalite zaznamenaná hodnota -4,4 bar. Táto sa na poškodennej lokalite dostala na hodnoty -0,25 bar až 20.7. po tom čo sa 18.7. vyskytli úhrny zrážok 32 mm nasledované 4,4 mm úhrnom dňa 20.7.2020. Neskôr v prvej dekáde až polovici mesiaca august sa vyskytlo niekoľkodňové obdobie bez zrážok, na ktoré reagovala referenčná plocha iba nevýrazným poklesom potenciálu na hodnoty -3,9 bar, zatiaľ čo v rovnakom období sa tento prepadol na poškodenom území až na minimálne merateľné hodnoty -15 bar (16.8.). Po zrážkach, ktoré sa vyskytli od 16.8 sa začal potenciál zdvíhať na oboch plochách, no s evidentným časovým odstupom v prípade poškodenej plochy. Výrazný rozdiel nastáva od 8.9 do 22.9, kedy sa vyskytuje už v meteorologickom rozboze spomenutá nadlhšia epizóda sucha v tomto roku. Táto výraznejšia epizóda sucha sa prejavila rýchlym a náhlym poklesom vodného potenciálu na poškodenej ploche v priebehu 10 dní (9.9-19.9) z hodnoty -0,25 bar na -15 bar, zatiaľ čo referenčná plocha zaznamenala svoje najnižšie hodnoty až 23.9 na úrovni -13,9 bar. Pokles potenciálu tiež datujeme do 9.9., tento však na svoje minimum klesal 14 dní (o štyri dni dlhšie oproti poškodenej ploche). Návrat do hodnôt blízko nuly nastal krátko po výdatných zrážkach od 23.9. V tomto prípade nastal návrat do normálu v rovnakých dátumoch, nakol'ko zrážkové obdobie ktoré začalo 23.9. bolo výdatné a plne saturovalo vodný deficit, čo sa ukázalo spoločným prudkým stúpaním potenciálu na oboch plochách.

Rok 2021 bol charakteristický relatívne chladnou a zrážkovo dobre zásobenou jarou. To sa prejavilo aj na priebehu vodného potenciálu, ktorý sa držal veľmi dlho na vysokých hodnotách až do 16.6.2021. Dobré zavlaženie pôdy z prvej a druhej dekády mája v súbehu s len veľmi pozvoľna nastupujúcou jarnou fenológiou spôsobilo, že vodný potenciál začal klesať iba k hodnotám -9 bar (Račkov laz) resp. -5,8 bar (referenčná plocha Čertove

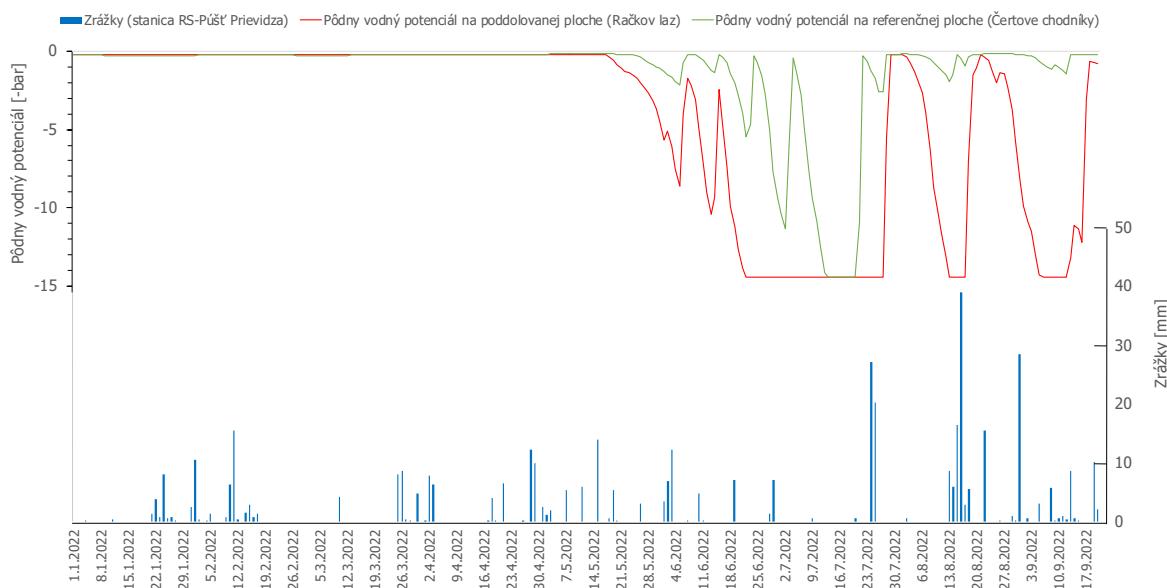
chodníky) dňa 10.7. resp. neskôr 25.7. s identickými hodnotami (obr. 8). Dokazuje to skutočnosť, že pokial' je zrážkové zabezpečenie vyvážené z časového a kvantitatívneho hľadiska, rozdiel medzi poškodenou plochou a referenčnou je relatívne zanedbateľný. Ak však nastane dlhotrvajúci nedostatok atmosférických zrážok (od 7.9. do 22.11) s relatívne slabými a občasnými zrážkovými situáciami, retenčná kapacita resp. poškodenie územia sa prejavia veľmi výrazne. A to aj s ohľadom na končiacu vegetačnú sezónu a nižšiu potrebu vody na transpiračné zabezpečenie lesných porastov. Počas vyššie spomenutého obdobia jesenného meteorologického sucha bol pokles pôdneho potenciálu na referenčnej lokalite zaznamenaný na minimálnu úroveň -3,6 bar dňa 2.11. zatiaľ čo na poškodenej lokalite pôdny potenciál dosahoval takmer minimálnych hodnôt -14,4 bar od 21.10. až -12 bar dňa 25.11. 2021. Z uvedeného vyplýva, že dynamiku pôdneho vodného potenciálu na poškodenej ploche najväčšmi ovplyvňuje predchádzajúce zrážkové zabezpečenie, priebeh potenciálnej evapotranspirácie (teploty vzduchu) a distribúcia zrážok z časového hľadiska. Ak sú splnené tieto podmienky, tak sú rozdiely medzi referenčnou plochou a poškodenou takmer zanedbateľné.



Obr. 8. Pôdny vodný potenciál v roku 2021.

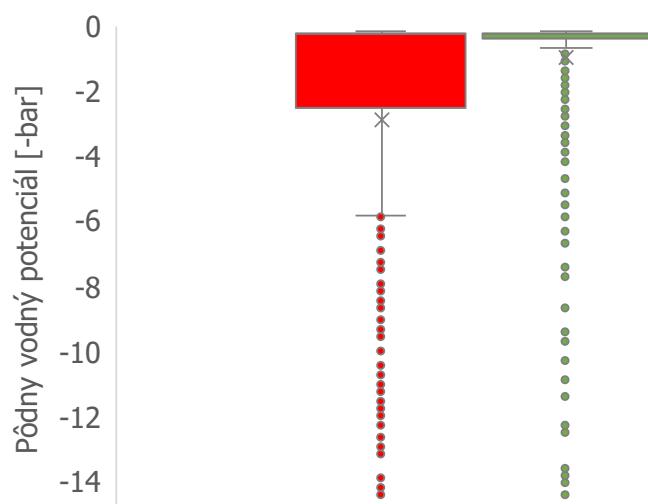
Dynamika vodného potenciálu v roku 2022 bola ovplyvnená najmä zrážkovo veľmi málo zásobenými mesiacmi február až júl (obrázok č. 9). V tejto časti roka spadlo dovedna počas 156 dní iba 157 mm zrážok (od 20.2. do 25.7.). Očakávateľný prepad vodného potenciálu pri takto nízkom úhrne zrážok však nastúpil pomerne neskoro (19.5. - poškodená plocha, 26.5. - referenčná plocha). Dôvodom pre tento zvláštne oneskorený nástup reakcie pôdneho potenciálu na nedostatok atmosférických zrážok je relatívne chladný priebeh mesiacov marec (priemerá teplota $3,78^{\circ}\text{C}$), apríl (priemerná teplota 7°C) a máj ($14,53^{\circ}\text{C}$). Tieto pri porovnaní s hodnotami dlhodobého normálmu (1981-2010) pre meteorologickú stanicu SHMÚ v Prievidzi nižšie o $0,42^{\circ}\text{C}$ v marci, $-2,9^{\circ}\text{C}$ v apríli a $0,47^{\circ}\text{C}$ v mesiaci máj. Toto relatívne chladnejšie obdobie malo za následok aj neskorší nábeh plného olistenia a spomalila sa aj transpiračnú potrebu lesného porastu. Deficit zrážok však viedol k tomu, že pokles vodného potenciálu bol razantný a na ploche postihnutej banskou činnosťou sa až na niekoľko dní trvajúce výnimky po výskytu veľmi občasných výdatnejších zrážok na konci júla (23.-24.7., a 15.8.) držal prakticky na minimálnych hodnotách -15 bar. Úplne najdlhším obdobím, kedy sa pôdny potenciál držal na úrovni -15 bar bola epizóda sucha od 23.6 do 27.7. Zaujímavou

skutočnosťou je, že tento kritický priebeh pôdneho potenciálu je charakteristický iba pre banskou činnosťou poškodenú lokalitu Račkov laz. Aj na referenčnej ploche bol priebeh potenciálu dynamický a došlo aj k poklesu na minimálnu úroveň -15 bar, no toto obdobie trvalo iba od 14.7. do 20.7. Je teda evidentné a potvrdzuje sa tvrdenie, že pokial' je zrážkové zabezpečenie nepriaznivé čo do časovej distribúcie a množstva, väčšmi sa prejavuje sucho resp. nízke hodnoty vodného potenciálu na poškodenej lokalite ako na referenčnej. Všeobecné zlepšenie stavu vodného potenciálu nastalo iba ku konci sledovaného obdobia (september 2022) výhradne na referenčnej lokalite, zatiaľ čo na ploche poškodenej banskou činnosťou sa situácia nezlepšila ani v súvislosti s výdatnými zrážkami z konca augusta a začiatku septembra



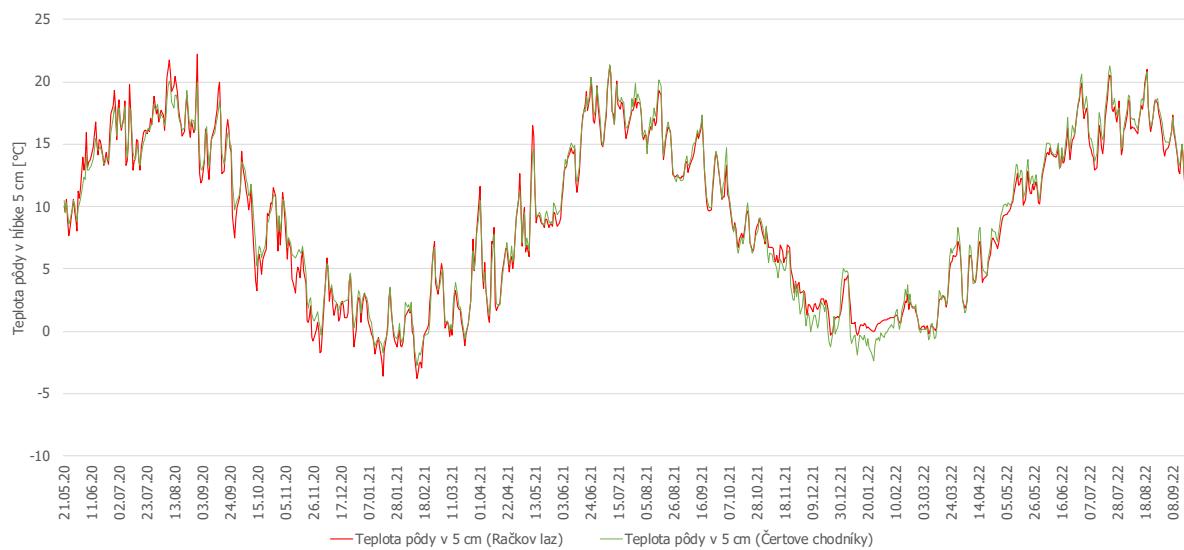
Obr. 9. Pôdny vodný potenciál v roku 2022.

Charakter dynamiky pôdneho vodného potenciálu na referenčnej (Čertove chodníky) a poškodenej ploche (Račkov laz) môžeme sledovať taktiež na výrazne odlišnej variabilite (obr. 10).

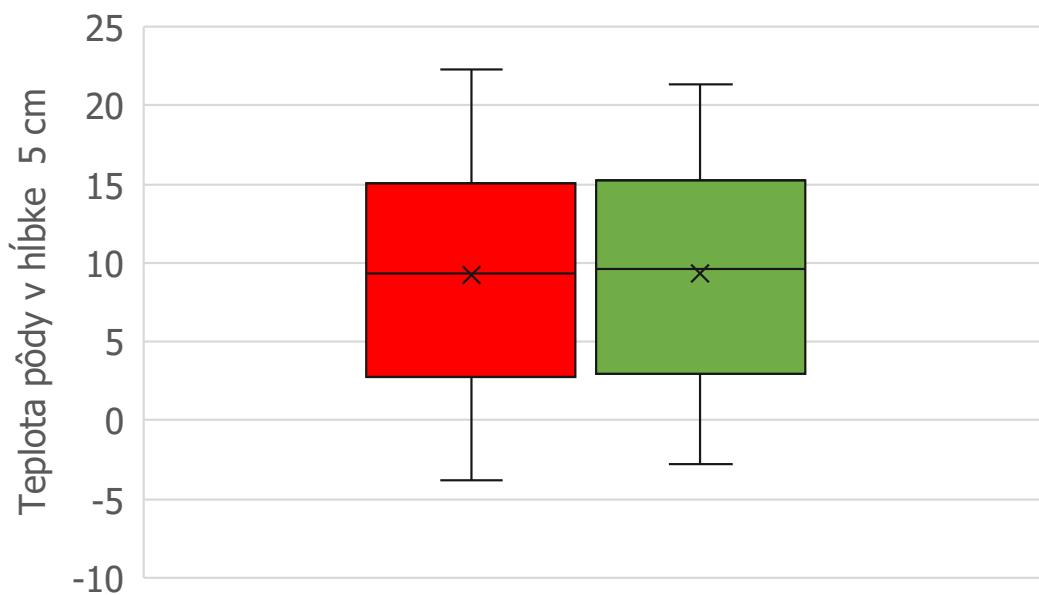


Obr. 10. Variabilita hodnôt pôdneho vodného potenciálu na poškodenej lokalite Račkov laz (červená farba) a intaktnej referenčnej ploche Čertove chodníky (zelená farba).

Z obrázku je evidentné, že dynamika vodného potenciálu na poškodenej lokalite je zreteľne vyššia, čím môžeme konštatovať, že poškodenie geologického podložia a tým aj pôdneho vodného režimu spôsobuje zosilňovanie dôsledkov sucha a vystavuje lesné ekosystémy zvýšenému stresu zo sucha. Z dôvodu potreby poukázania na rovnaký tepelný režim na oboch lokalitách si dovoľujeme na záver uviesť graf priebehu teploty pôdy v hĺbke 5 cm v období od 21.5.2020 do 22.9.2022 (obr. 11). Z grafu je evidentné, že tepelný režim v povrchovej vrstve pôdy, ktorá je kontaktnou zónou transformácie krátkovlnného žiarenia na infračervené je na oboch lokalitách relatívne zhodná čo vylučuje zásadný vplyv rozdielnej energetickej bilancie na vodný režim v pôde. Potvrzuje to aj obrázok 12, na ktorom nie je evidentná odlišná variabilita hodnôt teploty pôdy na oboch lokalitách, čo podporuje naše závery.



Obr. 11. Dynamika teploty pôdy v hĺbke 5 cm na lokalitách Račkov laz a Čertove chodníky v období od 21.5.2020 do 22.9.2022.



Obr. 12. Variabilita hodnôt teploty pôdy v hĺbke 5 cm na lokalitách Račkov laz (červená farba) a Čertove chodníky (zelená farba).

ZÁVER

V príspevku sme potvrdili rozdielny režim pôdneho vodného potenciálu na banskou činnosťou poškodené lokalite Račkov laz v porovnaní s intaktnou referenčnou plochou na lokalite Čertove chodníky. Z výsledkov je evidentné, že na poškodenej lokalite sa dosahujú nižšie hodnoty pôdneho vodného potenciálu, pokles má razantnejší priebeh a vodný potenciál dlhšie zotrvava na minimálnych hodnotách v prípade bezzáškrových situácií resp. v obdobiah s vyššími evaporačnými požiadavkami atmosféry. Taktiež možno konštatovať, že odolnostný potenciál ekosystémov na sledovaných lokalitách, vyjadrený v zmysle charakteristík pôdneho vodného potenciálu je slabší na poddolovanej lokalite Račkov laz ako na referenčnej lokalite Čertove chodníky. Teda aj pri relatívne menej priaznivom chode poveternosti, kedy sa kombinuje nedostatok zrážok s vysokými evaporačnými požiadavkami atmosféry, dokáže nepoškodená plocha čiastočne tlmit' s tým spojené dopady v pôdno-hydrologickom komplexe. Opak platí pri poddolovanej lokalite. Aj napriek tomu, že výsledky vychádzajú zatiaľ z troch rokov, rozdielnosť dynamiky vodného potenciálu pôdy nás vedie k záverom, že banskú činnosť na uvedenom území môžeme hodnotiť ako antropogénny disturbačný faktor znižujúci odolnosť lesných ekosystémov voči suchu. Je však potrebné vykonať ešte rozsiahlejší zber údajov o vodnom potenciáli ale aj objemovej vlhkosti pôdy, fyziologické a dendrometrické kontinuálne merania ktoré by umožnili nahliadnuť do retenčných vlastností pôd a fyziologickej manifestácie drevín na uvedených lokalitách.

Poděkovanie

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LITERATÚRA

- Bochníček, O., Borsányi, P., Čepčeková, E., Faško, P., Chmelík, M., Jancovicová, L., Mišaga, O. (2015): Climate atlas of Slovakia [Klimatický atlas Slovenska]. SHMU, Bratislava. 132p.
- Halmo, J., Šarkan, J., Gurský, S., Toma, S., Lalúch, I., Bogdan, P., (2010): 11. ľažobný úsek Bane Nováky, nová ľažobná kapacita na Hornej Nitre, Mineralia Slovaca, 42 (2010), 133 – 140, ISSN 0369-2086.
- Kučera, K., Novotná, Ž. (2015): Metodika hodnocení krajiny narušené težbou surovin. Výstup projektu Programu aplikovaného výzkumu a vývoje národní a kulturní identity (NAKI) financovaného MK ČR. Identifikační kód DF11P01OVV019 „Metody a nástroje krajinařské architektury pro rozvoj území“ (2011-2015).
- Vicente-Serrano S.M., Santiago Beguería, Juan I. López-Moreno, (2010): A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index - SPEI. Journal of Climate 23: 1696-1718.
- Vido, J., Nalevanková, P. (2021): Impact of Natural Hazards on Forest Ecosystems and Their Surrounding Landscape under Climate Change.

EFFECT OF SOIL MOISTURE ON EARTHWORM ABUNDANCE IN PROTECTED AREAS OF HUNGARY

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ABSTRACT

Soils have been under increasingly high pressure, mainly due to anthropogenic use. To understand the connection between soil properties and soil ecosystem services, finding suitable indicators is crucial. In our research, we chose earthworms as indicator species, because their presence, and its influencing factors can be monitored spatially and temporally, and they have been widely researched. On different protected areas in Szada and Sirok, Hungary, soil blocks of 25×25×25 cm have been taken randomly and hand sorted for earthworms 5 times at each site to quantify abundance and biomass of earthworms. Their species was identified for adult individuals, as well as ecotypes for juveniles. Soil properties were measured using a portable NIR device, to determine influencing factors of their presence, such as soil moisture, soil organic matter, pH, or calcium-carbonate content. Soil samples were analyzed also in the laboratory to compare the measuring methods. Based on the statistical analysis, the main conclusion is that samples with higher soil moisture, contained more earthworms, however, our assumption, that the bottom of a hill contains more earthworms could not be confirmed. Significantly more earthworms at Sirok Castle (Bottom) shows importance of soil type.

Keywords: soil properties, earthworm, protected area, land use, soil moisture

INTRODUCTION

Soils, from humanity's point of view, have been key asset for our survival and wealth for millennia. It is widely documented that it is an integrator, reactor and transformator of other natural resources (Stefanovits *et al.* 1999, Schon & Dominati 2020), due to its high biodiversity (Griffiths *et al.* 2016), it is a place for biomass production and natural storage medium of temperature, minerals, and water. During the 20th century, the questions of environmental protection raised, it became obvious, that protection of soils should be treated as top priority, because they are both natural filters and big capacity buffers. Furthermore, soil is a raw material for technical purposes; place of constructions and geological, as well as cultural archive (Pető *et al.* 2008, Barczi *et al.* 2009, Saláta *et al.* 2016), and a gene reservoir, too (Barczi *et al.* 2008). The value of soils and their ecosystem services can be decisive for legislators, land managers and future generations.

Soil organic carbon regulates most ecosystem services. The sequestration of soil organic carbon by ecosystems can potentially reduce the atmospheric concentration of carbon dioxide and, therefore, slow down global warming. That is why it is considered part of a strategy to reduce the effects of climate change (Canedoli *et al.* 2020, Panchal *et al.* 2022). The two most important areas of its buffering effect are: the acid/base buffer capacity and the ability to bind nutrients and toxic elements (Stefanovits *et al.* 1999). Marichal *et al.* (2017) also highlights support for primary production processes through soil quality and water storage. The sustainable management of soils requires soil monitoring, including biological indicators, to

be able to relate land use and management to soil functioning and ecosystem services (Pulleman *et al.* 2012). The criteria for the selection of biological indicators were summarized as follows: meaningful, standardized, measurable and cost efficient, policy relevance, spatio-temporal coverage, understandability and accuracy ([http1](#)).

Different EU policies, e.g. on water quality, pesticide use, waste management or nature conservation, contribute in some way to soil protection (Pulleman *et al.* 2012). In Europe, European Commission (COM) was approved in 2002 that was the initial step for a thematic soil protection strategy, that highlights the importance of soils and protecting it from degradation for its own right. The EU Soil Health Law foreseen for 2023 could couple land management practices beneficial for soil biodiversity with incentive-based instruments. Also, the EU has recently announced its new Soil Strategy to better protect soil ecosystems as part of the Biodiversity Strategy for 2030 (Königer 2022).

Only a few studies have linked soil properties to ecosystem services. However, the relationship between soil carbon, soil biota, soil nutrient cycling, and moisture retention to ecosystem services has been well documented, as well as effects of land use change and soil degradation (Centeri *et al.* 2012) and protective measures (Bolf *et al.* 2014). Soil ecosystem services depend on soil properties and their interaction and are mostly influenced by its use and management. Landslides, erosion, decline in soil carbon and biodiversity lead to soil degradation which is a serious global challenge for food security and ecosystem sustainability (Adhikari *et al.* 2016).

In case of Hungary, one soil ecosystem service, namely storing water, has the potential to be the biggest capacity of natural water reservoir, as its top layer could receive up to 45 km³ water and store 25 to 35 km³. Water balance determines air and temperature, biological activity and via these, the mineral circulation. These circulations also determine its buffer capacity for environmental stress. It is of crucial importance to adapt and mitigate the effects of climate change such as weather extremes that result in hydrological and soil moisture scenarios like floods, droughts, even on the same place with a year. Probability, frequency, duration, and intensity will likely increase in the future (Simon 2008).

Regulation of the water cycle in the soil is enhanced by the soil ecosystem engineers, like earthworms. They affect the infiltration and distribution of water in the soil, by creating soil aggregates and pore spaces. It has been observed that the elimination of earthworm populations due to soil contamination can reduce the water infiltration rate significantly, in some cases even by up to 93%. The diversity of microorganisms in the soil contributes to water purification, nutrient removal, and to the biodegradation of contaminants and of pathogenic microbes ([http1](#)).

Different types of indicators can be used to characterize the quality of an area of land or a given soil. They can be grouped, for example, based on the work of Mizik (ed.) (2018) as follows: 1. Visual, such as topography. 2. Physical: expresses the soil's resistance to various environmental influences. This also includes the ability of the soil to absorb and retain water. 3. Chemical - includes the soil's pH value, (electrical) conductivity (this refers to the number of ions and salinity), mineral and trace element content, nutrient retention, and absorption capacity. 4. Biological - the totality of organisms living in the soil. Earthworms were chosen for various investigations because, among the edaphon organisms, their role in the soil ecosystem has been proven in a wide range of climates, and they are significant indicators of the biological and physical condition of the soil (Bakti *et al.* (2017), Kalu *et al.* (2015)). Total abundance or biomass of earthworms are commonly used as indicators (Magyari-Meskó *et al.* 2019). Nevertheless, the functional group may be a better proxy for habitat quality and soil functions (Pulleman *et al.* 2012).

Dispersal plays a major role in shaping biodiversity, evolution, and ecosystem functioning. The direct consequence is that species abundance and genetic composition in different places

of a landscape are not independent. In this perspective, we need to study local community and genetic structure at both local and regional scales in order to understand the structure of local populations or communities, as well as their functional role (Sakraoui *et al.* 2022). It is, however, hard to track individuals, which is particularly true for earthworms, because they are subterranean and cannot be seen from surface (Mathieu *et al.* 2018).

Earthworms occur in large numbers in most soil types, they often form the major part of soil fauna biomass, representing up to 60% in some ecosystems ([http1](http://)). However, they are less frequent in agriculturally cultivated and quickly drying, sandy soils than, for example, in forested areas. Their role is very diverse, because they rotate and mix soil layers through their feeding and burrow-making movements, and improve the aeration, water balance and structure of the soil (Bakonyi *et al.* 2003). By producing soil structures such as burrows and excrements they strongly modify the habitat for other soil organisms, including plant roots (Pulleman *et al.* 2012). They are usually very sensitive to drying out. In soils around pH 4.2, they are no longer viable. Their distribution is mainly determined by the pH values of the soils (Szabó 2008). The study by Hoeffner *et al.* (2021) revealed that the most favorable factors for earthworm frequency and biomass were an increase in pH and soil organic matter content. It has also been shown that the hedge that surrounds the pasture or grassland increases earthworm species richness. In their study, Timmerman *et al.* (2006) found a lower occurrence of earthworms and a higher average individual body weight in the case of liquid fertilization than between the areas without fertilization and those treated with agricultural manure. Salomé *et al.* (2011) assumed that the occurrence of earthworm communities is greatly influenced by altitude, the successional phase of forests, and some other soil parameters. The results show that the composition of earthworm communities changes depending on the altitude gradient. However, a 20-year-long study by Butt *et al.* (2022) concluded, that even though e.g., precipitation and soil moisture records were markedly different over time, these resulted in small, discernible environmental effects. Site specific differences were more apparent with better conditions in field and less so on slopes sites.

The moisture requirements of earthworms vary from species to species. A water content value below 20% of the soil's total water capacity is no longer sufficient to ensure the living conditions of any species. Therefore, soil-friendly cultivation procedures that preserve the moisture content and structure of the soil are also favorable from the point of view of the survival and activity of the earthworm fauna (Pacs 1990). Birkás *et al.* (2004) found significantly more earthworms in undisturbed, non-compacted soil, and when the stubble remains were left on the ground surface than when the ground surface was left completely bare. Dekemati *et al.* (2019) found that better microclimatic conditions, like higher soil moisture content and less evaporation in the soil, manifested in measurably higher earthworm abundances. Positive correlation of earthworm biodiversity and distribution has been found with soil moisture (Singh *et al.* 2016). Initially by Darwin (1881) and Singh (1997) found a relative reduction in earthworm abundance and biomass when soil moisture, soil acidity, and food source palatability tended to decline.

Their reactions to the drought were reported to depend further on chemical stressors, supply of oxygen and soil food supplies (Nearing *et al.* 2004). It was highlighted that soil water capacity and organic matter content of soil are important factors that modulate earthworm reactions to drought conditions (Richardson *et al.* 2009).

Instead of assessing their contribution to separate ecosystem services, Schon & Dominati (2020) utilized in their study the status of earthworms as ecosystem engineers modifying soil properties and contributing to the provision of multiple ecosystem services. Their beneficial effects on soil microbes, soil microbial biomass, fungal community, soil structure, water retention and plant growth in different terrestrial ecosystems have been well reported (Al-Maliki 2021),

Earthworms help maintain and enhance the physical condition and function of soils. Their contribution to soil services, such as the flow of water, nutrients and gases, is influenced by earthworm abundance and diversity. However, how earthworms impact soil structure as their abundance and diversity increases remains poorly understood, particularly, in relation to how this might alter their contribution to soil services, and whether their contribution to these soil services change throughout the year (Schon *et al.* 2017).

The objective of our study was to determine the effect of soil moisture content on earthworm abundance, particularly in two protected areas of Hungary. As various earthworm research focuses their abundance and its influencing factors in sites dominated by agriculture such as pastures and there is a lack of research on nature protected areas. Our first hypothesis was that there is a positive correlation between abundance and biomass of earthworms and soil moisture content. Our second hypothesis was that on the bottom of the hill there will be more earthworms than on the top of the hill, due to the hillside effect.

METHODS

Two protected areas of Hungary were chosen for sampling. Altogether, 6 sampling locations were selected, of which two were in the Gödöllő Hillside Landscape Protection Area, nearby its peak at Margita (altitude 345 and 340 m, respectively) in Szada. Both Szada Hilltop and Hillside were located in an oak forest. The other 4 sampling locations were in Sirok. Two locations next to the Sirok, Lake Nyírjes Nature Protected Area, at the bottom and at the top of a hill (267 and 300 m of altitude, respectively) in a hornbeam-oak forest, another at a clear-cut of an oak forest (altitude 318 m) in a nearby forest and the last one at the bottom of the hill of The Castle of Sirok (257 m of altitude). Sampling sites are shown on Figure 1.

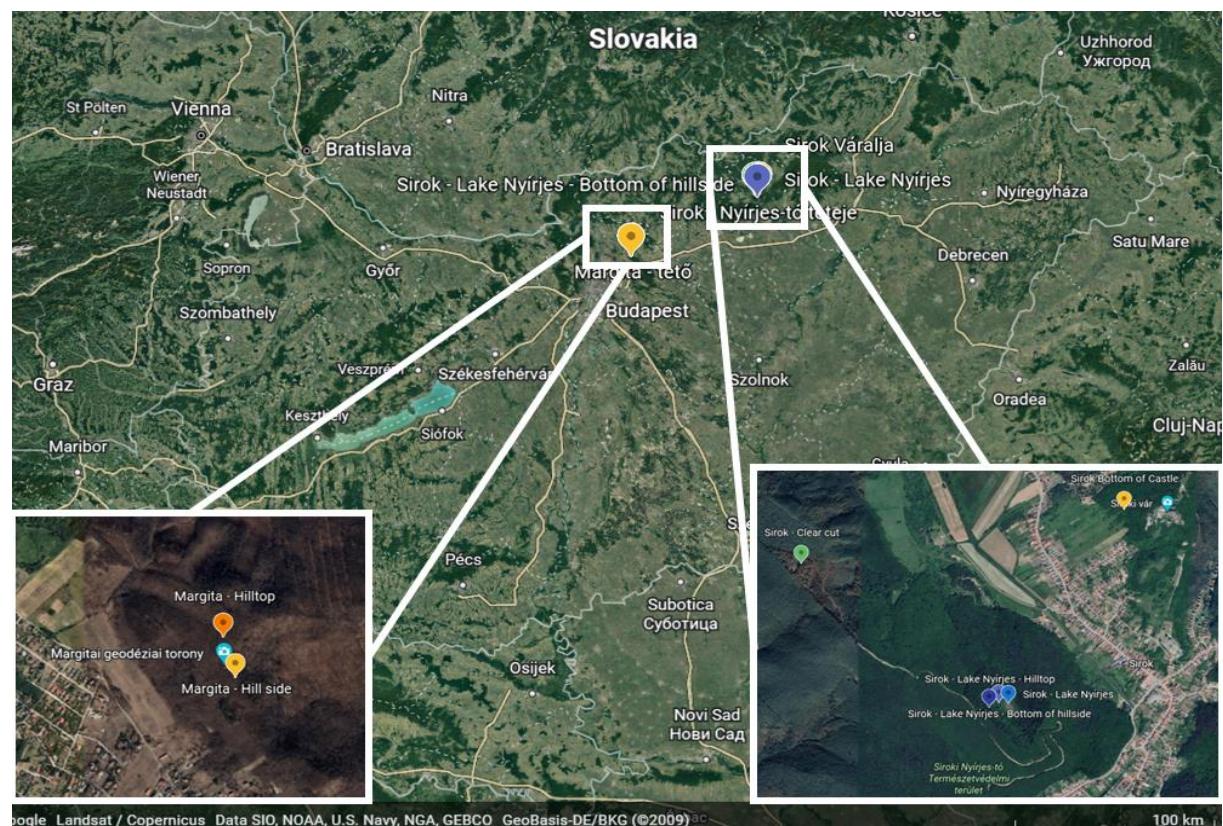


Fig. 1. Location of study sites in Szada and in Sirok (Source: Google Earth).

When deciding where the sample sites will be, it was important that they are nature protected. Also, we tried to select areas with different soil types. Both in case of the two Szada sample, as well as the two samples from the hill near Lake Nyírjes, the two sample sites are in the proximity of each other, however there is an altitude difference between them, so they were used to investigate the hillside effect. In case of the clear-cut, there is a major change in the ecosystem, and we wanted to model this effect.

Used methods

Soil types were assessed by Pürckhauer type soil core sampler with 1m depth on 25th and 30th of April and 1st of May 2022. At each of the 6 sampling sites, 5 samplings were done, by digging soil blocks of 25×25×25 cm, according to ISO (2006) standard. Earthworms were hand-sorted and collected in glass jars. Additionally, approx. 150 g of soil sample was taken from each sampling site to determine soil moisture content, pH and salt content in the university soil laboratory. Soil samples were also measured using a portable NIR (near-infrared) soil scanner from AgroCares for various soil parameters (pH, exchangeable Calcium (Ca), Potassium (K), Magnesium (Mg), potential mineralizable nitrogen, soil moisture content, clay content, and soil organic matter content, all phosphorous (P), all Aluminum (Al) and all Iron (Fe), as well as cation exchange capacity (CEC). Raw data was gathered in Microsoft Excel, where mean and standard deviation values were calculated. IBM SPSS and Statistica softwares were used for statistical analysis. When the distribution was non-normal, based on the Shapiro-Wilk test, then non-parametric Kruskal-Wallis test was performed. The effect of soil moisture on earthworm abundance and biomass was tested using a nested ANOVA for which sampling site (Sirok or Szada) was the principal factor and sampling site within the subordinate one. When necessary, data were square root transformed to respect the conditions for normality and the homogeneity of variance.

RESULTS AND DISCUSSION

Comparison of soil parameters and abundance, biomass, and adult/juvenile ratio of earthworms

Based on the statistical analysis, there is a correlation between soil parameters only in case of few parameters and the abundance of earthworms. There was a significant difference observed in the pH of the various sampling sites positive correlation was found between the pH and sum of earthworms ($p=0.011$). This finding was in line with McCallum *et al.* findings (2016).

There was also significant difference observed between sampling sites in case of all phosphorous (P) content ($p=0.099$), however, there is only a slight positive correlation between P content and sum of earthworms.

The third, observed parameter, that showed significant differences between the sampling sites, was the soil moisture content ($p=0.009$). The biggest positive correlation was observed in case of this parameter. In case of our sampling sites, the higher the soil moisture, the more earthworms were found.

Between earthworm biomass and soil parameters, and between adult/juvenile ratio and soil parameters, no significant correlation was observed. The main conclusion is that samples with higher soil moisture, contained more earthworms. Our assumption, that the bottom of a hill contains more earthworms could not be confirmed. Significantly more earthworms at Sirok Castle (Bottom) shows importance of soil type. The soil there contained higher ratio of clay, pH and CEC showed the highest values between the sampling sites.

Comparison of sampling sites regarding soil moisture

Univariate data analysis for soil moisture shows, that there is an effect of the sampling ID within each sampling site ($p=0.000208$) but also there is an effect whether the sample was taken in Sirok or Szada locations ($p=0.05756$). There is a significant difference between Sirok Castle (Bottom) and Sirok, Bottom of Hill at Lake Nyírjes ($p=0.0151$). Furthermore, Sirok Castle (Bottom) is significantly different from the other sampling locations as well, except for Sirok Clear Cut ($p=0.1438$). It significantly differs from the Sirok, Hilltop at Lake Nyírjes ($p=0.0124$), Szada, Hilltop, 1st sampling ($p=0.0009$) and 2nd sampling ($p=0.0056$) and Szada, Hill side ($p=0.0003$).

As it can be seen in Figure 2, samples from Sirok had slightly higher soil moisture content. However, sampling in case of Szada, Hilltop (1st) happened on 25 April 2022, while 2nd on 29th of May. Whereas sampling sites from Sirok were visited on the 30th of April 2022 and 1st of May 2022. The difference between the soil moisture content can partially be explained by different weather conditions, such as rainfall, prior to sampling.

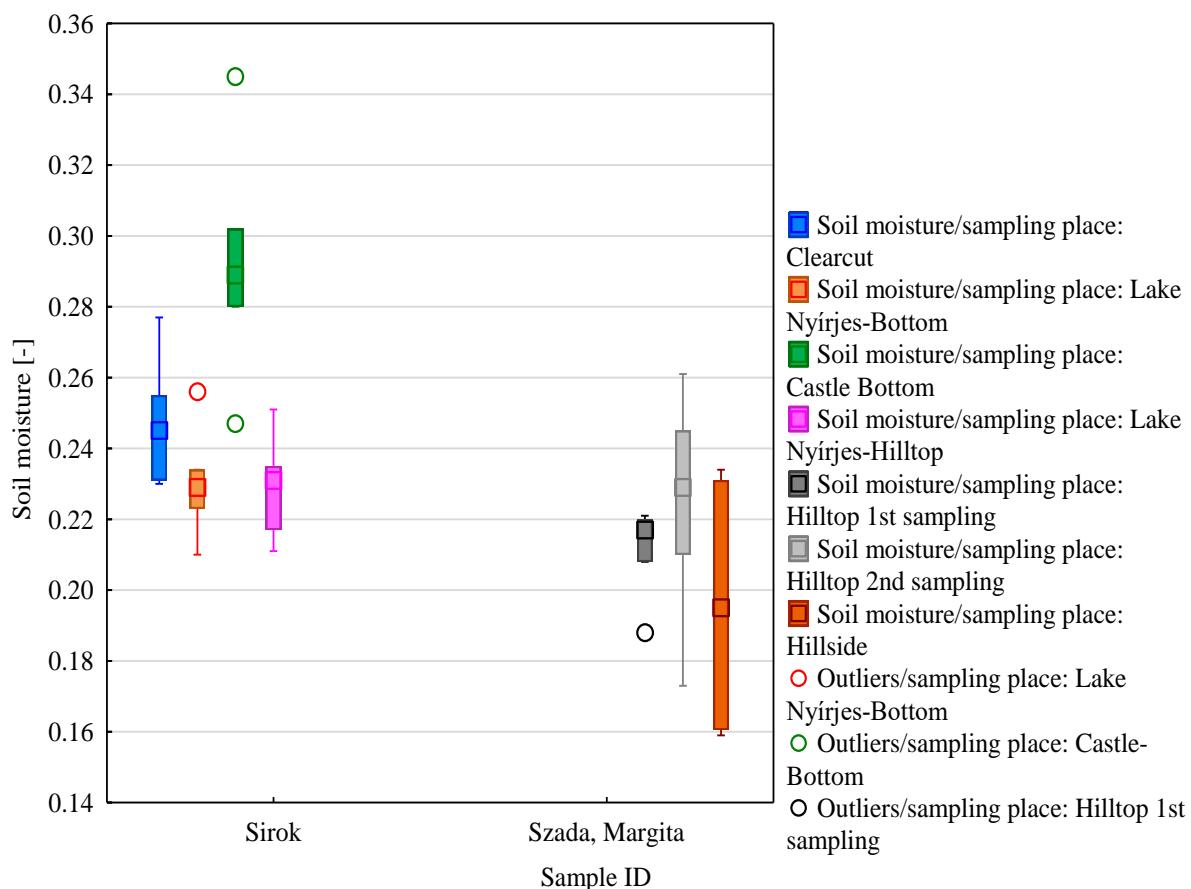


Fig. 2. Soil moisture content of soil samples by sampling place, Statistica software.

Comparison of sampling sites

Based on Dunn's test results, there is significant difference between the number of earthworms at Szada, Hillside Deep and Sirok Castle (Bottom) ($p=0.038$) and between Sirok Clear cut and Sirok Castle (Bottom) ($p=0.022$). In case of the other sampling sites, no significant differences have been observed. It means that there was no significant difference either between the two sites at Szada, the Hilltop and Hillside or between the Lake Nyírjes sampling sites, Hilltop and Bottom of the hill.

Sum of earthworms is significantly different between the sampling site ($p=0,001$), so the null hypothesis was rejected. In case of the sum of weight of the earthworms, again there is significant difference between the sampling sites ($p=0,006$). Dunn's test performed for sum of weight, but exact locations that differ could not be output using this method. Figure 3 shows summarized earthworms found at each site, and it can be seen, that Sirok Castle Bottom has the highest number (57) of individuals found.

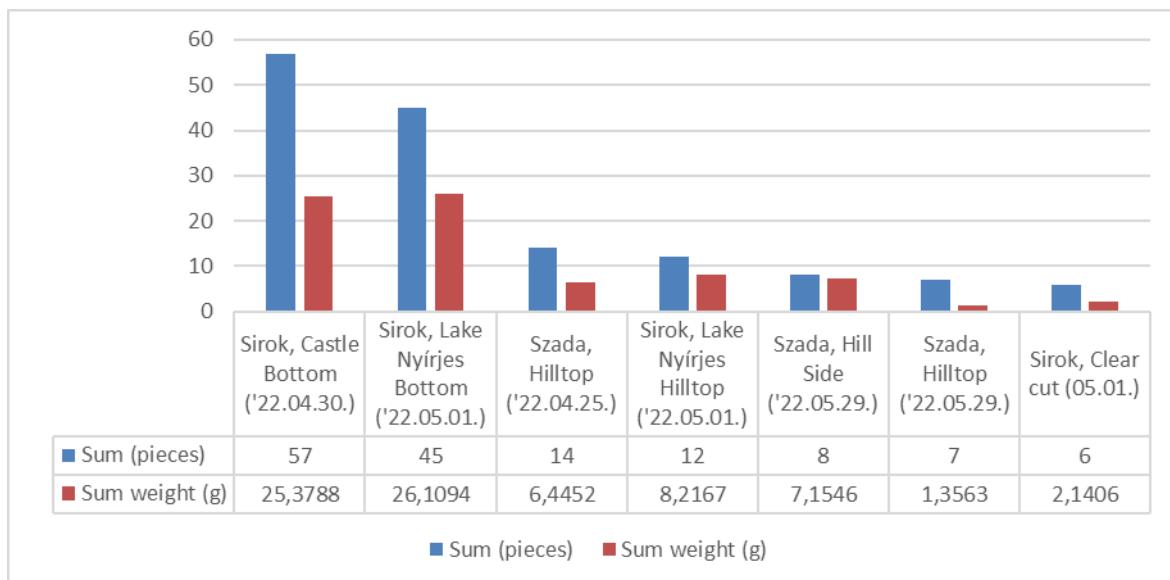


Fig. 3. Sum of earthworms and their weights at the sampling sites.

CONCLUSIONS

Our hypothesis that soils which contain more soil moisture are favorable for earthworms has been confirmed by statistical analysis. However, the second hypothesis, regarding the hillside effect on number of earthworms has failed. Other than soil moisture content and pH and all phosphorous, we could not statistically confirm any other soil parameters that influences earthworm abundance and biomass.

To confirm influencing parameters, the same sampling locations will be visited in different weather conditions and seasons, also to increase statistical confidence.

REFERENCES

- Adhikari, K., Hartemink, A. E. (2016): Linking soils to ecosystem services – A global review. *Geoderma* 262, 101–111.
- Al-Maliki, S., Al-Taey, D.K.A., Al-Mammori, H.Z. (2021): Earthworms and eco-consequences: Considerations to soil biological indicators and plant function: A review. *Acta Ecologica Sinica* 41, 512–523.
- Bakonyi, G., Juhász, L., Kiss, I., Palotás, G. (2003): Zoology. Mezőgazda Kiadó, Budapest, (314 pp.) 718 p.
- Bakti, B., Simon, B., Gyuricza, Cs. (2017): Earthworm (Lumbricidae) number and biomass study in a woody energy plantation. Alföldi Forests Association, Research Day. 116–125. Access: Kutatói Nap 2017. (oszk.hu) (2022.10.08.)
- Barczi, A., Centeri, Cs., Michéli, E., Penksza, K., Schubert, F., Stefanovits, P., Szabóné Kele, G., M. Tóth, T. (2008): A talajtan és természetföldrajzi alapjai. Szent István University, Gödöllő, 114 p.
- Barczi, A., Tóth, Cs., Tóth, A., Pető, Á. (2009): A Bán-halom komplex tájökológiai és paleotalajtani felmérése. Tájökológiai Lapok 7, 1, 191–208.
- Birkás, M., Jolánkai, M., Gyuricza, C., Percze, A. (2004): Tillage effects on compaction, earthworms, and other soil quality indicators in Hungary. *Soil & Tillage Research* 78, 185–196.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Bolf, G. B., Szabó, J., Szabó, B., Czakó, B., Németh, A. (2014): Protection measures against gully erosion in the Gödöllő Hillside Landscape Protection District. In: A., Čelková (ed.) 21st International Poster Day and Institute of Hydrology Open day: Transport of Water, Chemicals and Energy in the Soil-Plant-Atmosphere System: Proceedings of peer-reviewed contributors Bratislava, Slovakia: Institute of Hydrology SAS, pp. 24–37.
- Butt, K. R., Gilbert, J. A., Kostecka, J., Lowe, C. N., Quigg, S. M., Euteneuer, P. (2022): Two decades of monitoring earthworms in translocated grasslands at Manchester Airport. European Journal of Soil Biology 113, 103443
- Canedoli, C., Ferrè, C., Abu El Khair, D., Comolli, R., Liga, C., Mazzucchelli, F., Proietto, A., Rota, N., Colombo, G., Bassano, B., Ramona Viterbib, Padoa-Schioppa, E. (2020): Evaluation of ecosystem services in a protected mountain area: Soil organic carbon stock and biodiversity in alpine forests and grasslands. Ecosystem Services 44, 101135
- Centeri, Cs., Akác, A., Jakab, G. (2012): Land use change and soil degradation in a nature protected area of East-Central Europe. In: Aubrecht, C., Freire, S., Steinnocher, K. (eds) Land Use: Planning, Regulations, and Environment. New York (NY), United States of America: Nova Science Publishers pp. 211–241.
- Darwin, C. (1881): The formation of vegetable mould through the action of worms, with observation on their habits. Murray, p. 326, London
- Dekemati, I., Simon, B., Vinogradov, Sz., Birkás, M. (2019): The effects of various tillage treatments on soil physical properties, earthworm abundance and crop yield in Hungary. Soil & Tillage Research 194, 104334
- Griffiths, B.S., Römbke, J., Schmelz, R.M., Scheffczyk, A., Faber, J.H., Bloem, J., Pérés, G., Cluzeau, D., Chabbi, A., Suhadolc, M., Sousa, J.P., Martins da Silva, P., Carvalho, F., Mendes, S., Morais, P., Francisco, R., Pereira, C., Bonkowski, M., Geisen, S., Bardgett, R.D., de Vries, F.T., Bolger, T., Dirilgen, T., Schmidt, O., Winding, A., Hendriksen, N.B., Johansen, A., Philippot, L., Plassart, P., Bru, D., Thomson, B., Griffiths, R.I., Bailey, M.J., Keith, A., Rutgers, M., Mulder, C., Hannula, S.E., Creamer, R., Stone, D. (2016): Selecting cost effective and policy-relevant biological indicators for European monitoring of soil biodiversity and ecosystem function. Ecological Indicators 69, 213–223.
- Hoeffner, K., Santonja, M., Monard, C., Barbe, L., Le Moing, M. & Cluzeau, D. (2021): Soil properties, grassland management, and landscape diversity drive the assembly of earthworm communities in temperate grasslands. Pedosphere, 31(3), 375383.
- ISO - International Standard ISO23611-1 (2006): Soil Quality – Sampling of Soil Invertebrates – Part 1: Hand-sorting and Formalin Extraction of Earthworms. Reference number: ISO 23611-1:2006 (E). First edition
- Kalu, S., Koirala, M., Khadaka, U. R. (2015): Earthworm population in relation to different land use and soil characteristics. Journal of Ecology and the Natural Environment 7, 5, 124–131.
- Königer, J., Panagos, P., Jones, A., Briones, M.J.I., Orgiazzi, A. (2022): In defence of soil biodiversity: Towards an inclusive protection in the European Union. Biological Conservation 268 109475
- Magyari-Meskó, R., Kolár, A., Centeri, Cs., Biró, Zs (2019): Comparison of earthworm numbers and some soil parameters of conventional and organic farms in Hungary. In: A., Celková (szerk.) 26th International Poster Day and Institute of Hydrology Open Day: Transport of water, chemicals and energy in the soil-plant atmosphere system. Bratislava, Slovakia: Slovak Academy of Sciences, Institute of Hydrology, pp. 119–127.
- Mathieu, J., Caro, G., Dupont, L. (2018): Methods for studying earthworm dispersal. Applied Soil Ecology 123, 339–344.
- McCallum, H. M., Wilson, D. J., Beaumont, D., Sheldon, R., O'Brien, M. G., Park, K. J. (2016): A role for liming as a conservation intervention? Earthworm abundance is associated with higher soil pH and foraging activity of a threatened shorebird in upland grasslands. Agriculture, Ecosystems and Environment 223, 182–189.
- Mizik T. (ed.) (2018): Agricultural economics II. Akadémiai Kiadó. <https://doi.org/10.1556/9789634541875>. (Accessed: 2022. 08. 28. https://mersz.hu/hivatkozas/dj335agt_5_p10#dj335agt_5_p10)
- Nearing, M.A., Pruski, F.F., O'Neal M.R. (2004): Expected climate change impacts on soil erosion rates: a review. J. Soil Water Conserv. 59, 1, 43–50.
- Pacs, I., Puskás, F., Zicsi A. (1990): Earthworm, earthworm humus. Mezőgazdasági Kiadó Kft., Budapest, 94 p.
- Panchal, P., Preece, C., Penuelas, J., Giri, J. (2022): Soil carbon sequestration by root exudates. Trends in Plant Science, 27, 8, 749–757.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Pulleman, M., Creamer, R., Hamer, U., Helder, J., Pelosi, C., Pérés, G., Rutgers, M. (2012): Soil biodiversity, biological indicators and soil ecosystem services – an overview of European approaches. *Current Opinion in Environmental Sustainability* 4, 5, 529–538.
- Richardson, D.R., Snyder, B.A., Hendrix, P.F. (2009): Soil moisture and temperature: tolerances and optima for a non-native earthworm species, *Amynthas agrestis* (Oligochaeta: Opisthopora: Megascolecidae), *Southeast. Nat.* 8, 2, 325–334.
- Sakraoui R., Boukheroufa, M., Dadci, W., Abdallah, K., Senaoui, C., Sakraoui, F., Benyacoub, S. (2022): Environmental and Habitat Preferences of the Algerian Hedgehog *Atelerix Algirus* (Lereboullet, 1842) in El Kala National Park (North-East Algeria). *Journal of Bioresource Management* 9, 1, 165–174.
- Saláta, D. Krausz, E., Reményi, L., Kenéz, Á., Pető, Á. (2014): Combining historical land-use and geoarchaeological evidence to support archaeological site detection. *Agrokémia és Talajtan* 63, 1, 99–108.
- Salomé, C., Guenat, C., Bullinger-Weber, G., Gobat, J.-M. & Le Bayon, R.-C. (2011): Earthworm communities in alluvial forests: Influence of altitude, vegetation stages and soil parameters. *Pedobiologia* 54S, S89–S98.
- Schon, N. L., Mackay, A. D., Gray, R.A., van Koten, C., Dodd, M.B. (2017): Influence of earthworm abundance and diversity on soil structure and the implications for soil services throughout the season. *Pedobiologia* 62, 41–47.
- Schon, N.L., Dominati, E.J. (2020): Valuing earthworm contribution to ecosystem services delivery. *Ecosystem Services* 43, 101092
- Simon, L. (ed.) (2008): Soil-water interactions in the light of climate change. *Soil protection special issue* 17–30.
- Singh, S., Singh, J., Vig, A. P. (2016): Effect of abiotic factors on the distribution of earthworms in different land use patterns. *The Journal of Basic & Applied Zoology* 74, 41–50.
- Singh, J. (1997): Habitat preferences of selected Indian earthworm species and their efficiency in reduction of organic materials, *Soil Biol. Biochem.* 29, 3–4, 585–588.
- Stefanovits, P., Filep, Gy., Füleky, Gy. (1999): *Soil science*. Mezőgazda Kiadó, Budapest, 470 p.
- Szabó, I. M. (2008): *Biological foundations of general soil science*. Mundus Egyetemi Kiadó, 405 p.
- Szilágyi, A., Horváth, E., Nagy, P., Simon, B., Centeri, Cs (2019): Earthworm and nematode populations in conventional, organic and permaculture farms on Szentendre Island, Hungary: An explorative case study. In: A., Celková (szerk.) 26th International Poster Day and Institute of Hydrology Open Day: Transport of water, chemicals and energy in the soil-plant atmosphere system. Bratislava, Szlovákia : Slovak Academy of Sciences, Institute of Hydrology, pp. 213–221.
- Timmerman, A., Bos, D., Ouwehand, J., de Goede, R.G.M. (2006): Long-term effects of fertilisation regime on earthworm abundance in a semi-natural grassland area. *Pedobiologia* 50, 427–432.
- http:// Soil biodiversity: functions, threats and tools for policy makers. Technical report - 2010-049 biodiversity_report.pdf (europa.eu) (Access: 2022.10.13.)

FYTOINDIKÁCIA VLHKOSTI PÔDY

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ABSTRAKT

Množstvo vody v pôde určuje vlhkosť pôdy. Vlhkosť pôdy nie je konštantná. Na vlhkosť pôdy vplyvá pôdna textúra, zrážky, podzemná voda, hydraulická vodivosť pôdy, retencia vody pôdou, infiltrácia vody do pôdy a intercepčné zachytená voda. Zmeny vlhkosti pôdy spôsobujú rozdielne podmienky pre vegetáciu, ktorá sa musí prispôsobiť rozdielnemu množstvu vody v pôde počas vegetačného obdobia. Na výskum fytoindikácie vlhkosti pôdy sme vybrali rastlinu *Impatiens parviflora* a parameter, ktorý sme stanovovali bol obsah sušiny. Vybrali sme dve rozdielne výskumné miesta s rozdielnou vlhkosťou pôdy. Zistili sme odlišnosti v obsahu sušiny v závislosti od vlhkosti pôdy. Stanovili sme vyšší obsah sušiny 0.13 g.g^{-1} na výskumnom mieste kde sme namerali nižšie hodnoty vlhkosti pôdy a nižší obsah sušiny 0.11 g.g^{-1} sme stanovili na výskumnom mieste kde boli namenané vyššie hodnoty vlhkosti pôdy.

Keywords: phytoindication, dry matter weight in leaves, soil moisture, *Impatiens parviflora*

ÚVOD

Pôda obsahuje minerálnu zložku, organickú zložku, vzduch a vodu. Množstvo vody v pôde určuje vlhkosť pôdy. Vlhkosť pôdy nie je konštantná. Závisí od textúry pôdy, zrážok, podzemnej vody, hydraulickej vodivosti pôdy, retencie vody v pôde, infiltrácie vody do pôdy, intercepcie zrážok. Zmeny vlhkosti pôdy spôsobujú rozdielne podmienky pre rastliny, ktoré sa musia prispôsobiť na rôzne množstvo vody v pôde v rámci ich životných podmienok počas vegetačného obdobia.

Voda po prijatí koreňom sa pohybuje pozdĺž bunkových stien a cez medzi bunkové priestory z koreňových pletív cez xylémové cievy až do listov. Hnacou silou pohybu vody v rastline je gradient hydrostatického tlaku. Je to čisto fyzikálny proces, kde vyparovanie z bunkových stien listov znižuje vodný potenciál bunkových stien, čo zapríčinuje znižovanie vodného potenciálu na vrchole xylémových stôlcov a tým vzniká sanie (Meidner 1975).

Komplexné štúdium vztahov medzi rastlinami, rastlinnými spoločenstvami a abiotickými faktormi prostredia je obzvlášť významné z hľadiska porozumenia dôsledkov meniacich sa podmienok prostredia. Reakcia rastlín na aktuálne zmeny prostredia je flexibilná, pretože rastliny môžu meniť počet a veľkosť rastlinných orgánov, môžu odlišne alokovať a re-alkovať zásobné látky do rôznych pletív (Masarovičová a kol., 2015).

Jedným z faktorov, ktoré sa podľa predikcií budú v blízkej budúcnosti najviac meniť, sú pôdne vlastnosti, napr. obsah a dostupnosť vody pre rastliny v dôsledku klimatických zmien (Masarovičová a kol. 2002). Ukázalo sa, že v súčasnosti sú problémom nie len dlhodobé klimatické zmeny, ale ešte výraznejšie krátkodobé výkyvy počasia (Sobocká a kol. 2005). Krátkodobé výkyvy počasia sú špecifické pre každý skúmaný región a generujú zámer zistiť do akej miery sú vztahy medzi vegetáciou a abiotickými faktormi prostredia podmienenými špecifickými vlastnosťami daného územia a do akej všeobecnými trendmi zmien prostredia. Dalším z dôvodov pre štúdium vztahov v systéme pôda-rastlina-atmosféra je potreba zachovať vodu v pôde a v krajinе, aby sa zabránilo degradácii vegetačného krytu, zhoršeniu

pôdnych vlastností ako aj erózii. Vo všeobecnosti je, teda hydrologický cyklus ovplyvňovaný zmenami prírodných podmienok, vrátane vegetácie (Lapin, 2004).

Cieľom článku bolo vedeckým výskumom určiť na vybranej rastline *Impatiens parviflora* fytoindikovať vlhkosť pôdy cez vybraný parameter obsah sušiny.

METÓDY A ÚDAJE

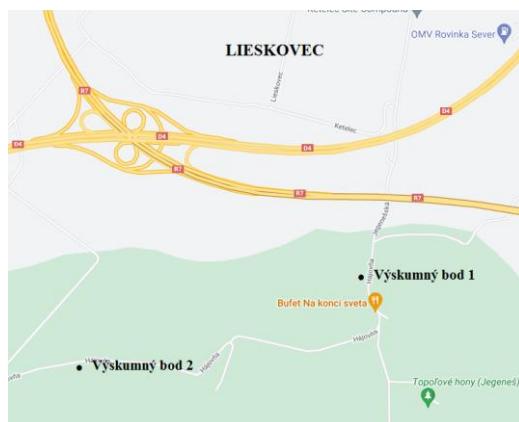
Kľúčovým pre výskum vplyvu vlhkosti pôdy na vegetáciu bolo určenie metód a výber skúmaného územia. Na meranie vlhkosti pôdy sme používali prístroj TRIME-FM, ktorý je určený pre mobilné použitie v teréne. Na vybraných výskumných bodoch v rámci skúmaného územia sme umiestnili do pôdy tekanové rúry určené na meranie vlhkosti pôdy so snímačom Tube probe T3. Snímač je prispôsobený pre meranie vlhkosti pôdy v tekanovej rúre. Vlhkosť pôdy sme merali po 10 cm krokoch do hĺbky pôdy 30 cm. Merania vlhkosti prebiehali v približne v rovnakých časových intervaloch od 30.5.2022 do 5.9.2022. Namerané údaje vlhkosti pôdy sme spracovali do grafického zobrazenia.

Na výskum fytoindikácie vlhkosti pôdy sme vybrali rastlinu *Impatiens parviflora* (netýkavka malokvetá) a na základe jej miest rastu sme vybrali výskumné body na meranie vlhkosti pôdy.



Obr. 1. *Impatiens parviflora* (netýkavka malokvetá).

V deň odberu 20.7.2022 sme odobrali 12 kusov listov *Impatiens parviflora* z každého výskumného bodu. Listy sme odobrali do namočených papierových servítok z dôvodu nasycovnia listov na 24 hodín po odbere. Po 24 hodinách sme listy odvážili na analytických váhach a zistili sme nasýtenú hmotnosť listov. Po odvážení sme listy vložili samostatne do sušičky a sušili pri teplote 80 °C minimálne 48 hodín. Takto sme zistili suchú hmotnosť listov. Na výpočet obsahu sušiny v listoch *Impatiens parviflora* sme použili nasledujúci výpočet: obsah sušiny v listoch = suchá hmotnosť listov / nasýtená hmotnosť listov ($\text{kg} \cdot \text{kg}^{-1}$). Výskumná lokalita Lieskovec bola v Bratislave – Podunajské Biskupice. Na výskumnej lokalite sme určili podľa porastu skúmanej rastliny *Impatiens parviflora* výskumné body 1 a 2 (Obrázok 2).



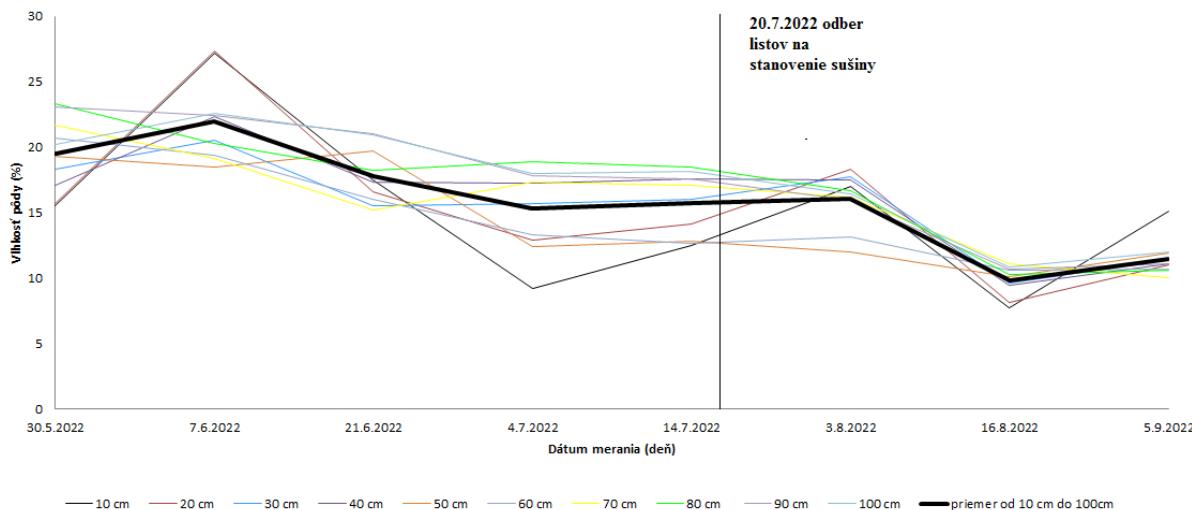
Obr. 2. Mapa výskumnej lokality Lieskovec s vyznačenými výskumnými bodmi 1 a 2.

VÝSLEDKY A DISKUSIA

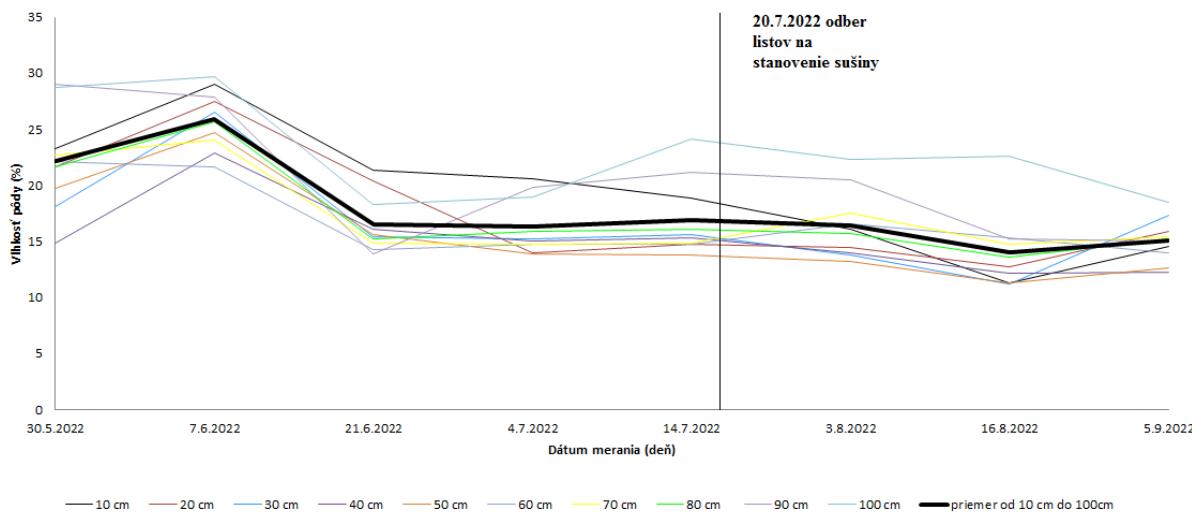
Z časového obdobia od 30.5.2022 do 5.9.2022 sme namerali údaje o vlhkosti pôdy na výskumných bodoch. Výsledky priemerných nameraných hodnôt vlhkosti pôdy sú v tabuľke 1. Obrázok 3. a 4. obsahuje grafický vývoj vlhkosti pôdy na výskumných bodoch za uvedené časové obdobie. Z porovnania priemerných hodnôt nameraných pre hĺbky pôdy od 10 cm do 100 cm po 10 cm sme zistili nižšie hodnoty vlhkosti pôdy na výskumnom bode 1, ako na výskumnom bode 2, čo potvrdzujú aj priemerné údaje za celé obdobie merania a za celú hĺbku od 10 cm do 100 cm merania vlhkosti pôdy (Tabuľka 1). Výskumný bod 1 a 2 je od seba vzdielený niekoľko metrov a namerali sme rozdielne vlhkosti pôdy. Dôvodom prečo bola nameraná vyššia vlhkosť pôdy na výskumnom bode 2 je vplyv podzemnej vody a jej premiestňovanie vplyvom kapilárnych sôl, ktoré pôsobia na vodu v pôde. Výskumný bod 2 sa nachádzal v kanáli (6 metrov nižšie pod úrovňou terénu ako výskumný bod 1) na zaplavovanie lokality Lieskovec. Z uvedeného vyplýva, že na výskumnom bode 2 je výraznejší vplyv podzemnej vody. Dôkazom sú namerané hodnoty vlhkosti pôdy, ktoré smerom do hĺbky pôdy narastajú.

Tabuľka 1. Priemerná vlhkosť pôdy v hĺbkach od 10cm do 100cm po 10 cm krokoch a priemerná vlhkosť v hĺbke pôdy od 10 cm do 100 cm za vegetačné obdobie *Impatiens parviflora* od 30.5.2022 do 5.9.2022

Hĺbka pôdy (cm)	Priemerná vlhkosť pôdy (%)	
	Výskumný bod 1	Výskumný bod 2
10 cm	15,31	18,46
20 cm	15,6	17,92
30 cm	15,59	18,12
40 cm	16,19	18,07
50 cm	14,59	19,42
60 cm	14,45	21,38
70 cm	15,96	23,18
80 cm	17,1	24,33
90 cm	17,55	28,16
100 cm	17,38	31,47
Priemer od 0 cm do 100 cm	15,97	22,05



Obr. 3. Graf nameraných a vypočítaných priemerných hodnôt vlhkosti pôdy s vyznačeným dátumom odberu listov na stanovenie sušiny za vegetačné obdobie *Impatiens parviflora* od 30.5.2022 do 5.9.2022, výskumný bod 1.



Obr. 4. Graf nameraných a vypočítaných priemerných hodnôt vlhkosti pôdy s vyznačeným dátumom odberu listov na stanovenie sušiny za vegetačné obdobie *Impatiens parviflora* od 30.5.2022 do 5.9.2022, výskumný bod 2.

Po výskumných prácach na určenie hmotnosti sušiny opísaných v metódach a údaje (skúmané územie) sme získali hmotnosti suchých a nasýtených listov. Po výpočte: obsah sušiny v listoch = suchá hmotnosť listov / nasýtená hmotnosť listov (g.g^{-1}), kde sme dosadili namerané hmotnosti sme zistili priemerný obsah sušiny v listoch na výskumnom bode 1 a 2, (Tabuľka 2). Porovnaním priemerných hodnôt hmotnosti sušiny v listoch sme zistili významný rozdiel. Na výskumnom bode 1, kde je priemerná vlhkosť pôdy nižšia sme stanovili vyššiu hmotnosť sušiny. Vyššia hmotnosť sušiny je spôsobená prerozdelením látok v tele rastliny a vytváraním rastlinných pletív vplyvom nižzej vlhkosti počas vegetačného obdobia na svojom mieste rastu. Vysvetlenie väčšej hmotnosti sušiny rastliny na suchšom mieste rastu možno hľadať u tzv. sukulentov, ktoré sa adaptovali na suché podmienky v mieste rastu vytvorením kožovitých listov. Stanovená vyššia hmotnosť sušiny určuje nižšie množstvo vody v listoch, ktoré sa odparilo počas sušenia v sušiarni a naopak nižšie množstvo sušiny určuje vyššiu hodnotu vody, ktoré sa v listoch nachádza v prírodnom prostredí.

Tabuľka 2. Nameraná priemerná hmotnosť sušiny v listoch *Impatiens parviflora* s dátumom odberu 20.7.2022

Priemerná hmotnosť sušiny v listoch (g.g ⁻¹)	
Výskumný bod 1	Výskumný bod 2
0,13	0,11

Objasnenie vzťahu medzi rastlinnými spoločenstvami a najvýznamnejšími ekologickými faktormi prostredia (zamerané najmä na meniacu sa pôdnú vlhkosť a dostupnosť vlahy v pôde) prehľbi naše poznanie o spätných väzbách medzi pôdou a vegetáciou a tak nás priblíži k pochopeniu a predikcie dôsledkov environmentálnych zmien. Ďalším pokračovaním vo výskume by bolo možné objasnenie študovaných procesov prebiehajúcich v systéme pôda-rastlina-atmosféra vo vzťahu k meniacim sa podmienkam prostredia z dlhodobého hľadiska.

ZÁVER

Na fytoindikáciu vlhkosti pôdy rastlinami sme vybrali *Impatins parviflora* a parameter, ktorý sme určovali bola hmotnosť sušiny. Vybrali sme dve rozdielne výskumné miesta s rozdielnou vlhkosťou pôdy. Zistili sme rozdiel v hmotnosti sušiny v závislosti od vlhkosti pôdy. Vyššiu hmotnosť sušiny 0,13 g.g⁻¹ sme stanovili na výskumnom mieste s nameranou nižšou vlhkosťou pôdy a nižšiu hmotnosť sušiny 0,11 g.g⁻¹ sme stanovili na výskumnom mieste s nameranou vyššou vlhkosťou pôdy.

Poděkovanie

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LITERATÚRA

- Lapin, M. (2004): Klimatické zmeny a ich možné dôsledky na hydrologický cyklus – scenáre klimatických zmien do roku 2100. www.dmc.fmpH.uniba.sk
- Meidner, H. (1975): Water supply, evaporation and vapour diffusion in leaves. Journal of Experimental Botany 26: 666-673.
- Masarovičová, E. – Repčák, M. a kol. (2002): Fyziológia rastlín, 1. vydanie, Bratislava: Univerzita Komenského, 304 s. ISBN: 80-223-1615-6.
- Masarovičová, E., Májeková, M., Vykouková, I. (2015): Funkčné znaky a plasticita rastlín, Univerzita Komenského v Bratislave, 84 s., prvé vydanie, ISBN: 978-80-223-4033-5
- Sobocká, J., Šurina, B., Torma, S., Dodok, R., (2005): Klimatická zmena a jej možné dopady na pôdny fond Slovenska, VÚPOP, Bratislava, 46 s.

INVESTIGATING THE GROWTH OF EUROPEAN BEECH (*FAGUS SYLVATICA*) BASED ON TREE-RING MEASUREMENTS AND SOIL PARAMETERS - A CASE STUDY FROM THE BAKONY MOUNTAINS

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ABSTRACT

The growth of forests is affected by various environmental factors. Among many others, soil cover plays an important role. The growth of a European beech (*Fagus sylvatica*) stand situated on a steep slope was examined through describing the soil properties and by analysing tree-ring data taken from specimen of different locations. Soil profiles were opened to describe environmental properties of the forest stand, while 5-5 tree-ring samples (with increment borer) were collected from trees of the lower, the middle and that of the upper section of the slope. Besides of on-site soil description methods (macro-morphology), basic soil physical and chemical parameters were measured to describe the habitat of the forest. The growth potential of the individual trees was examined by digital tree-ring measurements using QGIS software and statistical approach (heatmap method). Major differences were found in the average height and trunk perimeter of trees growing at different elevations. Data points to the relation between slope exposure and soil conditions.

Keywords: tree-ring analysis, dendroecology, soils, *Fagus sylvatica*, Carpathian Basin

INTRODUCTION

The European beech (*Fagus sylvatica*) is one of the most important forest-forming tree species of Europe, moreover the main species in Central Europe's deciduous forests (Bolte et al., 2007), and an important species in the Bakony Mountains, where the topography and the water movements related to the topographic conditions have a great influence on growing potential of the forest stands.

In our research, we primarily were focusing on the effect of this factor through the examination of the tree-rings of an European beech stand located on a hillside with homogeneous exposure, but located on different slopes conditions.

MATERIALS AND METHODS

The study area is located in the Bakony Mountains near Bakonybél and Iharkút. The steepness of the area is significant, as the forest part extends from the peak of the 531 meters high Pápavár mountain (Figure 1.). Beech (*Fagus sylvatica*) dominates the forest with 82%, while the remaining species include hornbeam (*Carpinus betulus*) and small-leaved linden (*Tilia cordata*). The forest area is part of the Natura 2000 network, but does not enjoy any further other protection

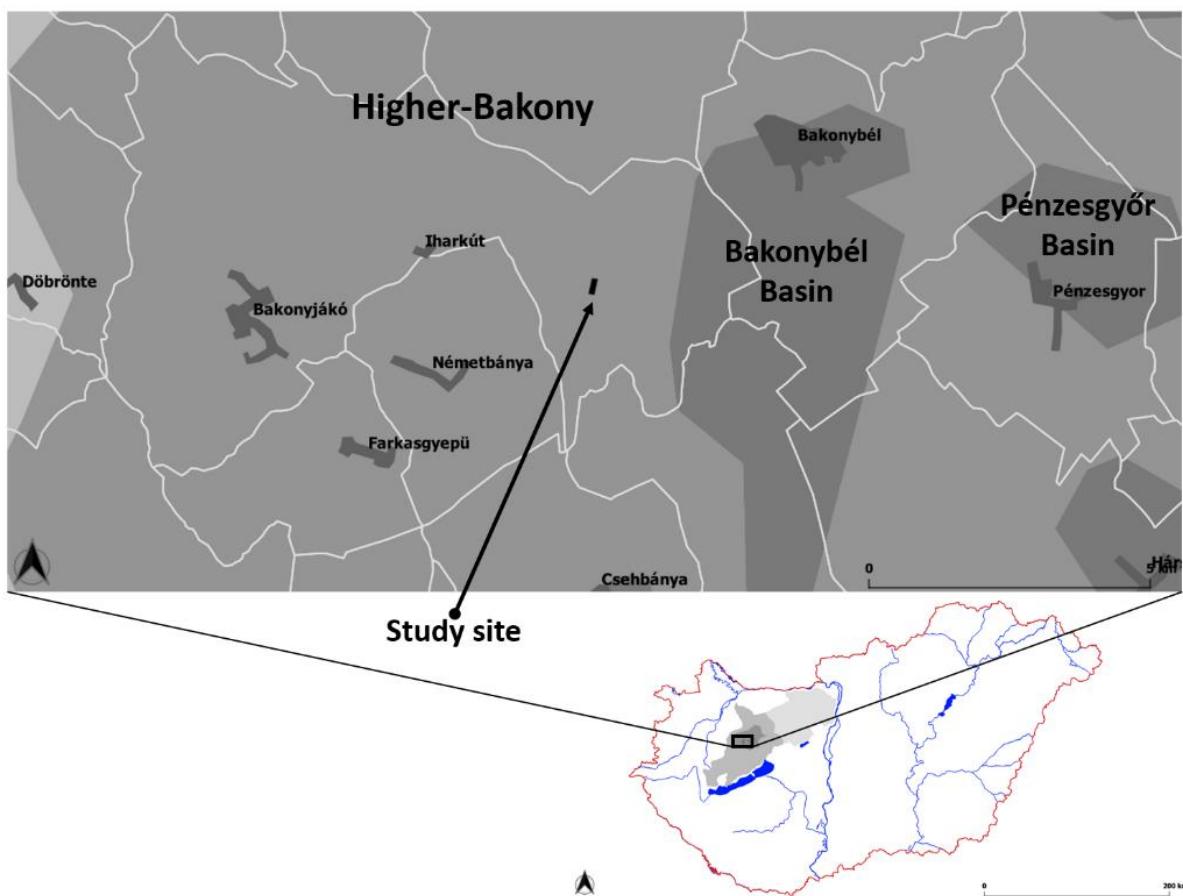


Fig. 1. Location of the study site within Hungary (compiled with QGIS 3.4.2. software based on Marosi-Somogyi (1990) and the OTAB database).

The investigated slope was divided into lower, middle and upper sections, taking into account the slope and micro-topography, based on the map sources and during the preliminary field work (Figure 2.). Five tree specimens were chosen at each location. Tree specimens were sampled using a 600 mm Pressler-type increment borer (Grissino-Mayer, 2003). The following basic dendroecological parameters were also measured: trunk perimeter at chest height, trunk diameter, height and health condition. The tree ring widths were measured digitally with analytical accuracy of thousands of mm using QGIS software (<http://>), and subsequently data manipulation was done using TRiCYCLE (Brewer et al., 2011), Tellervo (Brewer, 2014) and PAST software (Hammer, 1995-2005, Hammer et al., 2001).

In order to describe the soil conditions of each locality soil profiles were opened and sampled according to the Hungarian soil survey standards (MSZ 1398:1998; TIM 2005). On-site soil description followed the guidelines of the Soil Information and Monitoring System of Hungary (TIM 2005). Samples were collected from each genetic horizon in order to retrieve soil physical and chemical parameters. The following soil parameters were used to describe the soil properties of the three localities:

- pH (H₂O) (Hungarian standard: MSZ-08-0206-2: 1978)
- Texture (Arany-type coefficient - K_A) (Hungarian standard: MSZ-08-0205: 1978)
- salt content (m/m%) (Hungarian standard: MSZ-08-0206-2: 1978)
- carbonate content (CaCO₃ m/m%) (Hungarian standard: MSZ-08-0206-2: 1978)
- humus content (m/m%) (Hungarian standard: MSZ-08-0452:1980)

RESULTS AND DISCUSSION

Results of the soil examinations

As shown by the figure below (Figure 2.), the study area is relatively steep, which definitely affects the development of soil conditions. Soil profiles opened on the upper, middle and lower section of the slope showed different genetic horizons, with different relative depths.

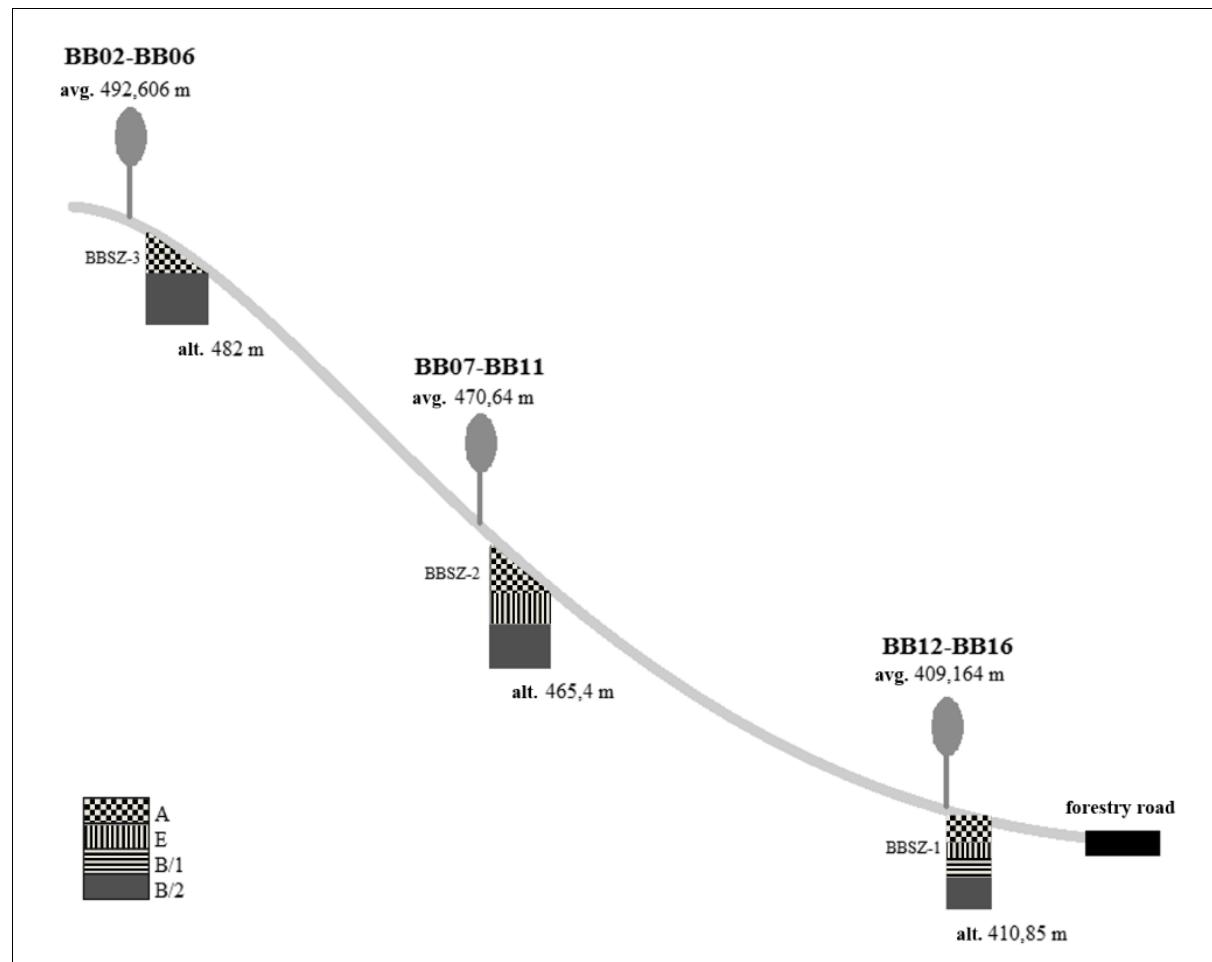


Fig. 2. The schematic pedological profiles of the examined slope at Pápavár, Bakony Mountains and the codes of the examined tree specimen (BB02-BB06, BB07-BB11, BB12-BB16).

All three soil profiles were classified as Luvisols (brown forest soils with clay enriched B horizons), but at the same time, differences were observed in the macro-morphological characteristics of the profiles due to their geomorphological position.

The morphological (Table 1.) and laboratory data (Table 2.) of the BBSZ-1 profile are consistent with the pedological characteristics of the geographical region, namely that the Luvisols within this microregion are silt – clayey silt textured and, despite the remnants of the carbonate-rich bedrock, the profiles are affected by leached and lime cannot be detected in the upper horizons. Compared to this, the BBSZ-2 profile, located in the middle of the slope, did neither show significant differences in its morphological features (Table 2.) nor in the soil physical and soil chemical parameters of the individual genetic soil horizons (Table 3.). The location of the BBSZ-3 profile was marked in the upper third of the examined slope, but not yet in a plateau position. The profile is in a partially eroded state, so the characteristics of the Luvisols could not be observed, but in its morphological features, the developmental affinity with the other two sections of the slope can be clearly seen.

Table 1. Basic macro-morphological description of the soil profiles opened at Pápavár, Bakony Mountains, Hungary (used after Saláta et al., 2022)

Profile code	Genetic soil horizon	Relative depth [cm]	Texture	Color	CaCO ₃	Remarks
BBSZ-3	A	0–15	clayey silt	10YR 3/3	0	- slope upper section - weathered rock fragments within the profile
	B	15–60	clay	10YR 6/3	0/+	
	BC	60–70	clay	mixed	-	
BBSZ-2	AO	0–2	silt	10YR 3/3	0	- slope middle section; - rock fragments in the BC horizon
	A	2–23		10YR 4/3	0	
	E	23–28	silt	10YR 6/2	0	
	B	28–70	silt	10YR 6/3	0	
	BC	70–75	clayey silt	10YR 5/8	-	
BBSZ-1	Ao	0–5	silt	10YR 3/3	0	- slope lower section; - iron flecks; - rock fragments in the BC horizon
	A	5–20		10YR 4/3	0	
	E	20–30	silt	10YR 6/2	0	
	B1	30–55	clayey silt	10YR 4/6	0	
	B2	55–80	clayey silt	10YR 6/3	0	
	BC	80–90	clayey silt	mixed / 10YR 5/8	-	

Table 2. Baseline laboratory data of the soil profiles opened at Pápavár, Bakony Mountains (used after Saláta et al., 2022)

Profile / sample code	Genetic soil horizon	Relative depth [cm]	Soil parameter				
			Humus %	pH (H ₂ O)	CaCO ₃ %	salt %	Textur e (K _A)
BBSZ-3/A	A	0–15	4.70	5.86	0	< 0.02	49
BBSZ-3/B	B	15–60	2.60	7.57	3.2	< 0.02	55
BBSZ-2/A	A	2–23	3.53	4.72	0	< 0.02	47
BBSZ-2/E	E	23–28	2.36	5.38	0	< 0.02	42
BBSZ-2/B	B	28–70	1.75	6.09	0	< 0.02	37
BBSZ-1/A	A	5–20	2.26	4.55	0	< 0.02	43
BBSZ-1/E	E	20–30	1.56	5.06	0	< 0.02	42
BBSZ-1/B1	B ₁	30–55	1.16	5.69	0	< 0.02	45
BBSZ-1/B2	B ₂	55–80	1.11	5.80	0	< 0.02	47

Results of the tree examinations

Looking at the tree ring data of the trees sampled at the three localities (Tables 3-4.), it can be said that the age of the trees sampled on the upper part of the slope significantly exceeds that of the trees living in the middle and bottom of the slope.

Table 3. Dendrological data of the examined tree specimens (used after Saláta et al., 2022)

ID	Perimeter [cm]	Height [m]	Sample length [cm]	Number of tree-rings	Pith	Missing tree-rings	Estimated age
BB2	146	21,6	34,5	108	N	5-10	110-120
BB3	133	19	26,8	151	N	5-10	155-160
BB4	156	19,4	24	152	Y	0	152-155
BB5	170	20,2	31	150	N	5-10	155-160
BB6	208	17,2	26,5	149	N	10-20	160-170
BB7	133,5	27,2	29	61	N	10-20	70-80
BB8	92,5	27,8	13,5	67	N	5-10	75-85
BB9	130	29,8	31,5	59	N	15-20	75-80
BB10	153	30,2	28,3	56	N	10-20	65-75
BB11	127	27,8	25,5	69	Y	0	69-72
BB12	168	32,8	32	71	N	5-10	75-80
BB13	168	28	33,3	72	N	5-10	75-80
BB14	171	30	32	73	N	5-10	75-85
BB15	148	33	34,2	69	N	5-10	75-80
BB16	108,5	32	25,3	70	N	5-10	75-80

Since the individual trees show a relatively mixed picture as a whole, it may be worth to examine the growth of the trees of each examined slope section by focusing on the last 50 years.

Table 4. Descriptive statistics of the tree-ring measurements (N – number of measured tree-rings) (used after Saláta et al., 2022)

STATISTICS OF TREE-RINGS ON LOCALITIES [mm]					
UPPER	BB02	BB03	BB04	BB05	BB06
N	108	151	152	150	149
Min	0,178	0,200	0,323	0,369	0,236
Max	4,219	4,047	3,908	5,470	5,267
Mean	1,039	1,228	1,509	1,552	1,643
MIDDLE	BB07	BB08	BB09	BB10	BB11
N	61	67	59	56	69
Min	0,428	0,296	0,720	0,802	0,875
Max	6,249	5,122	8,146	8,073	8,477
Mean	2,735	1,848	3,851	3,539	3,588
LOWER	BB12	BB13	BB14	BB15	BB16
N	71	72	73	69	70
Min	1,647	0,708	0,705	0,850	0,795
Max	7,188	8,551	5,289	7,313	4,148
Mean	4,028	4,601	2,832	4,105	2,122

Figure 3 shows the growth of trees per localities in a complex way. The specimens as a group of the upper section - adjusted to the coding of the soil profiles - was encoded as BB3, those of the middle section as BB2, and those of the lower section as BB1. Based on the averaged

data, it can be seen that the growth of the older trees of the upper slope section, partly due to their age, lags behind the growth of the younger trees of the other two localities. It is also worth mentioning that the growth of the two younger groups is much more hectic and shows larger extreme values. However, it should be mentioned that, despite the larger differences, there is a greater agreement between the growth of trees in the middle and lower slope sections than between the upper and any other slope localities. In the case of all three slope sections, a decreasing trend can be seen on the growth potential however there are some years and periods that clearly had an impact on the entire forest stand. One of the most interesting periods is the one between 2012 and 2014, but the period between 2008 and 2010 can also be mentioned. It is also worth observing the 6-7 years' period starting with the year 1993, when a stagnation and only a slight growth can only be detected in all three slope localities

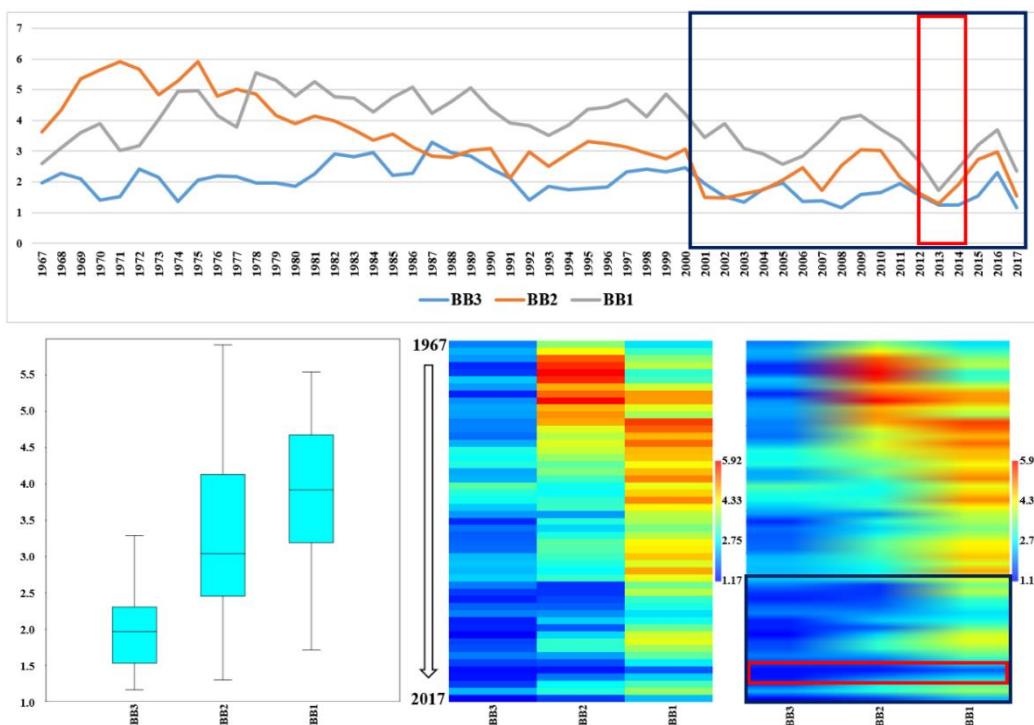


Fig. 3. The distribution of the tree-ring width of the trees of given slope sections (used after Saláta et al., 2022).

CONCLUSIONS

The soil analysis of the investigated lower, middle and upper sections of the slope, as well as the annual rings of the woody vegetation, yielded many interesting results. The profile of the upper section is partially eroded, so the morphological features of the Luvisols in general can only be partially observed, however its development clearly shows relation with the other two profiles of the slope. Based on the results, it can be concluded that the height of individuals standing on the upper part of the slope is lower than those on the middle and lower part of the slope. Since the height of the trees in the upper section would be expected to be higher than the others due to their older age under the same growing conditions, it can be assumed that the height increase of the individuals is influenced by the steepness of the slope and the depth of the available weathered soil layer. The shallower humus horizon and weathered soil stratum, as well as the increased speed of water flow apparently significantly hinders the trees in reaching greater heights. At the same time, it can also be observed that the tree specimens of the upper slope section show a larger trunk perimeter, which is primarily due to their age,

since the trees on this part of the slope are substantially 50-100 years older than the trees on the middle and lower part of the slope.

Based on the tree rind measurement data, there are clearly identifiable years (1984, 2001 or 2013) that had an impact on the growth of the trees of the forest. The tree ring data shows a relatively large variety, therefore it may be worthwhile to average the growth of trees belonging to the same group (slope section). In the course of the present investigation, the lack of growth between 2012 and 2014, which is also worth mentioning at the stock level, became clearly identifiable with this method.

REFERENCES

- Bolte, A., Czajkowski, T., Kompa, T. (2007): The north-eastern distribution range of European beech – a review. *Forestry*, 80, 4, 413–429.
- Brewer, P. W. (2014): Tellervo – A guide for users and developers. Laboratory of Tree-Ring Research, Tucson, 201 p.
- Brewer, P. W., Murphy, D., Jansma, E. (2011): Tricycle: A Universal Conversion Tool For Digital Tree-Ring Data. *Tree-Ring Research*, 67, 2, 135–144.
- Grissino-Mayer, H. D. (2003): A manual and tutorial for the proper use of an increment borer. *Tree-Ring Research* 59(2): 63–79.
- Hammer, Ø. (1999-2015): PAST – PAleontological STatistics Version 3.06 Reference Manual. Natural History Museum, University of Oslo. 225 p.
- Hammer, Ø., Harper D.A.T., P. D. Ryan (2001): PAST – Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, 4, 1, 1–9.
- Marosi, S., Somogyi, S. (1990): Magyarország kistájainak katasztere I-II. MTA FKI, Budapest, 1024 p.
- MSZ1398:1998. (1988): Talajszelvény kijelölése, feltárása és leírása talajterkép készítéséhez. Magyar Szabványügyi Testület, Budapest, 13 p.
- Saláta, D., Takács, M., Hüll, L., Pető, Á. (2022): Közönséges bükk (*Fagus sylvatica*) növekedésének vizsgálata évgyűrűk alapján a Pápavár deli lejtőjén (Bakony) (in Hungarian). *Tájékozólagai Lapok* (in press)
- TIM Módszertan (1995): Talajvédelmi Információs és Monitoring Rendszer 1. kötet: Módszertan. Földművelésügyi Minisztérium, Növényvédelmi és Agrár-környezetgazdálkodási Főosztály, Budapest.
- http1.: <https://qgis.org/hu/site/>

ODHAD NASYCENÉ HYDRAULICKÉ VODIVOSTI POMOCÍ PEDOTRANSFEROVÝCH FUNKCÍ VYUŽÍVAJÍCH VYBRANÉ METODY STROJOVÉHO UČENÍ

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ABSTRAKT

Nepřímé stanovení nasycené hydraulické vodivosti (K_s) pomocí pedotransferových funkcí (PTF) je známé již více než 30 let. V této studii byly testovány dva relativně nové typy PTF založené na principu strojového učení využívajících principy random forest a boosted regression tree, které umožňovaly použití různého počtu prediktorů. Celkem bylo zpracováno 126 datových souborů z 13 lokalit v České republice. Odhadnuté hodnoty K_s byly porovnány s odhady získanými pomocí běžně používaných hierarchických PTF implementovaných v počítačovém programu Rosetta. Všechny odhady K_s byly statisticky vyhodnoceny pomocí střední kvadratické chyby (RMSE), střední chyby (ME) a koeficientu determinace (R^2) v porovnání s naměřenými hodnotami K_s . Výsledky potvrdily předpoklad, že při použití vyššího počtu prediktorů se zvýší přesnost odhadu K_s . Kvalitní odhad s hodnotou RMSE pro log-transformovanou hodnotou $K_s < 0,5$ však byly nalezeny pouze pro 3 z 13 zkoumaných lokalit. Jedním z možných důvodů, proč testované PTF založené na strojovém učení nedosáhly takto kvalitních výsledků u všech lokalit, může být skutečnost, že data v jejich zdrojové půdní databázi nepocházejí z České republiky.

Klíčová slova: hydraulické parametry, kvalita odhadu, kombinované učící metody, neuronová síť

ÚVOD

Nasycená hydraulická vodivost (K_s) je jedním z nejdůležitějších a nejpoužívanějších půdních parametrů v řadě různých geotechnických a environmentálních modelů (Araya and Ghezzehei, 2019; Mbonimpa et al., 2002; Schaap et al., 2001; Tuffour et al., 2019). K_s popisuje schopnost pórů transportovat vodu vodou nasycenou půdou/horninou. Hodnota K_s je považována za rozhodující parametr při srážkových, závlahových či povodňových událostech a tání sněhu, jelikož determinuje proudění vody, rychlosť infiltrace, tvorbu povrchového odtoku či průsak do větších hloubek a perkolaci (Araya and Ghezzehei, 2019; Gamie and De Smedt, 2018). Byla vyvinuta řada metod pro přímé měření K_s aplikovatelných in-situ nebo v laboratoři (Klute, 1986). Nicméně pro charakteristiku větších a/nebo heterogenních územních celků, bylo potřeba odebrání vysokého počtu vzorků, což by průzkum neúměrně prodražilo. Právě z těchto důvodů byly zavedeny tzv. pedotransferové funkce (PTF), jakožto nepřímé metody stanovení půdních hydraulických charakteristik včetně K_s . Bouma (1989) představil termín „pedotransferové funkce“ a Minasny et al. (1999) je popsala jako funkce, které překládají data, která máme na data, která potřebujeme. Odhady K_s jsou založeny na snadno měřitelných a snadno dostupných vlastnostech půdy nazývaných prediktory, jako jsou zrnitostní složení (% obsah pískových, prachových a jílových částic), objemová hmotnost suché půdy a obsah organické hmoty nebo organického uhlíku. Za posledních 30 let byla navržena řada PTF a kvalita jejich odhadů byla hodnocena a porovnávána především pro odhad parametrů retenční křivky; vzhledem k historii odhadu K_s , detailní hodnocení používaných prediktorů a statistické techniky používané pro odvození PTF je uveden v práci Zhang a Schaapa (2019).

Nedávný technický pokrok ve vysoce výkonných výpočtech v kombinaci se shromažďováním hydraulických dat o půdách do rozsáhlých databází (např. Evropská databáze půd ESDB, Geografická databáze půdního průzkumu amerických půd SSURGO) umožnily vznik daty řízených metod, jako je metoda strojového učení (ML z anglického Machine Learning). PTF pro predikci Ks pomocí čtyř typů ML-algoritmů publikovali Araya a Ghezzehei (2019); modely využívající metody k-nearest neighbours, support vector regression, random forest a boosted regression trees pro různé úrovně prediktorů jsou k dispozici v rámci jejich veřejně dostupné aplikace. V této práci je testována hypotéza, že jimi prezentované PTF založené na velkém množství půdních dat (více než 18 000 datových sad) jsou dostatečně robustní, aby se s přijatelnou přesností daly aplikovat pro odhad Ks půd i mimo zemi jejich původu. Kvalita těchto odhadů byla vyhodnocena vzhledem ke změřeným datům a také vzhledem k již běžně používaným odhadům založených na metodě umělé neuronové sítě (ANN z anglického Artificial Neural Network) implementovaných v programu Rosetta (Schaap et al., 2001).

MATERIÁL A METODY

Data zahrnutá v této studii pocházejí ze dvou zdrojů: i) shromážděná data v rámci databáze HYPRESCZ (Miháliková et al., 2013) a ii) data pocházející z vlastních měření. Celkem bylo zpracováno 126 datových sad z 13 lokalit v rámci celého území České republiky. Základní informace o půdách jednotlivých lokalit jsou uvedeny v Tabulce 1, kde lze pozorovat zastoupení jednotlivých texturních tříd podle USDA (zastoupeno je 11 z 12 texturních tříd, není zastoupena třída „silt“ s velmi vysokým podílem prachových částic).

Pro testované PTF jsou používány následující prediktory: % obsah píska (částice o průměru $> 0,05$ mm), % obsah prachu (částice o průměru 0,05 – 0,002 mm), % obsah jílu (částice o průměru $< 0,002$ mm), dále pak objemová hmotnost suché půdy v g/cm³ a obsah organického uhlíku C_{ox} v %.

Aplikace PTF App (Araya and Ghezzehei, 2019) obsahující hodnocené modely PTF je vytvořena v programovacím jazyku a prostředí R (RStudio), které je určené pro statistickou analýzu dat a jejich grafické zobrazení. Pro odhad hydraulických vlastností půdy se ukazují jako vhodné algoritmy regresních stromů, jako je algoritmus boosted regression tree (BRT) a random forest (RF) (Araya and Ghezzehei, 2019; Gunarathna et al., 2019). Model BRT vznikl kombinací algoritmů rozhodovacích stromů (decision trees) a iterativní procedury boosting, která má za cíl zlepšit klasifikační přesnost daného strojového učení tím, že pružně mění rozložení učících dat. Rozhodovací strom se skládá z jednotlivých rozhodovacích uzlů, ze kterých vychází rozhodovací nebo situační hrany. Rozhodovací hrany představují dostupná řešení daného problému, situační hrany pak znázorňují možné důsledky. BRT modely jsou vhodné pro „méně vyčištěná“ data, vykazujícími nekonzistentnost např. kvůli různým metodám stanovení, což je právě případ měření Ks. Model RF je učící algoritmus vhodný pro více-účelové klasifikační a regresní metody. Byl úspěšně aplikován např. při řešení předpovědi kvality ovzduší, při řešení úloh v ekologii, bioinformatici a ekonometrii (Biau and Scornet, 2016). RF používá jednotlivé rozhodovací stromy, kde předpověď každého pozorování je průměrem ze všech stromů. Stromy se učí tak, že hledají vhodná vstupní data (prediktory), která zajistí nejlepší rozdělení, při kterém vzniká nejmenší chyba. Jednotlivé stromy využívají tzv. bootstrapové výběry (náhodná tréninková data) z tréninkové množiny. Při každém rozdělení je brána v úvahu jen malá skupina prediktorových proměnných, což zajišťuje minimální korelace mezi stromy (Araya and Ghezzehei, 2019).

Hodnoty Ks byly též odhadovány pomocí programu Rosetta (Schaap et al., 2001), který pro odhad Ks využívá metody umělé neuronové sítě (ANN – z anglického Artificial Neural Network). Přehled testovaných modelů PTF, jejich označení a použité prediktory jsou uvedeny v Tabulce 2.

Tabulka 1. Základní informace o půdách zájmových lokalit; čísla v závorkách uvádějí počet dostupných datových sad pro danou lokalitu/texturní třídu

Lokalita	Texturní třída podle USDA	Objemová hmotnost suché zeminy ρ_d - rozsah (g/cm ³)	Rozsah C _{ox} (%)	Rozsah změrených hodnot K _s (cm/den)	Zdroj dat
Podlesí (4)	Silty clay loam (1) Silt loam (3)	1.48-1.59	0.2-5.0	7.8 - 48.2	HYPRES CZ
U dvou louček (3)	Loam (1) Sandy loam (2)	1.30-1.59	1.05-5.1	40.5 - 370.8	HYPRES CZ
Slabčice (7)	Loam (1) loam (2) Sandy loam (4)	1.01-1.89	0.46-2.79	0.3 - 38.8	HYPRES CZ
Džbánov (4)	Silt loam (4)	1.45-1.62	0.1-5.0	5.6 - 22.4	HYPRES CZ
Žichlínek (4)	Clay loam (1) Silty clay loam (1) Silt loam (2)	1.38-1.74	0.2-5.0	2.5 - 75.4	HYPRES CZ
Ledenice (8)	Loam (5) Silt loam (2) Sandy loam (1)	1.15-1.79	0.3-3.36	0.1 - 21.9	HYPRES CZ
Cep (15)	Clay loam (7) Sandy clay loam (3) Loam (3) Sandy loam (2)	1.39-1.75	0.1-2.94	0.1 - 158.2	HYPRES CZ
Mimoň (9)	Silt loam (2) Loamy sand (4) Sand (3)	1.04-1.41	0.47-1.80	121.0 - 699.8	HYPRES CZ
Žďárky (12)	Clay loam (1) Silty clay loam (7) Silt loam (4)	1.43-1.70	0.14-2.03	30.0 - 550.0	HYPRES CZ
Majetín (15)	Clay (2) Clay loam (6) Loam (4) Sandy loam (1) Silt loam (1) Silty clay (1)	1.18-1.70	0.3-4.5	0.1 - 37.7	HYPRES CZ
Strašov (21)	Clay (1) Clay loam (1) Sandy clay loam (12) Sandy loam (3) Loamy sand (2) Sand (2)	1.22-1.74	0.48-3.31	1.0 - 964	Vlastní měření
Ruzyně (12)	Silty clay loam (6) loam (6)	1.13-1.36	1.05-1.87	10.2 - 1261.2	Vlastní měření
Uherčice (12)	Silty clay (4) clay loam (8)	1.13-1.45	1.29-1.85	0.3 - 524.5	Vlastní měření

Tabulka 2. Přehled testovaných modelů PTF a jejich prediktory

PTF model	Prediktory	Reference
BRT 3-0	% písku, % prachu, % jílu	Araya and Ghezzehei (2019)
BRT 3-1	% písku, % prachu, % jílu, ρ_d (g/cm ³)	Araya and Ghezzehei (2019)
BRT 3-2	% písku, % prachu, % jílu, ρ_d (g/cm ³), C_{ox} (%)	Araya and Ghezzehei (2019)
RF 3-0	% písku, % prachu, % jílu	Araya and Ghezzehei (2019)
RF 3-1	% písku, % prachu, % jílu, ρ_d (g/cm ³)	Araya and Ghezzehei (2019)
RF 3-2	% písku, % prachu, % jílu, ρ_d (g/cm ³), C_{ox} (%)	Araya and Ghezzehei (2019)
Rosetta-SSC	% písku, % prachu, % jílu	Schaap et al. (2001)
Rosetta-SSC+BD	% písku, % prachu, % jílu, ρ_d (g/cm ³)	Schaap et al. (2001)

Poznámka: ρ_d = objemová hmotnost suché půdy, C_{ox} = obsah organického uhlíku

Kvalita odhadu Ks je stanovena na základě porovnání se změřenými údaji. Vzhledem ke skutečnosti, že Ks nevykazuje normální rozdělení, veškeré statistické hodnocení je založeno na log-transformovaných hodnotách Ks (log = dekadický logaritmus). Při použití log-transformovaných hodnot Ks jsou pak výsledné statistiky bezrozměrné (Tóth et al., 2015). Střední chyba odhadu (ME, rov. 1), střední kvadratická chyba odhadu (RMSE, rov. 2) a koeficient determinace (R^2 , rov. 3) jsou běžně používány při vyhodnocování přesnosti odhadů pomocí PTF (Nemes et al., 2003; Lilly et al., 2008; Tóth et al., 2015). Hodnocení a určení pořadí testovaných modelů je provedeno na základě hodnot RMSE, kdy nejkvalitnější odhad s nejnižší hodnotou RMSE získal umístění č. 1. Jako model s nejkvalitnějším odhadem byl poté vyhodnocen ten model, který měl ve výsledném součtu umístění pro jednotlivé lokality nejnižší hodnotu. Výsledné odhady jsou také porovnány graficky pomocí boxplotů a korelačních grafů.

$$ME = \frac{1}{n} \sum_{i=1}^n (y_i - x_i) \quad (1)$$

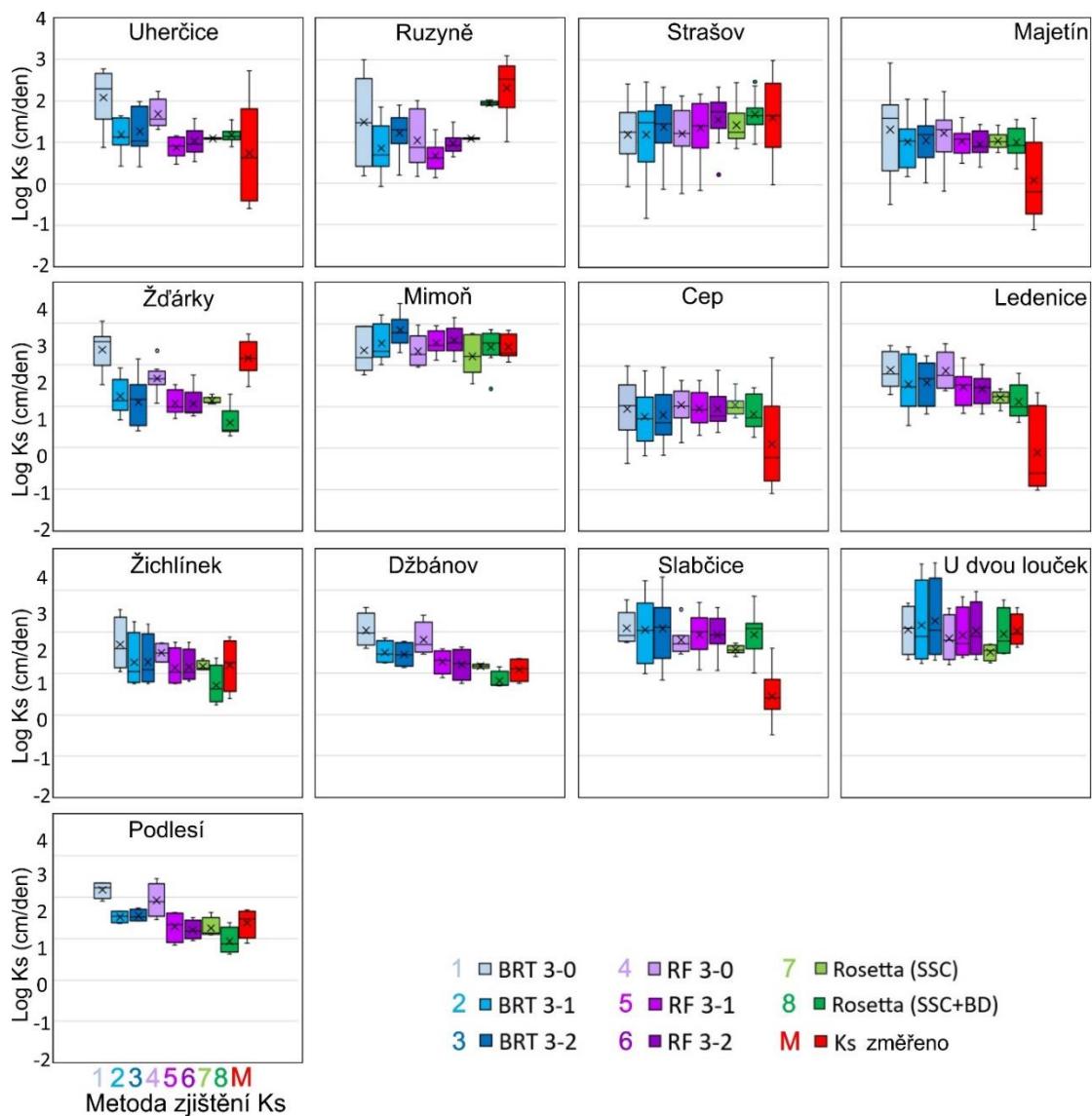
$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - y_i)^2} \quad (2)$$

$$R^2 = \left\{ \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{\sqrt{[n \sum_{i=1}^n x_i^2 - (\sum_{i=1}^n x_i)^2] [n \sum_{i=1}^n y_i^2 - (\sum_{i=1}^n y_i)^2]}} \right\}^2 \quad (3)$$

kde x_i jsou změřené hodnoty Ks, y_i jsou odhadnuté hodnoty Ks, a písmenem n je označen počet dvojic dat x_i y_i .

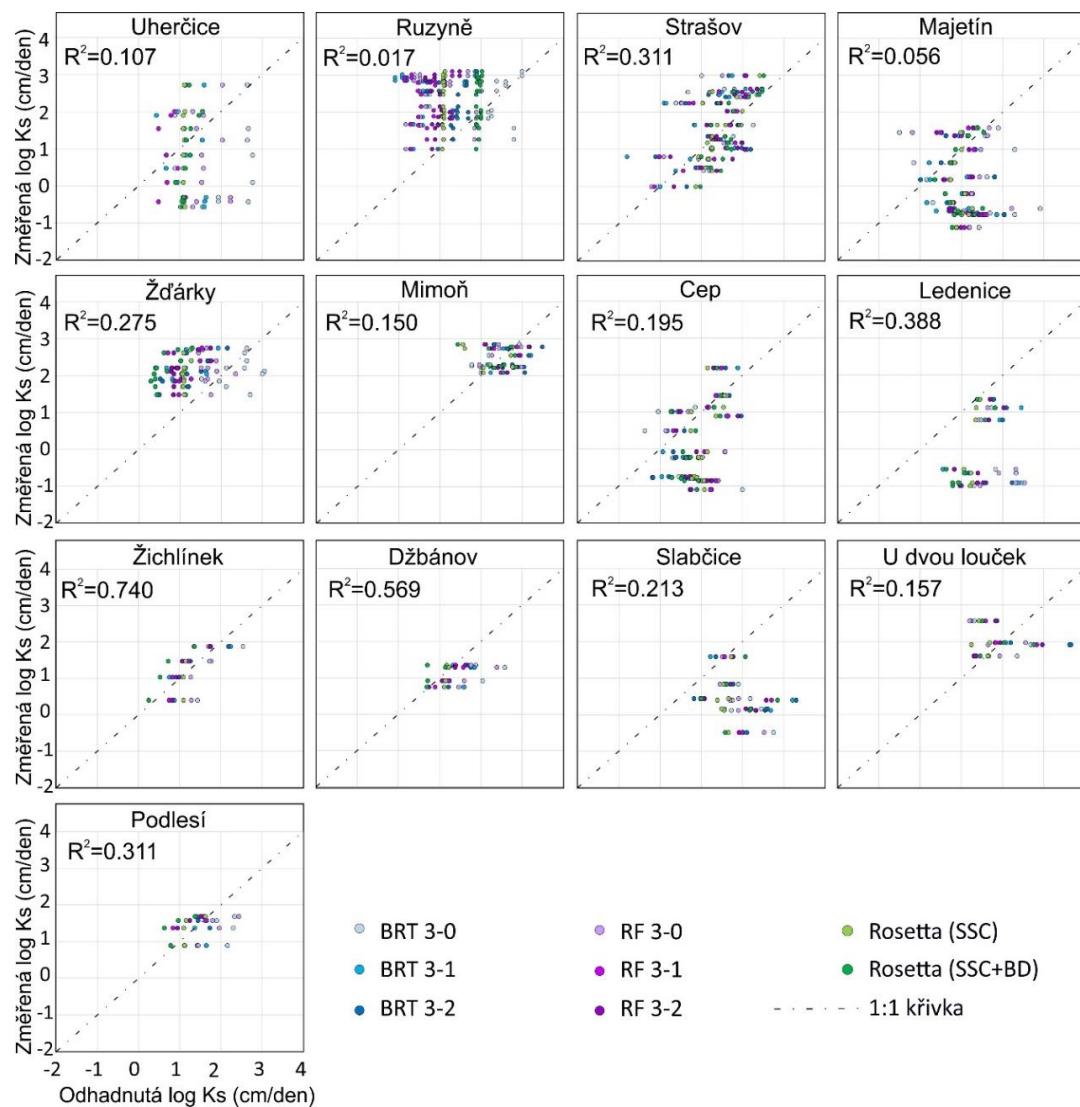
VÝSLEDKY A DISKUZE

Vzhledem k tomu, že naměřené hodnoty Ks vykazovaly značnou variabilitu, a to nejen mezi lokalitami, ale také v rámci některých jednotlivých lokalit, je na boxplotech (Obr. 1) možno pozorovat i značný rozptyl odhadovaných hodnot Ks. V rámci boxplotu je možno sledovat velikost „boxu“, tedy rozsah hodnot mezi 1. a 3. quartilem (tj. 25-75% dat), horizontální úsečku půlící box (medián) a křížek, kterým je vyznačena průměrná hodnota Ks. Variabilitu Ks dat pod 1. a nad 3. quartilem vyjadřují tzv. vousy a odlehlé hodnoty jsou vykresleny jako samostatné body.



Obr. 2. Grafické porovnání změrených a odhadnutých hodnot Ks pro jednotlivé lokality v ČR.

Poměrně kvalitní odhad Ks byly pozorovány pro lokality Strašov, Mimoň, Žichlínek, Džbánov a U dvou louček, kde průměry odhadů se příliš neliší od průměru měřených hodnot. Korelační grafy zobrazující přesnost jednotlivých odhadů Ks jsou uvedeny na Obr. 2. Jsou zde proti sobě vyneseny změrené a odhadnuté hodnoty; velmi přesné a kvalitní odhady jsou pak umístěny v blízkosti indikované křivky 1:1. Při naprosté shodě by zobrazený bod ležel přímo na dané křivce. Kvalitní odhad Ks byl zaznamenán pro lokalitu Žichlínek (Obr. 2; $R^2 = 0,740$), Džbánov (Obr. 2; $R^2 = 0,569$), ale i Strašov, kde hodnota koeficientu determinace R^2 byla pouze 0,311. Oproti tomu pro lokalitu Ledenice byl koeficient determinace vyšší než pro lokalitu Strašov ($R^2 = 0,388$) a přesto zde odhadnuté hodnoty Ks byly významně systematicky nadhodnoceny. Nadhodnocení odhadované hodnoty Ks konkrétním typem použité PTF je indikován kladnými hodnotami ME (Tab. 3) a pozicí pod křivkou 1:1 na korelačním grafu (Obr. 2). Obdobně, u lokality Mimoň byl zaznamenán nízký koeficient determinace ($R^2 = 0,150$) a přesto jsou odhady poměrně kvalitní s nízkými hodnotami RMSE (Tab. 4). Z tohoto důvodu bylo pro určení pořadí použitých PTF použito charakteristiky RMSE, která jednoznačně určuje průměrnou odchylku odhadovaných dat od dat změrených. Přehled hodnot RMSE pro jednotlivé typy PTF pro všechn 13 lokalit je uveden v Tab. 4 a pořadí jednotlivých PTF funkcí pak v Tab. 5.



Obr. 2. Korelační grafy pro změřené a odhadnuté hodnoty Ks pro jednotlivé lokality v ČR.

Tabulka 3. Přehled kvality odhadů Ks pomocí testovaných PTF pro jednotlivé lokality v ČR na základě ME

Lokalita	Použitá PTF						Rosetta SSC	Rosetta SSC+BD
	BRT 3-0	BRT 3-1	BRT 3-2	RF 3-0	RF 3-1	RF 3-2		
Podlesí	0.796	0.139	0.171	0.534	-0.097	-0.177	-0.131	-0.444
U dvou louček	0.025	0.134	0.239	-0.181	-0.109	-0.002	-0.515	-0.075
Slabčice	1.637	1.599	1.627	1.351	1.479	1.477	1.133	1.484
Džbánov	0.949	0.420	0.370	0.727	0.193	0.125	0.085	-0.265
Žichlínek	0.501	0.071	0.081	0.299	-0.065	-0.042	-0.027	-0.483
Ledenice	1.996	1.647	1.681	1.974	1.574	1.536	1.325	1.220
Cep	0.849	0.664	0.705	0.945	0.857	0.849	0.947	0.722
Mimoň	-0.082	0.088	0.410	-0.102	0.101	0.160	-0.226	-0.008
Žďárky	0.203	-0.921	-1.063	-0.494	-1.087	-1.103	-1.030	-1.558
Majetín	1.223	0.929	0.966	1.144	0.941	0.876	0.951	0.918
Strašov	-0.405	-0.403	-0.221	-0.378	-0.241	-0.041	-0.174	0.086
Ruzyně	-0.833	-1.466	-1.099	-1.274	-1.642	-1.350	-1.229	-0.371
Uherčice	1.340	0.452	0.527	0.945	0.133	0.295	0.354	0.445

Poznámka: Záporné hodnoty indikující podhodnocené odhady jsou zvýrazněné tučně, nejnižší ME v absolutní hodnotě je uvedena zvýrazněna červeně

Tabulka 4. Přehled kvality odhadů Ks pomocí testovaných PTF pro jednotlivé lokality v ČR na základě hodnot RMSE

Lokalita	Použitá PTF							
	BRT 3-0	BRT 3-1	BRT 3-2	RF 3-0	RF 3-1	RF 3-2	Rosetta SSC	Rosetta SSC+BD
Podlesí	0.869	0.403	0.333	0.568	0.296	0.306	0.276	0.508
U dvou louček	0.827	1.085	0.956	0.774	0.683	0.657	0.676	0.679
Slabčice	1.862	1.985	1.994	1.617	1.746	1.694	1.272	1.676
Džbánov	0.993	0.524	0.385	0.767	0.221	0.162	0.234	0.350
Žichlínek	0.633	0.356	0.262	0.483	0.249	0.299	0.466	0.529
Ledenice	2.316	1.880	1.868	2.340	1.767	1.698	1.560	1.368
Cep	1.461	1.092	1.079	1.352	1.271	1.243	1.297	1.077
Mimoň	0.369	0.387	0.610	0.360	0.406	0.473	0.604	0.586
Žďárky	0.655	1.016	1.133	0.688	1.144	1.148	1.082	1.578
Majetín	1.893	1.437	1.497	1.614	1.387	1.310	1.280	1.253
Strašov	0.978	0.961	0.872	0.803	0.720	0.665	0.662	0.595
Ruzyně	1.484	1.693	1.356	1.545	1.779	1.488	1.367	0.700
Uherčice	1.852	1.320	1.430	1.486	1.109	1.202	1.130	1.053
Průměr	1,246	1,087	1,060	1,107	0,983	0,949	0,916	0,919

Poznámka: Nejnižší hodnota RMSE korespondující s pořadím č. I je zvýrazněna červeně, průměrné hodnoty RMSE pro všechny lokality jsou zvýrazněné tučně

Čím nižší jsou hodnoty RMSE, tím kvalitnější a přesnější odhad dané charakteristiky je. Při srovnání s originální publikací testovaných PTF založených na principu strojového učení (BRT a RF) lze usuzovat na podprůměrné výsledky; 50 hodnot RMSE pro log-transformované hodnoty Ks v cm/den z celkových 78 je $> 0,7$, což je hodnota uváděná autory (Araya and Ghezzehei, 2019). Tóth et al. (2015) udávají výsledné RMSE v rozsahu 0,9 – 1,36 (pro log Ks v cm/den), což je srovnatelné s většinou odhadů BRT a RF použitých v této studii (jen 25 z celkových 78 RMSE > 1.36). Výsledky jsou srovnatelné i s výsledky studie, kterou publikovali Lilly et al. (2008), kde bylo dosaženo hodnot RMSE v rozmezí od 0,83 do 1,14 (pro log Ks v cm/den). Při porovnávání s jinými studiemi je třeba vzít v úvahu variabilitu naměřených hodnot a jejich rozsah, který se v odhadech může nebo nemusí nutně promítnout. Např. v lokalitě Ruzyně jsou jen 2 půdní typy a vzhledem k použití odlišného ořebního systému je rozsah naměřených hodnot Ks od 10 do 1200 cm/den. Obecně tato studie potvrídila předpoklad, že se zvyšujícím počtem prediktorů roste kvalita odhadu PTF založených na strojovém učení (RMSE hodnoty pro RF3-2 $<$ RF-31 $<$ BRT 3-2 $<$ BRT 3-1). Přestože metody strojového učení jsou poměrně slibné, výsledky nepřekonaly odhady získané pomocí programu Rosetta (Schaap et al., 2001) využívající metody ANN. Celkem překvapivě nejpřesnější odhad poskytl model Rosetta SSC o pouze jeden bod v umístění před Rosetta SSC+BD (průměrné hodnoty RMSE pro všech 13 lokalit dosáhly hodnot 0,916 a 0,919).

Vzhledem k faktu, že zrnitostní složení půdy, pro kterou je Ks odhadována, patří mezi základní prediktory, byla kvalita odhadu diskutovaných PTF aplikovaných na půdy použité v této studii vyhodnocena také z pohledu seskupených zrnitostních tříd. Výsledky tohoto vyhodnocení jsou prezentovány v publikaci Báťková et al. (2022).

Tabulka 5. Přehled kvality odhadů Ks pomocí testovaných PTF pro jednotlivé lokality v ČR na základě pořadí podle RMSE

Lokalita	Použitá PTF							
	BRT 3-0	BRT 3-1	BRT 3-2	RF 3-0	RF 3-1	RF 3-2	Rosetta SSC	Rosetta SSC+BD
Podlesí	8	5	4	7	2	3	1	6
U dvou louček	6	8	7	5	4	1	2	3
Slabčice	6	7	8	2	5	4	1	3
Džbánov	8	6	5	7	2	1	3	4
Žichlínek	8	4	2	6	1	3	5	7
Ledenice	7	6	5	8	4	3	2	1
Cep	8	3	2	7	5	4	6	1
Mimoň	2	3	8	1	4	5	7	6
Žďárky	1	3	5	2	6	7	4	8
Majetín	8	5	6	7	4	3	2	1
Strašov	8	7	6	5	4	3	2	1
Ruzyně	4	7	2	6	8	5	3	1
Uherčice	8	5	6	7	2	3	4	1
Suma	82	69	66	70	51	45	42	43
Celkové pořadí	8	6	5	7	4	3	1	2

Poznámka: Nejlepší umístění č. 1 pro každou lokalitu je zvýrazněno červeně; nejlepší celkové pořadí s nejnižší sumou jednotlivých pořadí je zvýrazněno červeně a tučně

ZÁVĚR

Přestože PTF založené na strojovém učení a odvozené na základě velkého počtu dat pro půdy USA (Araya and Ghezzehei, 2019) se jeví jako dostatečně robustní, aby byly obecně použitelné i pro půdy mimo USA, výsledky pro 13 lokalit v ČR vykazují spíše podprůměrné výsledky. Testované PTF poskytly kvalitnější odhady, pokud byly mezi základní vstupní prediktory (% obsah písku, prachu a jílu) také informace o objemové hmotnosti suché půdy (g/cm^3) a % obsah organického uhlíku. Nejkvalitnější odhady z modelů PTF využívající strojové učení poskytl model BRT 3-2, jehož výsledky byly srovnatelné s odhady získanými pomocí ANN implementovaných v programu Rosetta (Schaap et al., 2001) a s výsledky původní studie Araya a Ghezzehei (2019). Ostatní modely BRT a RF poskytovaly odhady s nižší přesností. Metody odhadu Ks nadále zůstávají výzvou, které je třeba vzhledem k důležitosti tohoto parametru, věnovat pozornost. Použití lokální databáze s informacemi o půdách v dané lokalitě/zemi původu v rámci zdrojových dat pro metody strojového učení, by mohlo přispět ke zlepšení kvality odhadů.

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REFERENCES

- Araya, S. N. and Ghezzehei, T. A. (2019): Using machine learning for prediction of saturated hydraulic conductivity and its sensitivity to soil structural perturbations, Water Resources Research, 55 (7), 5715-37.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Báťková, K., Matula, S., Hrúzová, E., Miháliková, M., Kara, R. S., and Almaz, C. (2022): A comparison of measured and estimated saturated hydraulic conductivity of various soils in the Czech Republic., *Plant Soil and Environment*, 68, 338-46.
- Biau, G. and Scornet, E. (2016): A random forest guided tour, *TEST*, 25 (2), 197-227.
- Bouma, J. (1989): Using soil survey data for quantitative land evaluation, *Advances in Soil Sciences*, 9, 177-213.
- Gamie, R. and De Smedt, F. (2018): Experimental and statistical study of saturated hydraulic conductivity and relations with other soil properties of a desert soil, *European Journal of Soil Science*, 69 (2), 256-64.
- Gunarathna, M. H. J. P., Sakai, K., Nakandakari, T., Momii, K., and Kumari, M. K. N. (2019): Machine learning approaches to develop pedotransfer functions for tropical Sri Lankan soils, *Water*, 11 (9), 1940.
- Klute, A. E. (1986): Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods Monograph 9 ASA and SSSA, Madison, WI.
- Lilly, A., Nemes, A., Rawls, W. J., and Pachepsky, Y. A. (2008): Probabilistic approach to the identification of input variables to estimate hydraulic conductivity, *Soil Science Society of America Journal*, 72 (1), 16-24.
- Mbonimpa, M., Aubertin, M., Chapuis, R. P., and Bussière, B. (2002): Practical pedotransfer functions for estimating the saturated hydraulic conductivity, *Geotechnical & Geological Engineering*, 20 (3), 235-59.
- Miháliková, M., Matula, S., and Doležal, F. (2013): HYPRESCZ - database of soil hydrophysical properties in the Czech Republic, *Soil and Water Research*, 8, 34-41.
- Minasny, B., Mc Bratney, A.B., Bristow, K.Y. (1999): Comparison of different approaches to the development of pedotransfer functions for water retention curves, *Geoderma*, 93 (3-4), 225-53.
- Nemes, A., Schaap, M.G., and Wösten, J.H.M. (2003): Functional evaluation of pedotransfer functions derived from different scales of data collection, *Soil Science Society of America Journal*, 67, 1093-102.
- Schaap, M. G., Leij, F. J., and van Genuchten, M. T. (2001): Rosetta: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions, *Journal of Hydrology*, 251 (no. 3/4), 163-76.
- Tóth, B., Weynants, M., Nemes, A., Makó, A., Bilas, G., and Tóth, G. (2015): New generation of hydraulic pedotransfer functions for Europe, *European Journal of Soil Science*, 66 (1), 226-38.
- Tuffour, H., Abubakari, A., Agbeshie, A., Khalid, A., Tetteh, E., Keshavarzi, A., Bonsu, M., Quansah, C., Oppong, J., and Danso, L. (2019): Pedotransfer functions for estimating saturated hydraulic conductivity of selected benchmark soils in Ghana, *Asian Soil Research Journal*, 2 (2), 1-11.
- Zhang, Y. and Schaap, M. G. (2019): Estimation of saturated hydraulic conductivity with pedotransfer functions: A review, *Journal of Hydrology*, 575, 1011-30.

POTENTIAL EFFECTS OF WILD BOAR ROOTING ON WATER RETENTION IN THE BABAT FOREST, HUNGARY

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ABSTRACT

Wild boar is considered one of the ecosystem engineer species. Their presence in high numbers is assuming significant effects in many of the forested areas. In the recent paper, the thickness of the soil horizons of the rooting was examined in order to evaluate the possible effects of wild boar on water retention. Five rooting were investigated by the Pürckhauer type core sampler. The middle and the ring of the so-called deep rooting were described and the values were related to the nearby unrooted areas. The thickness of the humus-rich A horizon was between 13 and 37 cm in the centre of the rooting, 22 and 62 cm in the ring of the rooting while 18 and 36 cm in the control areas. The thicker humus layer of the ring means bigger water-holding capacities while the deeper centre of the rooting functions as a water reservoir. Both parameters increase the possibility of the water holding and decrease the runoff. Furthermore, knowing the number of rooting on a hectare gives a possibility for the calculation of the wild boar effects on a larger area and thus further evaluation of this species' overall effects on natural areas.

Keywords: water holding, water reservoir, reduction of runoff erosion, retention, nature conservation

INTRODUCTION

Land use management is of utmost importance not only for its direct users (landowners, farmers, hunters, rangers, other users, and wildlife) (Penksza et al., 2016) but also from an overall ecosystem perspective, since the functioning and dynamics of organic and inorganic components define a multitude of parameters at varying ranges (Ballari & Barrios-García, 2014). Such is the case of the soil characteristics of the land, and its water retention potential. Currently, in grasslands and forested areas in Hungary, the wild boar (*Sus scrofa*) poses a considerable source of disturbance to soil properties, due to its rooting behaviour (Katona & Heltai, 2018). These activities have caused a spike in human-wildlife conflicts, given their impact on soil productivity, biodiversity, ecosystem composition, and water dynamics in the areas affected. Moreover, the demographic explosion of the wild boar population even in its native range added further complexity to its management (Fehér et al., 2014).

There were very little literature data available about the soil properties of the rooting (Alkhasova and Katona, 2021, Pitta-Osses et al. 2022).

Our aim was to better understand the impact of wild boar on soil characteristics in a forested area in Hungary, by evaluating the preliminary results of soil profile analyses performed on rooted and intact plots in a forest affected by sedimentation. In the recent paper, the thickness of the soil horizons of the rooting was examined in order to evaluate the possible effects of wild boar on water retention (deep rooting can withhold more water than a plain surface). We hypothesized that the topsoil (A) and the related humus-rich transitional horizon (AB) are significantly thicker in the external part of each rooting, whereas the middle of the rooted areas has a higher content of parent rock (C).

METHODS AND DATA

The study was carried out in the Babat Valley, a part of the Gödöllő Hillside Landscape Protection District, and part of the Natura 2000 network. It is located in Gödöllő, Pest County, Hungary ($47^{\circ}36'56.61''N$, $19^{\circ}22'50.40''E$). The study area (categorized by the Hungarian Agricultural Identification System (Mezőgazdasági Parcella Azonosító Rendszer - MePAR) as Q65K9-8-16 (block number), as seen in Figure 1) comprises 40 ha of mixed broadleaved coniferous and deciduous forest (EEA, 2006) with eroded areas.

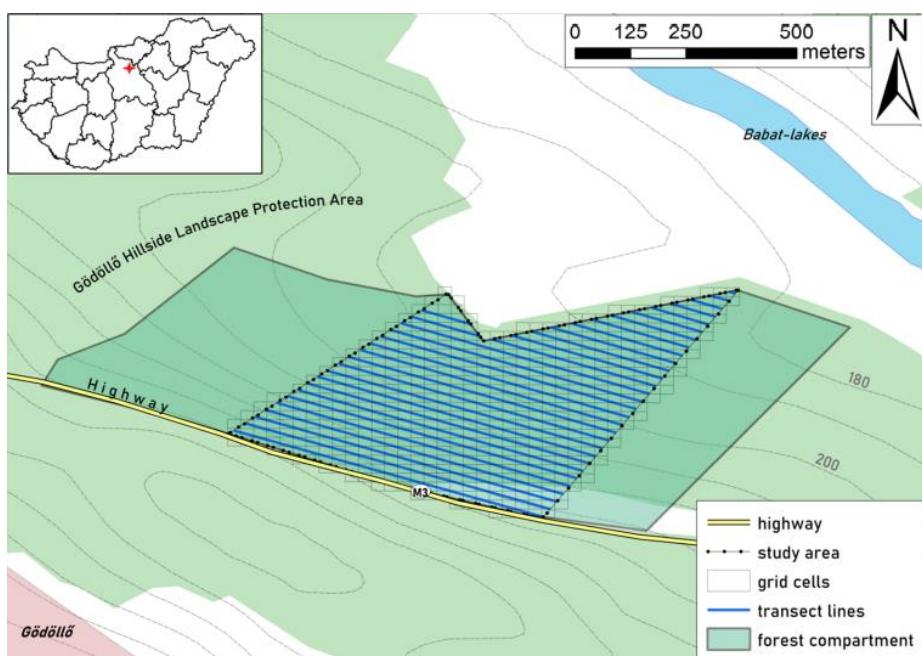


Fig. 1. Study area in the Babat Valley, Gödöllő.

The mean temperature in that zone ranges between $15^{\circ}C$ and $26.5^{\circ}C$ during the summer and $-4^{\circ}C$ and $1.2^{\circ}C$ during the winter. The yearly average rainfall is 49.4 mm, with the highest rainfall in June (69.8 mm) and the lowest rainfall in February (36.7 mm). The construction of a highway next to the study area has increased the already pre-existing tendency of water erosion to move sediments along the slope. Some containment structures have been installed to try to slow down the process, but it is evident that it continues to occur.

Location of sampling points

Soil sampling was performed with a Pürckhauer type soil probe (core diameter: 30 mm) in 5 wild boars rooting at up to 1 m depth, with 3 repetitions per wild boar disturbed patch (rooting, ring, and control, Figure 2), at a depth of 100cm in August 26th, 2020. The *in-situ* evaluation of the core sample included the visual identification of the soil horizon thickness (in cm); colour and texture; as well as a test for lime with 10% hydrochloric acid (Fehér et al., 2022).

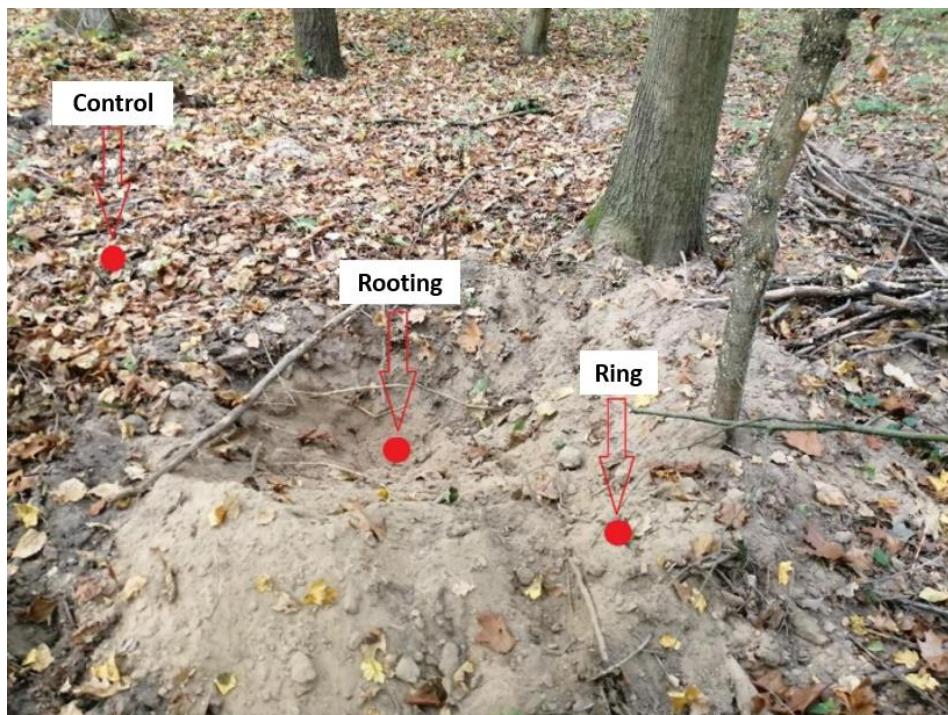


Fig 2. Sample distribution in each wild boar disturbance.

The thickness of the horizons was statistically evaluated in function of the 3 locations, using descriptive statistics. 15 soil profiles were obtained out of 5 rooting (3 samples per rooting, corresponding to rooting, ring, and control).

RESULTS AND DISCUSSION

The evaluation of each sample was done in the field, following the same format as that shown in Table 1.

Table 1. Description of soil horizons in rooting no. 1.

Sample type	Soil horizon	Depth (cm)	Color	Texture	Observations
Rooting	A	0-26	Grayish brown	Sandy loam	Reaction with acid in A horizon, CaCO ₃ (+). Higher reaction in C horizon, CaCO ₃ (+++)
	A-B	26-68	Mixed	Sandy loam	
	B	68-91	Reddish	Loamy sand	
	C	91-100	White	Sand (fine)	
Ring	A	0-39	Gray-brown	Sandy loam	No reaction with acid, lack of CaCO ₃
	A-B	39-71	Mixed	Sandy loam	
	B	71-100	Reddish	Sandy loam	
Control	A	0-36	Dark brown	Sandy loam	High reaction with acid in C horizon, CaCO ₃ (+++)
	B	36-86	Red	Sandy loam	
	C	86-100	White	Sand	

In the control sample, the hummus-rich A horizon had a thickness of 36 cm, higher than that of the rooting but slightly smaller than the thickness in the ring. The highest amount of disturbance is visible in the rooting, with the mixing of A and B horizons, and even reaching the C horizon (parent rock). As expected, the C horizon was only reached in one of the ring samples. The soil distribution due to wild boar disturbance could henceforth be creating pits in which water can be accumulated, or can even serve as traps for sediments, given the

erosion processes currently ongoing in the Babat Valley, noted also by the presence of sandy-rich horizons.

Statistical analysis

The thickness of all horizons identified in each core sample is presented in Table 2.

Table 2. Average minimum and maximum distance from the top (cm) of soil horizons in different locations.

Sample type	Soil horizon	Avg_min	Avg_max
Rooting	A	4.67±14.18	30.67±12.94
	AB	31.20±14.12	58.60±19.56
	B	53.5±21.29	83.83±14.96
	C	81.8±5.84	97.2±5.6
Ring	A	13.71±24.93	49.29±24.94
	AB	39.5±12.74	70.25±19.95
	B	66.33±3.68	96.33±5.19
	BC	66.5±22.5	81±19
Control	A	8.71±21.35	34.86±17.03
	AB	28±8.64	56.67±12.97
	B	63.17±16.07	97.67±5.22
	BC	47±0	74±8
	C	52±34	80.5±19.5

It was expected to find a thicker hummus-rich layer in the ring samples, given that the topsoil is removed from the middle of the rooting towards the edges, and to find a thicker C horizon inside the rooting, given that the distance to reach the parent rock is lower if the topsoil has been removed.

However, the results do not follow that pattern completely: the control samples follow the expected order of horizons, with only the BC horizon transition zone found at variable depths. It is worth noting that the B horizon in the control samples (i.e., those without any wild boar disturbance) can be found at a higher depth in all the locations, thus implying a previous mixing of the horizons B and C, presumably due to the sedimentation and erosion processes currently developing in the area.

Nonetheless, the hypothesis related to the thickness of hummus-rich layers being higher in the ring was found to be true, with AB and B horizons reaching up to 70.25±19.95 and 96.33±5.19cm, respectively. However, those depths are not too far from those found in the rooting and in the control samples.

CONCLUSIONS

The thickness of the hummus-rich horizons is an acceptable indicator of water retention potential. In the Babat Valley, where current erosion processes are affecting the composition and arrangement of the soil horizons, the wild boar rooting is not significantly altering the soil's physical properties. Further analyses are required to evaluate the potential alteration of the biochemical characteristics of the soil due to wild boar bio-disturbance. It is possible to assert that the disturbance in the soil by wild boar is not creating a significant impact on the soil horizons, and by extension, neither in the water retention potential of the soil. However, the middle of the deep rooting has a big potential to store the precipitation and leave enough time for infiltration instead of runoff.

REFERENCES

- Alkhasova, P., Katona, K. (2021): Comparison of some soil properties of wild boar (*Sus scrofa*) rootings. In: Botyanszká, L., Vitková, J. Hydrological Processes in the Soil–Plant–Atmosphere System. Bratislava, Slovakia: Ústav hydrologie SAV, pp. 25–30.
- Ballari, S. A., Barrios-García, M. N. (2014): A review of wild boar *Sus scrofa* diet and factors affecting food selection in native and introduced ranges. *Mammal Review*, 44, 2, 124–134. <https://doi.org/10.1111/mam.12015>
- Fehér, Á., Centeri, Cs., Alkhasova, P., Katona, K. (2022): Comparison of deep rooting of wild boar on soil properties in the Mátra Mountain and the Gödöllő Hillside. Proceedings Book of the VIth International Symposium-2022, Theme: “Biosphere & Environmental Safety,” 587–594. <https://www.researchgate.net/publication/363367133>
- Fehér, Á., Katona, K., Bleier, N., Hejel, P., Szemethy, L. (2014): Monitoring of ungulate impact in Hungarian forested Natura 2000 sites. *Review of Agriculture and Rural Development*, 3, 1, 126–130.
- Katona, K., Heltai, M. (2018): Diet composition and food habits of wild boar – A literature review. *Tájékológiai Lapok*, 16, 1, 65–74.
- Penksza, K., Fehér, Á., Saláta, D., Pápay, G., S. Falusi, E., Kerényi-Nagy, V., Szabó, G., Wichmann, B., Szemethy, L., Katona, K. (2016): Gyepregeneráció és vadhatás vizsgálata cserjeirtás után parádóhutai (Mátra) mintaterületen. *Gyepgazdálkodási Közlemények*, 14, 1, 31–41.
- Pitta-Osses, N., Centeri, Cs., Fehér, Á., Katona, K. (2022): Effect of wild boar (*Sus scrofa*) rooting on soil characteristics in a deciduous forest affected by sedimentation. *Forests* 13, 8, 1234.

PREJAVY EXTRÉMNEHO SUCHA V NENASÝTENEJ ZÓNE PÔD NA VÝCHODOSLOVENSKEJ NÍŽINE

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ABSTRACT

In connection with changes in the atmosphere, the periodicity of the occurrence of extreme hydrological situations has been increasing in recent years. In the natural conditions of Slovakia, periods without rain are lengthening and the incidence of precipitation of extreme intensity and abundance is increasing. Hydrological extremes are generally manifested in the form of floods and droughts. The increased incidence of drought is a new phenomenon in our latitudes. Drought basically means a lack of water in the soil, plants and in the atmosphere. Uniform criteria for quantitative definitions of drought do not exist with regard to the diverse approaches – meteorological, hydrological, agricultural, bioclimatic and a number of others. Soil drought is a phenomenon of the soil aeration zone, which is a source of water for the biosphere. From a systemic point of view, the atmosphere – plant cover – soil aeration zone – groundwater level (AT–PK–SAZ–GWL) is part of the system. Thus, all hydrological processes take place between the groundwater at its lower limit and the plant cover and atmosphere at the upper limit of the aeration zone. With its large retention capacity and hydrophysical properties, it is crucial for the water cycle, and its transformational effects decisively affect the speed and direction of water movement in the system. It follows from the above that the moisture condition of the soil in the aeration zone is the result of interaction processes of the aeration zone with the surrounding subsystems, while the intensity of these interactions depends on the hydrophysical properties of the soil. The East Slovakian Lowland is characterized by heavy, clayey and loamy soils. The growing season of 2022 ranks among the driest seasons. The article contains an analysis of the moisture regime in the unsaturated zone of the soil environment during the 2022 growing season.

Keywords: soil drought, unsaturated zone, volumetric soil moisture

ÚVOD

Sucho v podstate znamená nedostatok vody v pôde, rastlinách a v atmosfére. Jednotné kritériá pre kvantitatívne vymedzenia sucha neexistujú. Tie sú určené rozmanitými prístupovými hľadiskami – meteorologickými, hydrologickými, polnohospodárskymi, bioklimatickými a celým radom ďalších. Pôdne sucho je fenoménom zóny aerácie pôdy, ktorá je zdrojom vody pre biosféru. Zo systémového hľadiska je súčasťou systému atmosféra – rastlinný kryt – zóna aerácie pôdy – hladina podzemnej vody (AT–RK–ZAP–HPV) (Šoltész a Baroková, 2011; Červeňanská a kol., 2018; Červeňanská a kol., 2016).

Autori príspevku vychádzajú z predpokladu, že retenčná kapacita pôdy a dostupnosť pôdnej vody pre rastlinky je v rôznych pôdných druhoch rôzna. Pre posúdenie zásoby vody dostupnej pre rastlinný kryt sa používajú charakteristické body vlhkostnej retenčnej krivky. Bežne je to bod vädnutia (WP) predstavujúci hodnotu $pF = 4,18$, bod zníženej dostupnosti (TP) predstavujúci hodnotu $pF = 3,3$ a poľná vodná kapacita (FWC) predstavujúca hodnotu $pF = 2,0$ až $2,7$. Vlhkosť pôdy na úrovni FWC je tvorená vodou, ktorá v pôde ostane po odtečení gravitačnej vody. Bod zníženej dostupnosti je charakterizovaný vlhkosťou, pri ktorej pôdná voda začína byť pre rastlinný kryt nedostupná. Biologická aktivita rastlín sa znižuje a je orientovaná na prežitie. Pri bode vädnutia sú rastlinky nedostatočne zásobované vodou a hynú. Tieto skutočnosti sa odrážajú aj na výsledkoch monitoringu vlhkostného režimu. Sú

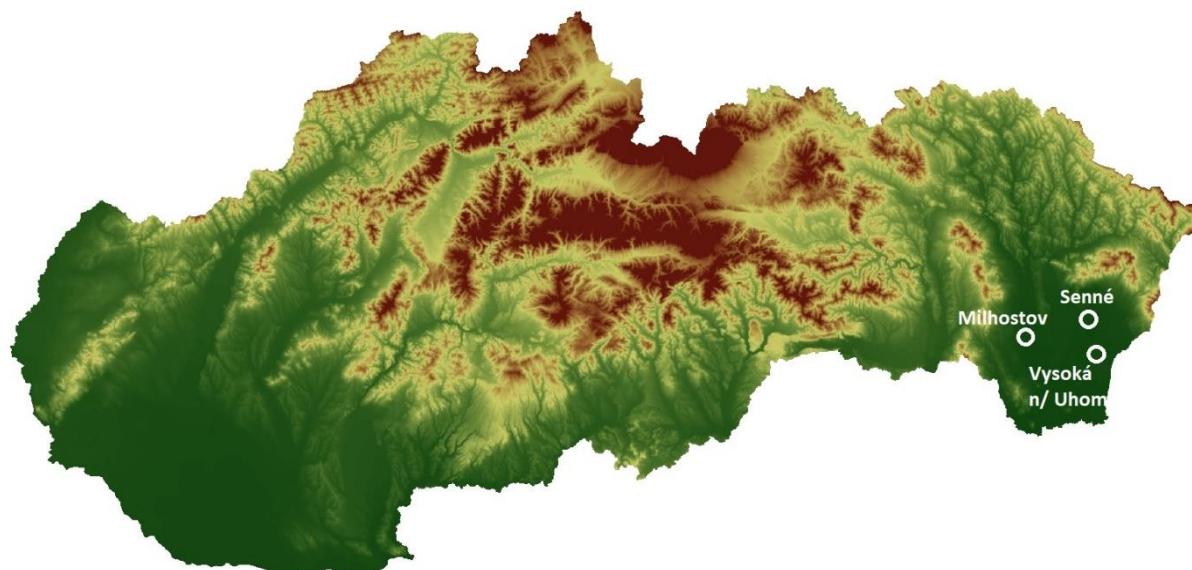
signifikantné pri štatistickej a grafickej interpretácii výsledkov (Tall a Gomboš, 2013; Šurda a Vitkova, 2016).

Cieľom príspevku je kvantifikovať rozdielne výsledky monitoringu objemovej vlhkosti a zásob vody v rôznych pôdnych druhoch v extrémne suchom vegetačnom období roku 2022. V rámci tejto kvantifikácie boli analyzované zásoby pôdnej vody, rozloženie objemovej vlhkosti po vertikále pôdnego profilu, časové a priestorové zmeny vlhkostného režimu a dostupnosť pôdnej vody pre rastlinný kryt vztiagnutá k hydrolimitom.

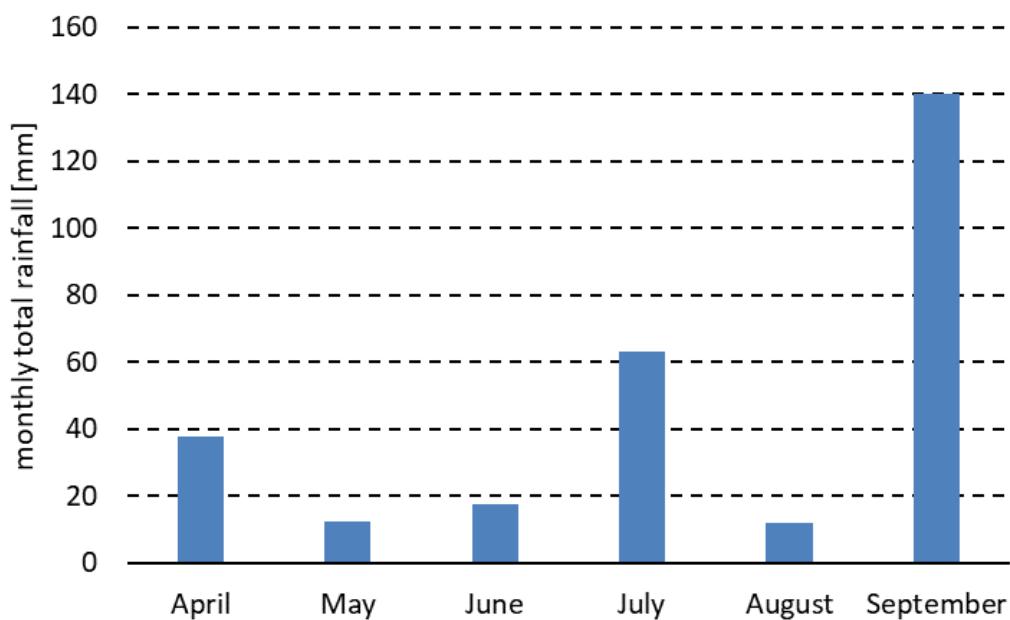
METODIKA

Pre prezentáciu rozdielov boli vybrané výsledky monitoringu objemových vlhkostí v troch lokalitách Východoslovenskej nížiny (VSN). Sú to lokality Milhostov, Senné a Vysoká nad Uhom. Ich situovanie je uvedené na obr. 1. Monitoring bol realizovaný do hĺbky 1,0 m po vrstvách 0,1 m. Analyzované výsledky monitoringu spadajú do teplého (vegetačného) polroku mesiacov apríl až september. Vo všetkých troch lokalitách boli odbery pôdnych vzoriek realizované v ten istý deň. Pre prezentáciu výsledkov monitoringu bolo vybrané vegetačné obdobie roku 2022. V tomto vegetačnom období bol v lokalite Milhostov zrážkový úhrn 295,4 mm čo v 53 ročnom rade meraní predstavuje 13 % pravdepodobnosť výskytu. V tejto súvislosti je potrebné uviesť, že 47,5 % (140,2 mm) celovegetačného úhrnu zrážok vypadlo na konci vegetačnej sezóny v mesiaci september obr. 2. Táto skutočnosť mala dopady na zásoby vody v pôde a vegetačné obdobie roku 2022 sa radí k absolútne najsuchším od roku 1970.

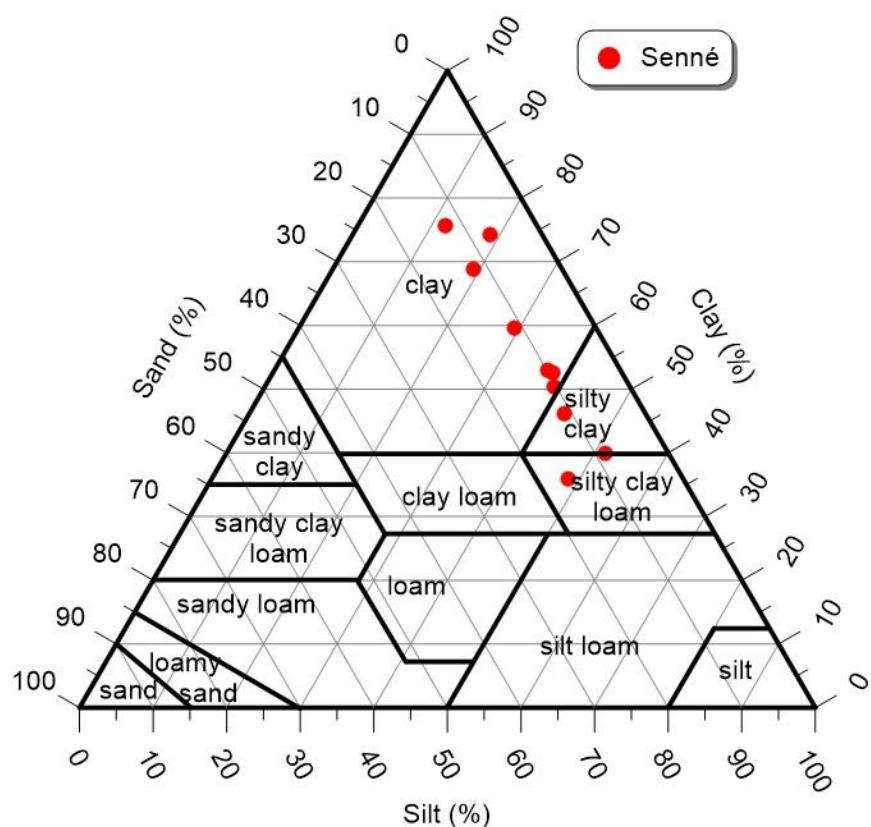
Z pôdneho hľadiska v lokalite Senné prevládajú ílovité pôdy (obr. 3), v Milhostove prachovito-ílovito-hlinité pôdy (obr. 4) a v lokalite Vysoká nad Uhom prachovito hlinité pôdy (obr. 5). Vlhkosti boli stanovené gravimetrickou metódou. V ďalšom postupe prác boli získané výsledky spracované metódami popisnej štatistiky a grafickými metódami vo forme chronoizoplet, a čiarových grafov.



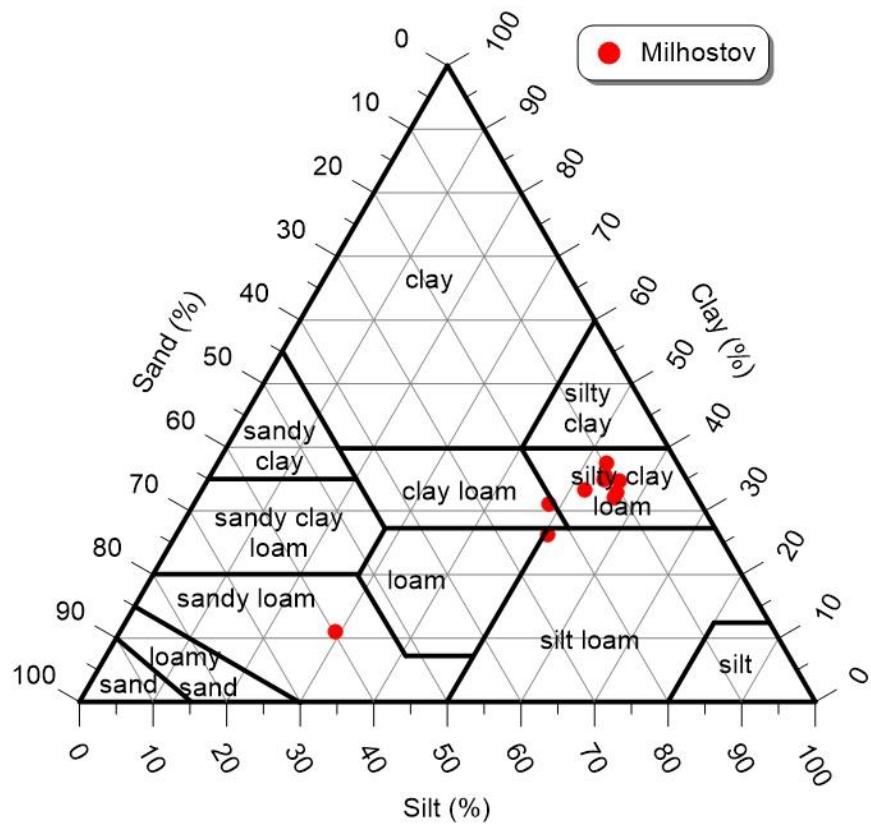
Obr. 1. Situovanie skúmaných lokalít.



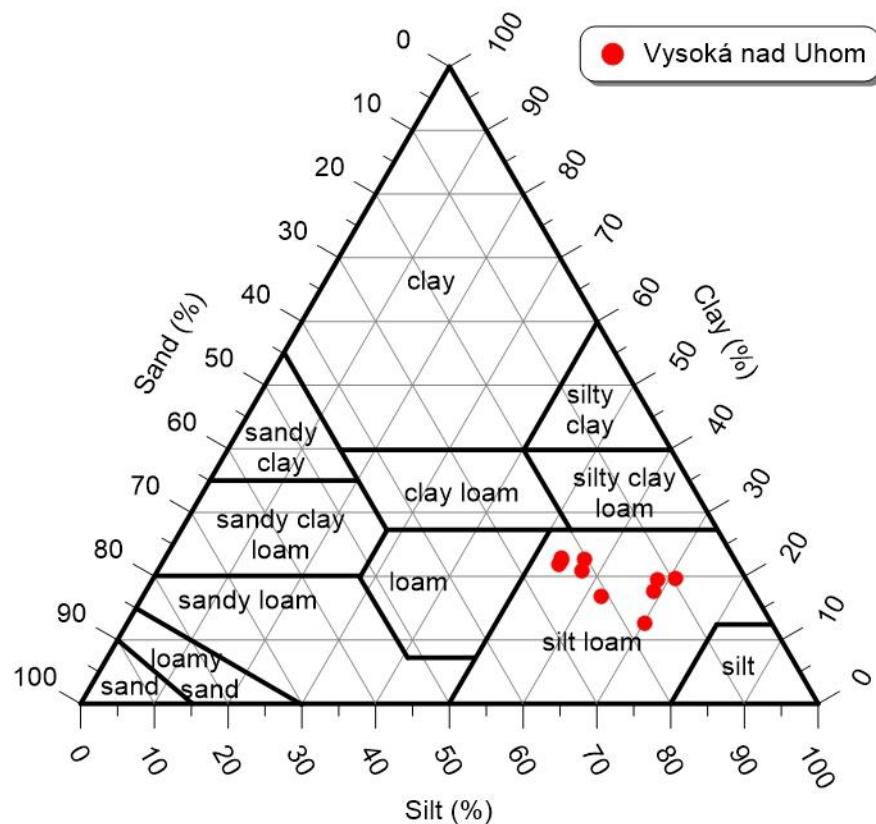
Obr. 2. Mesačné úhrny zrážok vo vegetačnom období roku 2022 v lokalite Milhostov.



Obr. 3. Identifikačný trojuholník pôd podľa USDA, lokalita Senné.



Obr. 4. Identifikačný trojuholník pôd podľa USDA, lokalita Milhostov.



Obr. 5. Identifikačný trojuholník pôd podľa USDA, lokalita Vysoká nad Uhom.

VÝSLEDKY A DISKUSIA

V tab. 1 sú uvedené priemerné retenčné charakteristiky odberných profilov do hĺbky 1,00 m. Z tab. 1 vyplýva, že využiteľná vodná kapacita (FWC – WP) má rozsah v intervale medzi 140 až 200 mm. Najväčšiu retenčnú kapacitu má ílovitý pôdny profil v Sennom. Súčasne je to profil s najmenšou dostupnosťou vody pre rastlinný kryt. Najdostupnejšia voda pre rastliny je v pôdnom profile Milhostov. Najmenšia retenčná kapacita je v prachovito-hlinitom pôdnom profile Vysoká nad Uhom. Rovnako sú zjavné retenčné rozdiely vyjadrené formou WP, TP, FWC v jednotlivých lokalitách.

Tabuľka 1. Retenčné charakteristiky

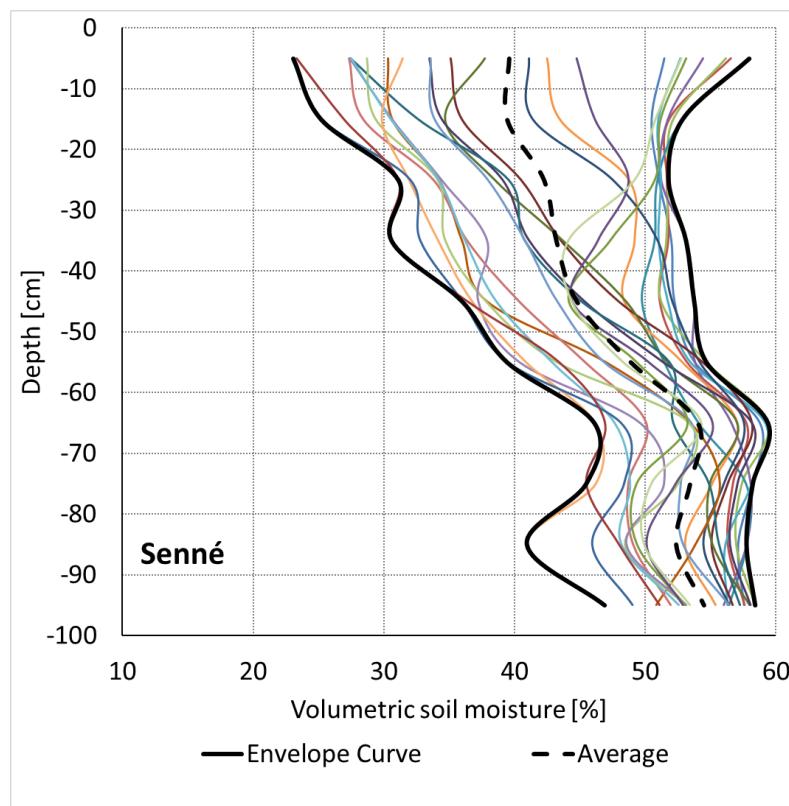
locality	Hydrolimits [mm]		
	WP	TP	FWC
Senné	320	480	520
Milhostov	230	310	420
Vysoká nad Uhom	240	310	380

V tab. 2 sú uvedené charakteristiky popisnej štatistiky zásob vody v jednotlivých profiloch do hĺbky 1,0 m. Priemerná hodnota zásoby vody do 1 m je v lokalitách Senné a Milhostov pod bodom zníženej dostupnosti. V týchto profiloch je rozdelenie hodnôt v nameranom súbore vzhladom k normálovému plochejšie. Profil Vysoká nad Uhom sa vlhkostne nachádza v optimálnom intervale medzi TP a FWC. Rozdelenie je špicatejšie. Pôdny profil sa nachádza v pririečnej zóne rieky Uh. Táto cez hladinu podzemnej vody zrejme nadlepšuje aj zásoby vody v nenasytenej zóne. Vo všetkých troch monitorovaných profiloch nie je priemer totožný s mediánom.

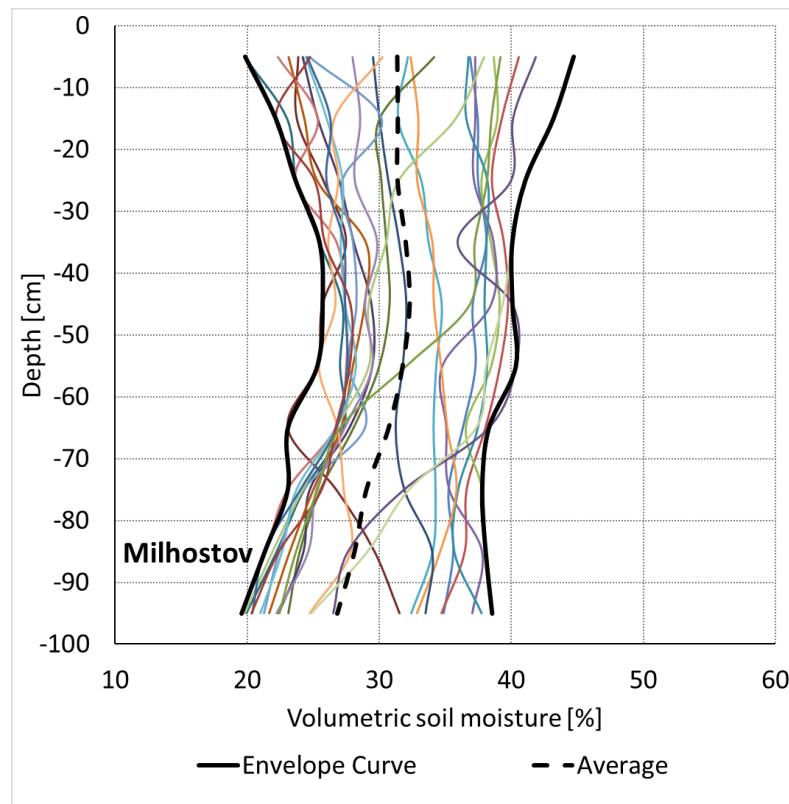
Tabuľka 2. Štatistické charakteristiky

Locality	Senné	Milhostov	Vysoká n/U.
Mean	472,4	304,7	358,2
Standard Error	11,8	10,6	9,0
Median	481,6	286,5	366,6
Standard Deviation	57,9	51,8	43,2
Sample Variance	3347,8	2683,9	1867,4
Kurtosis	-1,3	-1,6	0,1
Skewness	-0,2	0,3	-0,8
Range	169,8	142,6	155,7
Minimum	380,0	240,0	264,0
Maximum	549,8	382,6	419,7
Sum	11338,7	7313,3	8239,6
Count	24	24	23
Confidence Level (95,0 %)	24,4	21,9	18,7

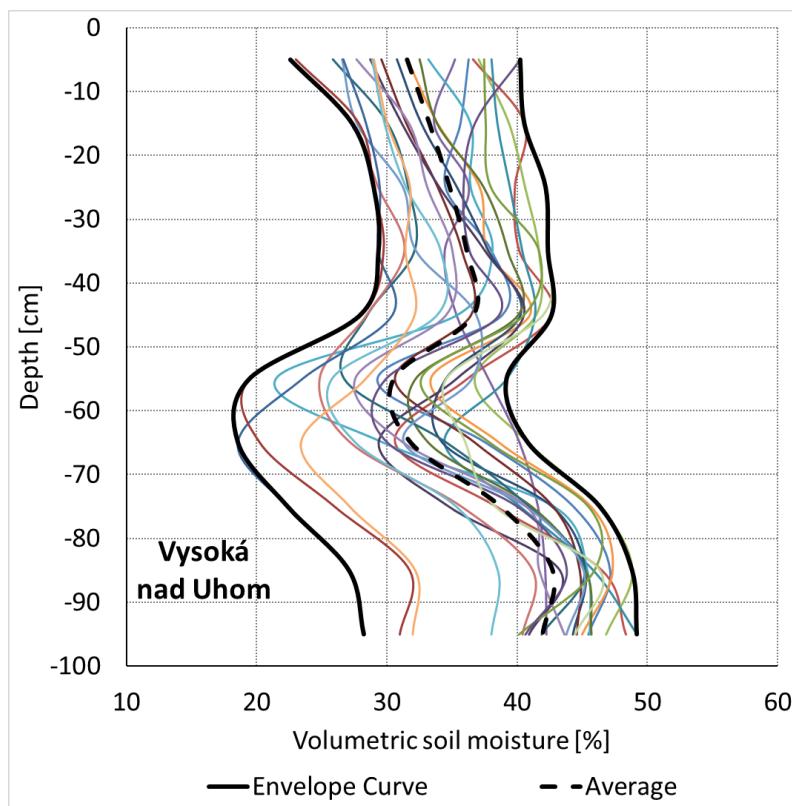
Na obr. 6, 7, a 8 sú v skúmaných lokalitách uvedené priebehy meraní objemovej vlhkosti po vertikále pôdneho profilu. Všetky priebehy boli merané v ten istý deň za rovnakých hydrometeorologických podmienok.



Obr. 6. Priebeh objemovej vlhkosti po vertikale pôdnych profilov do 1,0 m po vrstvach 0,1 m – lokalita Senné.



Obr. 7. Priebeh objemovej vlhkosti po vertikale pôdnych profilov do 1,0 m po vrstvach 0,1 m – lokalita Milhostov.



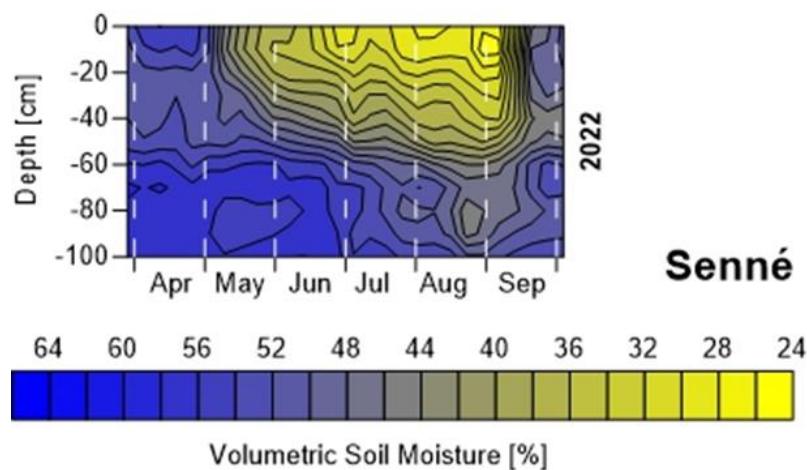
Obr. 8. Priebeh objemovej vlhkosti po vertikále pôdnych profilov do 1,0 m po vrstvách 0,1 m – lokalita Vysoká nad Uhom.

Uvedené zobrazenie výstižne ukazuje variabilitu vlhkosti v čase a priestore v rôznych pôdnych prostrediach. Na okrajoch jednotlivých zobrazení boli zostrojené obalové krivky.

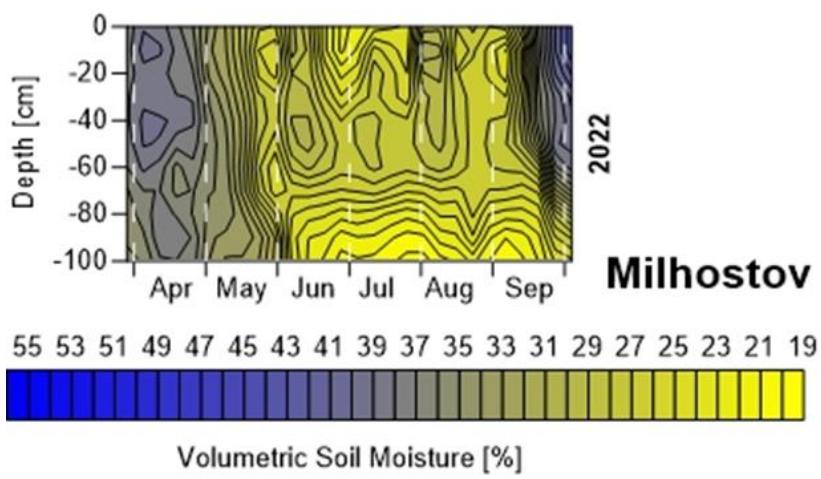
Tieto po vertikále pôdneho profilu udávajú variačné rozpäťie objemovej vlhkosti. Stredom zobrazenia prechádza hrubá červená čiara zobrazujúca priemerné hodnoty objemovej vlhkosti. Miera posunu priebehov vlhkostí, ich obalových kriviek a priemerných hodnôt na vlhkostnej osi je daná hydrofyzikálnymi vlastnosťami pôdy. Z obrázku 6 vyplýva, že v ľažkej, ilovitej pôde sa obalové krivky smerom do hĺbky k sebe približujú. To značí, že variabilita vlhkosti sa znižuje ale obsah vody v pôde stúpa. Ľahšie pôdy v Milhostove sú po vertikále rovnomerne presušované v celom skúmanom profile (obr. 7). V pôdnom profile Vysoká nad Uhom v spodných pôdnych horizontoch sa pravdepodobne prejavuje vplyv podzemných vôd a tým nepriamo rieky Uh (obr. 8).

Veľmi efektívnu zobrazovacou metódou je zobrazenie monitorovaných veličín pomocou izočiar (izolínie, izoplety). Izočiara je z fyzikálneho hľadiska definovaná ako čiara, pozdĺž ktorej má zvolená skalárna fyzikálna veličina rovnakú hodnotu. Názov izočiary závisí od toho akú veličinu zobrazuje. Izoplety, pozdĺž ktorých je v pôdnom profile v rôznych časoch rovnaká vlhkosť, sa nazývajú chronoizoply. Formou chronoizoply je získaný obraz o časovom vývoji vlhkosti v pôdnom profile.

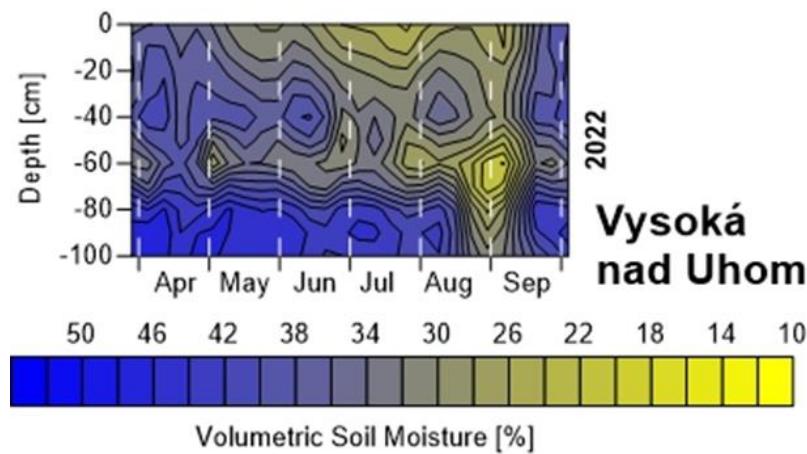
Touto metódou sú na obr. 9, 10 a 11 zobrazené priebehy objemovej vlhkosti v skúmaných profilocho počas vegetačného obdobia roku 2022. Na obrázku sú jednotlivé vlhkostné úrovne rozlíšené aj farebne. Z uvedených zobrazení je zrejmý odlišný vlhkostný režim v rôznych pôdnych prostrediach. V lokalite Senné bol pôdny profil presušovaný do hĺbky 0,60 m. V ľahšom pôdnom profile Milhostov bolo presušovanie v celom profile. V lokalite Vysoká nad



Obr. 9. Izočiary priebehov vlhkosti v skúmaných profilioch, (chronoizoplety), lokalita Senné.



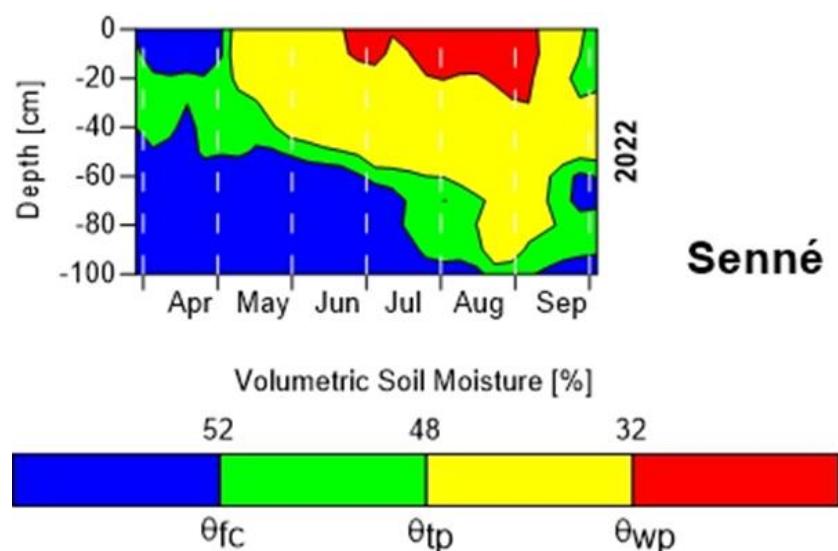
Obr. 10. Izočiary priebehov vlhkosti v skúmaných profilioch, (chronoizoplety), lokalita Milhostov.



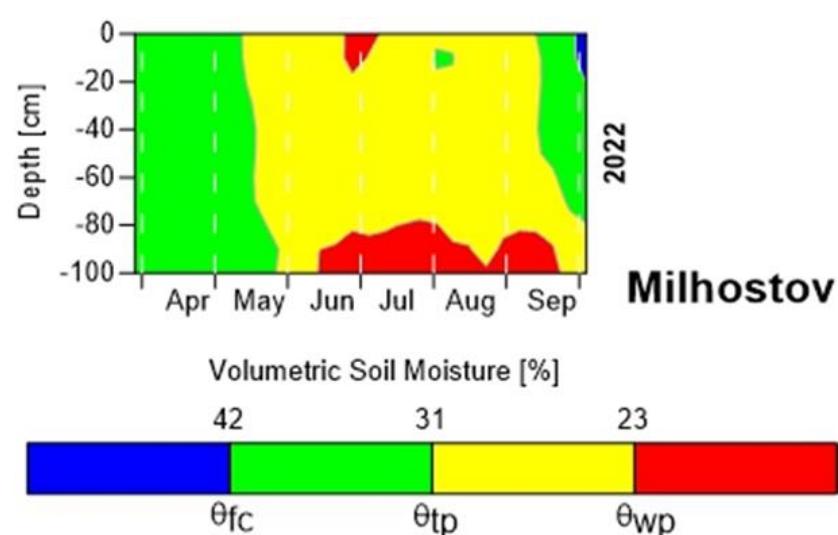
Obr. 11. Izočiary priebehov vlhkosti v skúmaných profilioch, (chronoizoplety), lokalita Vysoká nad Uhom.

Uhom boli presušované iba horné pôdne horizonty. Dolné pôdne horizonty začínali vysychať až na prelome augusta a septembra. Vo všetkých troch pôdných profiloch sa výrazne prejavili významné zrážky v septembri.

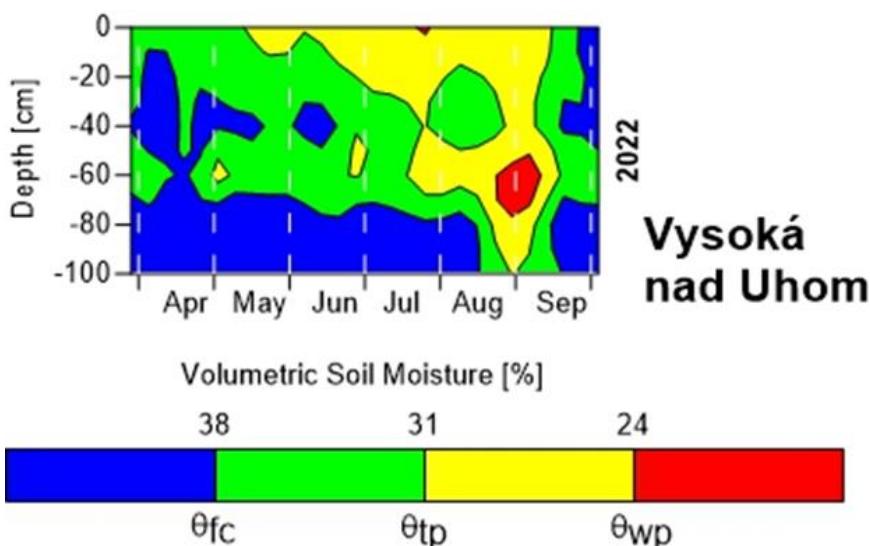
Informačná hodnota uvedeného zobrazenia sa zvýší, ak sú hranice vlhkostných intervalov medzi chronoizopletami dané hydrolimitami. Tým sa získa aj predstava o dostupnosti vody pre rastlinný kryt. Na obr. 12, 13 a 14 sú chronoizoplety určené hydrolimitami FWC, TP a WP (tab. 1). Z uvedených zobrazení je zrejmé, že v lokalite Senné boli horné pôdne horizonty asi 2,5 mesiaca vo vlhkostnom stave medzi pod bodom vädnutia. Tomu zodpovedal aj trávny porast, ktorý bol suchý. Spodné pôdne horizonty postupne vysychali. Pôdny profil na konci augusta bol vo vlhkostnom profile (TP, WP) až do hĺbky takmer jedného metra. V ľahšom pôdnom profile v lokalite Milhostov v mesiaci august bol celý monitorovaný pôdny profil do hĺbky 1,00 m presušený na vlhkostný stav medzi TP a WP. V lokalite Vysoká nad Uhom bol celý pôdny profil pod TP až na prelome augusta a septembra. Potom sa už prejavil vplyv zrážok v počas septembra.



Obr. 12. Chronoizoplety vymedzené hydrolimitami, lokalita Senné.



Obr. 13. Chronoizoplety vymedzené hydrolimitami, lokalita Milhostov.



Obr. 14. Chronoizoplety vymedzené hydrolimitami, lokalita Vysoká nad Uhom.

Na obrázku 15 sú uvedené ďalšie hydrofyzikálne prejavy pôdneho sucha v podmienkach t'ažkých pôd. Vizuálne sa to prejavuje vo forme puklín. Ich tvorba je dôsledkom objemových zmien v horizontálnej rovine. Vo vertikálnom smere sa objemové zmeny prejavujú vertikálnym pohybom povrchu pôdy. Analýza týchto procesov presahuje náplň tohto príspevku. Uvedené sú tu iba pre ilustráciu šírky problematiky skúmania prejavov sucha v nenasýtenej zóne pôd.



Obr. 15. Prejavy sucha – tvorba dvojdomenového pôdneho prostredia v lokalite Milhostov.

ZÁVER

V príspevku boli kvantifikované rozdielne výsledky monitoringu objemovej vlhkosti a zásoby vody do hĺbky 1,00 m v rôznych pôdných druhoch. Pre prezentáciu rozdielov boli vybrané výsledky monitoringu v troch lokalitách na VSN v extrémne suchom vegetačnom období roku 2022. Najťažšie pôdy, s najväčším obsahom ílovitých častíc boli v lokalite Senné, ľahšie v lokalite Milhostov a najľahšie v lokalite Vysoká.

Výsledky monitoringu potvrdili, že čím je pôdny profil ľahší, tým je variabilita zásob vody väčšia. Ľahšie pôdy sú po vertikále rovnomerne presušované po celom skúmanom profile. Po

vertikálne pôdneho profilu bol numericky a graficky identifikovaný významný posun priebehov vlhkostí, ich obalových krviek a priemerných hodnôt na vlhkostnej osi. Prírastok īlovitej zložky v textúre posúva priebehy vlhkostí k vyšším hodnotám.

Bola vypracovaná grafická analýza so zobrazením chronoizoplet. Tá v lokalite Senné preukázala, že vysušovanie pôdneho profilu sa postupne prejavilo v celom pôdnom profile. V lokalitách Milhostov bolo vysušovanie rovnomerné v celom skúmanom profile do hĺbky 1,00 m. Pôdny profil Vysoká nad Uhom sa nachádza v pririečnej zóne rieky Uh. Jeho vlhkostný režim v spodných pôdnych horizontoch je pravdepodobne ovplyvnený vodným režimom rieky. Aj tu sa však prejavilo vysušovanie pôdneho profilu. Počas septembrových výdatných zrážok sa všetky pôdne profily dosýtili.

Pre zistenie dostupnosti vody pre rastlinný kryt v čase a priestore boli chronoizoplety určené hydrolimitami FWC, TP a WP. Výsledky názorne ilustrovali rozdiely v dostupnosti vody pre rastliny v skúmaných lokalitách. V lokalite Senné boli povrchové vrstvy pôdneho prostredia približne 2,5 mesiaca pod bodom vädnutia. Porast na povrchu bol suchý.

Uvedené výsledky sú využiteľné pri návrhoc hospodárenia s vodou v krajinе a návrhoc adaptačných opatrení pre elimináciu pôdneho sucha.

Podčakovanie

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LITERATÚRA

- Červeňanská, M., Baroková, D., Šoltész, A. (2016): Modeling the groundwater level changes in an area of water resources operations. In *Pollack Periodica*, vol. 11, no. 3, 83–92. ISSN 1788-1994 (2016: 0.229 - SJR, Q3 - SJR Best Q). V databáze: SCOPUS: 2-s2.0-84994817325 ; DOI: 10.1556/606.2016.11.3.8.
- Červeňanská, M., Janík, A., Baroková, D. (2018): Infiltration experiments: Realization and evaluation. In *Pollack Periodica*, vol. 13, no. 1, 137–144. ISSN 1788-1994 (2018: 0.219 - SJR, Q3 - SJR Best Q). V databáze: SCOPUS: 2-s2.0-85044573505 ; DOI: 10.1556/606.2018.13.1.12.
- Šurda, P., Vitkova, J. (2016): Impact of biochar application on soil moisture dynamics and saturated hydraulic conductivity. In International Multidisciplinary Scientific GeoConference: SGEM: Surveying Geology & mining Ecology Management, zv.1., 445–451.
- Šoltész, A., Baroková, D. (2011): Impact of landscape and water management in Slovak part of the Medzibodrožie region on groundwater level regime. In Journal of Landscape Management, vol. 2, no. 2, 41–45.
- Tall, A., Gomboš, M. (2013): Rajonizácia oblasti na VSN podľa potenciálu objemových zmien pôd. In *Acta Hydrologica Slovaca*, vol. 14, no. 1, 66–74. ISSN 1335-6291.

REGULATING SUBSTRATE CONDITIONS WITH THE COLOUR OF GROWING BAGS

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ABSTRACT

Soilless cultivation allows the adaptation of horticultural production to external conditions. To evaluate the possibility of regulating growing substrate conditions by adjusting the color of the growing bags, seedlings of highbush blueberry (*Vaccinium corymbosum* L., cv. 'Duke') were planted in six green and six white growing bags in which the water content and temperature of the growing substrate were measured. The growing substrate in the white bags had a lower average temperature than the growing substrate in the green bags (by 5 °C) and contained more water (by 5.8%) during the measurement period. The change in temperature in the growing bags during winter followed the change in soil temperature on which the growing bags were placed. The temperature in the growing substrate was affected by both air temperature and soil temperature. In spring, the growing substrate in the green bags had warmed up slightly faster than the growing substrate in the green bags and had a higher average temperature (by 1.5 °C). Highbush blueberries planted in the white bags had higher average shoot growth per plant than blueberries planted in the green bags (by 10.5 cm). During the study, we were not able to determine whether the north or south side had an effect on the development of the root system in the bags with growing substrate.

Keywords: soilless media, growing bags, soil water content, soil temperature

INTRODUCTION

Highbush blueberry is a plant that is becoming increasingly popular in intensive plantations, but it can also be found in gardens. Blueberry requires acidic and moderately moist soil for growth, therefore for intensive production plants are usually grown in acidic peat soil or in growing bags, where plants are planted in the growing substrate. Peat substrate is the main substrate for plant production (Raviv and Leith, 2008). In general, peat substrates are used mainly for the cultivation of vegetable seedlings and ornamental plants (Raviv and Blom, 2001, Giancarlo, 2015; Zamljen et al., 2020a). Peat substrates have favorable water retention properties, low pH and are free from diseases and pests (Schwärzel et al., 2002; Faul et al., 2016; Zamljen et al., 2020b). They also have low mass which makes them suitable for transport. The water retention properties are particularly important for optimizing irrigation and thus water consumption in intensive plant production (Ismail et al., 2007; Zamljen et al., 2020b).

Blueberries have a fine, fibrous root system that is relatively shallow and free of root hairs (Eck, 1988). Abbott and Gough (1987) reported that roots of highbush blueberries grew throughout the year, but growth was greatly reduced in soils below 8°C. They found two periods of accelerated growth, the first in early June and the second in September. These periods occurred when soil temperatures were between 14 and 18 °C, and root growth declined when soil temperatures were below or above this range.

The cultivation of highbush blueberry in berry growing bags is becoming more common. Two types of growing bags are available on the market, white and green. With increasing weather extremes, drought and heat waves, horticultural production is exposed to extreme conditions. Therefore, every possible advantage that growers can take should be evaluated so that

production can be optimized and pressure on natural resources - water supply and energy demand - can be reduced.

In our experiment, we evaluated what effect, if any, do different colors of growing bags for berries have on the conditions in the growing substrate and thus on the growth of highbush blueberry. We also evaluated the substrate water content (under same irrigation treatment) and the development of the highbush blueberries.

METHODS AND DATA

For the evaluation of the color of growing bag on the growing substrate conditions, experiment was set-in north-east Slovenia (289 m a.s.l.). In the experiment, twelve highbush blueberry seedlings of the cv. 'Duke' in six green and six white growing bags (Fig. 1). Acid peat was used as the growing substrate (Green Terra, professional peat), and two sensors (SM 150, Delta-T UK) were placed in each bag, which we used to record the water content in the growing substrate (%) and the temperature of the growing substrate ($^{\circ}\text{C}$) with data logger (Type GP2, Delta-T UK) (Fig. 2). Sensor for air temperature and for ground soil were placed separately (S and T, respectively, Fig. 1). Meteorological data (air temperature) were obtained for the nearest meteorological station (Medlog, Environmental Agency of Slovenia, 2022). Drip irrigation was installed for all growing bags for homogenous water supply.

We were interested in the effect that the colors of the growing bags had on the temperature of the growing substrate and the amount of water in the growing substrate at different times of the year.

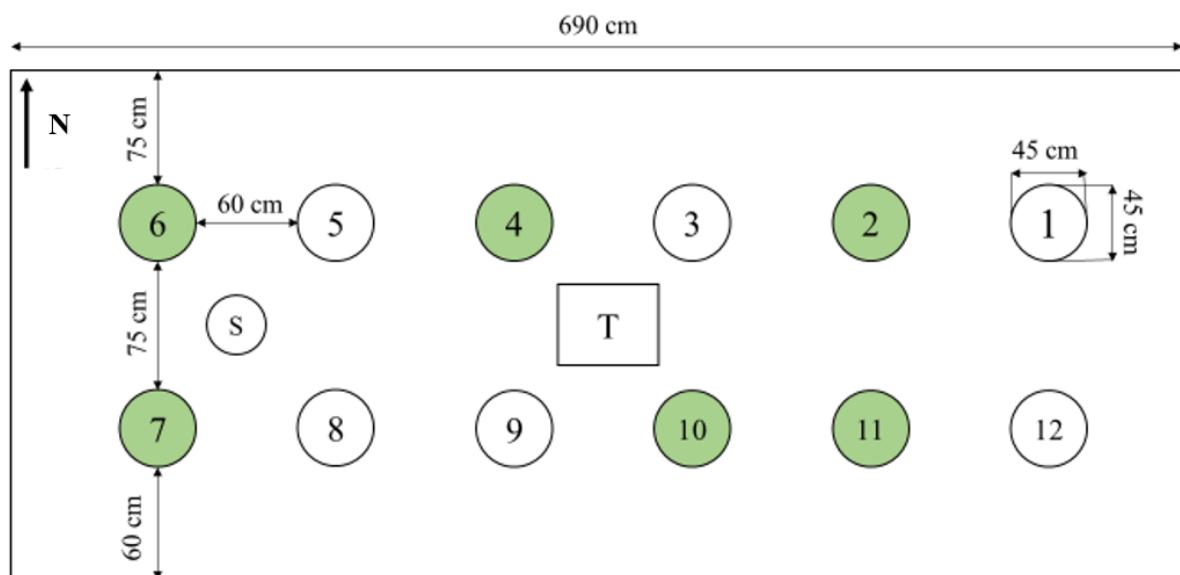


Fig. 1. Experimental scheme (the numbered circles from 1 to 12 are the bags placed in the experiment, the color of the circle indicates the color of the growing bag, the square marked T is the soil temperature sensor, the circle marked S is the position of the air temperature sensor, the arrow marked N at the very top left is the direction north).



Fig. 2. Data loggers for growing substrate water content and temperature measurements at the experimental set-up for highbush blueberry (Stražar, 2022).

RESULTS AND DISCUSSION

Measurements of the growing substrate temperature were conducted during the highbush blueberry growing season, between 5. 7. 2021 and 7. 8. 2021 (Fig. 3). The results show that the average temperature of the growing substrate was 5 °C higher in green growing bags. The temperature of the growing substrate was 23.8 °C in white bags and 28.8 °C in green growing bags. The highest temperature measured was in green bags, 34.8 °C (7. 7. 2021).

We were interested in the heating of the growing substrate in late winter and spring, which we measured between 1. 2. 2022 and 15. 3. 2022 (Fig. 4). We found that the growing substrate in the green growbags warmed faster than the growing substrate in the white growbags on a sunny day. During this period, the average temperature of the growing substrate in green bags was 1.5 °C higher than in white bags. This could potentially have implications for horticultural production and placement of the harvest on the market earlier.

During the fall and winter, measured between 27. 9. 2021 and 10. 1. 2022, we also monitored the temperature of the soil, i.e. the ground, on which the bags were placed, in addition to the temperature of the growing substrate (Fig. 5). The results show that the growing substrate in the grow bags cooled more than the soil on which the grow bags were placed.

During the growing season of highbush blueberry, we monitored the amount of water in the growing substrate measurement took place between 15. 4. 2022 and 15. 6. 2022 (Fig. 6). The results show that the average amount of water in growing substrate in white bags was 5.8% higher than the average amount of water in green bags. We concluded that evapotranspiration was lower in the white bags due to the lower temperatures in the growing substrate. Despite good water retention properties of peat substrate for horticultural production under our climate (Zamljen et al., 2020a, Zamljen et al., 2020b), irrigation is necessary for optimal water supply, as is clear from Fig 6, when for one-week irrigation was not applied to evaluate the conditions within growing bags.

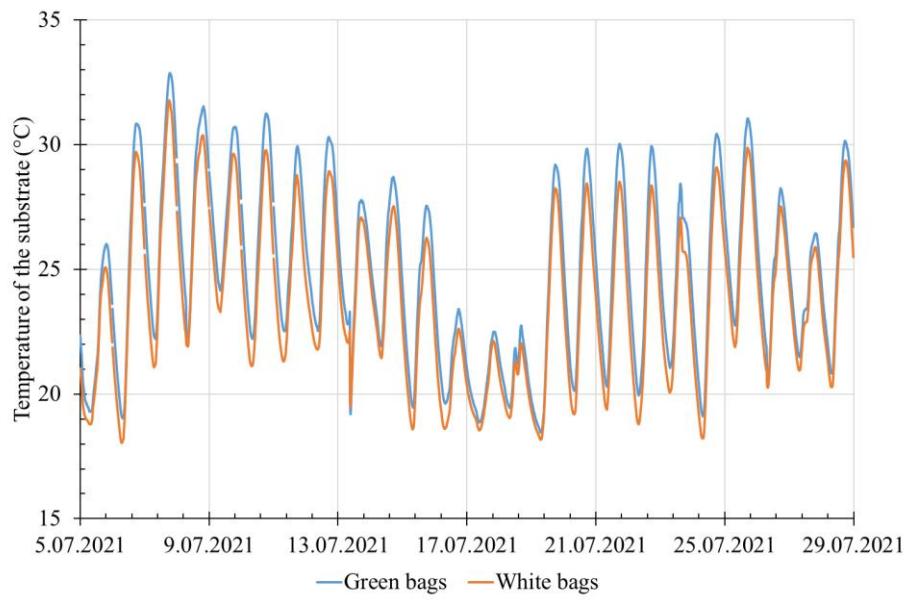


Fig. 3. Growing substrate temperature for green and white growing bags from 5.7. to 7. 8. 2021.

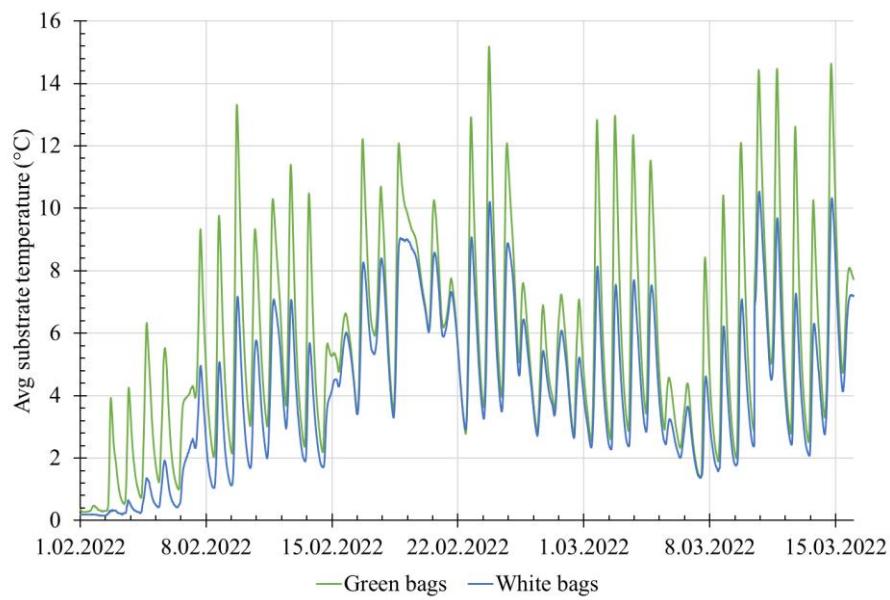


Fig. 4. Growing substrate temperature for green and white growing bags from 1. 2. to 15. 3. 2022.

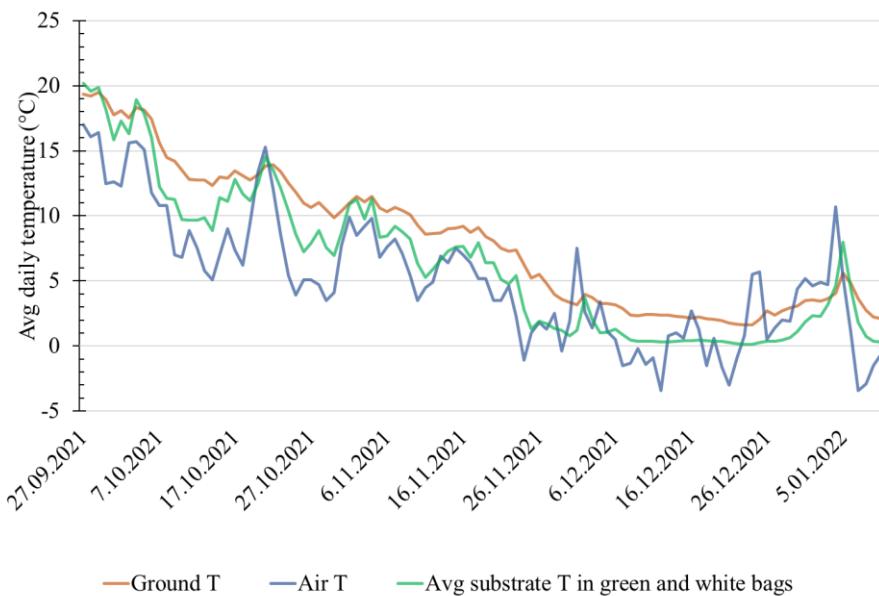


Fig. 5. Substrate temperature for green and white growing bags from 1. 2. to 15. 3. 2022.

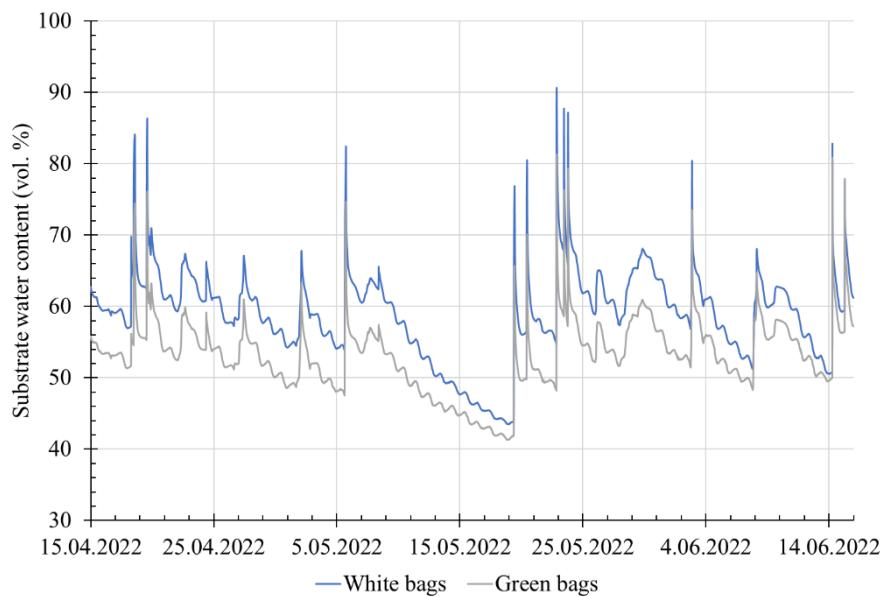


Fig. 6. Growing substrate water content from 15. 4. to 14. 6. 2022.

We were also interested in the growth of the shoots highbush blueberries. We found that the increase in shoot length of highbush blueberries sown in white growing bags from 4. 1. 2022 to 8. 7. 2022 was 30.1% higher than the increase in shoot length in green bags (Table 1). We examined the root system of four highbush blueberries (two plants from the green growing bag and two from the white growing bag) and found that the root system developed better in the white growing bags on the south side of the growing substrate and in the green bags on the north side of the substrate. We could not draw any definite conclusions because we studied a statistically unrepresentative sample of plants.

Table 1. Sum of shoot lengths (cm) at first (1.4.2022) and second (8.7.2022) measurement and annual growth (in cm and %) by plant and growing bag color

No. of the plant	Growing bag color	First measurement (cm)	Second measurement (cm)	Annual growth (cm)	Annual growth (%)
2	Green	49	176	127	259,2
4		153	209	56	36,6
6		70	180	110	157,1
7		97	310	213	219,6
10		112	387	275	245,5
11		34	120	86	252,9
1	White	15	89	74	493,3
3		223	551	328	147,1
5		134	342	208	155,2
8		135	367	232	171,9
9		90	222	132	146,7
12		150	305	155	103,3

CONCLUSIONS

The average temperature of the growing substrate in the green bag is higher than the average temperature of the growing substrate in the white bag. The results show that air temperature and soil temperature affect the temperature of the growing substrate in the bags of both colors. The growing substrate in the white bags contained larger amounts of water than the amount of water in the growing substrate in the green bags under the same irrigation. The average annual growth of shoots in the green bags is lower than the average annual growth of shoots in the white bags.

In our research, highbush blueberries in white bags grew better than blueberries in green bags. Further studies with multiple replicates are needed to properly evaluate the effect of growing bag color on root development. In addition, the results should be re-evaluated in a repeated experiment on a larger scale and with a larger number of plants, and until the plants are fully developed to properly observe their development. The possibility of improving the growing conditions by the color of the growing bags should be explored and used in the future production of highbush blueberries.

REFERENCES

- Abbott, J.E. and R.E. Gough. (1987): Seasonal development of highbush blueberry roots under saw-dust mulch. *J. Amer. Soc. Hort. Sci.* 112:60–62
- Eck, P. (1988): Blueberry science. Rutgers Univ.Press, New Brunswick, N.J.
- Faul, F., Gabriel, M., Roßkopf, N., Zeitz, J., Huyssteen, W. C., Pretorius, L. M., Grundling, P. (2016): Physical and hydrological properties of peatland substrates from different hydrogenetic wetland types on the Maputaland Coastal Plain, South Africa. *South African Journal of Plant and Soil*, 33(4), 265-278.
- Giancarlo, F. (2015): Growing Substrates Alternative to Peat for Ornamental Plants. InTech Publication: 47–67.
- Ismail, M. S., Ozawa, K., Khondaker, A. N. (2007): Effect of irrigation frequency and timing on tomato yield, soil water dynamics and water use efficiency under drip irrigation. Eleventh International Water Technology Conference, 69–84.
- Raviv, M., Blom, J. T. (2001): The effect of water availability and quality on photosynthesis and productivity of soilless-grown cut roses. *Scientia Horticulturae*, 88(4), 257–276.
- Raviv, M., Lieth, J. H. (2008): Soilless Culture: Theory and Practice. Elsevier. 587 pp.
- Schwärzel, K., Renger, M., Sauerbrey, R., Wessolek, G. (2002): Soil physical characteristics of peat soils. *Journal of Plant Nutrition and Soil Science*, 165, 479–486.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Stražar, P. (2022): Influence of the color of growing bags for berries on soil conditions and plant growth. University of Ljubljana, Graduation thesis for expert studies. 36 p.
- Zamljen, T., Zupanc, V., Slatnar, A. (2020a): Influence of irrigation on yield and primary and secondary metabolites in two chilies species, Capsicum annuum L. and Capsicum chinense Jacq. Agricultural Water Management, 234, <https://doi.org/10.1016/j.agwat.2020.106104>
- Zamljen, T., Zupanc, V., Slatnar, A. (2020b): Evaluation of soil physical properties of peat substrate. Acta agriculturae Slovenica, 116/2, 357–367, Ljubljana 2020 doi:10.14720/aas.2020.116.2.1851.

VPLYV APLIKÁCIE BIOUHLIA S JEMNÝMI ČASTICAMI NA DVA DRUHY PÔDY

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ABSTRAKT

Pre efektívne hospodárenie s vodou v konkrétnom pôdnom druhu je potrebné poznáť najvýznamnejšie vlastnosti daného pôdneho druhu vo vzťahu k vode. Piesočnatá pôda je známa tým, že je veľmi priepustná. Jedným z hlavných cieľov efektívneho poľnohospodárstva je spomaliť odtok vody z piesočnej pôdy, a tým zabezpečiť zadržanie vody v koreňovej oblasti rastlín. Naše výsledky potvrdzujú, že biouhlíe vyrobené z výby s veľkosťou <125 µm účinne znížuje nasýtenú hydraulickú vodivosť v piesočnej pôde, pričom toto zníženie je približne 80% pre biouhlíe vyrobené pri teplote pyrolízy 300 °C a 82% pre biouhlíe vyrobené pri teplote pyrolízy 520 °C v porovnaní s kontrolou. Vo všeobecnosti má hlinitá pôda optimálny vlhkostný režim. Ak však tento druh pôdy vplyvom otepľovania postupne vysychá, môže sa jeho vlahový režim zmeniť k horšiemu. Našou úlohou je preto hľadať metódy na zvýšenie hydraulickej vodivosti pôdy. Výsledky našej štúdie ukazujú, že biouhlíe s veľkosťou <125 µm účinne zvyšuje nasýtenú hydraulickú vodivosť hlinitej pôdy približne o 111% v prípade biouhlia vyrobeného pri teplote pyrolízy 300 °C a o 60% v prípade biouhlia vyrobeného pri teplote pyrolízy 520 °C v porovnaní s čistou pôdou.

Keywords: piesočnatá pôda, hlinitá pôda, veľkosť častic biouhlia

ÚVOD

Voda nachádzajúca sa v pôdnom profile v koreňovej zóne rastlín ovplyvňuje kolobeh života na Zemi. Podstatou pohľadu na pôdu prostredníctvom vodného režimu je vnímanie pôdy ako veľmi dynamického telesa (Rejšek a Vácha, 2018). Prúdenie vody v pôde z hľadiska rastlín, je najvýznamnejšou vlastnosťou pôdnej vody, nevyhnutnou pre zachovanie života. Vo svete sa stále hľadajú nové možnosti ako zlepšovať vlastnosti pôdy a v oblasti poľnohospodárstva sa preto kladie veľký dôraz aj na rôzne pôdne úpravy. Biouhlíe, ako produkt termálnej degradácie biomasy bohatý na uhlík, je aktuálne v centre pozornosti vedeckej komunity najmä pre svoju schopnosť zlepšovať kvalitatívne parametre pôdy a zmierňovať tempo klímatickej zmeny. Biouhlíe je produkt tepelného rozkladu (pyrolízy) organického odpadu (biomasy). Počas procesu pyrolízy, vysokoteplotnej degradácie v uzatvorenom prostredí so zníženou prítomnosťou kyslíka, sa biomasa mení na biouhlíe, vysoko pórovitý materiál s nízkou hustotou a vysokým podielom uhlíka (Lehmann a Stephen, 2015). Biouhlíe môže byť použité v súvislosti s úpravou pôdnich vlastností (Shakley a kol., 2016). Biouhlíe má potenciál zvýšiť schopnosť zadržiavania vody v pôdnom profile (Karhu a kol., 2011) a taktiež zvýšiť oblasť prístupnej vody pre rastlinky (Blanco–Canqui, 2020). Podľa Wanga a kol. (2019) vyššia dávka ($\geq 10 \text{ t.ha}^{-1}$) biouhlia s veľkým objemom pór môže zlepšiť zadržiavanie vody a môže zlepšiť odolnosť pôdy počas hydrologických extrémov. Samotný príspevok má za cieľ analyzovať vplyv aplikovaného biouhlia s veľkosťou častic veľkosť častic <125µm a v dávke 20 t.ha⁻¹ na hodnoty nasýtenej hydraulickej vodivosti piesočnej a hlinitej pôdy. Ako vstupný materiál sa použila výba švédska, z ktorej boli vyrobené 2 biouhlia a to pri teplote pyrolízy 300 a 520 °C.

METODIKA PRÁCE

Piesočnatá pôda použitá pri tomto experimente bola odobratá z okolia Plaveckého Štvrtka na Záhorskej nížine. Na tejto pôde bol urobený zrnitostný rozbor hustomernou metódou (Velebný, 1981). Tvorí ju 91 % piesku, 7,5 % prachu a 1,5 % ílu, je teda klasifikovaná ako piesok (Velebný, 1981). Hlinitá pôda bola odobratá z lokality Dolná Malanta (Nitra, Slovensko). Pôda v priemere obsahuje $360,4 \text{ g} \cdot \text{kg}^{-1}$ piesku, $488,3 \text{ g} \cdot \text{kg}^{-1}$ prachu a $151,3 \text{ g} \cdot \text{kg}^{-1}$ ílu (Horák, 2017).

Biouhlie použité pri tomto experimente bolo vyrobené v reaktore UNYPIR, ktorý je súčasťou centra AgroBioTech patriaceho Slovenskej poľnohospodárskej univerzite v Nitre. Vstupným materiálom pri oboch typoch biouhlia bola vŕba švédska, odrada Tordis (*(Salix schwerinii x S. viminalis)* x *S. viminalis*). Pri výrobe oboch biouhlí bol použitý rovnaký tlak (101 kPa), avšak teplota pyrolyzy bola rozdielna. Pri prvom biouhlí bola použitá teplota 300°C a pri druhom 520°C . Vyrobené biouhlia boli zomleté na elektrickom mlynčeku a preosiaté na sitách s veľkosťou ôk $125\mu\text{m}$.

Pôdne vzorky zmesí boli pripravené v laboratórnych podmienkach s pomerom množstva biouhlia $20 \text{ t} \cdot \text{ha}^{-1}$ do Kopeckého valčekov (100 cm^3). Boli pripravené nasledovné varianty laboratórneho experimentu: zmes piesočnej pôdy a biouhlia vyrobenom pri teplote 300°C s veľkosťou častíc $<125\mu\text{m}$, zmes piesočnej pôdy a biouhlia vyrobenom pri teplote 520°C s veľkosťou častíc $<125\mu\text{m}$, zmes hlinitej pôdy a biouhlia vyrobenom pri teplote 300°C s veľkosťou častíc $<125\mu\text{m}$, zmes hlinitej pôdy a biouhlia vyrobenom pri teplote 520°C s veľkosťou častíc $<125\mu\text{m}$. Pre každý variant boli následne pripravené 3 opakovania. Tieto pripravené zmesi sa porovnali s referenčnou pôdou (čistý piesok a čistá hlina), ktoré boli pripravené taktiež v 3 opakovaniach. Nasýtená hydraulická vodivosť pôdy bola stanovená na vzorkách v Kopeckého valčekoch na všetkých variantoch laboratórneho experimentu. Pre každý variant boli pripravené 3 pôdne vzorky, spolu bolo teda meranie robené na 54 vzorkách. Na každej pôdnej vzorke sa uskutočnili 3 merania nasýtenej hydraulickej vodivosti pôdy. To znamená, že pre každý variant sme mali spolu 9 nameraných hodnôt nasýtenej hydraulickej vodivosti pôdy. Nasýtená hydraulická vodivosť pôdy bola stanovená pomocou zariadenia s premenlivým hydraulickým sklonom (Obr. 1) (Igaz a kol., 2017).

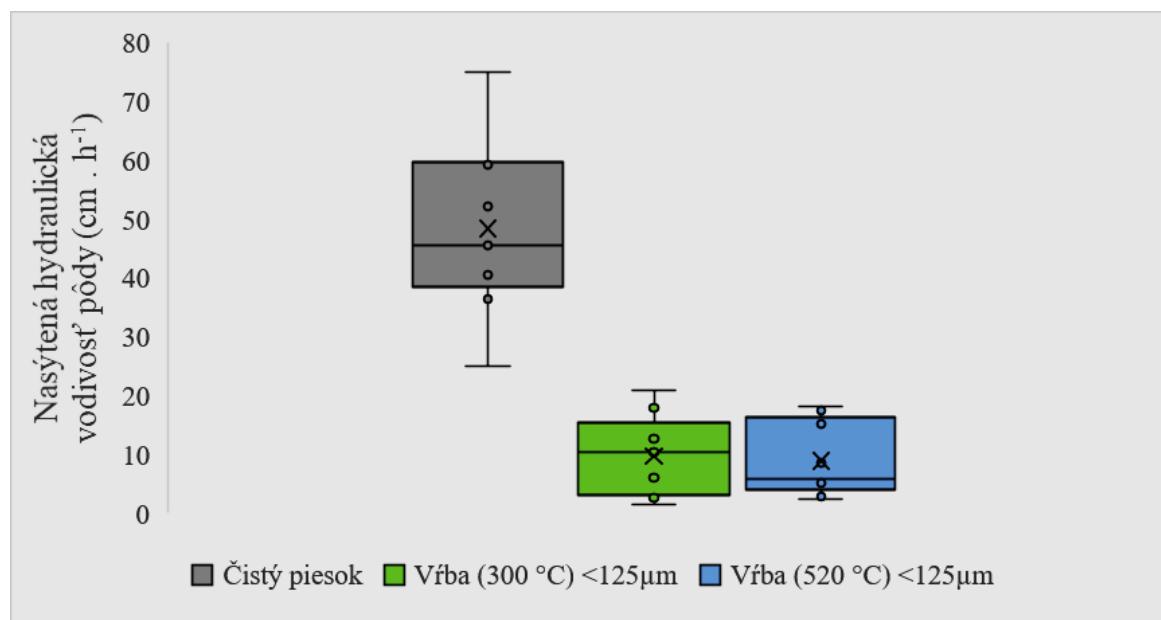


Obr. 1. Laboratórne meranie nasýtenej hydraulickej vodivosti pôdy.

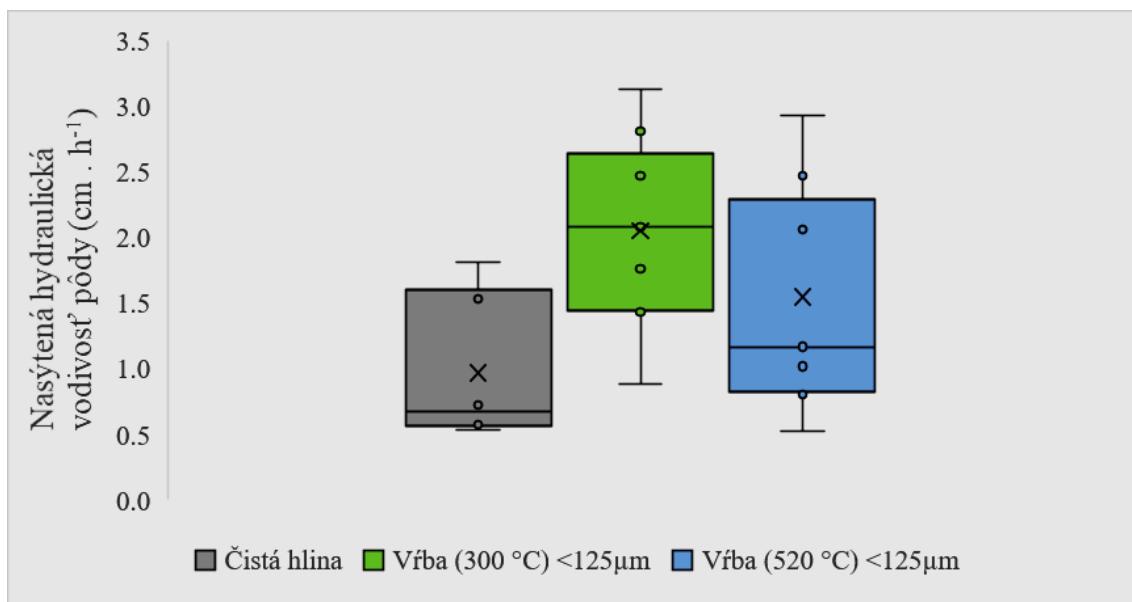
Vyhodnotenie vplyvu biouhlia na nasýtenú hydraulickú vodivosť pôdy sa robilo jednofaktorou analýzou odchýlok (ANOVA testom) a štatisticky významný vplyv pri $p < 0,05$ bol stanovený testom LSD. Na štatistickú analýzu sme použili softvér Statgraphics Centurion XV.I (Statpoint Technologies, Inc., Warrenton, VA, USA). Grafické znázornenie sa robilo pomocou programu Microsoft Excel.

VÝSLEDKY A DISKUSIA

Z našich výsledkov vyplýva, že sa nasýtená hydraulická vodivosť vplyvom aplikácie biouhlia s časticami $<125\mu\text{m}$ mení v závislosti od druhu pôdy (Obr. 2 a Obr. 3). Pri zmesiach piesočnej pôdy s biouhlím sa nasýtená hydraulická vodivosť znížila v porovnaní s čistým pieskom a to nasledovne [čistý piesok] $>$ [Vŕba (300°C) $< 125\mu\text{m}$] $>$ [Vŕba (520°C) $< 125\mu\text{m}$] s priemernými hodnotami nasýtenej hydraulickej vodivosti $48,4 > 9,61 > 8,89 \text{ cm.h}^{-1}$. V oboch prípadoch bolo pozorované štatisticky významné zníženie ($p < 0,05$) (Tab. 1). Naopak pri zmesiach hlinitej pôdy s biouhlím sa nasýtená hydraulická vodivosť zvýšila v porovnaní s čistou hlinou nasledovne [čistá hлина] $<$ [Vŕba (520°C) $< 125\mu\text{m}$] $<$ [Vŕba (300°C) $< 125\mu\text{m}$] s priemernými hodnotami nasýtenej hydraulickej vodivosti $0,97 < 1,55 < 2,05 \text{ cm.h}^{-1}$. Aj v tomto prípade bolo toto zvýšenie štatisticky významné ($p < 0,05$), ale iba v prípade variantu s nižšou teplotou pyrolýzy (Tab. 2).



Obr. 2. Grafické znázornenie vplyvu aplikácie biouhlia s veľkostnou frakciou $<125\mu\text{m}$ vyrobenom pri teplote pyrolýzy 300 a 520°C na nasýtenú hydraulickú vodivosť piesočnej pôdy. Krabicový graf uvádza: minimálnu a maximálnu hodnotu (okrajové čiary), horný a dolný kvartil (hrany obdlžníka), medián (čiara v obdlžníku) a priemernú hodnotu (križik v obdlžníku).



Obr. 3. Grafické znázornenie vplyvu aplikácie biouhlia s veľkostnou frakciou <125µm vyrobenom pri teplote pyrolýzy 300 a 520 °C na nasýtenú hydraulickú vodivosť hlinitej pôdy.
Krabicový graf uvádza: minimálnu a maximálnu hodnotu (okrajové čiary), horný a dolný kvartil (hrany obdĺžnika), medián (čiara v obdĺžniku) a priemernú hodnotu (krížik v obdĺžniku)

Tabuľka 1. Vplyv aplikácie biouhlia s veľkostnou frakciou <125µm vyrobenom pri teplote pyrolýzy 300 a 520 °C na nasýtenú hydraulickú vodivosť piesočnej pôdy. Rozdielne písmená (a, b) naznačujú štatisticky významný rozdiel ($p<0,05$) v hodnotách podľa testu LSD

Variant	Homogénne skupiny
Čistý piesok	b
Víba (300 °C) < 125µm	a
Víba (520 °C) < 125µm	a

Tabuľka 2. Vplyv aplikácie biouhlia s veľkostnou frakciou <125µm vyrobenom pri teplote pyrolýzy 300 a 520 °C na nasýtenú hydraulickú vodivosť piesočnej pôdy. Rozdielne písmená (a, b) naznačujú štatisticky významný rozdiel ($p<0,05$) v hodnotách podľa testu LSD

Variant	Homogénne skupiny
Čistá hlina	a
Víba (300 °C) < 125µm	b
Víba (520 °C) < 125µm	ab

Naše výsledky jednoznačne preukazujú, že aplikované biouhlie vyrobené z víby efektívne znižuje nasýtenú hydraulickú vodivosť v piesočnej pôde a efektívne zvyšuje nasýtenú hydraulickú vodivosť v hlinitej pôde. Vysvetľujeme si to tým, že biouhlie v piesočnatých pôdach spôsobuje pomalší odtok vody a tým aj efektívne potláča stratu vody (Dan a kol., 2015) a v hlinitých naopak zvyšuje nasýtenú hydraulickú vodivosť pôdy (Lehmann a Stephen, 2015). Liu a kol. (2017) uvádzajú, že veľkostné frakcie biouhlia ovplyvňujú ukladanie vody v pôde zmenou priestoru pôrov medzi pôdnymi časticami, inými slovami medzipórami, ale aj pridaním pôrov, ktoré boli súčasťou samotného biouhlia. Lehmann a Stephen (2015) uvádzajú, že biouhlie s menšími časticami ako sú pôdne častice nachádzajúce sa v pôdnom profile môžu po aplikácii znížiť hydraulickú vodivosť pôdy, naopak biouhlia s väčšími časticami ako sú pôdne častice by mohli hydraulickú vodivosť zvýšiť. V našom prípade sa použila piesočnatá pôda v kombinácii s biouhlím o veľkosti $< 125\mu\text{m}$ a hlinitá pôda v kombinácii s biouhlím o veľkosti $<125\mu\text{m}$, čiže jemnejšia frakcia biouhlia. Podľa

Esmaelnejada a kol. (2017) jemnejšie frakcie biouhlia vedia lepšie vyplniť priestory medzi časticami pôdy. Následne pridanie biouhlia bud' upchá, ako v prípade piesočnatých pôd, alebo zväčší pôry ako v prípade kombinácie hliny a biouhlia.

ZÁVER

Môžeme konštatovať, že nasýtená hydraulická vodivosť zmesí pôdy a biouhlia sa mení v závislosti od textúry pôdy a častíc biouhlia. Z našich výsledkov vyplýva, že jemnejšia veľkostná frakcia biouhlia $< 125\mu\text{m}$ efektívne spomaľuje rýchlosť infiltrácie v piesočnatých pôdach, čo bolo potvrdené aj štatisticky a efektívne zrýchľuje rýchlosť infiltrácie v hlinitých pôdach, taktiež potvrdené štatisticky.

Poděkovanie

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LITERATÚRA

- Blanco-Canqui, H. (2020): Does biochar improve all soil ecosystem services? In *Bionergy*, 2020, 13, 4, 291–304. Dostupné na: <<https://doi.org/10.1111/gcbb.12783>>.
- Dan, T., Zhong-Yi, Q., Mang-Mang, G., Bo, L., Yi-Jia, L. (2015): Experimental study of influence of biochar on different texture soil hydraulic characteristic parameters and moisture holding properties. *Polish Journal of Environmental Studies*, 2015, 24, 1435–1442.
- Esmaelnejad, L., Shorafa, M., Gorji, M., Hosseini, S. M. (2017): Impacts of woody biochar particle size on porosity and hydraulic conductivity of biochar–soil mixtures: An incubation study. *Communications in Soil Science and Plant Analysis*, 48, 1710–1718. Dostupné na: <<https://doi.org/10.1080/00103624.2017.1383414>>.
- Horák, J. (2017): Vplyv biouhlia v kombinácii s rôznymi dávkami N hnojív na emisie oxidu dusného (N_2O) v podmienkach poľného experimentu: Effect of biochar in combination with different doses of N fertilizer on nitrous oxide (N_2O) emissions in condition of field experiment. *Ochrana Ovzdušia Air Protection*. Bratislava: Konges STUDIO, 22–24, 147–156. ISBN 978–80–89565–30–6.
- Igaz, D., Kondrlová, E., Horák, J., Čimo, J., Tárník, A., Bárek, V. (2017): Základné merania v hydropedológií. Nitra: SPU, 110, ISBN 978–80–552–1686–7.
- Karhu, K., Mattila, T., Bergström, I., Regina, K. (2011): Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity – Results from a short-term pilot field study. In *Agriculture, Ecosystems and Environment*, 140, 1–2, 309–313. Dostupné na: <<https://doi.org/10.1016/j.agee.2010.12.005>>.
- Lehmann, J., Stephen, J. (2015): Biochar for environmental management: Science, technology and implementation. 2nd ed. London: Routledge, Taylor and Francis Group, 928, ISBN 978–0–415 – 70415–1.
- Liu, Z., Dugan, B., Masiello, C. A., Gonnermann, H. M. (2017): Biochar particle size, shape and porosity act together to influence soil properties. *PLoS One*, 12. Dostupné na: <<https://doi.org/10.1371/journal.pone.0179079>>.
- Rejšek, K., Vácha, R. (2018): Náuka o pôdě. Olomouc: Agriprint, s.r.o. p. 527, ISBN 978-80-87091-82-1.
- Shackley, S., Ruzschaert, G., Zwart, K., Glaser, B. (2016): Biochar in european soils and agriculture. New York: Routledge, Taylor and Francis Group. P. 302, ISBN 978-0-415-71166-1.
- Velebný, V. (1981): Hydropedológia – učebná pomôcka na cvičenia. Bratislava: SVŠT, p. 173, ISBN 85341–81.
- Wang, D., Li, C., Parikh, S. J., Scow, K. M. (2019): Impact of biochar on water retention of two agricultural soils – A multi-scale analysis. In *Geoderma*, 185–191. Dostupné na: <<https://doi.org/10.1016/j.geoderma.2019.01.012>>.

VPLYV ZMENY VYUŽITIA KRAJINY NA PÔDNU VLHKOSŤ V POVODÍ BOLNISISTSKALI V GRUZÍNSKU

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ABSTRAKT

Pôdna vlhkosť zohráva významnú úlohu pri raste plodín a zachovaní vhodných podmienok na obnovu vegetácie. Jej priestorová a časová variabilita vyplýva z topografie, pôdy, vegetácie a využitia krajiny. Tento príspevok sa zaobera analýzou pôdnej vlhkosti v povodí rieky Bolnisistskali v podmienkach súčasného využitia krajiny. Výsledky analýzy boli porovnané so scenárom zmeny vo využití krajiny. Scenár je zameraný na využitie krajiny na poľnohospodárske účely a chov dobytka. Na výskum a porovnávanie analýzy bol použitý zrážkovo-odtokový model s priestorovo rozčlenenými parametrami. Z výsledkov modelovania je zrejmé, že použitím scenára zmeny vo využití krajiny je možné dosiahnuť lepší stav pôdnej vlhkosti v simulovanom povodí.

Kľúčová slová: využitie územia, pôdna vlhkosť, model WetSpa

ÚVOD

Obsah vody v pôde (t. j. pôdna vlhkosť) je kľúčovým faktorom ovplyvňujúcim štruktúru vegetácie v prostrediach s obmedzeným množstvom vody (Rodriguez-Iturbe a kol., 1999); vegetácia zasa vykonáva životne dôležité kontroly celej vodnej bilancie prostredníctvom zložitých a vzájomne sa ovplyvňujúcich hydrologických procesov (Porporato a kol., 2002). Rôzne spôsoby využívania krajiny môžu výrazne ovplyvniť vlastnosti pôdy, ako je objemová hmotnosť, nasýtená hydraulická vodivosť, rýchlosť infiltrácie a dostupný obsah pôdnej vody (pôdnej vlhkosti) (Tellen a kol., 2018). Pretože vlastnosti pôdy sú hlavnými faktormi ovplyvňujúcimi variácie vody v pôde (Tiwari a kol., 2019), využívanie krajiny by mohlo ovplyvniť variácie vody v pôde zmenou vlastností pôdy. Využívanie krajiny je jedným z hlavných faktorov regulujúcich variabilitu pôdnej vlhkosti (Qui a kol., 2001; Gao a kol., 2014).

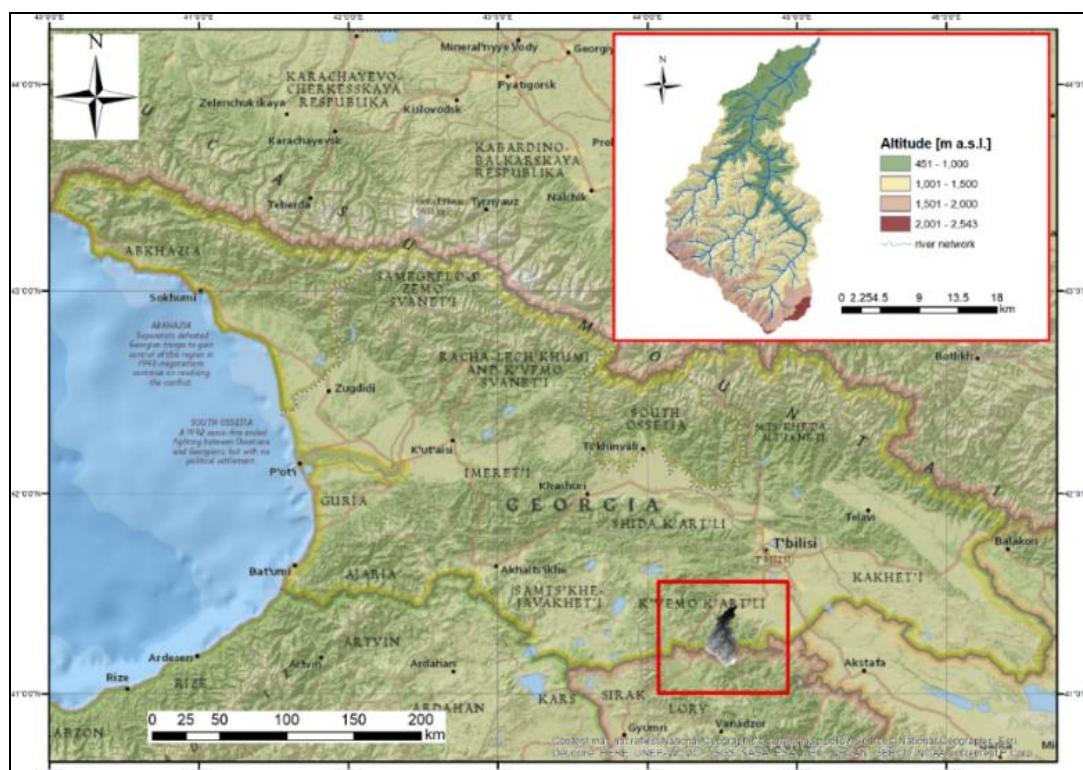
Zmeny vo využívaní krajiny môžu spôsobiť degradáciu pôdy, ktorá je definovaná ako dočasný alebo trvalý pokles produkčnej kapacity pôdy, pričom pôda úplne stratí svoju produkčnú schopnosť (Hlavčová a kol., 2019). Poľnohospodárske aktivity na veľkých plochách sú považované za jeden z hlavných antropogénnych faktorov negatívne ovplyvňujúcich pôdnú eróziu a ekologickú stabilitu krajiny, ktorú je však možné eliminovať efektívnym manažmentom krajiny (Výleta a kol., 2019).

Tento článok nadväzuje na výskum (Rončák a kol., 2018), v ktorom sa autori zaoberali vplyvom zmien využívania krajiny na odtokové procesy s použitím rovnakých vstupov. V tomto článku sme sa zamerali na vývoj scenára zmeny využívania krajiny a simulácie pôdnej vlhkosti na odhadnutie potenciálnych zmien v zmenených podmienkach využívania krajiny v povodí Bolnisistskali. Zmena pôdnej vlhkosti v scenári využitia krajiny bola porovnaná so súčasným stavom.

MATERIÁL A METÓDY

Skúmaná lokalita

Povodie rieky Bolnisistskali s konečným profilom Samtsverisi s rozlohou 360 km² a nadmorskou výškou od 450 do 2 540 m n. m. bolo vybrané ako študijné územie na simuláciu pôdnej vlhkosti zrážkovo-odtokovým modelom. Povodie sa nachádza v juhovýchodnej časti Gruzínska v regióne Kvemo Kartli (obr. 1). Z hľadiska využitia krajiny tu prevládajú listnaté lesy (obr. 2a). Orná pôda sa nachádza v severnej časti povodia. Z hľadiska pôdných druhov sú dominantné najmä piesčito-hlinité a hlinité pôdy (Elizbarashvili a kol., 2006).

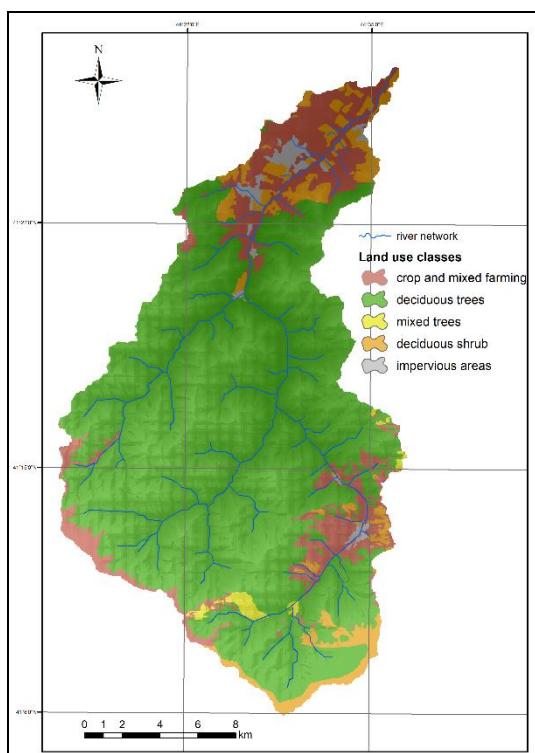


Obr. 1 Poloha záujmového územia s detailom povodia Bolnisistskali – Samtsverisi (DEM).

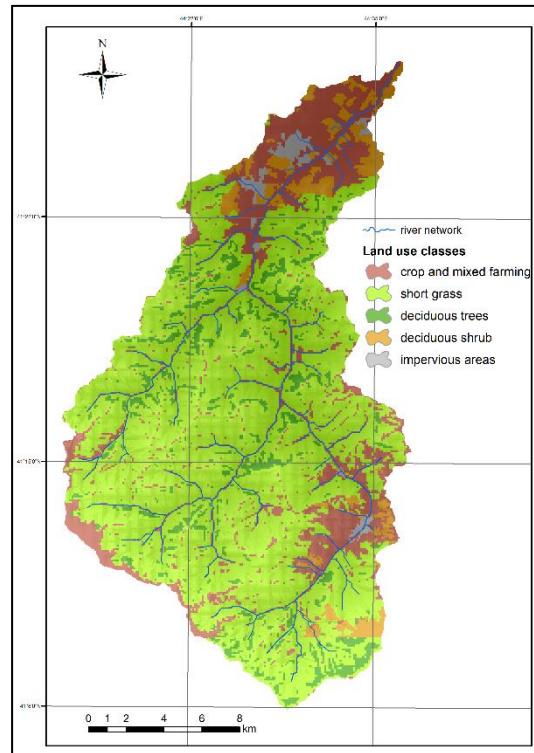
Použité boli hydrometeorologické a klimatické dátá v dennom kroku za obdobie 1971 – 1985. Tieto vstupné údaje (v textovej forme) boli tvorené priemernými dennými zrážkami z 2 zrážkomerných staníc, priemernými dennými teplotami vzduchu zo 4 klimatických staníc a priemernými dennými prietokmi z vodomernej stanici Samtsverisi. Pre potreby modelovania boli použité tiež digitálne priestorové údaje v podobe digitálneho modelu reliéfu (DEM), mapy pôdných druhov, súčasnej mapy využitia územia a vrstiev priestorovo rozčlenených parametrov, ktoré boli odvodené z 3 spomínaných základných máp. Vstupné údaje boli poskytnuté organizáciou NEA (National Environmental Agency – Tbilisi).

V rámci výskumu sme pracovali so súčasným využitím krajiny a nami vytvoreným modelovým scenárom (Obr. 2a, 2b). Súčasné využitie krajiny v povodí Bolnisistskali bolo v rámci scenára zmenené na základe svahovitosti terénu podľa delimitačných kritérií. Územie so sklonom menším ako 12° by bolo vhodné využiť na poľnohospodárske účely (orná pôda), krajina od 12° do 20° v podobe lúk a pasienkov by sa využívala na chov dobytka a kosenie (nízka tráva) a miesta s najvyššími sklonmi by ostali i nadálej zalesnené (listnaté a zmiešané lesy). Pre posúdenie vplyvu zmien využitia územia v modelovom scenári na odtok z povodia bol aplikovaný hydrologický model WetSpa. V danej prípadovej štúdie sa kvalita simulovala

posudzovala porovnaním zhody medzi meranými a modelovanými priemernými dennými hodnotami prietokov v záverečnom profile Samtsverisi na základe Nash – Sutcliffovho koeficientu (NS). V našom prípade pre kalibračné obdobie 1971 – 1985 nadobudol koeficient hodnotu NS = 0,65, čo predstavuje dostatočnú presnosť simulácie.



Obr. 2a) Mapa súčasného využitia krajiny



2b) Mapa scenára zmeny využitia krajiny.

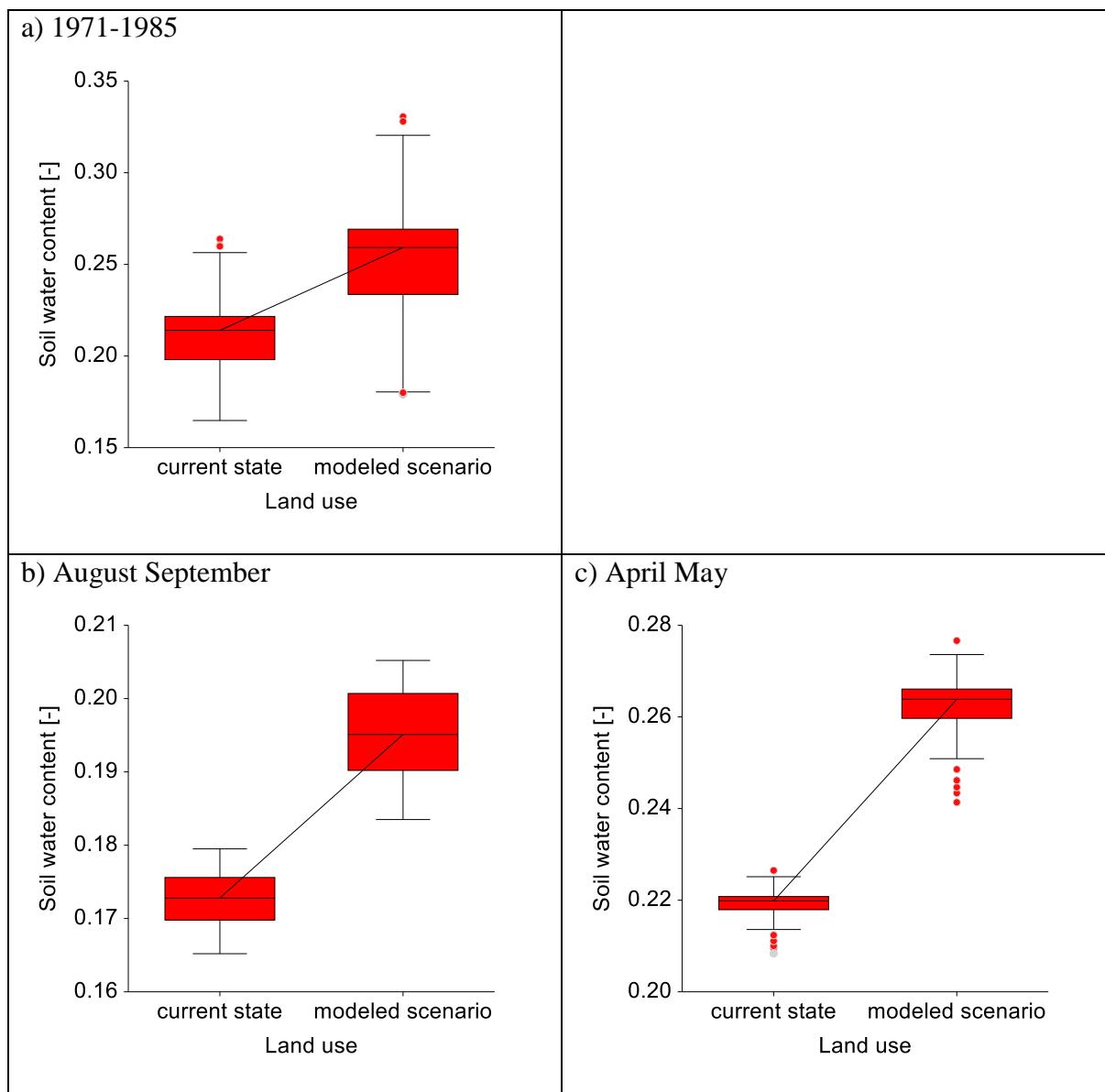
Zóny so sklonmi menšími ako 12 % a pokryté trávou sa zmenili na ornú pôdu. Plochy s deklináciou (12-20%) pokryté ornou pôdou sa zmenili na trávnaté plochy. Na plochách s viac ako 20% sklonom, sa orná pôda a trávnaté plochy zmenili na listnaté lesy.

VÝSLEDKY

Priemerné hodnoty pôdnej vlhkosti v modelovanom povodí za obdobie 1971–1985, simulované pre dva scenáre (súčasné využitie krajiny a alternatívny scenár) sú uvedené v tabuľke 1. ako aj prostredníctvom škatuľových grafov na obr. 3. Scenár alternatívneho využívania krajiny ukázal pozitívny vplyv na obsah vody v pôde v skúmanej lokalite, keďže podľa výsledkov modelovania došlo v rámci scenára k štatisticky významnému zvýšeniu priemernej ročnej SWC (obsah vody v pôde) v porovnaní so súčasným stavom. Okrem priemernej ročnej hodnoty SWC je dôležité sledovať aj hodnotu SWC počas najsuchších a tiež vlhkých období. Rozdiely v modelovaných hodnotách SWC medzi scenármami MS (alternatívny scenár zmeny využitia krajiny) a CS (súčasné využitie krajiny) boli štatisticky významné aj v období sucha a vlhka v období 1971–1985 a môžeme konštatovať, že použitie alternatívneho scenára využitia krajiny by malo pozitívny vplyv na zvýšenie pôdnej vlhkosti v danom povodí.

Tabuľka 1. Štatistické parametre obsahu pôdnej vlhkosti v skúmanej lokalite a) za obdobie 1971–1985, b) za dva najsuchšie mesiace za obdobie 1971–1985, c) za dva najvlhkejšie mesiace za obdobie 1971–1985, odhadované pre 2 scenáre využitia krajiny

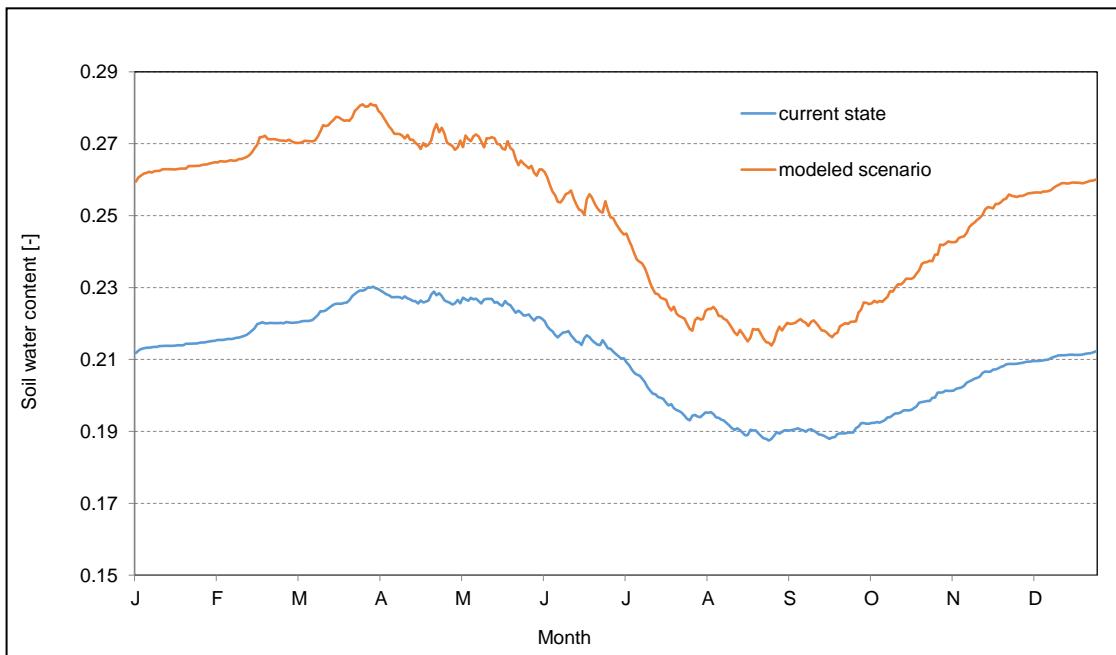
Attribute	Time period	Land Use	Minimum	Maximum	Median	Mean	SD	Skewness	Kurtosis
SWC[-]	1971-1985	CS	0.165	0.264	0.214	0.210 ^a	0.018	-0.470	2.685
		MS	0.179	0.331	0.259	0.251 ^b	0.027	-0.682	2.765
	A-M (1971-1985)	CS	0.208	0.227	0.220	0.219 ^a	0.004	-1.072	4.294
	A-S (1971-1985)	CS	0.165	0.180	0.173	0.173 ^a	0.004	-0.244	2.122
		MS	0.184	0.205	0.195	0.195 ^b	0.006	-0.135	1.854



Obr. 3. Škatuľový graf obsahu vody v pôde na študovanej lokalite a) za obdobie 1971–1985, b) za dva najsuchšie mesiace v období 1971–1985, c) za dva najvlhkejšie mesiace v období 1971–1985, odhadované pre 2 scenáre využitia krajiny.

Dynamika priemerného denného obsahu vody v pôde v diagnostikovanom horizonte zóny aerácie pôdy má cyklický charakter s jednorocnou periódou opakovania na skúmanej lokalite. Vo väčšine rokov analyzovaného obdobia možno tento cyklus rozdeliť na obdobie nasýtenia a

obdobie odtoku. Obsah pôdnej vody sa od jesene zvyšuje s vrcholom v skorých jarných mesiacoch (obr. 4). Začiatok vegetačného obdobia sa prejavuje výrazným poklesom zimných zásob a dostupnosť pôdnej vody je plne ovplyvnená aktuálnymi zrážkami. Táto situácia môže vytvárať podmienky pre vodný stres rastlín.



Obr. 4. Cyklický priebeh priemerného denného obsahu vody v pôde za obdobie 1971–1985 bol odhadnutý pre 2 scenáre využitia krajiny.

ZÁVER

Tento článok popisuje možný vplyv zmeny využívania krajiny na zložku vodnej bilancie. Pôdná vlhkosť je dôležitá v mnohých hydrologických procesoch. Preto je dôležité poznať jej správanie v zmenených podmienkach, najmä to, ako zmena využívania krajiny ovplyvňuje vlhkosť pôdy. Zmeny pôdnej vlhkosti boli vyhodnotené porovnaním simulovanej priemernej pôdnej vlhkosti pre súčasný stav a scenár zmeny využívania krajiny. Scenár zmeny využívania krajiny ukázal pozitívny vplyv na obsah vody v pôde v skúmanom povodí, keďže podľa výsledkov modelovania došlo v rámci scenára k štatisticky významnému zvýšeniu priemernej ročnej hodnoty pôdnej vlhkosti v porovnaní so súčasným stavom.

Vytvorený scenár bol tiež použitý na analýzu schopnosti modelu Wetspa simulať zmeny vo využívaní krajiny. Model WetSpa preukázal dostatočnú schopnosť simulať vlhkosť pôdy pri meniacich sa podmienkach využívania krajiny. Pri interpretácii týchto zistení však netreba zabúdať na limity zrážkovo-odtokového modelovania. Počítacové simulačné modely sú vo svojej podstate neisté, a to ešte viac pri zvažovaní budúcich projekcií.

Podčakovanie

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LITERATÚRA

- Elizbarashvili E. S., Chavchanidze Z. B., Elizbarashvili M. E., Maglakelidze R. V., Sulkhanishvili N. G., Elizbarashvili S. E. (2006): Soil-climatic zoning of Georgia. *Eurasian Soil Science*, 39(10): 1062-1065.
- Gao X., Wu P., Zhao X., Wang, J., Shi, Y. (2014): Effects of land use on soil moisture variations in a semi-arid catchment: implications for land and agricultural water management. *Land Degradation & Development*, 25(2): 163-172.
- Hlavčová K., Danáčová M., Kohnová S., Szolgay J., Valent P., Výleta R. (2019): Estimating the effectiveness of crop management on reducing flood risk and sediment transport on hilly agricultural land–A Myjava case study, Slovakia. *Catena*, 172: 678-690.
- Porporato A., D'odorico P., Laio F., Ridolfi L., Rodriguez-Iturbe I. (2002): Ecohydrology of water-controlled ecosystems. *Advances in Water Resources*, 25(8-12): 1335-1348.
- Qiu Y., Fu B., Wang J., Chen L. (2001): Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. *Journal of Hydrology*, 240(3-4): 243-263.
- Rodriguez-Iturbe I., D'odorico P., Porporato A., Ridolfi, L. (1999): On the spatial and temporal links between vegetation, climate, and soil moisture. *Water Resources Research*, 35(12) 3709-3722.
- Rončák P., Malíariková M., Nosko R., Kordzakhia G., Kordzakhia M. (2018): Utilization of a rainfall-runoff hydrological model in studies on the impact of land use changes: Case Study from Georgia. *Bull. Georg. Nat. Acad. Sci*, 12(2):63-69.
- Tellen V. A., & Yerima B. P. (2018): Effects of land-use change on soil physicochemical properties in selected areas in the North West region of Cameroon. *Environmental Systems Research*, 7(1): 1-29.
- Tiwari S., Singh C., Boudh S., Rai P. K., Gupta V. K., Singh J. S. (2019): Land use change: a key ecological disturbance declines soil microbial biomass in dry tropical uplands. *Journal of Environmental Management*, 242: 1-10.
- Výleta R., Valent P., Nemetova Z., Hlavcová K. (2019): An Assessment of Changes in Ecological Stability and Landscape Management Practices over the Last Centuries: A Case Study from Vrbovce, Slovakia. In IOP Conference Series: Materials Science and Engineering (603, 2: 022083).

ZÁSOBY VODY V PÔDE PO APLIKÁCII BIOUHLIA POČAS VEGETAČNÉHO OBDOBIA 2021

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ABSTRAKT

Pôdna vlhkosť zohráva dôležitú úlohu pri monitorovaní v poľnohospodárstve, pri predpovediach sucha a povodní, predpovedi lesných požiarov, manažmente zásobovania vodou a iných aktivitách v oblasti prírodných zdrojov. V našom príspevku sa venujeme monitoring vlhkosti pôdy a zásobám vody v povrchovej vrstve pôdy počas vegetačného obdobia v roku 2021, pričom porovnávame plochy s aplikovaným biouhlím a bez neho. Výsledky ukázali, že na plochách s biouhlím bola vlhkosť pôdy, a teda aj zásoba vody v pôde vyššia takmer počas celého monitorovaného obdobia. Dôležitosť výsledku je predovšetkým v tom, že počas období bez zrážok bol rozdiel medzi plochami markantnejší, čo potvrdilo pozitívny vplyv biouhlia na dlhšie zadržanie vody v krajine.

Keywords: biouhlie, pôdna vlhkosť, zásoby vody v pôde, monitoring

ÚVOD

Pôdna vlhkosť je podľa Americkej meteorologickej spoločnosti (AMS, 2012) „celkové množstvo vody vrátane vodnej pary v nenasýtenej pôde“. Pôdna vlhkosť – niekedy nazývaná aj pôdna voda – predstavuje vodu v zóne aerácie pôdy, ktorá sa nenachádza v riebach, jazerách alebo podzemných vodách, ale nachádza sa v póroch pôdy. Pôdna vlhkosť je daná množstvom faktorov vrátane typu pôdy a súvisiacej vegetácie. Zároveň pôdnú vlhkosť ovplyvňuje celý rad procesov súvisiacich s dynamikou pôdy a rastlín. Povrchová vlhkosť pôdy je voda, ktorá sa nachádza v horných 10 cm pôdy. Pôdna vlhkosť zohráva dôležitú úlohu pri monitorovaní v poľnohospodárstve, pri predpovediach sucha a povodní, predpovedi lesných požiarov, manažmente zásobovania vodou a iných aktivitách v oblasti prírodných zdrojov. Pozorovania pôdnej vlhkosti môžu predpovedať blížiace sa sucho alebo záplavy skôr, ako sa spustia iné štandardnejšie indikátory. Voda zo zrážok preniká cez vegetačný kryt a povrch pôdy do zóny aerácie, kde sa akumuluje, prerozdeľuje a časť preniká do nižších geologických štruktúr, kde sa transformuje na podpovrchový odtok. Z tohto aspektu niektorí autori označujú vegetačný kryt za "zelený filter" a pôdny pokryv za "hnedý filter" zrážok vzhladom na ich transformáciu na odtok z povodia (Šútor et al., 2008). Dopad klimatickej zmeny na zásoby vody v zóne aerácie pôdy počas hydrologického roku, resp. vo vegetačnom období, je evidentný. Zásoba vody v zóne aerácie pôdy predstavuje disponibilný zdroj vody pre poľnohospodárske a lesné ekosystémy, čím determinuje ich existenciu. Kvantifikuje sa priamym monitoringom (Šútor et al., 2007). V posledných rokoch sa takmer každý rok vyskytujú dlhšie bezzrážkové obdobia, ktoré počas vegetačného obdobia ovplyvňujú kvalitu i kvantitu pestovaných poľnohospodárskych plodín. Akonáhle má rastlina k dispozícii málo prístupnej vody vzniká sucho, ktoré vyvoláva v rastlinách stres. Takáto situácia nastáva v dôsledku vysychania pôdy a intenzívnej transpirácie. Vznikajúci vodný deficit je v rastlinách výsledkom nerovnováhy medzi príjomom a výdajom vody rastlinou. V dôsledku jeho pôsobenia vzniká súbor fyziologických a metabolických reakcií, ktoré vedú z pravidla k nižšej fotosyntetickej aktivite, poklesu listovej plochy a rovnako aj k nižšiemu počtu odnoží, vetví a

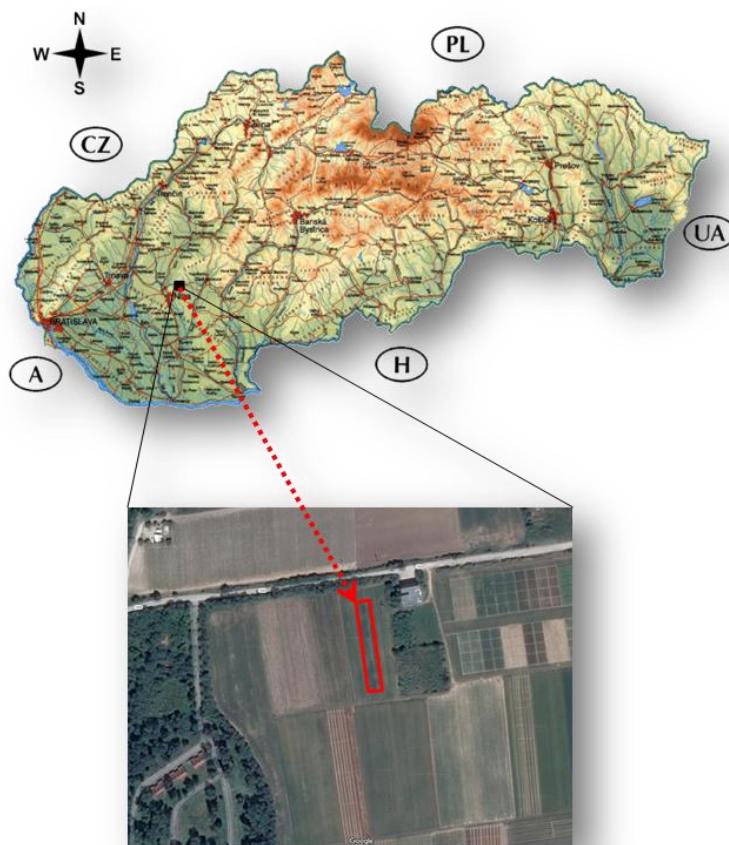
v neskoršom období sa znižuje počet zŕn (semien), čo má dopad na celkovú úrodu a biomasu poľných plodín. V posledných rokoch sa veľká časť odborníkov zameriava na výskum aplikácie biouhlia do pôdy. Biouhlie ako produkt termálnej degradácie organických materiálov bez prítomnosti vzduchu (Lehmann a Joseph, 2009a) môže zlepšiť pôdne vlastnosti zmenou fyzikálnych charakteristík pôdy. Medzi ne patria pórovitosť, objemová hmotnosť, hydraulická vodivosť alebo retenčná kapacita pôdy (Githinji, 2013; Tárník, 2019). Okrem toho môže meniť aj niektoré chemické vlastnosti pôdy, napr. pH, kapacitu výmeny kationov alebo dostupnosť živín (Deal et al., 2012).

V našom príspevku sme skúmali zmeny zásoby vody v povrchovej vrstve pôdy počas vegetačného obdobia v roku 2021, pričom sme porovnali plochy bez biouhlia a s prídomkom biouhlia v množstve 20 t.ha^{-1} . Na základe vedeckých štúdií a našich predchádzajúcich výskumov sme predpokladali, že na plochách s biouhlím bude vyššia zásoba vody v povrchovej vrstve pôdy.

MATERIÁL A METÓDY

Skúmaná lokalita

Pravidelný monitoring vlhkosti pôdy počas vegetačného obdobia vykonávame od roku 2015 na experimentálnej lokalite Dolná Malanta (obr. 1), ktorá patrí Slovenskej poľnohospodárskej univerzite v Nitre. Lokalita sa nachádza v nadmorskej výške 175 m n. m. a pôda je klasifikovaná ako prachovito-hlinitá s obsahom piesku 15,2 %, prachu 59,9 % a ílu 24,9 % (Šimanský a Klimaj, 2017).



Obr. 1. Experimentálna lokalita Dolná Malanta.

Biouhlie

Na experimentálne lokalite bolo v roku 2014 aplikované biouhlie do hĺbky 0-15 cm pod povrhom terénu. Biouhlie použité pre tento poľný experiment bolo vyrobené firmou Sonnenerde (Rakúsko) z papierenkého kalu a obilných šupiek v pomere 1:1 vzhladom k hmotnosti. Vzniklo pyrolýzou pri teplote 550 °C a aplikovaná veľkosť frakcie biouhlia bola 0-5 mm. Ďalšie základné parametre biouhlia popísali Domanová et al. (2015) a niektoré z nich sú zobrazené v Tabuľke 1.

Tabuľka 1. Chemické zloženie použitého biouhlia

	C (%)	N (%)	H (%)	O (%)	pH _(CaCl₂) (-)
Biouhlie	53.1	1.4	1.84	5.3	8.8

Monitoring vlhkosti pôdy a výpočet zásoby vody v pôde

Meranie vlhkosti pôdy začalo inštaláciou dielektrických senzorov vlhkosti pôdy (obr. 2) typu 5TM (Decagon Devices, USA) a záznamy sa ukladali v 5 minútových intervaloch do dataloggerov EM50 (Decagon Devices, USA). Senzory boli inštalované do hĺbky 10 cm pod povrhom terénu na dve plochy bez biouhlia (Control) a na dve plochy s aplikovaným množstvom biouhlia 20 t.ha⁻¹ (B20). V prvom variante (Control) boli inštalované štyri senzory, v druhom variante (B20) bolo inštalovaných 5 senzorov. V tomto príspevku prezentujeme priemerné denné hodnoty vlhkosti pôdy pre každý variant. Počas vegetačného obdobia roku 2021 sa na experimentálnej lokalite pestovala pšenica ozimná (*Triticum aestivum L.*), ktorá bola vysiata na jeseň 2020. Nás monitoring začal 9.4.2021 a bol ukončený pred zberom úrody, 21.7.2021.



Obr. 2. Inštalácia senzorov na experimentálnej lokalite Malanta, 9.4.2021.

Zásobu vody v pôdnom profile možno vypočítať pomocou nameraných aktuálnych vlhkostí jednotlivých vrstiev pôdneho profilu zo vzťahu (1), ktorý uvádzajú Antal et al. (2014):

$$W = \sum_{i=1}^n \theta_i \cdot h_i \quad [mm], \quad (1)$$

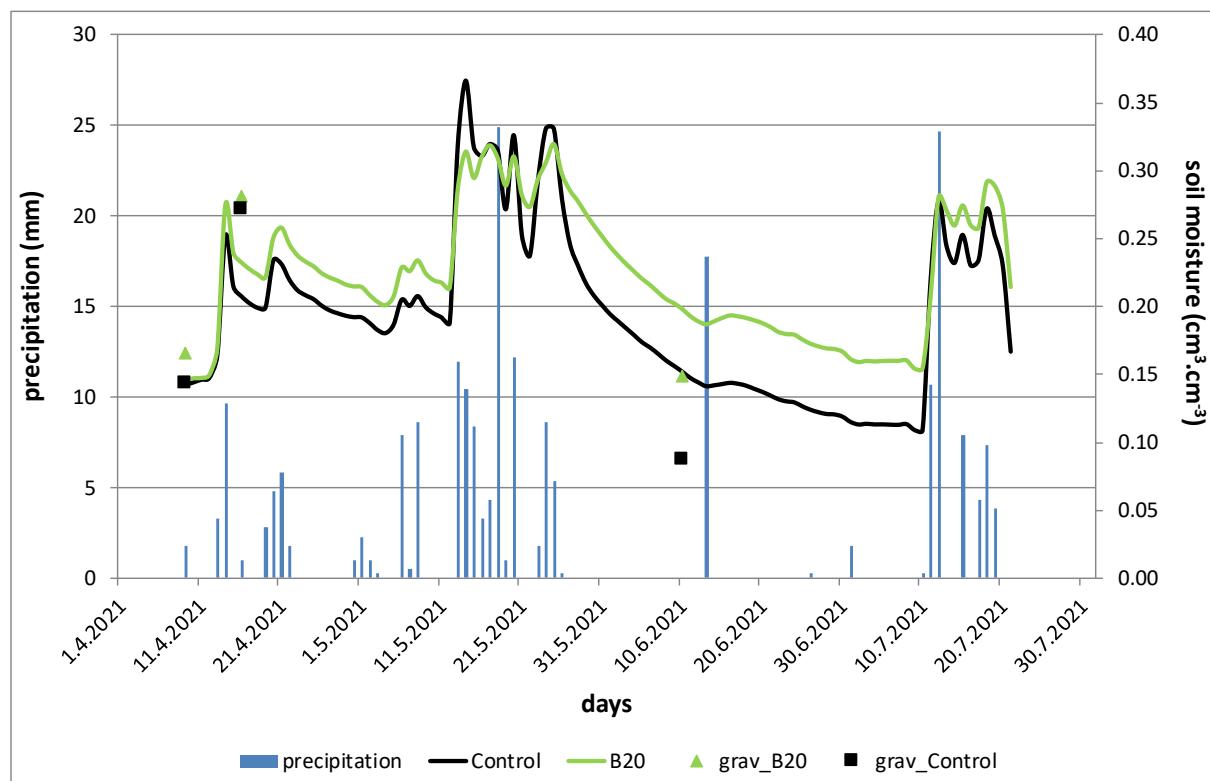
kde:

W - zásoba vody (mm),

θ_i - aktuálna vlhkosť i-tej vrstvy ($\text{cm}^3 \cdot \text{cm}^{-3}$),
 h_i - hrúbka i-tej vrstvy pôdneho profilu (mm).

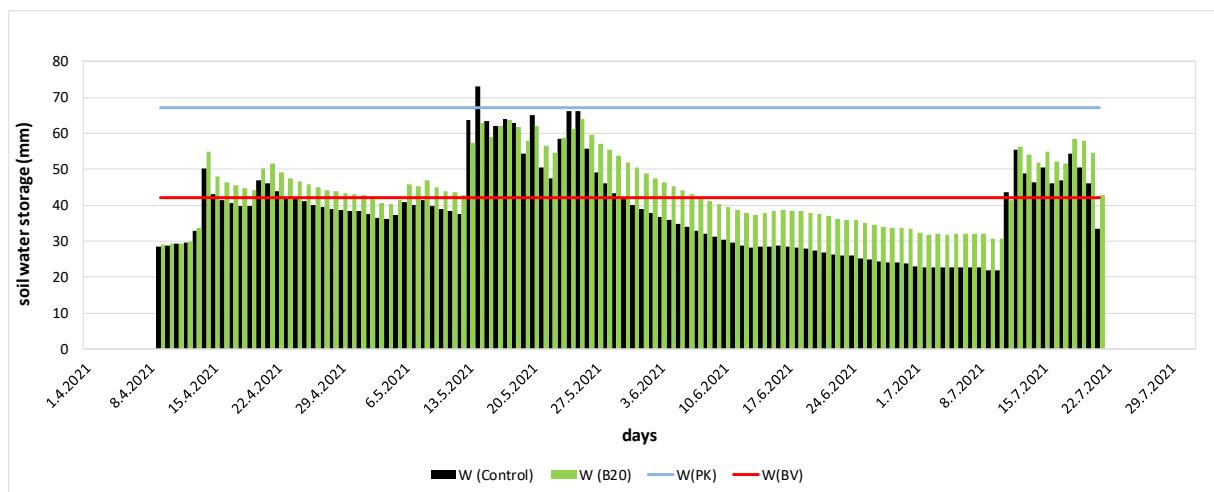
VÝSLEDKY A DISKUSIA

Priemerné denné namerané vlhkosti pôdy na variante Control a B20 sú zobrazené na obr. 3. Z meraných hodnôt vyplýva, že takmer počas celého monitorovaného obdobia bola vlhkosť pôdy vyššia na plochách s biouhlím (B20). Opačné výsledky boli namerané iba počas daždivého obdobia od 13 do 26.5.2021, rozdiel ale neboli významný. Počas monitorovaného obdobia boli trikrát odobraté vzorky pôdy na zistenie vlhkosti gravimetrickou metódou (9.4., 16.4. a 10.6.2021). Z obr. 3 vyplývajú rozdiely medzi vlhkostami pôdy zistenými gravimetrickou metódou a nameranými pomocou senzorov 5TM. Trend je však rovnaký, a sice že vo všetkých troch prípadoch bola vyššia vlhkosť pôdy na ploche B20.



Obr. 3. Namerané vlhkosti pôdy pomocou senzorov 5TM a zistené gravimetrickou metódou v porovnaní s dennými úhrnnmi zrážok na experimentálnej lokalite Malanta.

Denné zásoby vody boli prepočítané na pôdnú vrstvu 0-20 cm, pretože senzory vlhkosti 5TM zaberajú diameter 10 cm. Boli porovnané so zásobou vody pre hydrolimity poľná vodná kapacita (W(PK)) a bod vädnutia (W(BV)). Rozdiel medzi týmito hydrolimitmi je využiteľná vodná kapacita, teda voda prístupná pre rastliny (Antal et al., 2014). Z obr. 4 vyplýva, že dostatok prístupnej vody pre rastliny bol iba počas vlhkých dní a krátko potom. Vlhkosť pôdy klesla na dlhšie obdobie na ploche Control pod kritickú hodnotu 30.5.2021 a na B20 o 10 dní neskôr 8.6.2021. V nasledujúcom období s minimálnym množstvom zrážok boli zásoby vody v povrchovej vrstve pôdy výrazne pod kritickou hodnotou (pod bodom vädnutia). Napriek tomu boli ale vyššie zásoby pôdnej vody na ploche B20.



Obr. 4. Vypočítané zásoby vody (W) v povrchovej vrstve pôdy na plochách Control a B20 v porovnaní so zásobami prístupnej pôdnej vody pre rastlinu (rozdiel medzi W(PK) a W(BV)).

ZÁVERY

Zásoba vody v pôde je dôležitým faktorom ovplyvňujúcim kvalitu i kvantitu poľnohospodárskych plodín. V našom príspevku sme porovnali množstvo zásob vody prístupnej pre pšenicu ozimnú pestovanú vo vrchnej vrstve prachovito hlinitej pôdy. Výsledky ukázali, že počas dlhšieho obdobia zrážkových dní a krátko po nich bolo na plochách s biouhlím aj bez neho porovnatelné množstvo vody. Naša hypotéza sa potvrdila počas dlhších bezzážkových dní, kedy nastali významnejšie rozdiely medzi variantmi. Hoci boli v tomto období zistené nízke zásoby pôdnej vody pri oboch variantoch, napriek tomu boli vyššie na plochách s biouhlím. V čase vegetačného obdobia je pôdne sucho negatívny faktor, ktorý spôsobuje rastlinám stres, čo sa negatívne prejavuje na ich kvalitatívnych aj kvantitatívnych parametroch. Z nášho výskumu vyplýva, že hoci bolo biouhlie aplikované ešte v roku 2014, má aj po ôsmich rokoch významný dopad na hydrofyzikálne vlastnosti pôdy a v čase suchých letných dní aj pozitívny efekt na zásoby v povrchovej vrstve prachovito hlinitej pôdy.

Podčakovanie

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LITERATÚRA

- American Meteorological Society (2012): Dostupné online: <https://glossary.ametsoc.org/wiki/Soil_moisture>. cit. [6-10-2022].
- Antal, J., Bárek, V., Čimo, J., Halaj, P., Halászová, K., Horák, J., Igaz, D., Jurík, L., Muchová, Z., Novotná B., Šinka, K. (2014): Hydrológia poľnohospodárskej krajiny. Nitra: SPU v Nitre, 371 p., ISBN 978-80-552-1257-9.
- Deal, C., Brewer, C.E., Brown, R.C., Okure, M.A.E., Amoding, A. (2012): Comparison of kiln-derived and gasifier-derived biochars as soil amendments in the humid tropics. Biomass Bioenergy, 37, 161–168.
- Domanová, J., Igaz, D., Borza, T., Horák, J. (2015): Retenčné charakteristiky pôdy po aplikácii biouhlia. Acta Hydrologica Slovaca, 16 (2), 193–198.
- Githinji, L. (2013): Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. Arch. Agron. Soil Sci., 60, 457–470.

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- Lehmann J., Joseph S. (2009): Biochar for Environmental Management: Science and Technology. London: Earthscan/James & James, UK, 450 p.
- Šimanský V., Klimaj A. (2017): How does biochar and biochar with nitrogen fertilization influence soil reaction? *Journal of Ecological Engineering*, 18, 50–54.
- Šútor, J., Gomboš, M., Tall, A., Kandra, B. (2007): Potential and monitored water storage in the soil aeration zone in the territory of Medzibrožie (in Slovak). *Acta Hydrologica Slovaca*, 8, 182–192.
- Šútor, J., Štekauerová, V., Nagy, V. (2008): Dynamic of the water storage in soils on the locality Hurbanovo through vegetation period in 2008 (in Slovak). *Acta Hydrologica Slovaca*, 9, 153–160.
- Tárník, A. (2019): Impact of Biochar Reapplication on Physical Soil Properties. IOP Conf. Ser.: Mater. Sci. Eng. 603 022068.

Section II: Surface Hydrology

ANALÝZA MINIMÁLNYCH DENNÝCH PRIETOKOV A STANOVENIE ICH NÁVRHOVÝCH HODNÔT V POVODÍ RIEKY IPEĽ

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ABSTRAKT

V poslednom desaťročí 2011–2020 v takmer všetkých slovenských povodiach bol zaznamenaný výrazný pokles prietokov. Prvoradou otázkou, na ktorú sa pokušajú v súčasnosti vodohospodári a hydrológovia nájsť odpoveď je, čo je príčinou tohto poklesu. Či ide o trvalý úbytok odtoku (v dôsledku zvyšovania teploty vzduchu), alebo príčiny treba hľadať v prirozenom kolísaní odtoku a antropogénnej činnosti človeka. Cieľom predloženej štúdie je štatistická analýza zmien hydrologického režimu troch subpovodí v povodí rieky Ipel s dôrazom na malú vodnosť na základe priemerných denných prietokov za 90-ročné obdobie pozorovaní (1931–2020).

Kľúčové slová: analýza odtoku, minimálne prietoky, rieka Ipel', návrhové hodnoty

ÚVOD

Slovensko je vzhľadom na svoju rozlohu veľmi rôznorodá krajina s členitým reliéfom, pestrým geologickým podložím, početnými pôdnymi druhmi, bohatou krajinnou pokrývkou, vysokou lesnatostou. K tomu všetkému sa pridávajú klimatické činitele, predovšetkým zrážky, ktoré sú takisto rôznorodé v čase a priestore. Vzhľadom na to je zložité nájsť regióny s analogickým režimom odtoku. Preto je potrebné analyzovať zmeny odtoku osobitne vo veľkom počte tokov.

Už v šesťdesiatych rokoch minulého storočia v bývalom Československu sa analýze vývoja hydrologických radov venoval celý rad vodohospodárov (napr. Křivský (1957), Bratránek (1960, 1964), Švec (1962), Balek (1968)). Vo svojich prácach Bratránek vyslovil domnienku, že v hydrosfére dochádza k prirodzenému, približne 90 ročnému kolísaniu. Koncom minulého storočia sa tejto tematike – v súvislosti so zmenou klímy – venovali napr. Klige a kol. (1989), Bradley (1994), Majerčáková a Škoda (1993), Brázdiel a Kolář (1994), Lapin a kol. (1994), Přenosilová a kol. (1994), Koníček (1996), Hladný (1997), Miklánek (1997), Szolgay a kol. (1997), Petrovič (1997), Lukjanetz a Soszedko (1998), Gomboš a kol., (1999), Halmová (1999).

V 21. storočí sa hydrológovia venujú predovšetkým analýze dlhodobých trendov prietokov. Poórová a kol. (2013) skúmali trendy minimálnych ročných a mesačných prietokov za obdobie rokov 1961–2012 v slovenských povodiach. Podľa ich výsledkov ročné minimá klesajú v povodí Moravy, dolného Váhu, Nitry, Hrona, Ipl'a, Slanej a Bodvy. Stúpajúci trend ročných miním majú toky v povodí horného Váhu, Popradu, Hornádu a Bodrogu. Pekárová a kol. (2017) porovnávali trendy ročných miním a maxím prietokov na desiatich významných slovenských tokoch v dvoch obdobiach (1931–1972 a 1973–2014). Zistili, že minimálne ročné prietoky majú rastúci trend (okrem Váhu a Krupinice), rastú aj 3- a 7-dňové minimá. Naopak, klesajú maximálne ročné prietoky, 3- a 7-dňové maximá. Ďurigová a kol. (2019) analyzovali priemerné mesačné prietoky na vybraných 14.-tich slovenských tokoch pomocou základnej popisnej štatistiky a trendovej analýzy. Zistili, že najväčšie zmeny v trendovej a periodickej zložke sú na toku Hron. Z menších povodí, najmä toku Kysuca, Bystrica a Čierny

Váh vykazujú štatisticky významne klesajúce trendy. Ďurigová a Hlavčová (2020) detekovali zmeny dekádnych hydro-meteorologických radov na hornom Váhu, Pavelková a kol. (2021) na Východnom Slovensku. Podrobnej analýza vývoja prietokov najvýznamnejších tokov v povodí Dunaja bola spracovaná v rámci spolupráce podunajských krajín v monografii „Flood regime of rivers in the Danube River basin“ (Ed. Pekárová a Miklánek, 2019). V poslednom dvadsaťročí boli zaznamenané už aj zmeny v hydrologickej bilancii v slovenských povodiach (Blaškovičová a kol., 2022; Halmová a kol., 2022). V poslednej dekáde po roku 2010 sa vyskytli v celom povodí Dunaja viaceré suché roky. V Európe sa sucho vyskytuje viac v mediteránnej oblasti, v Španielsku, Taliansku, alebo Grécku. No aj v povodí Dunaja sa v minulosti vyskytli viaceré extrémne suchá, napr. v roku 1921, 1947, 1992–93, 2003, 2015.

Cieľom predloženého príspevku je:

- štatistická analýza hydrologického režimu troch subpovodí v povodí rieky Ipeľ na základe priemerných denných prietokov za 90-ročné obdobie pozorovaní (1931–2020);
- analýza extrémnych (minimálnych a maximálnych) prietokov uvedených troch riek.

OPIS POVODÍ, POUŽITÉ ÚDAJE

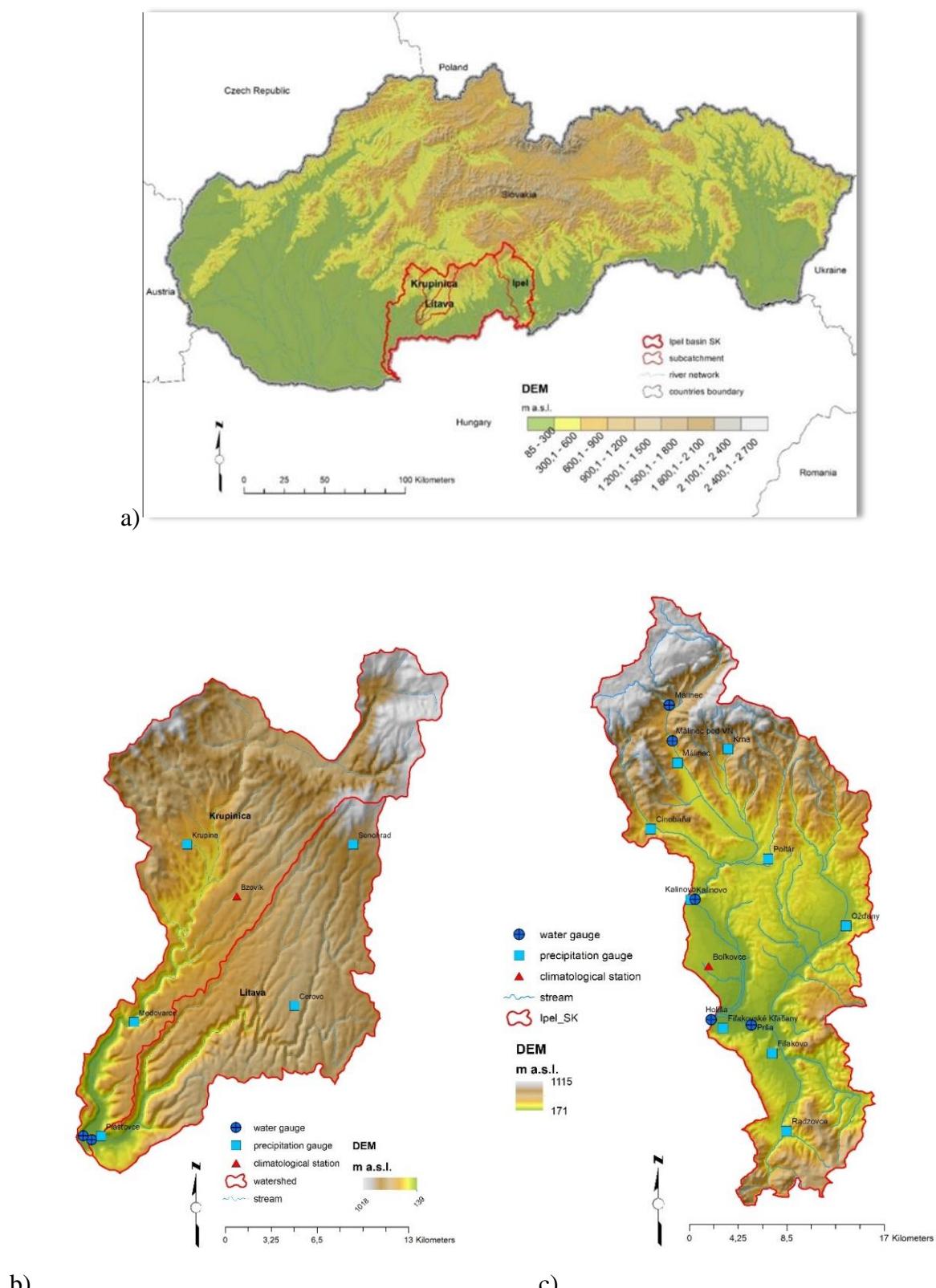
V práci boli použité rady priemerných denných prietokov z troch vodomerných staníc s dlhými radmi pozorovaní zo slovenskej časti povodia rieky Ipeľ: 1. Ipeľ po stanicu Holiša; 2. Krupinica po stanicu Plášťovce; a 3. Litava po stanicu Plášťovce (obr. 1a).

Ipeľ je posledným priamym pravostranným prítokom Dunaja na území Slovenska. Jeho povodie sa rozprestiera na Slovensku a v Maďarsku. Slovenská časť predstavuje 3650 km^2 , čo je 7,4% plochy Slovenska. Rieka Ipeľ pri svojej dĺžke 233 km tečie zväčša južným smerom a odvodňuje juhozápadnú časť Slovenského Rudohoria, Javorie a celú Ipeľskú planinu. Najvyššiu nadmorskú výšku v povodí dosahuje vrch Drahová (1118 m n. m.) vo Veporských vrchoch. Priemerná nadmorská výška povodia je 380 m n. m. a priemerný sklon reliéfu v smere spádovej krivky je $6,5^\circ$. Ipeľ a jeho prítoky na slovenskej a maďarskej časti povodia spolu vytvárajú perovitú riečnu sieť. Jej hustota je $1,8 \text{ km/km}^2$. Priemerný ročný úhrn zrážok na povodie je 635 mm. Z tejto hodnoty sa 80% vyparí a 20% prestavuje odtok. Povodie sa nachádza vo vrchovinovo – nížinnej oblasti s dažďovo snehovým režimom odtoku s najvyššou vodnosťou v jarných mesiacoch. Povodie Ipl'a po stanicu Holiša (obr. 1c) má $685,26 \text{ km}^2$. Dlhodobý priemerný prietok Ipl'a v stanici Holiša (1931–2020) je $3 \text{ m}^3 \cdot \text{s}^{-1}$.

Povodie Krupinice (obr. 1b) po stanicu Plášťovce má $302,79 \text{ km}^2$. Rieka Krupinica pramení v pohorí Javorie pod vrcholom Veľký Lisec. Je pravostranným prítokom rieky Ipeľ. Rieka sa zarezáva do Pliešovskej kotliny, Štiavnických vrchov, Krupinskej planiny a Ipeľskej pahorkatiny. Dlhodobý priemerný prietok Krupinice v stanici Plášťovce bol v období 1931–1960 $2,2 \text{ m}^3 \cdot \text{s}^{-1}$. Za obdobie 1931–1960 dlhodobá priemerná ročná teplota vzduchu v povodí bola $8,2^\circ \text{C}$. Priemerne spadlo v povodí 695 mm zrážok za hydrologický rok (Charakteristické hydrologické údaje slovenských tokov, 1963). Z tejto hodnoty 229 mm odtieklo prostredníctvom riečnej siete a 466 mm sa odparilo. Toky vytvárajú v povodí prevažne paralelnú riečnu sústavu. Vzhľadom k nie veľmi členitému reliéfu povodia dosahuje priemerná nadmorská výška 450 m n. m.

Litava je významný ľavostranný prítok Krupinice. Povodie Litavy po stanicu Plášťovce má $214,27 \text{ km}^2$. Litava má celkovú dĺžku 45 km. Pramení v Krupinskej planine, prameň leží vo výške asi 650 m n. m. na južnom svahu pod sedlom medzi vrchmi Kopaný závoz (775 m n. m.) na západnej a Jaseňový vrch (724 m n. m.) na východnej strane (obr. 1b). Územie patrí do vrchovinovo - nížinnej oblasti s typom režimu odtoku dažďovo-snehovým s akumuláciou v mesiacoch december - január, vysokými vodnosťami vo februári až apríli. V minulosti bolo výrazné podružné zvýšenie vodnosti koncom jesene a začiatkom zimy.

V tabuľke 1 sú uvedené základné hydrologické charakteristiky daných tokov.



Obr. 1. a) Lokalizácia vybraných subpovodí v povodí Ipľa, (slovenská časť).
 b) Povodie Krupinica: Plášťovce a Litava: Plášťovce
 c) Povodie Ipel: Holiša.

Tabuľka 1. Základné hydrologické charakteristiky vybraných vodomerných staníc s dlhým radom priemerných denných prietokov.

Databankové číslo	Stanica	Tok	Pozoruje od roku	Plocha pov. A [km ²]	Dĺžka údolia L [km]	Lesnosť [%]	Tvar povodia A/L ²	Priem. prietok 1931–1980
7440	Holiša	Ipel'	1931	685,26	56,1	30	0,22	3,257
7580	Plášťovce	Krupinica	1931	302,79	54,5	40	0,1	1,91
7600	Plášťovce	Litava	1931	214,42	43,9	30	0,11	1,175

METÓDY

Pri hodnotení hydrologického sucha sa vyhodnocujú:

- **prietkové charakteristiky** (minimálne priemerné denné prietoky (v mesačnom, resp. ročnom kroku, za celé obdobie), M-denné prietoky (krivka prekročenia priemerných denných prietokov), minimálne mesačné a ročné prietoky, N-ročné minimálne prietoky);
- **neprietkové charakteristiky** časový výskyt suchých období (dátum výskytu, počet dní málo vodných období, najdlhšia epizóda sucha) a nedostatkové objemy.

V tejto práci sme sa zamerali na vyhodnotenie oboch charakteristík. Jednotlivé charakteristiky odtoku boli počítané z radov priemerných denných prietokov. Vypočítané boli:

- priemerný ročný prietok (Q_r) – vypočítaný z priemerných denných prietokov za kalendárny rok;
- ročné maximum ($Q_{d\max}$) – najväčší priemerný denný prietok v kalendárnom roku;
- ročné minimum ($Q_{d\min}$) – najmenší priemerný denný prietok v kalendárnom roku.

Stanovenie a hodnotenie N-ročných minimálnych prietokov a malej vodnosti vo vodomerných staniciach na Slovensku upravovala OTN 3113-1 (2007), a dnes navrhnutá OTN ŽP 3113-1:04. Na Slovensku sa výber minimálneho prietoku vykonáva podľa OTN ŽP 3113-1:04 za vodohospodársky rok (začiatok 1. apríla), keďže však spracovávame aj maximálne priemerné denné prietoky, a chceme, aby údaje boli porovnatelné so zahraničnými výsledkami použili sme kalendárny rok (začiatok 1. januára). Návrhové hodnoty maximálnych ročných prietokov sa určujú za hydrologický rok. Za hydrologický rok sa na Slovensku považuje obdobie od 1. novembra do 31. októbra. Je určený tak, aby všetky spadnuté zrážky v danom roku tiež odtiekli. Predpokladá sa, že väčšina zrážok, ktoré spadnú v novembri a v decembri, má na horách formu snehu, kde sa akumulujú. Roztopia sa a odtečú až v jarnom období v nasledujúcim roku. Upozorňujeme, že v tejto štúdiu nepoužívame rad Q_{\max} – kulminačných prietokov, ale rad maximálnych priemerných denných prietokov $Q_{d\max}$.

Pri pravdepodobnostnom hodnotení minimálnych prietokov vo vodomerných staniciach najdôležitejším krokom je výber teoretických čiar nedostúpenia, tj. výber najvhodnejšieho typu teoretickej čiary a metódy odhadu jej parametrov. Na Slovensku sa používa „Metodika DVWK“, podľa ktorej sa vyberá najlepšie z viacerých typov rozdelení (Gumbelovo rozdelenie (E1), generalizované extremálne rozdelenie (GEV, AE), Rossiho rozdelenie (ME), 3-parametrické logaritmicko-normálne rozdelenie (LN3), 3-parametrické rozdelenie Pearsona (P3, tiež označované PE3), 3-parametrické rozdelenie log-Pearson (LP3), 3-parametrické rozdelenie Weibulla (WB3)). Pre odhad parametrov rozdelenia sa odporúčajú: metóda momentov, metóda kvantilov, alebo metóda maximálnej vierošodnosti.

My sme pri hodnotení N-ročných minimálnych a maximálnych prietokov použili Log-Pearsonovo rozdelenie III. Typu (LP3). Zmenami koeficientu šíkmosti pri tomto rozdelení je

možné zlepšiť odhad v oblasti miním, alebo v oblasti maxím). Vzhľadom na možnosti regionalizácie parametrov rozdelenia neodporúčame používať rôzne typy rozdelení, ale rozhodnúť sa pre jedno rozdelenie a podľa toho spracovať všetky údaje a parametre regionalizovať. Na prevod pravdepodobnosti nedostúpenia (P) na priemernú dobu opakovania 1x za N rokov platí vzťah:

$$P = (1 - e^{-\frac{1}{N}}) \cdot 100 \quad (1)$$

ktorý pre zaužívané kvantily pravdepodobnosti P (v %), resp. priemerné doby opakovania N (v rokoch) je uvedený v nasledujúcej Tabuľke 2.

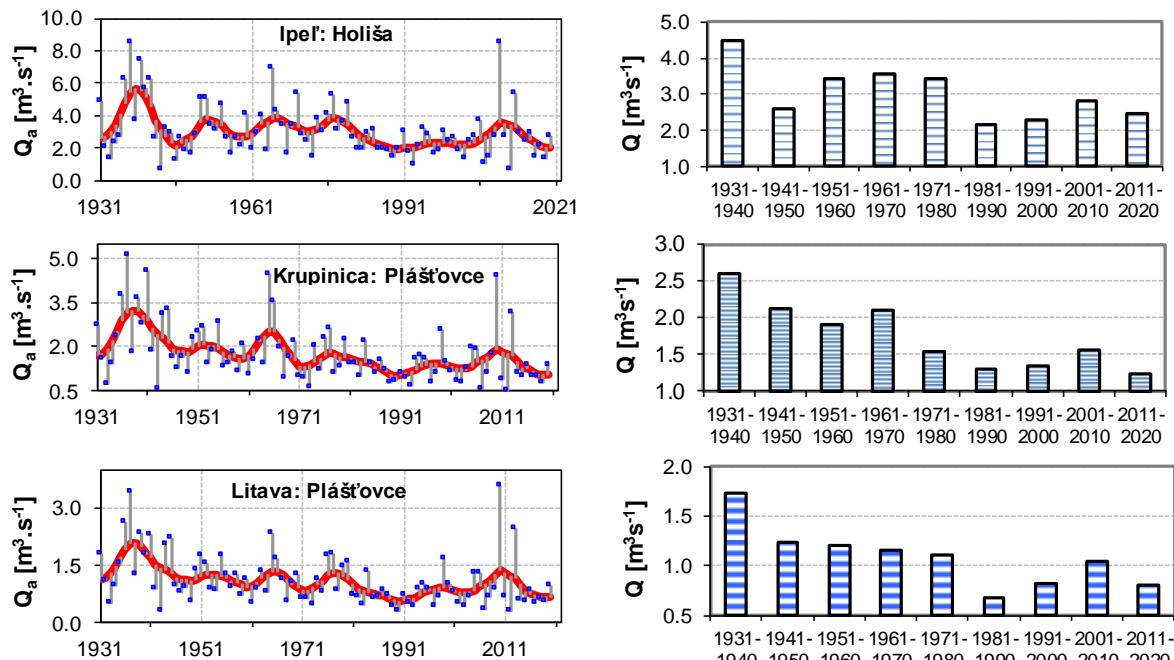
Tabuľka 2. Prevod pravdepodobnosti na priemernú dobu opakovania

P [%]	1	2	5	9,5	18,1	39,3	63,2
N[počet rokov]	100	50	20	10	5	2	1

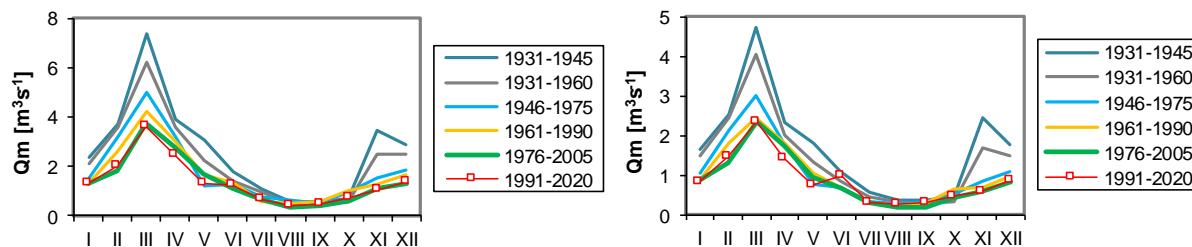
VÝSLEDKY

Štatistická analýza prietokových charakteristík

Na obrázku 2 vľavo sú znázornené priebehy priemerných ročných prietokov vybraných troch povodí. Vo všetkých troch tokoch bolo prvé desaťročie mimoriadne vodné, predovšetkým roky 1936–1940. Najsuchšie desaťročné obdobie sa vyskytlo v rokoch 1981–1990 v Ipli a Litave, v Krupinici v dekáde 2011–2020. Najvodnejší rok bol 1937, v Litave 2010. Najmenej vodný rok v Litave a Krupinici bol rok 2012, v Ipli po Holišu rok 1943.



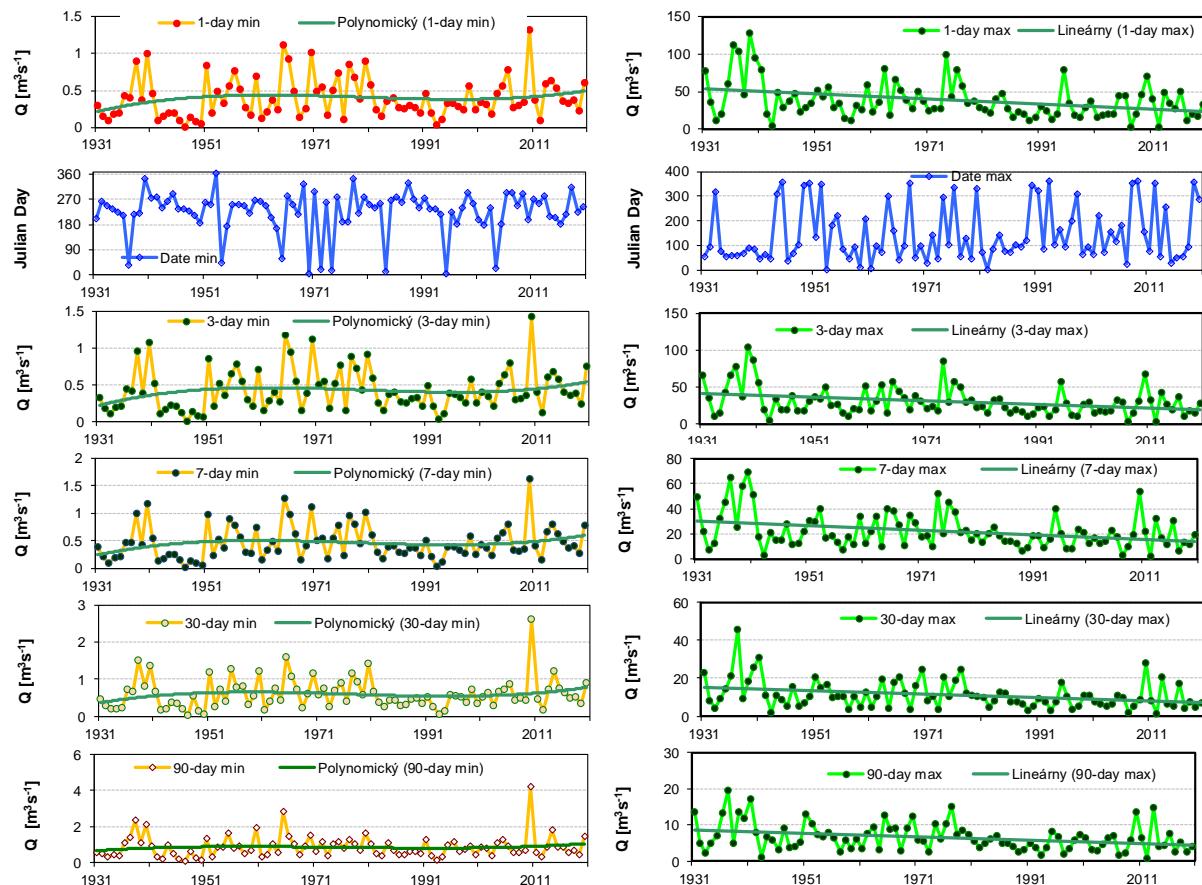
**Obr. 2. Vľavo - priebeh priemerných ročných (modré body) a 7-ročných kĺzavých priemerov (červená čiara), vpravo - dekadne prietoky; obdobie 1931–2020.
Zhora Ipeľ: Holiša, Krupinica: Plášťovce, Litava: Plášťovce.**



Obr. 3. Priebehy priemerných 30-ročných mesačných prietokov (s 15-ročným posunom) v období 1931–2020. (vľavo - Krupinica: Plášťovce, vpravo - Litava: Plášťovce).

Mesačný chod prietokov Krupinice, Litavy a Ipl'a po stanicu Holiša je veľmi podobný, najvyššie prietoky sa vyskytujú v marci, najnižšie v auguste. Na obrázkoch 3 je evidentný pokles prietokov Krupinice a Litavy v zimno-jarnom období, v mesiacoch november – apríl.

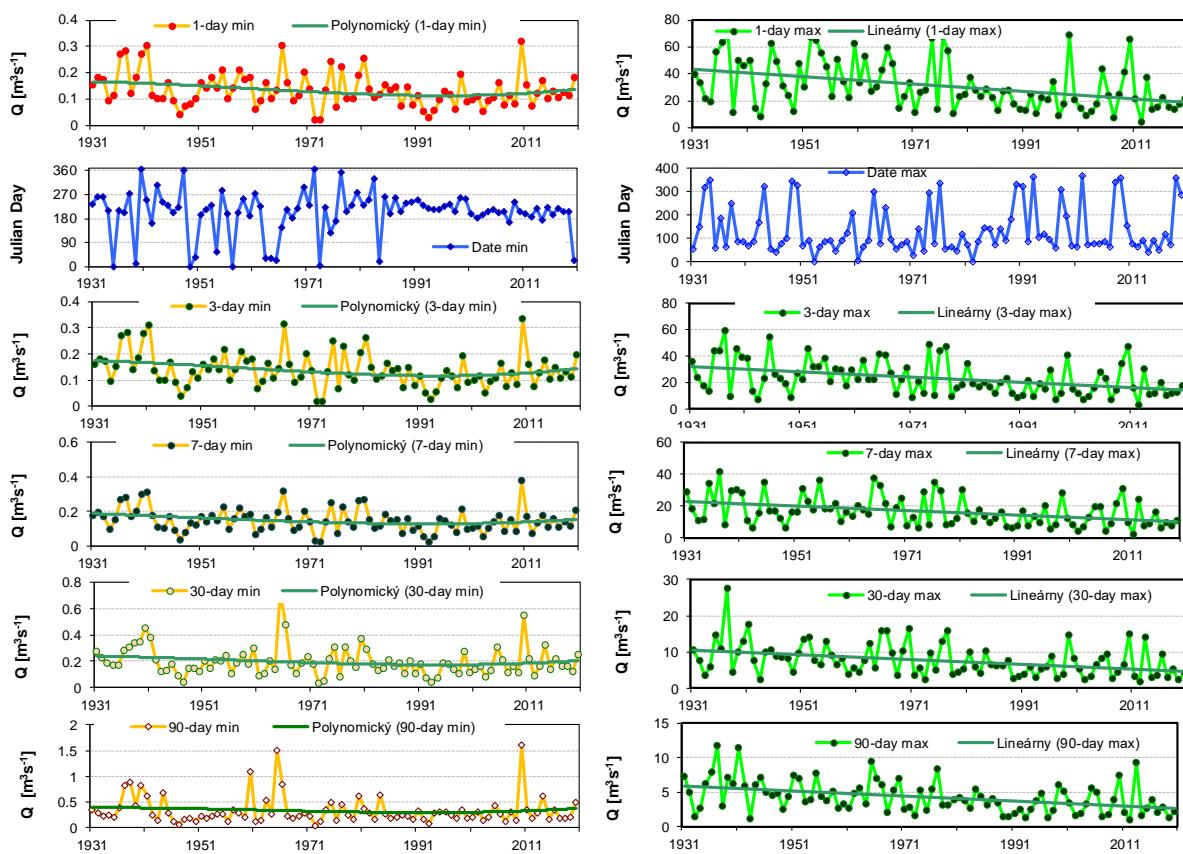
Trendy radov minimálnych a maximálnych charakteristík priemerných denných prietokov
Z radu priemerných denných prietokov Ipl'a za obdobie 90 rokov sme vytvorili rady 1-, 3-, 7-, 30- a 90- denných maximálnych (obr. 4, vpravo) a minimálnych (obr. 4, vľavo) prietokov. V období 1982–1996 boli minimálne 7-denné prietoky Ipl'a pod hranicou $0,5 \text{ m}^3 \text{s}^{-1}$.



Obr. 4. Priebeh 1-, 3-, 7-, 30- a 90- denných maximálnych (vpravo) a minimálnych (vľavo) prietokov za obdobie 1931–2020; Ipel': Holiša. Modrými bodmi sú znázornené dni výskytu minimálnych a maximálnych prietokov v danom roku (Juliánsky deň).

Z obr. 4 vyplýva, že minimálne prietoky sa v Ipli vyskytovali aj v zimných mesiacoch (modrá čiara na grafe). V mokrom roku 2010 bol minimálny prietok najvyšší. Maximálne priemerné denné prietoky v Ipli majú klesajúci trend, ani povodeň v roku 2010 nedosiahla prietoky

z rokov 1937–1941. V Krupinici bol priebeh vybraných charakteristik minimálnych a maximálnych prietokov podobný (obr. 5). Až na minimálne charakteristiky Ipl'a, ostatné rady všetkých charakteristik majú klesajúci trend (Tabuľka 3).



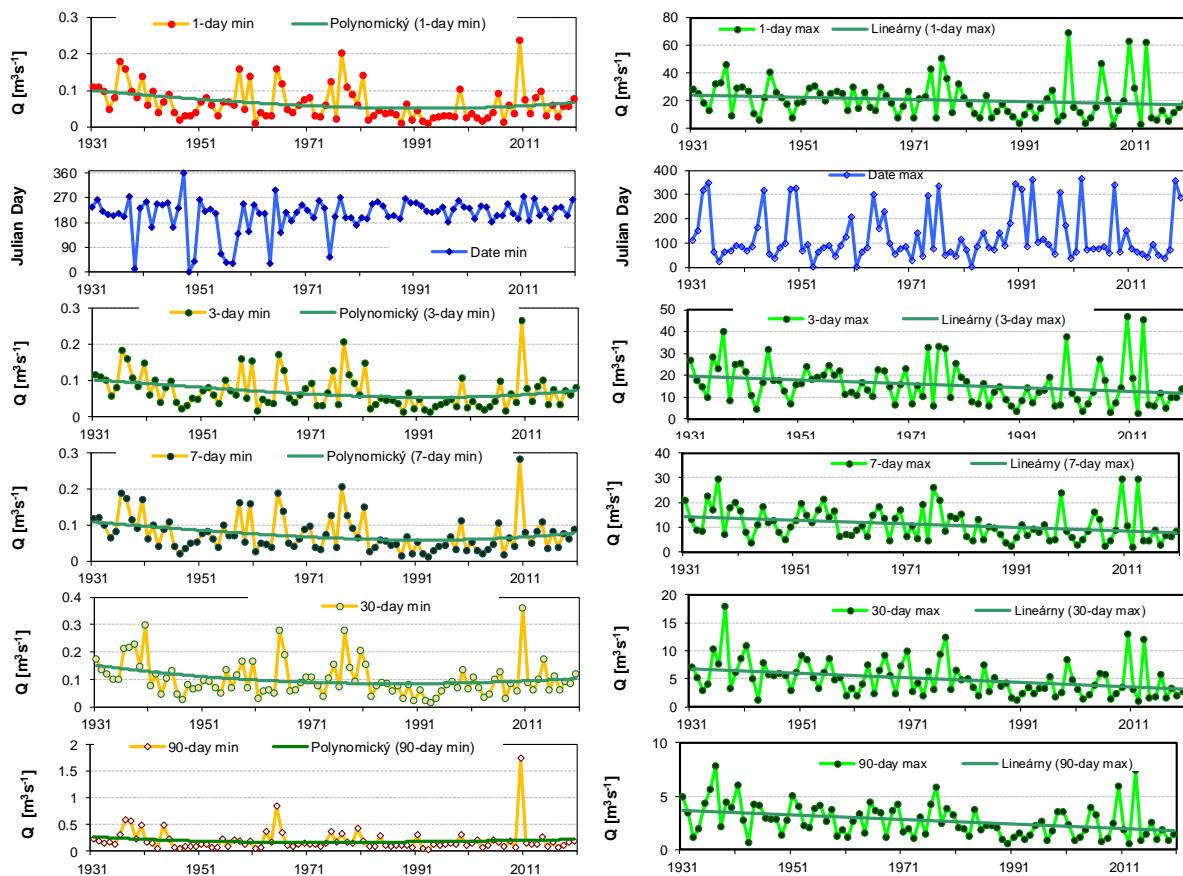
Obr. 5. Priebeh 1-, 3-, 7-, 30- a 90- denných maximálnych (vpravo) a minimálnych (vľavo) prietokov za obdobie 1931–2020; Krupinica: Plášťovce. Modrými bodmi sú znázornené dni výskytu minimálnych a maximálnych prietokov v danom roku (Juliánsky deň).

Tabuľka 3. Sklon - lineárny trend vybraných hydrologických charakteristik priemerných denných prietokov v Ipli, Krupinici a Litave za obdobie 1931–2020. Q_{PX} – priemerný denný prietok dosiahnutý X% dní v roku

	Ipel'	Krupinica	Litava
$Q_{d\min}$	0.0010	-0.0006	-0.0004
Q_r	-0.0174	-0.0146	-0.0087
$Q_{d\max}$	-0.3302	-0.2703	-0.0794
Q_{P99}	-0.2168	-0.1428	-0.0873
Q_{d30}	-0.0568	-0.0444	-0.0309
Q_{P50}	-0.0037	-0.0030	-0.0021
Q_{d330}	0.0014	-0.0006	-0.0004
Q_{P01}	0.0012	-0.0006	-0.0005

V období 1981–1998 minimálne 7-denné prietoky Litavy boli pod hranicou $0,09 \text{ m}^3 \text{s}^{-1}$ (obr. 6). Všetky rady vybraných charakteristík v Litave majú klesajúci trend (Tabuľka 3). Minimálne prietoky sa do roku 1975 vyskytovali aj v zimných mesiacoch. Po roku 1975 už len v letných mesiacoch. Rok 2010 bol čo sa týka minimálnych prietokov najextrémnejší. Výskyt maximálnych priemerných denných prietokov v Litave má súčasť mierne klesajúci trend, ale v rokoch 1999, 2006, 2010 a 2014 sa na Krupinici i Litave v Plášťovciach vyskytli

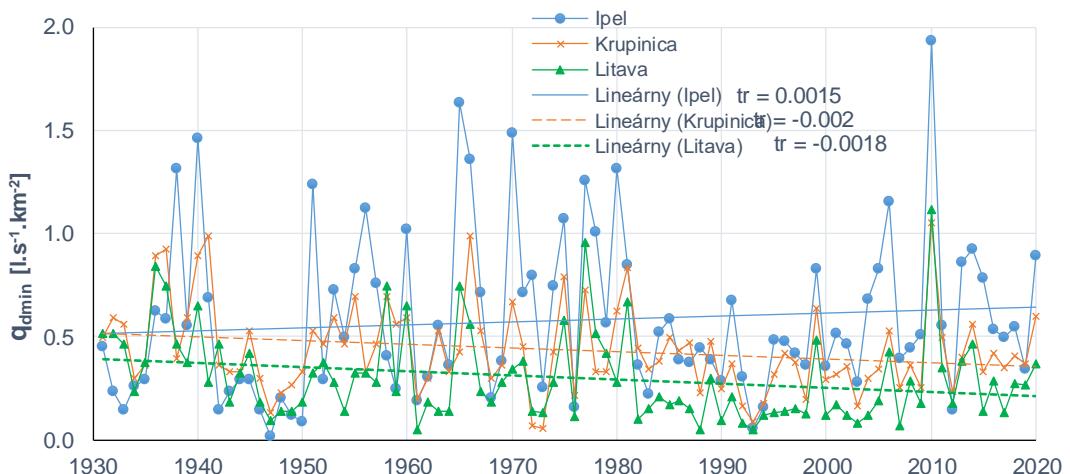
extrémne povodne. Na základe častejšieho výskytu povodní boli v roku 2016 pri tokoch Litava a Krupinica v Plášťovciach vybudované protipovodňové hrádze. (obr. 7). Zatiaľ, čo v Ipli minimálne prietoky rástli, v Krupinici a Litave klesali (obr. 8).



Obr. 6. Priebeh 1-, 3-, 7-, 30- a 90- denných maximálnych (vpravo) a minimálnych (vľavo) prietokov za obdobie 1931–2020; Litava: Plášťovce. Modrými bodmi sú znázornené dni výskytu minimálnych a maximálnych prietokov v danom roku (Juliánsky deň).



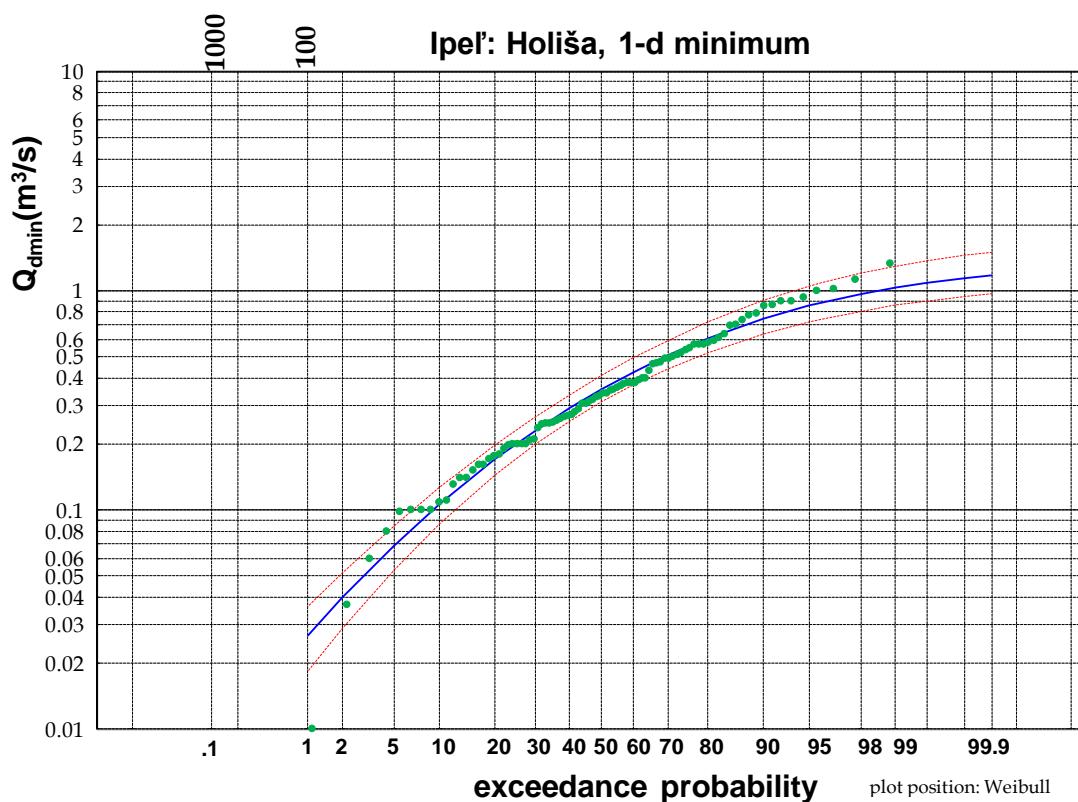
Obr. 7. Vodomerná stanica Litava: Plášťovce, nová protipovodňová hrádza (Foto 2021, J. Mészároš).



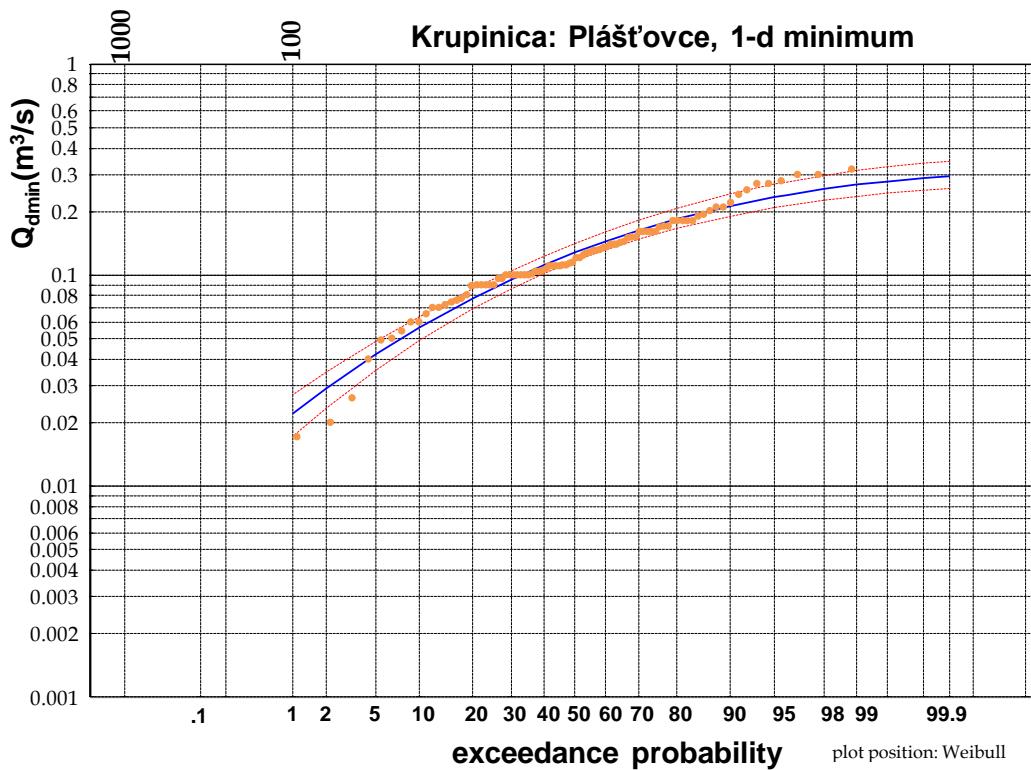
Obr. 8. Minimálne priemerné denné špecifické odtoky $q_{d\min}$ pre tri rady, trend.

N-ročné minimálne prietoky

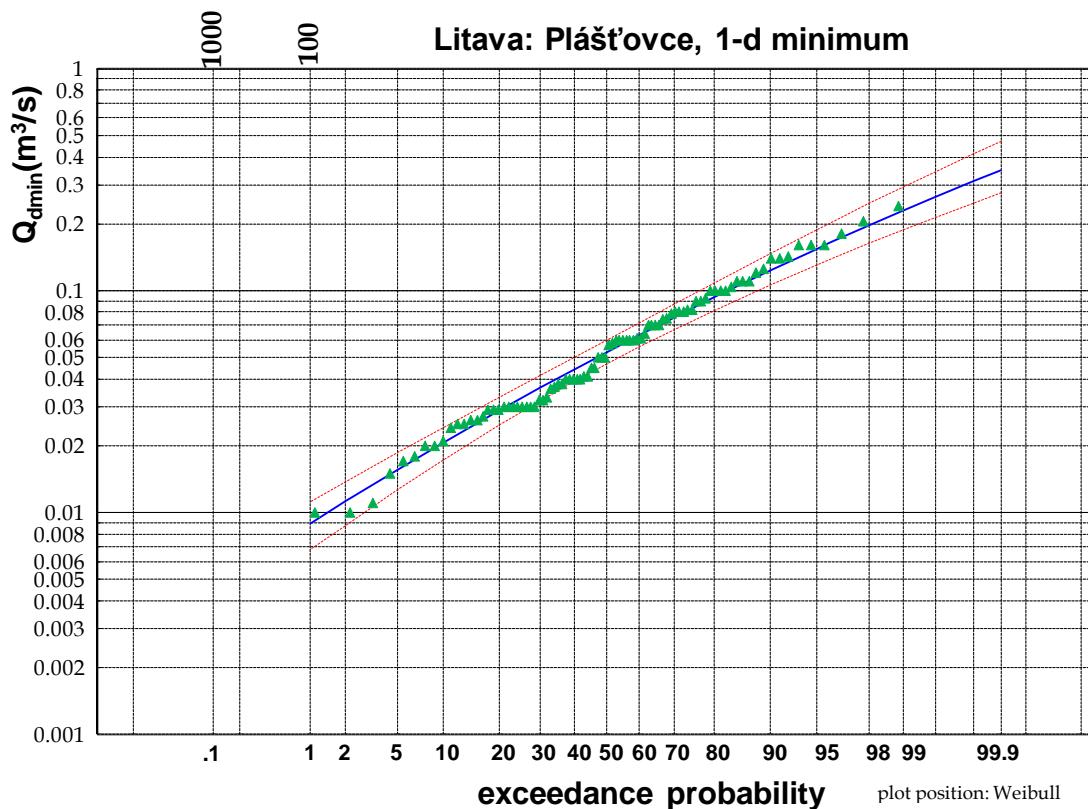
Teoretické LP3 čiary nedostúpenia/podkročenia radu 1-dňových minimálnych ročných prietokov $Q_{d\min}$ daných tokov sú vykreslené na obr. 9a-c. Aby bolo možné porovnať N -ročné minimálne hodnoty medzi sebou, budeme v ďalších analýzach pracovať aj s radmi minimálnych špecifických odtokov $q_{d\min}$ v litroch z km^2 z daných troch povodí.



**Obr. 9a. Teoretická LP3 čiara nedostúpenia 1-denných minimálnych prietokov (modrá čiara)
97,5 a 2,5 horný a dolný limit (červené čiary), a empirické hodnoty (zelené body),
Ipel: Holiša.**



Obr. 9b. Teoretická LP3 čiara nedostúpenia 1-denných minimálnych prietokov (modrá čiara)
 97,5 a 2,5 horný a dolný limit (červené čiary), a empirické hodnoty (zelené body),
b) Krupinica: Plášťovce



Obr. 9c. Teoretická LP3 čiara nedostúpenia 1-denných minimálnych prietokov (modrá čiara)
 97,5 a 2,5 horný a dolný limit (červené čiary), a empirické hodnoty (zelené body),
c) Litava: Plášťovce.

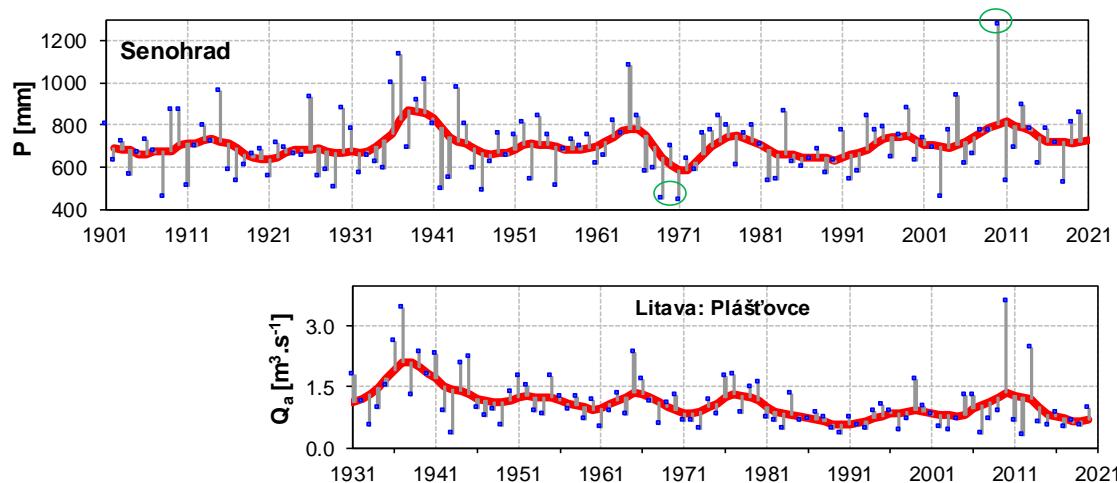
Odhadnuté hodnoty N -ročných minimálnych 1-denných pretokov a špecifických odtokov sú zosumarizované v Tabuľke 4.

Tabuľka 4. N -ročné 1-dňové minimálne prietoky Q [m^3s^{-1}] a špecifické odtoky q v [$\text{l.s}^{-1}\text{km}^{-2}$] vo vodomerných staniciach Ipel': Holiša, Krupinica: Plášťovce a Litava: Plášťovce

Litava N -ročnosť	p %	Q	Q(5) [m^3s^{-1}]	Q(95)	q	q(5) [$\text{l.s}^{-1}\text{km}^{-2}$]	q(95)
100	0.01	0.009	0.011	0.007	0.042	0.052	0.032
50	0.02	0.011	0.014	0.009	0.052	0.064	0.041
20	0.05	0.016	0.019	0.013	0.073	0.087	0.059
Krupinica N -ročnosť	p %	Q	Q(5) [m^3s^{-1}]	Q(95)	q	q(5) [$\text{l.s}^{-1}\text{km}^{-2}$]	q(95)
100	0.01	0.022	0.027	0.017	0.073	0.090	0.057
50	0.02	0.029	0.035	0.023	0.096	0.114	0.077
20	0.05	0.042	0.048	0.035	0.139	0.160	0.117
Ipel'	N -ročnosť	Q	Q(5) [m^3s^{-1}]	Q(95)	q	q(5) [$\text{l.s}^{-1}\text{km}^{-2}$]	q(95)
100	0.01	0.027	0.036	0.018	0.039	0.053	0.027
50	0.02	0.040	0.052	0.029	0.058	0.075	0.042
20	0.05	0.069	0.085	0.053	0.100	0.124	0.078

ZÁVER

Vo všetkých troch tokoch v slovenskej časti Ipl'a bolo prvé desaťročie mimoriadne vodné, predovšetkým roky 1936–1940. Najsúššie desaťročné obdobie sa vyskytlo v rokoch 1981–1990 v Ipli a Litave, v Krupinici v dekáde 2011–2020. Najvodnejší rok v Ipli a Krupinici bol rok 1937, v Litave 2010 (obr. 10). Najmenej vodný rok v Litave a Krupinici bol rok 2012, v Ipli po Holišu rok 1943. Vysoké prietoky z obdobia 1936–1941 zodpovedajú nadpriemerných zrážkovým úhrnom v tomto období.



Obr. 10. Priebeh ročných úhrnov zrážok v stanici Senohrad a priemerných ročných prietokov Litavy v Plášťovciach.

Následný pokles prietokov v druhom tridsaťročí bol spôsobený poklesom zrážok v období 1967–1972 (obr. 10). Po roku 1993 napriek vyšším zrážkovým úhrnom prietoky nedosahujú úroveň z obdobia 1936–1940. Pravdepodobným dôvodom je významný rast teploty vzduchu v poslednom tridsaťročí a z toho dôvodu zvýšeným výparom (Halmová a kol. 2022).

Hodnoty denných prietokov v Ipli v stanici Holiša majú mierne klesajúci trend, ani povodeň v roku 2010 nedosiahla prietoky z rokov 1937–1941.

V ďalšej práci sa treba zameriť na analýzu radov maximálnych ročných kulminačných prietokov v povodí Ipla a na budúci vývoj prietokov za použitia scenárov vývoja teploty vzduchu na Slovensku (Melo a Gera, 2021).

Variabilita hydrometeorologických pomerov v rôznych častiach povodia Dunaja sa zákonite odzrkadľuje v špecifických odtokoch v jednotlivých staniciach. Napríklad 100-ročné 1-dňové minimálne špecifické odtoky vo vodomerných staniciach na Dunaji sú najvyššie v stanici Achleiten pod sútokom s Innom $4,75 \text{ l.s}^{-1}\text{km}^{-2}$, až po Bratislavu si zachovávajú podobnú úroveň, ale na strednom a dolnom toku klesajú až na $1,77 \text{ l.s}^{-1}\text{km}^{-2}$ v stanici Reni (Halmová a kol., 2021). Variabilita je i na prítokoch Dunaja, kde na rieke Morave a Tisze je 100-ročný špecifický odtok $0,35/0,51 \text{ l.s}^{-1}\text{km}^{-2}$, ale na Lechu a Sáve presahujú $5 \text{ l.s}^{-1}\text{km}^{-2}$. Z tohto pohľadu sú odhadnuté hodnoty 100-ročných minimálnych špecifických odtokov v povodí Ipla extrémne nízke.

Poděkovanie

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LITERATÚRA

- Balek, J. (1968): Lineární extrapolace průměrných ročních průtoků vybraných řek čtyř kontinentů. *J. Hydrol. Hydromech.*, 16, 3, 402–428.
- Blaškovičová, L., Jeneiová, K., Melová, K., Poórová, J., Liová, S., Slivková, K., Síčová, B. (2022): Changes in Selected Low-Flow Characteristics in the 2001–2015 Period Compared to the 1961–2000 Reference Period in Slovakia. *Climate*, 10 (6), art. no. 81. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85132009677&doi=10.3390%2fccli10060081&partnerID=40&md5=449aa372a8e1a9d774bcfc9ac63377>
- Bradley, R., S. (1994): Reconstruction of Climate from A.D. 1000 to the Present. In: Proc. Contemporary climatology. Ed. by Brázdil and Kolář. Brno, 12–21.
- Bratránek, A. (1960): Výskyt období extrémních vodností ve střední Evropě a jejich význam z vodohospodářského hlediska. *J. Hydrol. Hydromech.*, 8, 1, 3–14.
- Bratránek, A. (1964): Stoleté řady průtokové v povodí Labe. Ověření spolehlivosti a jejich použití k extrapolaci dalších řad. *J. Hydrol. Hydromech.*, 12, 4, 361–387.
- Brázdil, R., Kolář, M. (Ed.) (1994): Contemporary climatology, Brno, 620 s.
- Ďurigová, M., Ballová, D., Hlavčová, K. (2019): Analyses of Monthly Discharges in Slovakia Using Hydrological Exploratory Methods and Statistical Methods. *Slovak J. Civ. Eng.* 27, 36–43. file:///C:/Users/PavlaP.UH/Downloads/Analyses_of_Monthly_Discharges_in_Slovakia_Using_H.pdf
- Ďurigová, M., Hlavčová, K. (2020): The detection of changes in the upper Váh river basin according to decadal analysis. *Acta Hydrologica Slovaca*, 21, 1, 39–47. <https://doi.org/10.31577/ahs-2020-0021.01.0005>
- Gomboš, M., Ivančo, J., Šťastný, P. (1999): Analýza časového vývoja ročných zrážkových úhrnov za dlhšie časové obdobia. In: Vplyv antropogénnej činnosti na vodný režim nížinného územia. ÚH SAV, Michalovce, 198–204.

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Interdisciplinary Approach in Current Hydrological Research*

- Halmová, D. (1999): Očakávané dôsledky klimatických zmien v oblasti vodného diela Domaša. In: Vplyv antropogénnej činnosti na vodný režim nižinného územia. ÚH SAV, Michalovce, 78–83.
- Halmová, D., Pekárová, P., Mészáros, J., Miklánek, P., Bačová Mitková, V. (2021): Identifikácia výskytu historických súch na Dunaji a jeho prítokoch. In Hydrologické dny 2021 : IX. národní konference českých a slovenských hydrologů a vodohospodářů, Sborník rozšířených abstraktů [elektronický zdroj]. - Praha : Český hydrometeorologický ústav, s. 33–34. ISBN 978-80-7653-019-5.
- Halmová, D., Pekárová, P., Podolinská, J., Jeneiová, K. (2022): The assessment of changes in the long-term water balance in the Krupinica River basin for the period 1931–2020. Acta Hydrologica Slovaca, 23, 1,21–31, doi: 10.31577/ahs-2022-0023.01.0003.
- Hladný, J. (Ed.) (1997): Impacts of a potential climate change on hydrology and water resources in the Czech Republic. Praha 1997, 134.
- Klige, R., K. Selivanov, A., O., Voronov, A., M., (1989): Izmenenia vodnogo režima territorii SSSR za poslednye tysjačiletie. Vodnye resursy, 5, 28–40.
- Koníček, A. (1996): Trendy zkladných zložiek hydrologickej bilancie experimentálneho povodia Lesný v rokoch 1965–1994. J. Hydrol. Hydromech., 44, 4, 25–260.
- Křivský, L. (1957): Kolísání podnebí u nás a klimatologická prognosa pro nejbližších několik desetiletí. Meteorologické zprávy, 10, 3, 71–72.
- Lapin, M., Faško, P., Zeman, V. (1994): Contribution to analysis of possible global warming impacts upon climate change in Slovakia. In: National climate programme of the Slovak Republic. Bratislava, Vol. 2., 39–77.
- Lukjanetz, O., Soszedko, M. (1998): Runoff estimate for the next years in the Carpathians with regard to multi-annual fluctuations. In. Proc.: XIX conference of the Danube countries, Osijek, Croatia, 393–401.
- Majerčáková, O., Škoda, P. (1993): Vývoj zrážok a odtokov na území Slovenska a jeho možné ovplyvnenie klimatickými zmenami. Meteorologické zprávy, 46, 164–168.
- Melo, M., Gera, M. (2021): Scenáre teploty vzduchu pre vybrané stanice na území Slovenska v období 2071–2100 podľa regionálnych klimatických modelov MPI a KNMI. In Hydrological Processes in the Soil–Plant–Atmosphere System - Book of peer-reviewed papers. - Bratislava: Institute of Hydrology, Slovak Academy of Sciences, 310–316. ISBN 978-80-89139-50-7.
- Miklánek, P. (1997): Study of water balance elements in Slovak experimental basins. In: Proc. Experimental hydrology with reference to hydrological processes in small research basins. St. Petersburg.
- Pavelková, D., Kandra, B., Tall, A. Gomboš, M. Hlavatá, H. (2021): Porovnanie trendového vývoja základných hydrometeorologických prvkov s ich trendovým vývojom v normálových obdobiah. In Hydrological Processes in the Soil–Plant–Atmosphere System - Book of peer-reviewed papers. Bratislava: Institute of Hydrology, Slovak Academy of Sciences, 274–285. ISBN 978-80-89139-50-7.
- Pekárová, P., Miklánek, P. (eds.), (2019): Flood regime of rivers in the Danube River basin. Follow-up volume IX of the Regional Co-operation of the Danube Countries in IHP UNESCO. IH SAS, Bratislava, 215 p. + 527 p. app., DOI: <https://doi.org/10.31577/2019.9788089139460>.
- Pekárová, P., Miklánek, P., Pekár, J., Pramuk, B. (2017): Identifikácia zmien režimu denných prietokov slovenských riek. II. Časť: Porovnanie dvoch období. Acta Hydrologica Slovaca, 18, 2, 183–192.
- Petrovič, P. (1997): Climate change impact on the water management in the Nitra basin (Slovakia). Proc. of the 22nd General EGS Assembly. Part II. Supplement II. Vol. 15. Annales Geophysicae.
- Poórová, J., Blaškovičová, L., Škoda, P., Šimor, V. (2013): Trendy minimálnych ročných a mesačných prietokov na slovenských tokoch. In: Proc. Seminar Sucho a jak mu čelit. Prague, 20–23.
- Přenosilová, E., Nacházel, K., Patera, A. (1994): Estimating the impact of climate change on utilisation of surface water resources. In: XVIIth Conference of the Danube Countries on Hydrological Forecasting and Hydrological Bases of Water Management. HNC IHP, Budapest.
- Szolgay, J. - Hlavčová, K. - Parajka, J. - Čunderlík, J. (1997): Vplyv klimatickej zmeny na odtokový režim na Slovensku. NKP 6/1997 - Klimatické zmeny - hydrológia a vodné hospodárstvo SR. MŽP SR a SHMÚ, Bratislava, 11–110.
- Švec, G.I. (1962): Pokus o rekonštrukciu hydrologických údajov o Dnepri. J. Hydrol. Hydromech., 10, 1, 3–10.

CONTEMPORARY AND PROJECTED RAINFALL-DURATION-INTENSITY RELATIONSHIPS IN SLOVAKIA – APPLICATION OF THE BAYESIAN APPROACH

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ABSTRACT

Rainfall Intensity-Duration-Frequency (IDF) relationships express how quantiles of extreme rainfall intensities vary with rainfall duration and the frequency of their occurrence. IDF relationships are essential for the design of hydraulic structures in urban areas. A multi-scenario ensemble of EUROPE-CORDEX simulations of rainfall can provide important information on how future rainfall extremes may translate into IDFs in a changing climate. In our preliminary analyses we chose the RCP 8.5 scenario, which corresponds to a 8.5 W/m² forcing across the planet and a temperature increase of about 4.3°C by 2100 (relative to pre-industrial temperatures). Two types of input data have been used in this study to describe the current and future climate conditions: 1-minute resolution data measured with self-registering rain gauges, and a multi-model ensemble of EUROPE-CORDEX daily precipitation. Due to the relatively short length of sub-daily rainfall observations (typically < 20 years), the Bayesian inference of GEV distribution parameters was used. Local rainfall scaling relationships have been estimated and used to construct sub-daily IDF relationships from the 24-hr EUROPE-CORDEX quantiles.

Keywords: IDF, GEV distribution, rainfall, EUROPE-CORDEX, RCM

INTRODUCTION

According the Clausius-Clapeyron relation the atmosphere's water holding capacity increases with rising air temperature at a rate of approximately 7% per 1°C (Onderka et al., 2021, 2022). There is an ongoing debate about how rising air temperature will affect the occurrence of rainfall extremes in the future (Ganguli and Coulibaly 2017; Agilan and Umamahesh, 2016). Statistics of rainfall extremes is essential for reliable design of numerous engineering infrastructures and prevention of soil erosion and estimation of soil losses (Onderka et al., 2021, 2022; Yan et al., 2021). In a recent study conducted in the Netherlands, Lenderink et al. (2017) found that extreme sub-hourly precipitation extremes increased above the Clausius–Clapeyron relation, a phenomenon described as super-CC scaling. Similar findings were reported recently also from other regions of the world (Ban et al. 2015; Berg et al. 2013, Blenkinsop et al., 2015; Miao et al. 2015; Schroeer and Kirchengast, 2018; Wasko and Sharma 2017, 2015; and Shaw et al. 2011). However, the rate at which rainfall extremes increase with rising air temperature is not universal, which means that regional and local peculiarities are to be expected. The EUROPE-CORDEX rainfall projections are an important piece of information for studies concerned with how rainfall extremes may evolve in the near future.

The objectives of this study are threefold: (1) to estimate GEV distribution parameters of annual maximum rainfall intensities using data from rain gauges in Slovakia over the period 1991-2021, and an ensemble of EUROPE-CORDEX RCMs (RCP 8.5) over the period 2021-2099; (2) to estimate IDF relationships and local scaling functions from the quantiles inferred from station-based data series; (3) to apply the envelope curve of the local scaling functions to

the ensemble of EUROPE-CORDEX simulations in order to project IDF relationships of sub-daily intensities for 5, 15, 30, 60, 120 and 180-minute rainfall durations.

METHODS AND DATA

Input data

Two types of input data have been used to describe the current and future climate conditions: 1-minute resolution data measured with self-registering rain gauges, and a multi-model ensemble of EUROPE-CORDEX daily precipitation with approx. 12 km grid spacing. In our preliminary analyses we focused on using climate projections downloaded via API on <https://cds.climate.copernicus.eu>.

Table 3. List of RCMs used to create multi-scenario ensemble

GCM	RCM	RCP	RCP	RCP
		2.6	4.5	8.5
cnrm cerfacs cm5	aladin63	-	-	X
cnrm cerfacs cm5	knmi racmo22e	-	-	X
mohc hadgem2e	gerics	-	-	X
	remo2015			
mohc hadgem2e	knmi racmo22e	-	-	X
mohc hadgem2e	rca4	-	-	X

Regional climate models (RCMs) were used to create a multi-model ensemble of rainfall quantiles (Table 1). In the presented analyses the RCP 8.5 scenario was chosen. This scenario corresponds to 8.5 W/m² forcing across the planet and a temperature increase of about 4.3°C by 2100 (relative to pre-industrial temperatures). Another source of data was rain gauge observations. An annual series of maximum rainfall extending through approx. 1991-2021 was extracted from the digital databases of the Slovak Hydrometeorological Institute. First, the raw rainfall data were checked for quality and aggregated to 5, 10, 15, 30, 40, 50, 60, 90, 120, 180, 240...1440 minutes rainfall intensities.

Data processing

Due to the relatively short length of sub-daily rainfall observations (typically < 20 years), the Bayesian inference of GEV distribution parameters was deployed. The method of annual maxima series (AMS) was used in combination with the General Extreme Value (GEV) distribution parameters (Onderka et al., 2022). The GEV distribution is defined as:

$$F_{GEV}(x) = \exp\left[-\left(1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-1/\xi}\right] \quad (1)$$

where:

x denotes the random variable representing the annual maximum rainfall intensity, F_{GEV} is the distribution function defined for $\{x: 1 + (\xi(x-\mu)/\sigma) > 0\}$, $-\infty < \mu < \infty$, $\sigma > 0$. and $-\infty < \xi < \infty$, where μ is the location parameter, σ is scale parameter, and ξ is the shape parameter (Ragno et al., 2019; Cheng et al., 2015; Smith et al., 2001). The inverse function of the GEV distribution was used to calculate the individual quantiles. The ProNEVA package developed in Matlab® by Ragno et al. (2019) was used to calculate the individual quantiles from the available annual maxima (5-min to 1440-min intensities) calculated from the rain gauge records and the EURO-CORDEX data (24-hr rainfall depths). First, the parameters of the GEV distribution

and the corresponding quantiles of rainfall intensities were estimated for 150 locations in Slovakia. A more detailed procedure of applying the Bayesian approach is shown in a recent paper of Onderka et al. (2022). The same procedure was then applied to annual maxima series from CORDEX data. The resulting 24-hr quantiles were averaged to get ensemble quantiles for each grid-point. For the purposes of this conference paper, the methodology used to construct IDF relationships for sub-daily rainfall durations was inspired by the work of Koutsoyiannis et al. (1998a, b), who combined the records of daily maximum rainfall depths with rain-recording (sub-daily observations) to construct an IDF curves (a generalizing graphical form of IDF relationships). The shape of IDF curves can be written the general form:

$$i(d, T) = \frac{a(T)}{b(D)} = \frac{\lambda T^\kappa}{(D+\theta)^\eta} \quad (2)$$

where:

$i(D, T)$ is the rainfall intensity corresponding to duration d and return period T_r , and $a(T)$ and $b(D)$ are functions of T_r and D , respectively. The nominator $a(T)$ in Eq. 2 can be derived directly from the distribution of rainfall intensities (or 24-hr rainfall depths) using data of self-registering or classical non-recording gauges (Koutsoyiannis et al..1998a, b), or even rainfall projections such as the EURO-CORDEX data used in this paper. On the other hand, the denominator $b(D)$ in Eq. 2 has to be derived from self-recording (with sub-daily resolution) rain gauge data. In the presented work, local scaling functions were derived for 150 locations equipped with rain gauge. A simplified flowchart of the applied procedure in shown in Fig. 1. An envelope curve representing the whole territory of Slovakia was calculated from the individual scaling functions as the 95th percentile of the scaling parameters (Fig. 2). The 24-hr quantiles calculated from EUROPE-CORDEX data were down-scaled to sub-daily durations (5, 15, 30, 60, 120 and 180-minute rainfall durations) by applying the envelope curve to the CORDEX ensemble 24-hr quantiles.

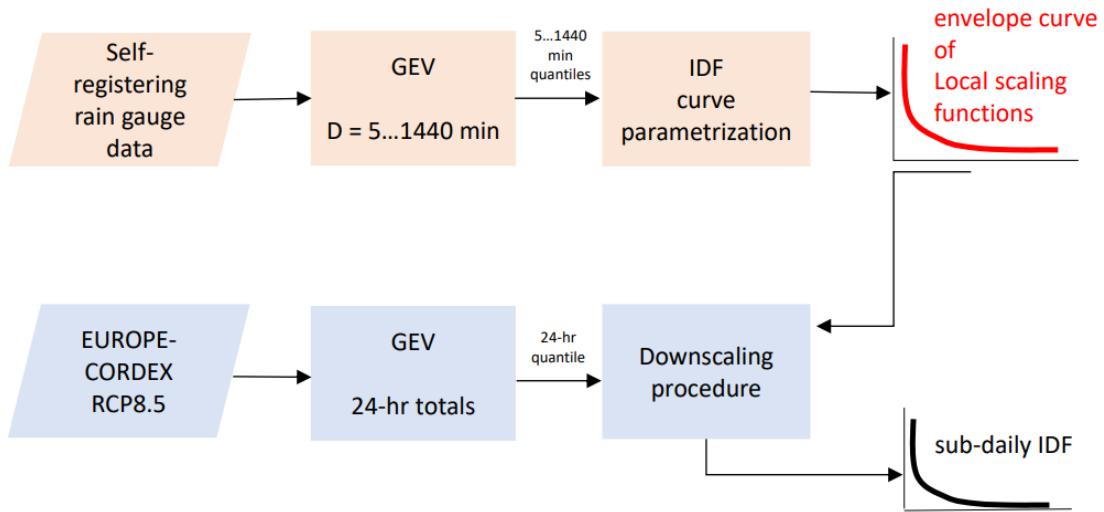


Fig. 3. Schematics of the downscaling procedure.

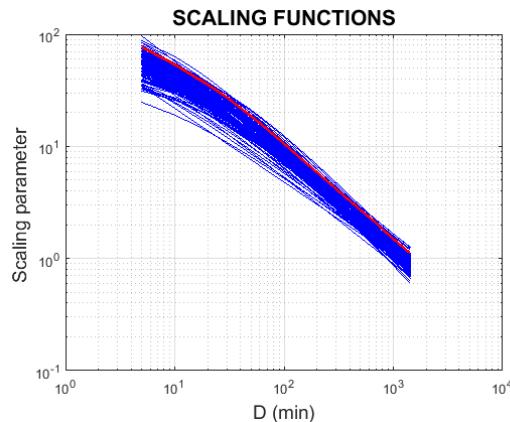


Fig. 2. Scaling functions derived for all 150 locations that are equipped with self-registering and automatic rain gauges. The envelope curve (indicated in red) is defined as the 95th percentile of scaling parameters corresponding to individual rainfall durations D .

RESULTS AND DISCUSSION

An example of quantiles generated for 5, 10, 15, 20, 30, 60, 120 and 180-min rainfall intensities for locations equipped with rain gauges is shown in Fig. 3.

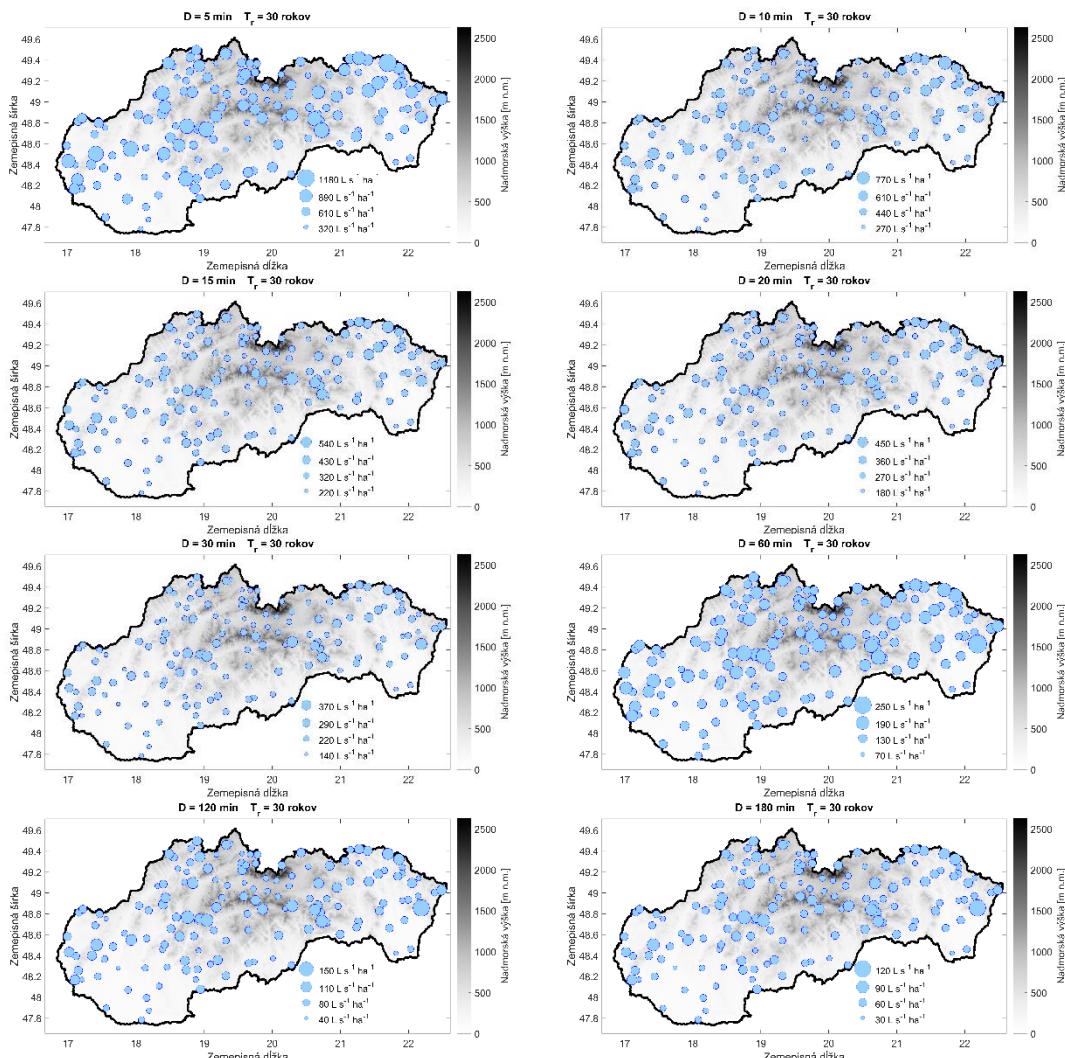


Fig. 3. Local estimates of selected 30-year short-duration rainfall intensities.

The intensities are expressed in $\text{L s}^{-1} \text{ha}^{-1}$. Due to the limited space in this conference paper, only the quantiles corresponding to the 30-year return period are presented. In general, the effect of orographic precipitation enhancement is apparent. Low-land areas located in the southern portion of western and eastern Slovakia exhibit low rainfall intensities. The down-scaled sub-daily quantiles obtained from the EUROPE-CORDEX projections are presented in Fig. 4 for 10-year return period.

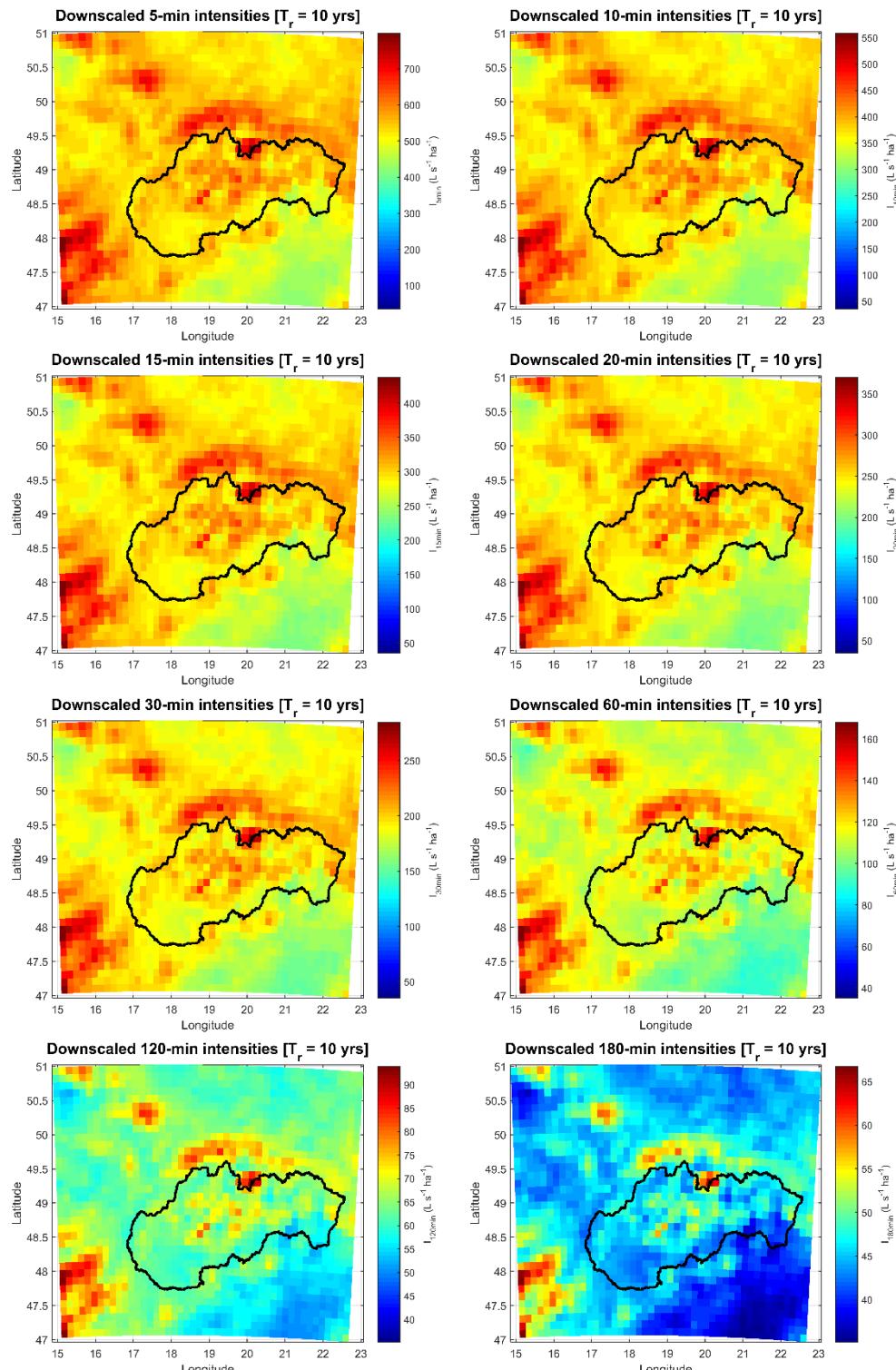


Fig. 4. Example of down-scaled quantiles derived from 24-hr ERUROPE-CORDEX ensemble.

The highest quantile values are found in mountainous regions due to the orographic effects, especially in the High Tatras, where the 5-min intensity exceeds $550 \text{ L s}^{-1} \text{ ha}^{-1}$. In contrast to the mountains, much lower rainfall intensities are projected for low land areas, with the lowest intensities in the east-southern part of Slovakia ($\sim 450 \text{ L s}^{-1} \text{ ha}^{-1}$). So far, the downscaling procedure described in this paper is based on applying a single scaling function (defined as the 95th envelope curve) to the EUROPE-CORDEX 24-hr quantiles. However, a greater amount of regional differences could be achieved by regionalizing the scaling functions, which an interesting avenue for future research.

CONCLUSIONS

Although the presented results are preliminary and more analyses are still being done, the partial conclusions can be summarized as follows:

- IDF relationships for rainfall durations ranging from 5 to 1440 minutes have been established for selected locations in Slovakia
- Local scaling functions have been derived for a broad range of periodicities and rainfall durations
- Sub-daily IDF relationships have been downscaled for a multi-model ensemble of EUROPE-CORDEX runs
- A higher robustness of the estimated IDF relationships will be achieved with more ensemble members and other RCPs

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REFERENCES

- Ban N., Schmidli J., Schär C. (2015): Heavy rainfall in a changing climate: Does short-term summer rainfall increase faster? *Geophys Res Lett*, Vol. 42, p. 1165–72. ISSN 1944-8007.
- Berg P., Moseley C., Haerter J., O. (2013): Strong increase in convective rainfall in response to higher temperatures. *Nat Geosci*, p. 181–5. ISSN 1752-0908.
- Blenkinsop, S.C., Chan, E.J., Kendon, N.M., Roberts, H.J., Fowler (2015): Temperature influences on intense UK hourly precipitation and dependency on large-scale circulation. *Environ. Res. Lett.*, 10 (5), doi:Artn 05402110.1088/1748-9326/10/5/054021.
- Cheng, L., AghaKouchak, A. (2015): Nonstationary Rainfall Intensity-Duration-Frequency Curves for Infrastructure Design in a Changing Climate. *Sci Rep*, Vol. 4, p. 7093. <https://doi.org/10.1038/srep07093>
- Koutsoyiannis D., Kozonis D., Manetas A. (1998a): A mathematical framework for studying rainfall intensity-duration-frequency relationships, *Journal of Hydrology*, 206 (1–2), 118-135.
- Koutsoyiannis, D., Kozonis, D., Manetas, A. (1998b): A comprehensive study of rainfall intensityduration-frequency relationship, *J. of Hydrol.*, 206, 118-135.
- Lenderink G., Barbero R., Loriaux J.M., Fowler, H.J. (2017): Super-Clausius–Clapeyron Scaling of Extreme Hourly Convective Rainfall and Its Relation to Large-Scale Atmospheric Conditions. *Journal of Climate* Vol. 30, p. 6037–52. ISSN: 0894-8755.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Miao, C., Ashouri, H., Hsu, K.L., Sorooshian, S., Duan, Q., Miao, C., et al. (2015): Evaluation of the PERSIANN-CDR Daily Rainfall Estimates in Capturing the Behavior of Extreme Rainfall Events over China. *Journal of Hydrometeorology*, Vol. 16, p. 1387–96. ISSN: 1525-755X.
- Onderka, M., Pecho, J. (2021): Sensitivity of selected summertime rainfall characteristics to pre-event atmospheric and near-surface conditions. *Atmospheric Research*, 259, doi: 10.1016/j.atmosres.2021.105671.
- Onderka, M., Pecho, J., et al. (2022): Relationships between intensity, duration and frequency of short-term rains determined by Bayesian inference of GEV distribution parameters. *Meteorologické zprávy* (75), 81-88.
- Ragno, E., AghaKouchaka, A., Cheng, L., Sadegh, M. (2019): A generalized framework for process-informed nonstationary extreme value analysis. *Advances in Water Resources*, 130, 270-282, doi: 10.1016/j.advwatres.2019.06.007.
- Schroeder, K., Kirchengast, G. (2018): Sensitivity of extreme rainfall to temperature: the variability of scaling factors from a regional to local perspective. *Climate Dynamics*, Vol. 50, p. 981–94. ISSN: 1432-0894.
- Shaw, S.B., Royem, A.A., Riha, S.J., et al. (2011): The Relationship between Extreme Hourly Rainfall and Surface Temperature in Different Hydroclimatic Regions of the United States. *Journal of Hydrometeorology*, Vol. 12, p. 319–25. ISSN: 1525-755X.
- Smith, B., Prentice, I.C., Sykes, M.T. (2001): Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space. *Global Biology and Biogeography*, Vol. 10, p. 621–37. ISSN: 1466-8238.
- Wasko, C., Sharma, A. (2015): Steeper temporal distribution of rain intensity at higher temperatures within Australian storms. *Nature Geoscience*, Vol. 8, p. 527–9. ISSN: 1752-0894.
- Wasko, C., Sharma, A. (2017): Continuous rainfall generation for a warmer climate using observed temperature sensitivities. *Journal of Hydrology*, Vol. 544, p. 575–90. ISSN: 0022-1694.

HODNOTENIE pH A ELEKTROLYTICKEJ VODIVOSTI V KANÁLOVEJ SIETI ŽITNÉHO OSTROVA

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ABSTRAKT

V rokoch 2010 – 2020 sme merali hodnoty pH a elektrolytickej vodivosti v kanálovej sieti Žitného ostrova. Zo získaných výsledkov vyplýva, že priemerná hodnota pH sa počas celého sledovaného obdobia pohybovala od 6 do 8,5. V čistých prírodných vodách (povrchových aj podzemných) je hodnota pH zvyčajne určená rovnováhou medzi voľným CO₂ a viazaným CO₂ (karbonátová rovnováha). Nízke hodnoty vodivosti boli namerané v zime a na jar. V letných mesiacoch sa hodnoty zvýšili až na maximálnu hodnotu v auguste.

Chemické a biologické procesy prebiehajúce vo vode môžu výrazne ovplyvniť pH a vodivosť vody. Zistili sme všeobecne stúpajúcu tendenciu hodnôt vodivosti v pozdĺžnom profile vodného toku. Pozorovali sme pravidelnosť v sezónnej dynamike hodnôt pH a vodivosti. Miesto odberu vzoriek malo väčší vplyv na pH a vodivosť ako sezónna dynamika.

Keywords: elektrolytická vodivosť, pH, kvalita vody

ÚVOD

Žitný ostrov (ŽO) je územie medzi Bratislavou a Komárom, ohraničené Dunajom a Malým Dunajom. Charakter využitia krajiny (poľnohospodársky využívané územia) sa premieta do zvýšených hodnôt pH a elektrickej vodivost (EC). Nevhodné hospodárenie na pôde môže ohrozíť kvalitu povrchových a podzemných vód. Z tohto hľadiska je región ŽO veľmi zraniteľná oblasť, ktorá je územím najbohatším na zásoby podzemných vód. Zároveň je najvýznamnejším poľnohospodárskym regiónom Slovenska. Prebieha tu intenzívna poľnohospodárska činnosť, ktorá determinuje charakter krajiny (Kobza et al. 2002, Noskovič et al. 2007).

Monitorovaná lokalita je napájaná tzv. hlavným prúdom podzemnej vody, ktorý smeruje juhovýchodným smerom rovnobežne s Dunajom. Podzemné vody monitorovanej lokality sú trvale napájané pri všetkých vodných stavoch Dunaja brehovou filtriáciou. V režime rozkyvu podzemnej vody sa však prejavuje výrazne vplyv zrážok a úhrnného výparu, ktoré vzhľadom na charakter napájania a drénovania územia sú dôležitým faktorom vplývajúcim na vodný režim (Biskupič 2001, Dubová et al. 1996, Dulovičová et al. 2021).

Kvalita povrchovej vody je ovplyvňovaná zdrojmi znečistenia, ktoré sa v záujmovom území nachádzajú. Najčastejšími bodovými zdrojmi znečistenia povrchových vód sú mestské a priemyselné odpadové vody. Prejavy znečistenia urbanizovaného územia sú hlavne v nárate elektrolytickej vodivosti, obsahu dusičnanov, síranov, chloridov a organického znečistenia. Najväčším plošným zdrojom znečistenia prírodných vód je poľnohospodárstvo. Nadmerné a nesprávne používanie priemyselných hnojív môže negatívne ovplyvniť pôdu, ako aj povrchové a podzemné vody (Blaine et al. 2011, Rathore et al. 2016).

V októbri 2000 bola prijatá Rámcová smernica o vode (RSV, Water Framework Directive, WFD) a Smernica 2000/60/EC Európskeho parlamentu a Rady, ktorá ustanovuje rámec pre činnosť Spoločenstva, týkajúceho sa politiky v oblasti ochrany vód. V súlade s RSV vyplýva pre SR úloha zhodnotiť dlhodobý vývoj vplyvov a dopadov ľudskej činnosti na povrchové a podzemné vody.

Prítomnosť anorganických rozpustených látok (celková mineralizácia) je jedným z hlavných indikátorov kvality vody a jej vlastností. pH významne ovplyvňuje priebeh chemických a biochemických procesov vo vodách. Umožňuje rozlíšiť jednotlivé formy výskytu niektorých prvkov vo vodách, je jedným z hľadísk uplatňujúcich sa pri posudzovaní mnohých technologických procesov používaných pri úprave vôd (Noskovič 1999, Tölgessy et Melichová, 2000).

V čistých prírodných vodách (povrchových aj podzemných) je hodnota pH v rozmedzí od 4,5 až do 8,3 daná zvyčajne rovnováhou medzi voľným CO_2 a viazaným CO_2 (tzv. uhličitanovou rovnováhou) (Gábriš et al., 1998). Túto závislosť môžu ovplyvňovať humusové látky a kationy rýchlo podliehajúce hydrolyze. Pokles pH vody pod 4,5 spôsobuje prítomnosť voľných anorganických aj organických kyselín. Prírodné vody s pH nad 8,3 obsahujú ióny CO_3^{2-} a pri hodnotách nad 10 sa na hodnote pH výrazne podieľajú aj ióny OH^- (Biskupič, 1991, Pitter, 1999).

Chemické a biologické procesy prebiehajúce vo vode môžu výrazne ovplyvniť pH vody. Ide buď priamo o uvoľňovanie alebo spotrebu iónov H_3O^+ , resp. OH^- , alebo nepriamo o uvoľňovanie alebo spotrebu voľného oxida uhličitého. Napríklad pri biologickej nitrifikácii sa uvoľňujú vodíkové ióny, ktoré reagujú s prítomnými hydrogenuhličitanmi za súčasného uvoľnenia voľného CO_2 . Tiež respiráciou prítomných organizmov sa uvoľňuje CO_2 a pH vody klesá. Vzostup pH vody sa dá naopak pozorovať pri biologickej denitrifikácii alebo redukcii síranov (Holobradý et al., 1991).

Elektrolytická vodivosť je miera koncentrácie ionizovaných anorganických a organických súčastí vody. Závisí od koncentrácie iónov, ich pohyblivosti a teplote. Pri prírodných a úžitkových vodách s veľmi nízkou koncentráciou organických látok je mierou anorganických elektrolytov (aniónov a kationov), v zriedených roztokoch je lineárnu funkciou koncentrácie iónov (Gábriš et al., 1998, Hudec, 1996, Stredanský, 1999).

Na vzostup vodivosti má podľa Noskoviča et al. (2001) vplyv aj antropogénna činnosť. Podľa ich výsledkov dochádza k zvýšeniu vodivosti vo vodnom toku následkom znečisťovania odpadovými vodami, ktoré obsahujú veľké množstvo rozpustených anorganických a organických látok. Vodivosť umožňuje získať okamžitú predstavu o časových zmenách v koncentráции anorganických látok v prírodných, úžitkových a odpadových vodách, pretože meranie môže prebiehať kontinuálne. To má značný význam pri priebežnej kontrole kvality týchto vôd (Pitter, 1999).

Elektrolytická vodivosť je približná miera koncentrácie elektrolytov (iónovo rozpustených látok) vo vode. Vyjadruje teda nepriamo obsah minerálnych látok („solí“, rozpustených látok – RL) vo vode. Limit vodivosti pre pitnú vodu je 125 mS.m^{-1} , čo zodpovedá obsahu RL asi 1000 mg.l^{-1} . Optimálne by však pitná voda mala obsahovať RL menej, asi $200 - 400 \text{ mg.l}^{-1}$ (asi $25 - 50 \text{ mS.l}^{-1}$). Vody s mineralizáciou viac ako 1000 mg.l^{-1} sa považujú za minerálne a nie sú vhodné na stále pitie (Blaine et al. 2011, Randall et al. 2001).

Moderné prístrojové vybavenie umožňuje rýchle a spoľahlivé meranie pH a vodivosti.

METÓDY A DÁTA

V priebehu rokov 2010 – 2020 sme odoberali vzorky vody za účelom monitorovania a hodnotenia jej kvality na základe vybraných ukazovateľov kvality povrchových vôd. Odbery vzoriek sa realizovali pravidelne mesačne z 9 odberových miest, ktoré boli vybrané tak, aby pokryli oblasť Žitného ostrova. Pri hodnotení získaných výsledkov je možné použiť viaceru matematicko-štatistikých metód:

- Metódy vzájomného porovnávania
- Post-hoc porovnávanie

Kvalita vody sa hodnotila porovnaním charakteristickej hodnoty pre jednotlivé ukazovatele vo všetkých odberových miestach vypočítanej podľa STN 75 7221 s odporúčanou hodnotou pre tieto ukazovatele uvedenou v Nariadení vlády č. 269/2010 Z. z.

Post-hoc testov je celý rad. Medzi nejznámejšie patrí metóda Tukeyho, Schedého, Duncanova, Newmanova–Keulsova, Fisherova, Bonferroniho, atď. Každá z týchto metód má svoje výhody i nevýhody. Ich množstvo už samo osebe naznačuje, že žiadna z nich nie je všeobecne prijímaná ako ideálna.

Tukeyho metóda mnohonásobného porovnávania je vlastne obdobou t-testu a používa sa v prípade vyváženého triedenia, teda ak $n_1 = \dots = n_I = n$. Z hľadiska sily testu a prípadnej robustnosti k porušeniu predpokladov analýzy rozptylu je u tohto testu doporučený rovnaký počet pozorovaní ešte dôraznejšie ako pri analýze rozptylu. Pre rôzne počty pozorovaní n_i a n_j v porovnávaných skupinách i a j bola vytvorená aj modifikacia tohto testu (Tukey HSD).

Testuje sa nulová hypotéza $H_0: \mu_i = \mu_j$, oproti alternatívnej hypotéze $H_1: \mu_i \neq \mu_j$, tj. nulová hypotéza tvrdí, že stredné hodnoty porovnávaných skupín i a j se nelisia. Testované kritérium má tvar:

$$Q = \frac{|\hat{\mu}_i - \hat{\mu}_j|}{S_*} \quad (1)$$

Kde smerodajná odchylka S_*

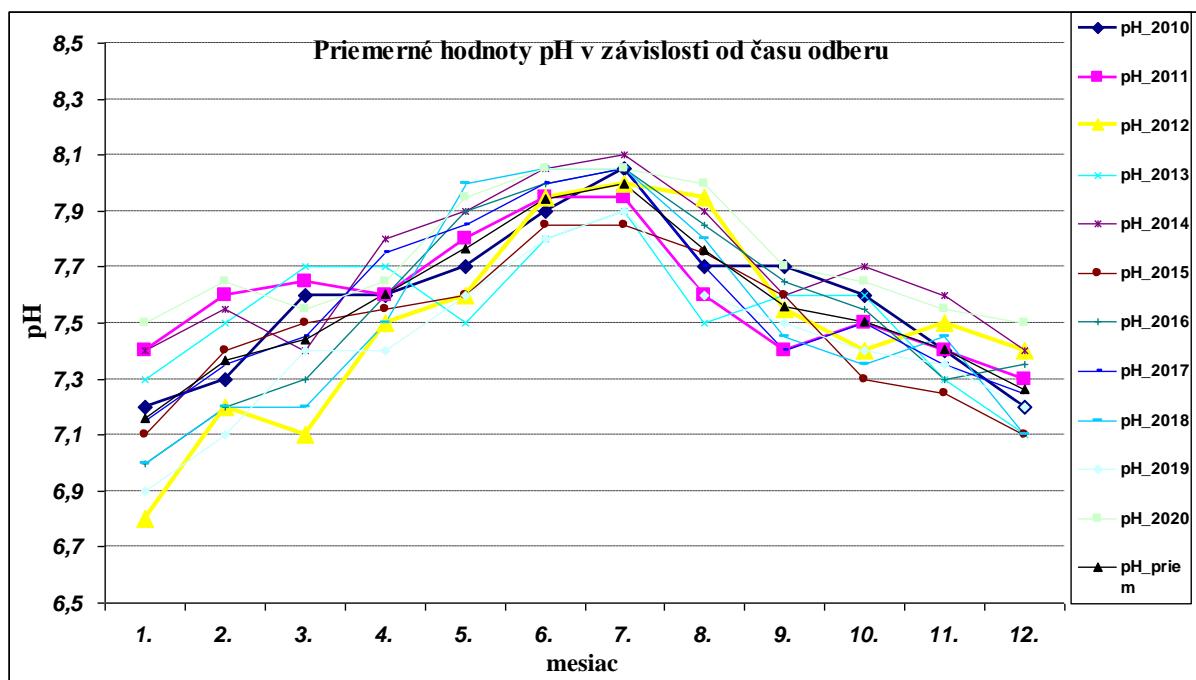
$$S_* = \sqrt{\frac{S_E}{\eta(N-I)}} \quad (2)$$

$$S_* = \sqrt{\frac{S_E}{2(N-I)} \left(\frac{1}{\eta_i} + \frac{1}{\eta_j} \right)} \quad (3)$$

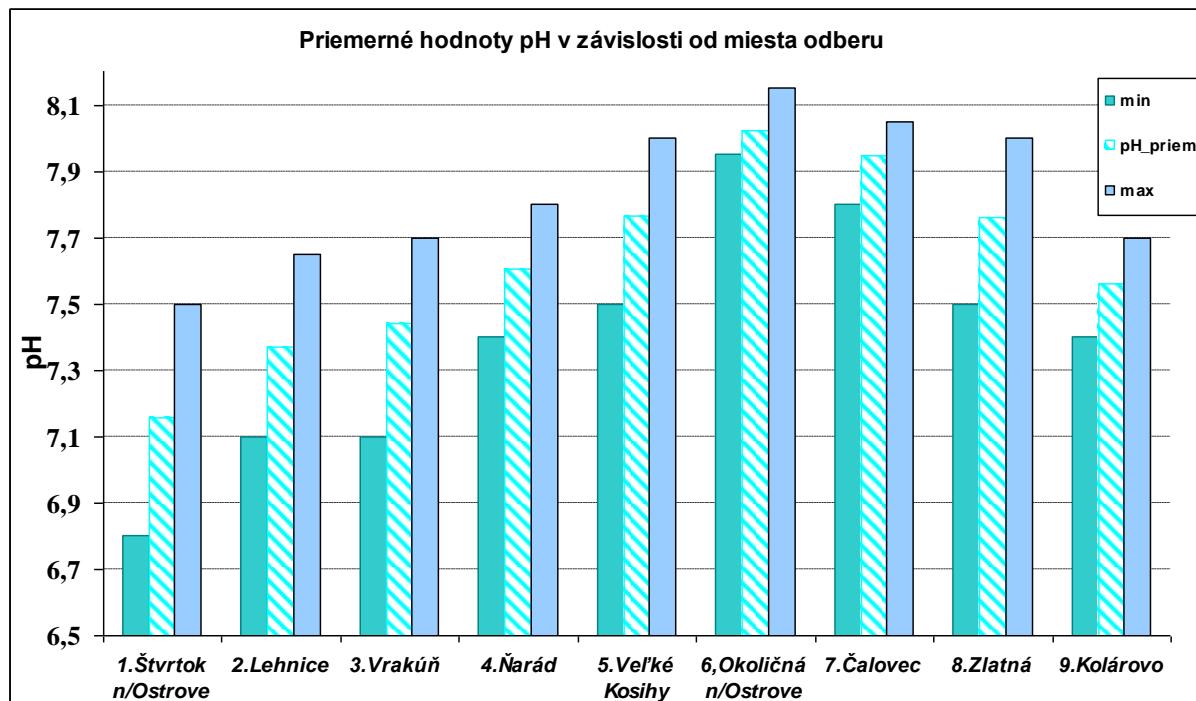
VÝSLEDKY A DISKUSIA

Pri hodnení kvality vody v kanálovej sieti Žitného ostrova sme vychádzali z údajov, získavaných Ústavom hydrológie na jednotlivých kanáloch Žitného ostrova vo vybraných odberných miestach v období rokov 2010-2020. Vzorky povrchových vôd boli odoberané z Chotárneho kanála (profil Nárad), kanála Gabčíkovo-Topoľníky (profil Vrakúň) a Komárňanského kanála (profil Okoličná na Ostrove) v mesačných intervaloch. Odberné miesta boli zvolené tak, aby plošne pokrývali čo najširšiu časť Žitného ostrova. V daných vzorkách bola meraná hodnota pH a EC. Na obr.1-4 sú znázornené časové priebehy meraných hodnôt v kanáloch Žitného ostrova.

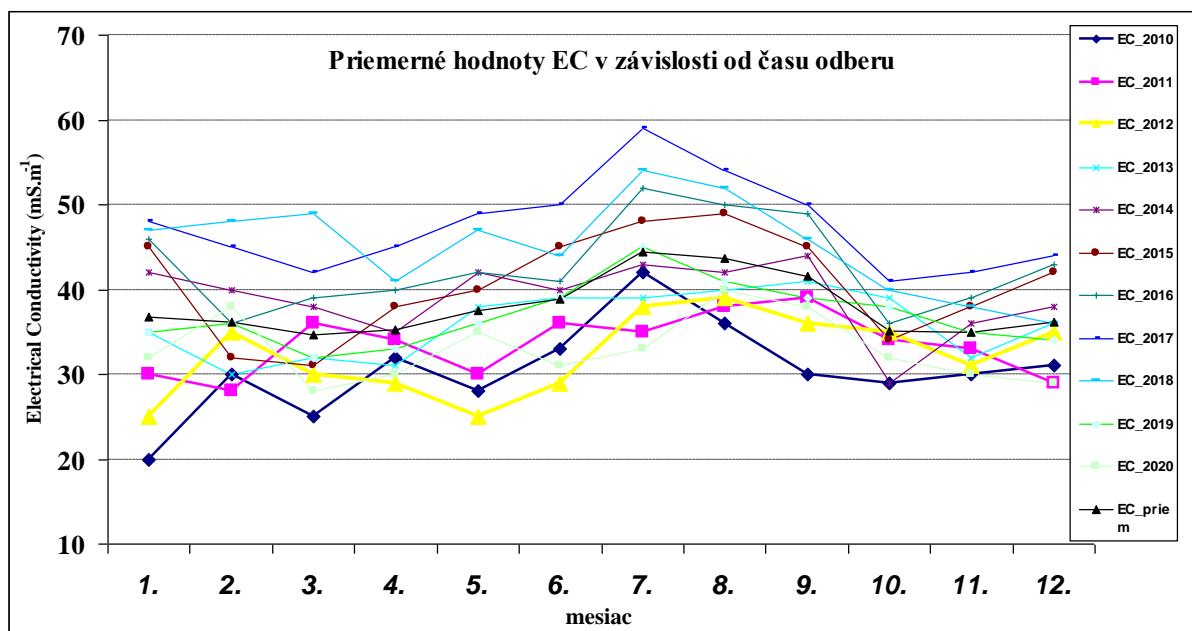
Kvalitatívne ukazovatele sledované v monitorovaných miestach boli zhodnené podľa Nariadenia vlády SR č. 269/2010 Z. z., ktorým sa ustanovujú požiadavky na dosiahnutie dobrého stavu vôd, resp. predchádzajúca norma STN 75 7221.



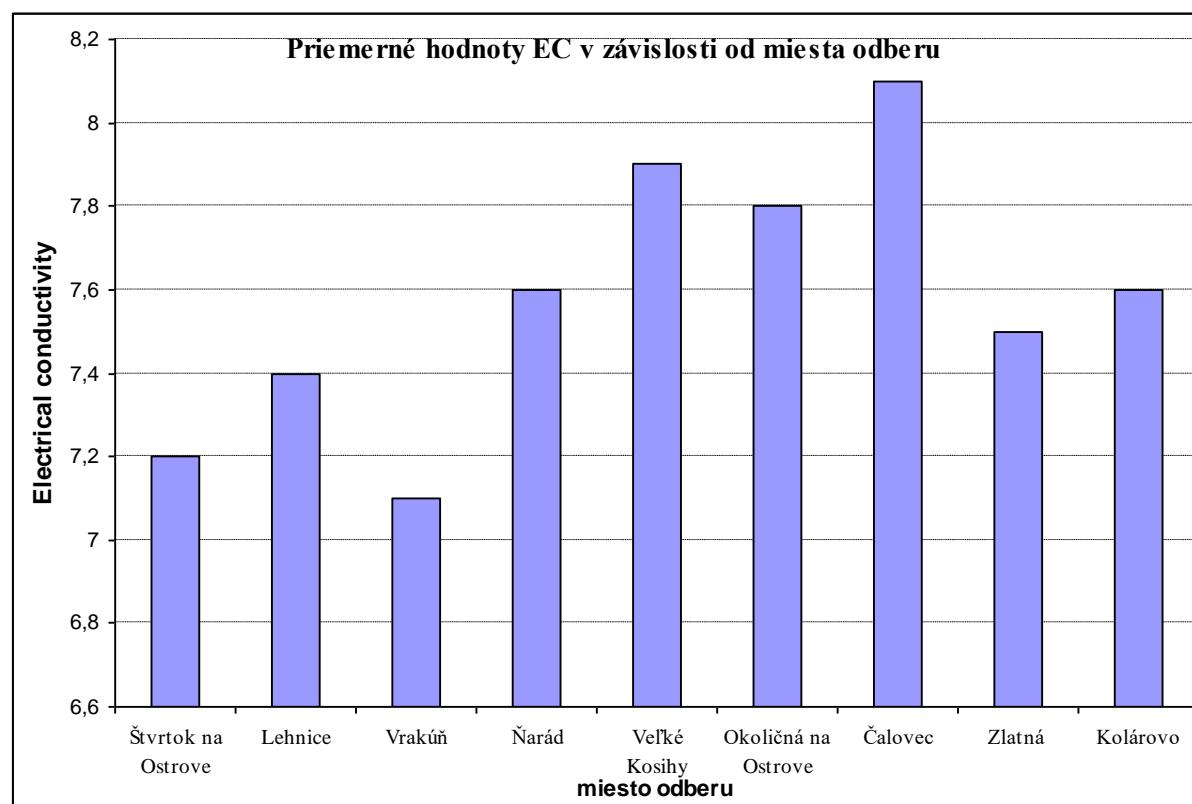
Obr. 1. Priemerné hodnoty pH v závislosti od času odberu.



Obr. 2. Priemerné hodnoty pH v závislosti od miesta odberu.



Obr. 3. Priemerné hodnoty EC v závislosti od času odberu.



Obr. 4. Priemerné hodnoty EC v závislosti od miesta odberu.

Priemerná hodnota pH v sledovanom období predstavovala 7,56. V rokoch 2010-2020 sa hodnota pH pohybovala od 6,8 do 8,1, teda prevažne v alkalickej oblasti. Zaznamenali sme pravidelnosť v sezónnej dynamike hodnôt pH. Najvyššie namerané hodnoty boli v letnom období (jún – august). Hodnoty elektrolytickej vodivosti dosahovali priemerne $37,92 \text{ mS.m}^{-1}$ (variovali v rozmedzí $30,5 - 47,41$). Miesto odberu malo väčší vplyv na hodnoty pH a EC ako sezónna dynamika. Nízke hodnoty vodivosti boli namerané v zime a na jar s minimom v decembri 2010 ($25,93 \text{ mS.m}^{-1}$). V letných mesiacoch sa jej hodnoty zvýšili až na maximálnu

hodnotu ($61,71 \text{ mS.m}^{-1}$). V závislosti od miesta odberu sme zistili všeobecne stúpajúcu tendenciu hodnôt vodivosti v pozdĺžnom profile vodného toku.

ZÁVER

Monitorovaná lokalita je napájaná tzv. hlavným prúdom podzemnej vody, ktorý smeruje juhovýchodným smerom rovnobežne s Dunajom. Podzemné vody monitorovanej lokality sú trvale napájané pri všetkých vodných stavoch Dunaja brehovou filtráciou. V režime rozkyvu podzemnej vody sa však prejavuje výrazne vplyv zrázok a úhrnného výparu, ktoré vzhľadom na charakter napájania a drénovania územia sú dôležitým faktorom vplývajúcim na vodný režim.

Štúdia bola zameraná na identifikáciu dlhodobých trendov kvality povrchových vôd v kanálovej sieti v regióne Žitný ostrov. Príspevok ukazuje zmeny nameraných hodnôt jednotlivých iónov v povrchovej vode v rokoch 2010-2020. Ukázalo sa, že kvalita vody vykazuje sezónnosť pH a EC, s maximom v letných mesiacoch (jún – august).

Podčakovanie

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LITERATÚRA

- Biskupič, F. (1991): Chémia vody. Bratislava: STU, 160 s. ISBN 80-227-0447-4.
- Blaine, R.M., Nordstrom, D.K., Ryan, J.N. (2011): Electrical conductivity method for natural waters. Applied Geochemistry, S227 – S229.
- Dubová, M., Bublinec, E. (1996): Kvalita povrchových vôd v rámenej sieti Dunaja v oblasti Vodného diela Gabčíkovo. In Acta facultatis forestalis Zvolen, roč. 38, s. 5161.
- Dulovičová, R., Velíšková, Y., Schügerl, R. (2021): Assesment of selected empirical formulas for computation of saturated hydraulic conductivity. Acta Hydrologica Slovaca, Vol. 22, s. 78.
- Gábriš, Ľ., Bandlerová, A., Hraško, J. et al. (1998): Ochrana a tvorba životného prostredia v poľnohospodárstve. Nitra: SPU, 461 s. ISBN 80-7137-506-3.
- Holobradý, K. et al. (1991): Chémia vody. Nitra: VŠP, 80 s. ISBN 80-85175-88-6.
- Hudec, I. (1996): Hydrobiológia. Bratislava: Príroda, 236 s. ISBN 80-07-00828-4.
- Kobza, J. et al. (2002): Soil monitoring of Slovak republic. Present state and development of monitored soil properties. VÚPOP, Bratislava, 180 s. ISBN 80-89128-04-1
- Nariadenie vlády SR č. 269/2010 na dosiahnutie vhodného stavu vôd.
- Noskovič, J., Palatícká, A., Porhajašová, J. (2007): Hodnotenie pH a elektrolytickej vodivosti vo vodnom toku. Katedra environmentalistiky SPU Nitra, p. 49-56.
- Noskovič, J., Tobiašová, E., Urmanská, J. et al. (2001): Impact of different ecosystems and urbanistic areas on conductivity values in water flow. In Acta fytotechnica et zootechnica, vol. 4, special edition, p. 244-245. ISBN 80-7137-959-X.
- Noskovič, J. (1999): Vplyv rôznych ekosystémov a urbanizovaných celkov na akosť vody vo vodnom toku: habilitačná práca. Nitra: SPU, 120 s.
- Pitter, P. (1990): Hydrochemie. SNTL Praha, 565 s.
- Randall, G.W., Mulla, D.J. (2001): Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. In: J. Environ. Qual., vol. 30, p. 337-344.
- Rathore, S.S., Chandravanshi, P., Jaiswal, K. (2016): Eutrophication: Impact of Excess Nutrient Inputs on Aquatic Ecosystem. J. of Agriculture Science, Vol. 9, Issue 10, p. 89 – 96.
- Stredanský, J. (1999): Hodnotenie kvality životného prostredia. 1 vyd. Nitra: SPU, 125 s. ISBN 80-7137-577-2.
- Tölgessy, J., Melichová, Z. (2000): Chémia vody (Voda a jej ochrana). Banská Bystrica: UMB, 154 s. ISBN 80-8055-293-2.

POTENTIAL POSITIVE AND NEGATIVE EFFECTS OF A SOLAR PARK ON WATER MANAGEMENT

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ABSTRACT

Solar energy capacity is almost doubling each year. The target for 2030 is to achieve a 20% share of renewable energy. 98.6 % of installed capacity of the projects were greenfield investments (approved by the Hungarian Energy and Utilities Regulatory Authority in 2020). We examined the potential effects and possible optimal use of excess water, runoff from the solar panels in a case study area. The evaluation of the solar park's technical parameters proved that there were difficulties to be solved, e.g. soil erosion and sediment is created by the water arriving from the panels to the soil surface. On the other hand, in our case study area there are water habitats in close proximity of the solar park where this excess water could be used while it is stored in a newly created ditch. Based on the case study, suggestions are made for the habitat developments. The final output of such hydrological management examination can lead to a win-win situation of solving the technical problems of solar parks (that are expanding inevitably) and improving the water supply of a wetland area, increasing its climate resilience. Further related research questions were also formulated.

Keywords: excess water, runoff erosion, retention, nature conservation, solar park

INTRODUCTION

The recent energy crisis increases the importance of renewable energy production all over the world. Europe also struggles its way towards energy union and zero emission anyway which goal can be fostered by this energy crisis. On the other hand, social acceptance (Frantál, 2015) of renewable energy production might increase, or, we might expect less resistance towards the implementation of new, not so favourable installations (Frantál and Prousek, 2016) from the point of view of landscape quality and agricultural production (Martinát et al. 2016).

While the total installed capacity of solar power plants in Hungary was only one MW in 2010, this value exceeded 3,000 MW in April 2022, but an additional 5,000 megawatts of connection demand is registered. This also means that solar energy accounts for nearly 26% of the gross installed capacity of the Hungarian electricity system (10,419 MW) (Major, 2022). In addition, Hungary has set the goal of achieving a 20% share of renewable energy in its energy strategy by 2030, in which it relies heavily on solar energy. As a result, by 2030, 6,645 MW of solar panels are predicted and intended to be achieved (Major, 2022).

In 2020, 98.6 % or 207 MW of the 210 MW installed capacity of the projects approved by the Hungarian Energy and Public Utilities Regulatory Office were green field investments. Large-scale solar farms are therefore almost exclusively installed in open fields, typically in areas removed from agricultural production, while brownfield investments (former industrial areas, abandoned mining areas and barren pits, landfills, etc.) would be more desirable due to land use, environmental protection and easier network connection (Szolidáris Gazdaság Központ, 2021). In the so-called 'Metár system', which was developed to support solar power plants in Hungary, the extra scoring of "brownfield" investments has not been a competitive advantage for the applicants in any case so far (Munkácsy 2021). The land to be built on, which is typically under agricultural cultivation, will be permanently taken out of cultivation. As a

result of the technical investment, the industrial nature of the landscape increases significantly (Rusvai and Czóbel, 2021), the value of their biological activity decreases, and the amount of excess water that cannot leak out increases as a result of the sealed surfaces (solar panels). In addition, poorly planned watersheds increase the occurrence rate of insects sensitive to polar light pollution and their death (Szász, 2016).

Agri-environmental management research in recent years has shown that the populations of wild animal species can be significantly increased in agricultural areas with appropriate land use and the strengthening of plant associations. Less than 5% of the area of the solar parks is physically built, this proportion is on average around 50% including the areas shaded by the panels, and for a long time after their construction (typically 20–30 years) they appear as areas free of significant human disturbance (Takács 2022). As a result, after appropriate planning (biodiversity management plan) that takes into account local characteristics, solar parks can function as habitats and thus contribute to the preservation of biodiversity.

When planning, it must be taken into account that the reservoirs that collect rainwater flowing from the surface of the panels may be suitable for creating a wetland, but their open water surface may increase the number of aquatic insects that are sensitive to polar light pollution. In the course of evolution, a group of animals became capable of orientation based on the light polarization of water. Some aquatic insects (e.g. mayflies, dragonflies, water bugs, water beetles, and water bugs) recognize their habitat with the help of horizontally polarized light (positive polarotaxis). Horizontally polarized light reflected from solar panels can deceive and attract large numbers of polarotactic aquatic insects. The insects attracted to these surfaces often die, while the eggs they lay die in all cases. This effect can be particularly significant for solar panels that are installed near wetlands, such as river banks (Horváth et al., 2016). Polar light pollution is significantly reduced by installing panel versions with a white grid frame and grid, or with a matte surface, and by increasing the distance between the solar park and the wetland.

It can be seen that the solutions must be selected in such a way that they fit the physical properties of the solar park, connect to the existing habitats, take into account the needs of valuable species on the site and in the immediate vicinity of the installation, and they must also be compatible with the primary goal of producing solar energy (BRE, 2014).

METHODS AND DATA

When selecting the sample area, the following aspects were taken into account:

1. it should be in the green field investment garden of the solar park,
2. it should be on the outskirt area of a settlement,
3. it should be in an agricultural environment and,
4. it should be located near valuable natural areas.

Based on the above criteria, two realized investments (one with an area of 4.4 and one with an area of 1.2 ha) will be selected (Table 1.).

Table 4. The main technical data of the sample areas

Technical data	Sampe area No. 1.	Sample area No. 2.
Location	Szabadszállás, Hungary	Szabadszállás, Hungary
Start date	2019	2022
Installed capacity (kWp)	4 x 607.75	652
Output capacity of the inverter (Kva)	4 x 499	498
Total area (ha)	5.3	1.3
Area of the PV park (ha)	4.4	1.2
Target area of habitat development (ha)	2.3	0.5

In the next step, taking into account international and domestic recommendations (BRE, 2014, Bennun et. al, 2021, Takács 2022), habitat mapping and use analysis will be carried out in a radius of 1 km surrounding the investment using map databases (Agrárminisztérium, 2019) and field visits followed. When analyzing the wildlife, we used the maintenance plans of the two nearby Natura 2000 areas (HUKN10002, HUKN20010) as a basis (Král, 2016, MME, 2015). Taking into account the habitat map, typical land use, and Natura 2000 maintenance plans, the range of possible interventions can be determined. The solutions selected in this way, which prove to be beneficial from the point of view of the living world, are further narrowed down by taking into account the physical and topological features of the solar park and the undisturbed requirements of solar energy production.

The sample areas are located at a distance of 0.7-2.1 km from the Kiskunság saline lakes and the Turjánvidék (HUKN10002) and the Szabadszállás grassland of ground squirrels (HUKN20010) Natura 2000 areas. The HUKN10002 area is an important bird habitat of the Danube watershed both during the migration and the breeding season, and the HUKN20010 area is the habitat of the socially important ground squirrel (*Spermophilus citellus*).

A significant part of the areas surrounding the sample areas are dominated by small plots of land, built-up areas with significant green areas and abandoned orchards (Figure 1).

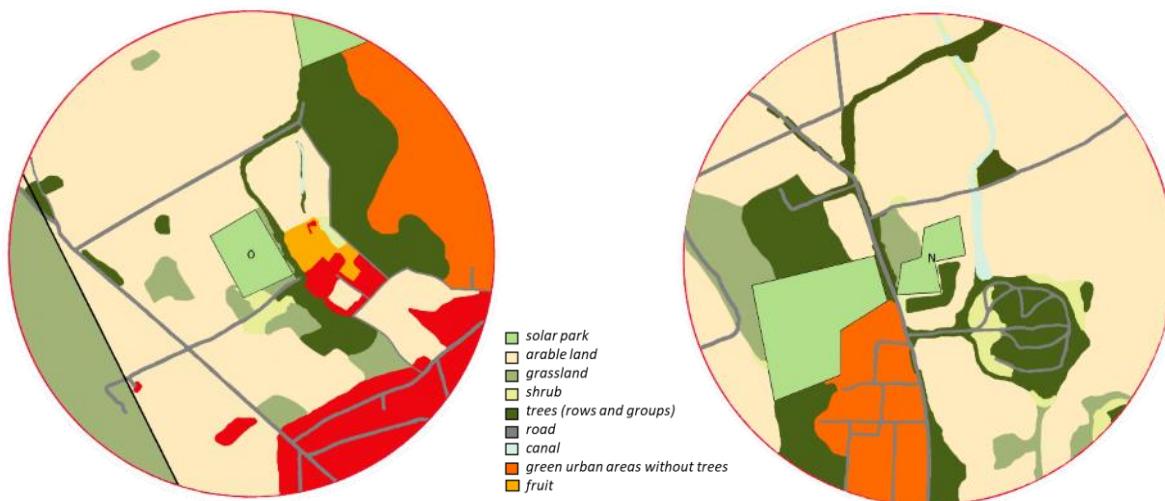


Fig. 1. Habitat map of the areas surrounding the sample areas.

Fresh and dry-semi-arid grasslands, wetlands, and non-native tree groups and rows of trees are wedged between them in an island-like fashion.

RESULTS AND DISCUSSION

In terms of increasing the biological diversity of the sample areas, the task is twofold. On the one hand, for the preservation of complex areas, canal and ditch banks, water-logged areas, and their rows of trees, groups of trees, grassy elms, and shrubs, and on the other hand, their improvement and development. By preserving and restoring these values, the diversity, mosaic, and diversity of the landscape can be maintained. The investigated solar panels can also be involved in this preservation and development process. On the one hand, the area of the park is suitable for the creation of natural lawns, grassy meadows, and bee pastures, and on the other hand, outside the fence, but within the plot, rows of shrubs and patches of shrubs consisting of native species (hawthorn-greenish-juniper dry shrubs) can be planted. The excess rainwater generated in the park area can contribute to the maintenance of aquatic habitats, which will become increasingly important due to the drier climate that related to

climate change. However, in order to avoid the problems arising from the polar light pollution presented earlier, it is not advisable to create an open water habitat from the runoff rainwater in the area of the solar parks (Figure 2.).



Fig. 2. The current precipitation collection ditch created in sample area No. 2.

A solution that ensures natural water retention, but does not cause the above ecological problem, can be the draining of the excess water and govern it to the surrounding, deep-lying grasslands (fens and mesotrophic wet meadows) that are periodically affected by water and thereby ensuring their water replenishment. The two depressions located near the sample areas (30–50 m), which are still periodically covered by water (Figure 3.), provide a good opportunity for this.



Fig. 3. Location and vegetation of periodically flooded areas near the sample areas.

In the next step, we will examine the technical possibilities of draining based on the technical, soil, and water management properties of the property suitable for the solar park and the amount and annual distribution of the generated rainwater, as well as the annual water supply of the depressions and their absorption capacity. Similar brownfield regeneration schemes were examined in the nearby countries (Frantál et al., 2013, 2015; Frantál, 2015).

The mentioned energy crisis that can be a factor that foster the implementation of renewables all over the world can also cause some issues related to environmental, nature conservation and landscape quality (Centeri et al. 2018) or landscape management issues. Traditional agricultural landscapes are already under the scope of investigation for many reasons (Slámová et al., 2015, Centeri et al. 2016). The energy transition schemes are also manyfold in Europe (Frolova et al. 2019). It is obvious that many related issues are to be discussed in the near future and serious attention is needed for finding an optimal solution.

CONCLUSIONS

Around the world and especially in Hungary, the dynamically growing solar park investments realized within the framework of green field investment have drawn attention to the fact that, in addition to their positive role in curbing climate change, they can have a significant negative impact on the biological diversity of built-up areas. However, several studies (Fthenakis and Turney, 2011, Hernandez et al., 2019, Blaydes et.al. 2021) have pointed out that after careful planning, the features of these areas can be improved and they can play an important role as habitats. The tests carried out so far in the two domestic sample areas have pointed out that not only plant planting, but also the possibilities of rational drainage of excess water flowing from the surface of the panels should be included in the scope of the tests.

REFERENCES

- Agrárminisztérium (2019): Ökoszisztemá alaptérkép és adatmodell kialakítása. Agrárminisztérium, Budapest KEHOP-430-VEKOP-15-2016-00001.
- Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021): Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.
- Blaydes, H., Potts, S.G., Whyatt, J.D., Armstrong, A. (2021): Opportunities to enhance pollinator biodiversity in solar parks. Renewable and Sustainable Energy Reviews 145, 11065.
- BRE (2014) Biodiversity Guidance for Solar Developments. National Solar Centre, Eds G E Parker and L Greene.
- Centeri, Cs., Renes, H., Roth, M., Kruse, A., Eiter, S., Kapfer, J., Santoro, A., Agnoletti, M., Emanueli, F., Sigura, M., Slámová, M., Dobrovodska, M., Štefunková, D., Kučera, Z., Saláta, D., Varga, A., Villacreses, S., Dreer, J. (2016): Wooded Grasslands as Part of the European Agricultural Heritage. In: Agnoletti, M., Emanueli, F. ed. *Biocultural Diversity in Europe*. Environmental History 5, Springer International Publishing Switzerland, p. 75–103.
- Centeri, Cs., Frolova, M., Herrero-Luque, D (2018): Pan-European policy aspects of RE and landscape quality. In: Roth, M., Eiter, S., Röhner, S., Kruse, A., Schmitz, S., Frantál, B., Centeri, Cs., Frolova, M., Buchecker, M., Stober, D., Karan, I., van der Horst, D (szerk.) Renewable Energy and Landscape Quality. Berlin, Germany: Jovis Verlag GmbH, 295 p., pp. 128–129.
- Frantál, B. (2015): Have local government and public expectations of wind energy project benefits been met? Implications for repowering schemes. Journal of Environmental Policy & Planning, 17, 2, 217–236.
- Frantál, B., Kunc, J., Nováková, E., Klusáček, P., Martinát, S., Osman, R. (2013): Location Matters! Exploring Brownfields regeneration in a Spatial Context (Case Study of the South Moravian Region, Czech Republic). Moravian Geographical Report, 21, 2, 5–19.
- Frantál, B., Kunc, J., Klusáček, P., Martinát, S. (2015): Assessing Success Factors of Brownfields Regeneration: Inter-national and Inter-stakeholder Perspective. Transylvanian Review of Administrative Sciences, 44E, 91–107.
- Frantál, B., Prousek, A. (2016): It's not right, but we do it. Exploring why and how Czech farmers become renewable energy producers. Biomass & Bioenergy, 87, 26–34.
- Frolova, M., Frantál, B., Ferrario, V., Centeri, Cs., Herrero-Luque, D., Grónás, V., Martinát, S., Puttilli, M., Almeida, L., D'Angelo, F. (2019): Diverse energy transition patterns in Central and Southern Europe: A

*Electronic book
Interdisciplinary Approach in Current Hydrological Research*

- comparative study of institutional landscapes in the Czech Republic, Hungary, Italy, and Spain. *Tájékológiai Lapok*, 17, Special Issue, 65–89.
- Fthenakis, V., Turney, D. (2011): Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, 15, 3261–3270.
- Hernandez, R.R., Armstrong, A., Burney, J., Ryan, G., Moore-O’Leary, K., Diédhieu, I., Grodsky, S.M., Saul-Gershenson, L., Davis, R., Macknick, J., Mulvaney, D., Heath, G.A., Easter, S.B., Hoffacker, M.K., Allen, M.F., Kammen, D.M. (2019): Techno–ecological synergies of solar energy for global sustainability. *Nature Sustainability*, 2, 560–568.
- Horváth, G., Farkas, A., Kriska, Gy. (2016): A poláros fény környezetoptikai és biológiai vonatkozása. ELTE Eötvös Kiadó, Budapest.
- Králl, A. (ed.) (2016): A Kiskunsági szikes tavak és az Őrjegi Turjánvidék Különleges Madárvédelmi Terület (HUKN10002) Natura 2000 fenntartási terve. Körtáj Tervező Iroda Kft. Pilisszentlászló.
- Major, A. (2022): Napenergia: óriási mérőföldkönél Magyarország, tovább gyorsulhat a növekedés. Portfolio, Net Média Zrt. 2022. április 12
- Martinát, S., Navrátil, J., Dvořák, P. Van der Horst, D., Klusáček, P., Kunc, J., Frantál, B. (2016): Where AD plants wildly grow: The spatio-temporal diffusion of agricultural biogas production in the Czech Republic. *Renewable Energy*, 95, 85–97.
- MME (2015): A Szabadszállási ürgés gyep különleges természetmegőrzési terület (HUKN20010) Natura 2000 fenntartási terve. Magyar Madártani és Természetvédelmi Egyesület, Budapest.
- Munkácsy, B. (szerk.) (2021): Csak nappal! Csak nappal? Avagy a napelemes áramtermelés jövője Magyarországon a területhasználat nézőpontjából. Energiaklub Szakpolitikai Intézet és Módszertani Központ.
- Nemzeti Energia- és Klímaterv (2020): Innovációs és Technológiai Minisztérium.
- Rusvai, K., Czóbel, Sz. (2021): Changes in Soil Seed Bank and Vegetation at Abandoned Bait Sites in a Central European Hilly Area. *Biology and Life Sciences Forum*, 2, 1, Paper: 15.
- Slámová, M., Beláček, B., Jančura, P., Prídavková, Z. (2015): Relevance of the historical catchwork system for sustainability of the traditional agricultural landscape in the Southern Podpolanie region. *Agriculture and Agricultural Science Procedia*, 4: 10–19.
- Szász, D., Mihályi, D., Farkas, A., Egri, Á., Barta, A. Kriska, Gy., Robertson, B. Horváth, G. (2016): Polarized light pollution of matte solar panels: anti-reflective photovoltaics reduce polarized light pollution but benefit only some aquatic insects. *J. Insect. Conserv.*, 20, 663–675.
- Szolidáris Gazdaság Központ (2021): A napelemboom sötét oldala. Budapest.
- Takács, Á. (szerk.) (2022): Szakmai Iránytű az újgenerációs napelemparkok fejlesztéséhez. SolServices Kft., Budapest 2022.

VÝSKYT ĽADOVÝCH JAVOV A POVODNÍ NA RIEKE VÁH V TRENČÍNE V ROKOCH 1704-1705

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ABSTRACT

The records of the Trenčín Jesuit Diary from the beginning of the 18th century contain some valuable hydrological information such as the occurrence of ice phenomena and floods on the River Váh in Trenčín. In this paper, we focus on the evaluation of such recorded events during the years 1701-1705. Daily records from this period were kept by two administrators of the Jesuit dormitory (“regens convictus”) Ján Garajský and Juraj Košetič. Hydrological phenomena in their records were mentioned just during the years 1704-1705.

In the cold winter of 1704/1705 several ice phenomena occurred on the River Váh in Trenčín, ranging from partial to complete ice cover formation on river up to ice break-up (floating river ice, ice jam with probable ice flood). Ice phenomena lasted for a relatively long time. They occurred in December 1704 and probably lasted continuously until at least the end of February 1705.

In evaluated period (1704-1705) there was 7 times mentioned high water on the River Váh in Trenčín. We may assume that in five cases it could have been a flood, when the water from the Váh flooded the banks. However, we classified all recorded floods as minor, just one of them was caused by ice phenomena.

Keywords: Jesuit Diary, ice phenomena, floods, river, Váh, Trenčín

ÚVOD

Prvé známe hydrologické merania vodného stavu vo svete boli vykonávané v Magdeburgu na rieke Labe v roku 1727, na rieke Dunaj to bolo vo Viedni v rokoch 1784-1785, v Bratislave sa meral vodný stav na Dunaji v rokoch 1819 a 1820 a bol zaznamenaný v novinách Preßburger Zeitung (Brázil a kol. 2012). Podľa Horváthovej (2003) pozorovania hladín riek na Slovensku boli realizované najskôr v 2.štvrťine 19. storočia na vodočtoch na Dunaji (Bratislava, Komárno) a neskôr od roku 1860 aj na Váhu v Trnovci. Na slovenských tokoch bolo postupne do konca 19. storočia vybudovaných vyše 20 vodočetných staníc (Horváthová 2003). Z viacerých lokalít na území Slovenska máme namerané hydrologické údaje k dispozícii až od druhej polovice 20. storočia.

Hydrologické informácie z obdobia pred začiatkom systematických hydrologických meraní čerpáme z rôznych historických prameňov, ako sú napr. listiny, knihy, denníky, korešpondencia, narratívne pramene, noviny, epigrafické záznamy, mapy a pod. (Brázil a Kundzewicz 2006, Brázil a kol. 2012, Kiss 2019, Horváthová 2003, Melo a Bernáthová 2013, Melo a kol. 2014a, 2014b, 2014c, Melo a kol. 2019, Miklánek a kol. 2013, Pekárová a Miklánek 2012, Pekárová a kol. 2011, Pišút a kol. 2016). Tieto pramene ponúkajú pomerne značný a zatiaľ dostatočne nevyužitý potenciál ohľadom nových poznatkov pri štúdiu hydrometeorologických extrémov na našom území. Historické záznamy o významných hydrologických udalostiach v povodiach našich riek, ako sú napríklad povodne, suchá, ľadochody a podobne, sú veľmi dôležité pre lepšie poznanie častoti, dĺžky a intenzity výskytu týchto javov, čo nám umožňuje spresniť výsledky vyhodnotenia takýchto udalostí aj smerom do budúcnosti. Napr. objavenie nových údajov o historických povodniach nám

umožní správnejšie zhodnotiť významnosť kulminačného prietoku. Informácie z archívnych zdrojov nám môžu pomôcť tiež pri časovej a priestorovej rekonštrukcii významných hydrometeorologických udalostí z minulosti a pomáhajú nám doplniť a objasniť doposiaľ neznáme takéto prípady.

V tomto príspevku čerpáme informácie z Diária jezuitského konviku v Trenčíne 1701-1710 (*Diarium convictus Trenchiniensium nobilium 1701-1710*), ktoré sa nám podarilo získať z Národnej Széchényiho knižnice v Budapešti a zameriavame sa tu na vyhodnotenie hydrologických informácií o rieke Váh v Trenčíne, ktoré sa objavili v prvej časti záznamov tohto Diária, týkajúceho sa obdobia 1701-1705.

Trenčín je významný mestom na Považí s bohatou históriou (Šišmiš 1993).

PÔSOBENIE JEZUITOV NA ÚZEMÍ SÚČASNÉHO SLOVENSKA A V TRENČÍNE

Na územie súčasného Slovenska prišli prví jezuiti dňa 23. apríla 1561, a to konkrétnie do mesta Trnava. Jezuiti v nasledujúcich rokoch ovplyvnili nielen duchovný, ale aj kultúrny a vzdelanostný život obyvateľov. Zakladali tu sieť škôl: kolégia s gymnáziami (Trnava, Kláštor pod Znievom, Šaľa, Humenné, Bratislava, Skalica, Trenčín, Banská Štiavnica, Banská Bystrica, Levoča, Prešov, Košice) a dve univerzity (Trnava v roku 1635, Košice v roku 1657). Jezuiti dosahovali v tej dobe kvalitnú úroveň svojho školstva. Tieto inštitúcie významnou miere prispeli k rozvoju vedy vo svete i na našom území (Udiás 2015). Jezuitskú rehoľu zrušil pápež Klement XIV. 21. júla 1773. Po obnove jezuitskej rehole, ktorú schválil pápež Pius VII. v roku 1814, prišli jezuiti opäťovne na územie dnešného Slovenska v roku 1853. Jej pôsobenie malo už odlišný charakter (Hudaček 2012).

Podľa Bernáta (2013; 2020) v Trenčíne začali jezuiti účinkovať 2. decembra 1646. Založili tu konvikt – chlapčenský ubytovací a výchovný ústav pre šľachtickú mládež (*convictus nobilium*), v ktorom chovanci dostali celé zaopatrenie. V čele konviku stál správca (*regens convictus*). V roku 1653 už je Trenčín uvádzaný ako kolégium „*collegium Trinchiniense*“. V čele stál rektor. Základy novej budovy noviciátu a kolégia položili v roku 1655. Kolégium aj kostol boli funkčné už v roku 1657 (Obr. 1). Slubne rozvíjajúcu sa činnosť kolégia, noviciátu a gymnázia prerušili morové epidémie v rokoch 1656, 1679, 1680, 1681 a najviac v roku 1710. Ďalšou prekážkou pre rozvoj kolégia boli Turci, ktorí v roku 1663 prenikli do okolia Trenčína. Činnosť tohto rádu v Trenčíne prerušovali stavovské povstania, tak napríklad v roku 1678 a 1680 museli jezuiti ujsť pred Tökoliho povstalcami. Po vypuknutí protihabsburgského povstania Františka Rákociho II. odišli jezuiti (okrem niekoľkých členov) s novicimi z Trenčína do Trnavy v roku 1703. Vo februári 1704 prepadli kuruci predmestie Trenčína a začali mesto obliehať. Luteránski mešťania 14. februára zložili zbrane a prinútili ku kapitulácii aj ostatných. Cisárska posádka sa bránila na hrade. Mesto v máji obsadilo znova cisárské vojsko, ale v meste sa začal šíriť hlad. Požiar v roku 1708 zničil veľkú časť centra mesta vrátane kostola a kolégia jezuitov. Z kláštora a kostola jezuitov zostali väčšinou len holé múry. Jezuiti nechali kostol a kolégium renovovať už od roku 1710 v barokovom slohu. Kolégium pôsobilo po roku 1715 už bez prerušenia a väčších problémov. Po zrušení rádu pápežom Klementom XIV. breve „*Dominus ac redemptor noster*“ z 21. júla 1773, bolo gymnázium v Trenčíne odovzdané piaristom. Exjezuiti naďalej mohli pokračovať v práci pedagógov na tejto škole (Bernát 2013, Bernát, 2020).

Podľa Bernáta (2013) v čele kolégia, jezuitského gymnázia a noviciátu stál predstavený rehoľného domu (rector), ktorého menoval provinciál. Rektor (superior) navrhoval prefekta školy (*praefectus studiorum, prefectus scholarum*), ktorý bol pomocníkom predstaveného rehoľného domu, resp. jeho pravou rukou. Prefekt školy bol v pravom zmysle slova dnešným riaditeľom školy. Mal na starosti vyučovací proces, disciplínu, náboženské cvičenia a dozeral tiež na učiteľov. Jezuitské kolégia sa od seba odlišovali významom a počtom členov. Význam

trenčianskeho jezuitského kolégia zvyšoval noviciát. V noviciáte sa neštudovalo, ale pripravovalo na vstup do rádu. Školy, ktoré sa nachádzali pri kolégiach, sa delili na nižšie a vyššie. Jezuiti menili svoje pôsobiská takmer každý rok a nebolo ani výnimcočné, že k zmene došlo uprostred školského roka. V jezuitskom ráde mal každý člen nejakú funkciu, resp. niekoľko funkcií (Bernát 2013).



Obr. 1. Pohľad na bývalý jezuitský kostol a kolégium v Trenčíne v súčasnosti (Foto: M.Melo, september 2022).

Podľa Bernáta (2013) sú významným prameňom jezuitského kolégia v Trenčíne kroniky *Historia et annuae collegii societatis Jesu Trenchiniensis ab anno 1645- ad a. 1685* a *Annuae collegii et probationis Trenchiniensis societatis Jesu, ab anno 1686 – usque 1727*, ktoré sú uložené v Eötvös Loránd Tudományegyetem, Egyetemi Könyvtár v Budapešti, v oddelení Manuskript v časti Societas Jesu pod signatúrami Ab 114 a 115 (prvá z nich je prístupná aj v elektronickej podobe:

https://edit.elte.hu/xmlui/static/uv/uv.html?key=10831/33285&fname=Ab114_001.jpg.jpg.

Vznikli z povinnosti v rehoľných domoch písat' kroniky, k čomu bol priamo určený kronikár kolégia. Obsahujú záznamy o personálnej skladbe rehoľného domu vrátane pedagogického zboru a veľmi stručne o činnosti školy. Maximálnu pozornosť ale venujú činnosti kolégia v oblasti pastorácie (Bernát 2013).

Okrem kroník si jezuiti na miestach svojho pôsobenia viedli aj diáriá, ako napr. v Košiciach (Brázdil a Kiss 2001) a v Trenčíne. Denné záznamy tohto druhu prameňov sa týkajú bežného života, resp. denného režimu členov trenčianskeho konviktu (škola, odpočinok, pobožnosť) a opisu udalostí, ktoré sa odohrali v lokalite pôsobenia jezuitov a boli písané v latinčine. Tieto denníky viedli správcovia konviktu, ako to bolo s najväčšou pravdepodobnosťou v Košiciach (Brázdil a Kiss 2001) a ako sa to teraz ukázalo pri našom výskume aj v prípade Trenčína.

DIARIUM CONVICTUS TRENCHINIENSIMUM NOBILIUM 1701-1710

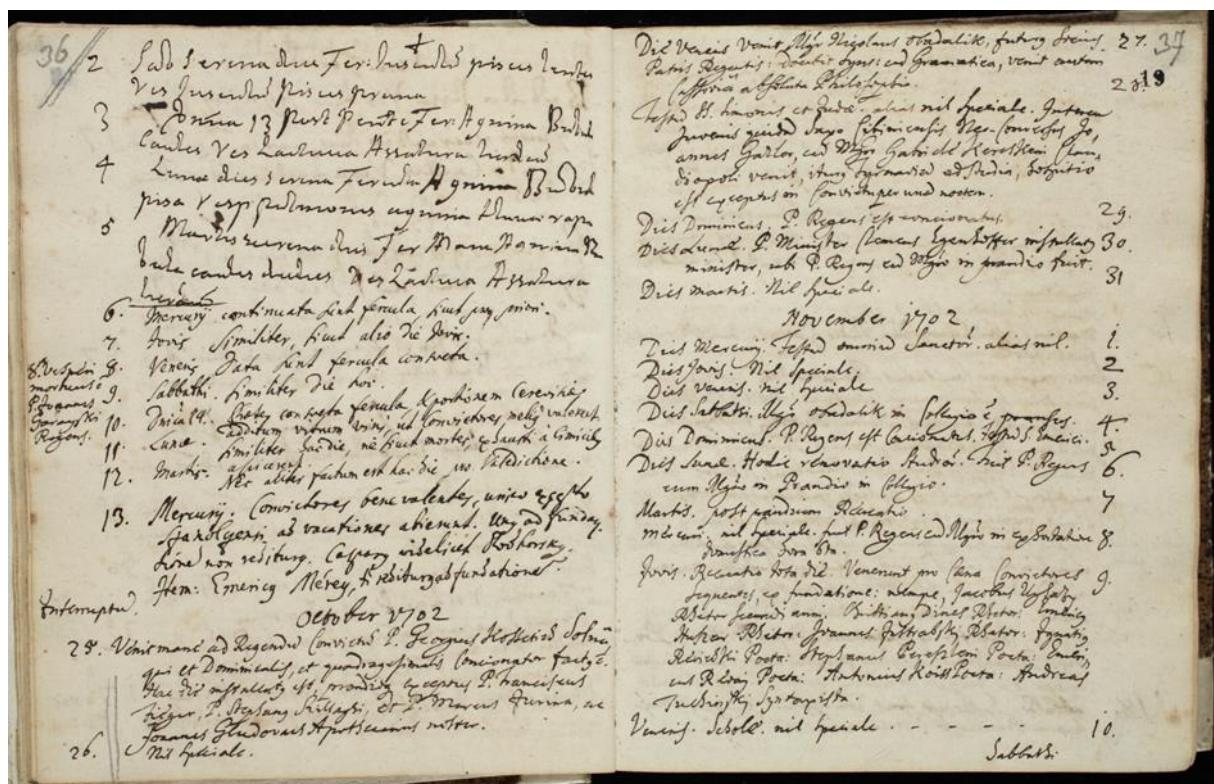
Z Národnej Széchényiho knižnice v Budapešti máme k dispozícii záznamy z Denníka jezuitského konviku v Trenčíne 1701-1710 (*Diarium convictus Trenchiniensium nobilium 1701-1710*), ktoré sa týkajú obdobia od 7. novembra 1701 do 4. marca 1710. Na titulnej strane obálky je rukou dopísané, že ide o zväzok No.5, čo môže svedčiť o tom, že toto dielo je pokračovaním nejakých predchádzajúcich zväzkov diária. O ostatných zväzkoch však v tejto chvíli nemáme žiadne ďalšie vedomosti.

Na titulnej strane tohto zväzku diária sú dve pečiatky. Prvá pečiatka, ktorá sa zároveň nachádza aj na poslednej strane denníka, je označená nasledovným textom: „W.JANKOVICH MIKLOS GYÜJTEMENYE 1830“ (z maďarského prekladu: Zbierka Miklosa W.Jankovicha 1830) a je doplnená erbom. Druhú a novšiu pečiatku na titulnej strane označuje text: „Ex Museo Hungarico“ (Bývalé Uhorské múzeum).

Podľa pečiatky vo vnútri tento zväzok diária do svojej zbierky v roku 1830 získal Miklós Jankovich (1772-1846), významný maďarský zberateľ a mecén umenia, historik, bibliograf, čestný člen Uhorskej vedeckej spoločnosti. Knižničná časť jeho zbierky prešla po zakúpení uhorským parlamentom v roku 1836 (spolu asi 63 tisíc zväzkov kníh) najprv do vlastníctva Uhorského národného múzea a neskôr bola presunutá do dnešnej Národnej Széchényiho knižnice v Budapešti.

V tomto príspevku vyhodnocujeme hydrologické informácie uverejnené v prvej časti tohto zväzku diária, ktoré sa týkajú záznamov od 7. novembra 1701 do 31. decembra 1705. Mená autorov týchto zápisov v diári nie sú priamo uvedené, nenašiel sa tu o tom žiadny záznam, avšak nepriamo môžeme autorstvo týchto záznamov priradiť dvom menám. Zapisovatelia písali o sebe v tretej osobe. Z nepriamych dôkazov vyplýva, že to boli správcovia (regenti) konviku (v latinčine: „*regens convictus*“), ktorých počas ich krátkodobých absencií zastúpili niektorí ďalší (nám neznámi) jezuiti, pôsobiaci v ich okolí resp. zápisu absentovali úplne (napr. v prípade choroby). Chýba tu tiež uvedená informácia, o čom sa bude v denníku písat’.

Podľa rukopisu viedol tieto záznamy v období od 7. novembra 1701 do 5. septembra 1702 jeden a ten istý zapisovateľ. Záznamom venoval pozornosť na dennej báze, s výnimkou dvoch súvislejších párov dňových období, keď bol odcestovaný mimo Trenčín (na Oravu), resp. sa venoval inej činnosti (exercíciám). Na str. 18 tohto diária (Obr. 2) je viditeľná zmena pisára, pričom sa na margu zapísalo, že 8. septembra (1702) zomrel páter regent Ján Garajský. A zápisu dovedajšou (jeho) rukou skončili tri dni predtým, 5. septembra 1702. Táto skutočnosť nám dovoľuje prisúdiť autorstvo zápisov vtedajšiemu správcovi konviku Jánovi Garajskému. Podľa Bernáta (2013) sa Ján Garajský narodil 24. decembra 1643 v Jaslovciach (v súčasnosti Jaslovské Bohunice). Do jezuitského rádu vstúpil v kurze rétorov 17.11.1661 v Trnave. V rokoch 1701-1702 bol v Trenčíne prefektom školy, ďalej správcom konviku, prézesom kongregácie, kazateľom, poradcom a spovedníkom. Zomrel 8. septembra 1702 v Trenčíne (Bernát 2013). Údaj o jeho smrti večer uvedeného dňa je zapísaný aj na margu trenčianskeho diária.



Obr. 2. Ukážka rukopisných záznamov z Denníka jezuitského konviktu 1701-1710 (*Diarium convictus Trenchiniensium nobilium 1701-1710*) zo septembra, októbra a novembra 1702 (str. 18-19). Zdroj: Országos Széchényi Könyvtár Budapest (Národná Széchényi knižnica Budapešť).

Od 6. do 13. septembra 1702 začínajú zápisu inou rukou bez uvedenia mena zapisovateľa. Pravdepodobne išlo o niekoho z prostredia konviktu, ktorý dočasne prevzal zápisu, podľa charakteru rukopisu to mohli byť až dve rôzne osoby. Od 14. septembra do 24. októbra 1702 bolo zapisovanie úplne prerušené s poznámkou, že sa členovia konviktu rozišli na vakácie. Dňa 25. októbra 1702 sa v Denníku objavuje informácia, že zo Žiliny prišiel do konviktu nový správca (regent) páter Juraj Košetič, o ktorom predpokladáme, že práve on bol autorom, ktorý prevzal od 25. októbra 1702 pokračovanie zápisov Denníka trenčianskeho konviktu po zosnulom Jánovi Garajskom. Svedčia o tom nasledujúce tri okolnosti. Dňa 10. decembra 1702 odišiel správca konviktu (Košetič) na rekreáciu a mení sa aj rukopis zápisov, to naznačuje, že ich dovtedy pravdepodobne písal on. Dňa 19. decembra sa opäť vrátil a zápisu sú opäť písané pôvodnou (jeho) rukou. Dňa 11. júna 1703 páter regent (Košetič) odišiel do kúpeľov a mení sa znova rukopis zápisov. Po jeho návrate dňa 17. júna sa opäť vracia predchádzajúci rukopis zápisov. Rukopis záznamov sa opäť mení dňa 6. júla 1703, keď páter regent odišiel na Oravu a zápisu píše nový pisár (menom neuvedený) a po návrate regenta dňa 23. júla sa opäť objavuje predchádzajúca ruka zápisov.

Rozdiel v zápisoch vedených Garajským a Košetičom sa odrazil aj na ich obsahovej stránke. Od čias, keď písanie diára prevzal do svojich rúk nový regent, absentuje v ňom opis stravy podávanej v konvikte. Regent Garajský zaznačoval každý deň do diára dennú a večernú stravu na rozdiel od jeho nástupcu, ktorý si jedálny lístok osobitne nevšímal, hoci pre historikov skúmajúcich každodenný život v minulosti má aj takáto informácia veľký význam. Za celé nasledujúce obdobie sú záznamy vynechané okrem dvoch jednotlivých dní už len raz, avšak v tomto prípade to bolo až na takmer dva mesiace (od 24. mája do 20. júla 1705), a to kvôli chorobe zapisovateľa. Dňa 26. mája sa ešte v denníku objavuje krátka informácia o aktuálnom počasí pochádzajúca rukopisom od iného jezuitu: „*takmer celý deň daždivý*“ a nasleduje poznámka: „*Kvôli ochoreniu na skorbut prerušil páter regent záznamy, pretože sa*

cítil veľmi zle už od začiatku marca. Aj dnes kvôli bolesti nôh nedokázal vstať z posteľe a Boh vie, kedy táto skorbutová choroba pominie“. Zápisy potom až do 20. júla úplne absentujú, ešte 6. augusta 1705 sa v diáriu spomína skorbut pátra regenta.

Denník, ktorý máme k dispozícii, končí rokom 1710 (posledný zápis je 4. marca). Charakter zápisov a rukopisu sa nemení ani v ďalšom období, ktoré sme zatiaľ ešte nespracovali. Opäť je po uvedení dátumu stručne zaznamenané panujúce počasie, ďalej výkon duchovných povinností regenta: spovedanie a bohoslužba a ďalšie riadky obstarali udalosti, ktoré sa odohrali v meste Trenčín, na hrade a v jeho okolí. Zaujímavosťou je, že pisár občas latinský text svojich zápisov obohatil slovenskými vetami alebo slovami vyjadrujúcimi bolest' a smútok nad panujúcou situáciou. Akurát po požiaru mesta 14. mája 1708 začína pisár písat' diár novým atramentom a zápisu po deväť dní zostručňuje opakováním výrazu „ako včera“, čo nepriamo naznačuje, že požiar sa dotkol aj konviktu. Na druhej strane regent sa o podrobnostiach a následkoch požiaru veľmi nerozpisuje, uspokojil sa len s tvrdením, že oheň spálil celé mesto okrem fary, farského kostola a pára chatrčí na Hôrke. Regent Juraj Košetič zomrel až po vyše dvoch týždňoch po poslednom zápisu v tomto zväzku diária, takže to by tiež podporovalo jeho autorstvo zápisov.

Predpokladáme teda, že v období od 25. októbra 1702 až do posledného dňa, ktorý je v tomto zväzku denníka zaznamenaný, t.j. do 4. marca 1710, bol ich zapisovateľom vtedajší správca konviktu páter Juraj Košetič, ktorého pri jeho krátkodobých absenciách pri písaní textov dočasne nahradili niektorí ďalší (nám neznámi) jezuiti z jeho okolia.

Podľa Bernáta (2013) sa Juraj Košetič (Kossetich) narodil 1. februára 1649 v Trenčíne. Do jezuitského rádu vstúpil ako magister filozofie 8.10.1670 v Trnave. V rokoch 1703-1710 pôsobil v Trenčíne vo funkciách správcu konviktu, kazateľa, spovedníka, operaria a poradcu. Predtým bol v rokoch 1697-1702 v Žiline ako predstavený rezidencie, kazateľ, operarius a spovedník. (Poznámka: zo zdrojov diária vyplýva, že do Trenčína prišiel pôsobiť na uvoľnené miesto po zosnulom správcovi konviktu Jánovi Garajskom už v októbri 1702). Zomrel 21. marca 1710 v Trenčíne (Bernát 2013).

VYHODNOTENIE ZÁZNAMOV DIÁRIA JEZUITSKÉHO KONVIKTU V TRENČÍNE Z ODBOBIA 1701-1705, TÝKAJÚCICH SA HYDROLOGICKÝCH INFORMÁCII

Na začiatku študovaného obdobia (od novembra 1701 do septembra 1702) vykonával zápisu v diáriu páter Ján Garajský. V jeho záznamoch sme nenašli žiadne zmienky o výskytu ľadových javov, povodní, prípadne nízkych stavov hladiny Váhu. Na strane druhej venoval v tomto období pozornosť stavu počasia počas jednotlivých dní, to však nie je predmetom tohto spracovania. Páter Juraj Košetič, ktorý prevzal v októbri 1702 zapisovanie tohto denníka po Jánovi Garajskom, najskôr vo svojich záznamoch nevenoval žiadnu pozornosť ani meteorologickým a ani hydrologickým informáciám. Informácie o počasí sa postupne objavujú až od 30. apríla 1703, a to najskôr len sporadicky a potom od 1. augusta 1703 súvisle (takmer na dennej báze), a to až do 31. decembra 1705, dokedy sa nám podarilo zatiaľ spracovať tieto zápisu. Približne od začiatku roka 1704 sa v záznamoch začínajú objavovať aj správy o výskytu ľadových javov a povodniach na Váhu v Trenčíne. Za celé sledované obdobie sa pritom v Denníku nenašla žiadna správa o prípadnom nízkom stave hladiny na Váhu. Pri vyhodnocovaní zaznamenaných informácií si treba uvedomiť, že v druhej polovici 17. a na začiatku 18. storočia malo koryto Váhu pri Trenčíne inú polohu ako v súčasnosti, tieklo o niečo bližšie k hradnej skale a k mestu (Obr. 3 a 4), pričom tu rieka vytvárala meandre, bočné ramená a ostrovky, tak ako to vidíme napr. na mape z roku 1670 (Obr. 3). Ľadové javy sa na Váhu vyskytli v obidvoch zimách 1703/04 i 1704/05, pričom výrazne sa prejavili najmä v druhom zmienenom období. Tvorba ľadu na riekach je silne závislá od

režimu riečneho toku, ktorý je ovplyvnený atmosférickými faktormi (teplota vzduchu, atmosférické zrážky, topenie snehu), morfológiou koryta (tvar, sklon) a hydrologickými faktormi (teplota vody, rýchlosť prúdenia, množstvo vody). V roku 1704 je v denníku zachytená zmienka o dvoch povodniach na Váhu, v nasledujúcom roku 1705 sa dozvedáme spolu až o piatich prípadoch veľkej vody, avšak z toho asi iba v troch mohlo ísiť o povodeň, pri ktorej Váh zaplavil svoje brehy.

V nasledujúcom texte sú v chronologickom poradí zoradené jednotlivé zaznamenané prípady s výskytom ľadových javov alebo povodní na rieke Váh v Trenčíne, ktoré sme objavili v diáriu v období 1704-1705.

Ľadochod na Váhu v Trenčíne dňa 30. januára 1704

Tejto udalosti predchádzali chladné dni, ktoré nastali v Trenčíne už koncom roku 1703 a trvali od 22. decembra až do 23. januára nasledujúceho roku 1704. Predpokladáme, že počas tohto chladného obdobia sa na hladine Váhu vytvoril zámrz. Po 24. januári sa oteplilo, objavujú sa zápisu o mierne teplom až teplom počasí v Trenčíne, dňa 29. januára bol zaznamenaný daždivý a mierne teply deň. Došlo tak k uvoľneniu ľadov na Váhu a vytvoreniu ľadochodu, ktorý spôsobil poškodenie dreveného mosta. Dňa 30. januára je v diáriu o tom zaznamenaná stručne nasledujúca správa: „*Zamračene, vlhko. Lad strhol päť nosníkov mostov*“. Pravdepodobne ide o most, ktorý bol lokalizovaný blízko hradnej skaly a je ho vidieť na vedute mesta i na mape z roku 1706 úplne vľavo (Obr. 4).

Povodeň na Váhu v Trenčíne v dňoch 22.-27. septembra 1704

Mesiac september 1704 začal striedaním teplých dní s trochu chladnejšími. Tento charakter počasia sa zmenil 14. septembra vo večerných hodinách, keď prišlo daždivejšie počasie, ktoré sa počas nasledujúcich dní zopakovalo aj v dňoch 16., 17., čiastočne i 18., ďalej 21. a 22. septembra, keď sa prvý krát objavuje v diáriu zmienka o rastúcej hladine rieky: „*Váh kvôli dažďu mierne stúpol*“. Zrážky pokračovali aj v nasledujúcich troch dňoch, a to s nasledujúcimi zápismi v denníku, dňa 23. septembra: „*Dážď, chladno*“, 24. septembra: „*Chladno, daždivo. Váh (je) veľký*“, 25. septembra: „*Dážď, chladno. Váh (je) veľký, ako včera a stupeň tretí*“. Nasledujúci deň (26. september) už bol bez zrážok, v denníku je pre tento deň uvedený zápis: „*Oblačno, trochu chladno. Váh (je) veľký*“ a napokon dňa 27. septembra: „*Trochu chladno, oblačno, napokon po raňajkách sa začalo vyjasňovať. Váh značne klesol*“. Príčinou tejto povodne na Váhu, ktorá kulminovala v dňoch 24.-26. septembra, bolo dlhšie trvajúce zrážkové obdobie. O prípadných škodách, ktoré by táto povodeň spôsobila, nie sú žiadne zmienky, takže predpokladáme, že išlo o povodeň bežnej (priemernej) veľkosti a rozsahu.



Obr. 3. Pohľad na hrad a mesto Trenčín od Váhu (horný obrázok) a pôdorys (dolný obrázok) v roku 1670 (kópia z roku 1808). Zdroj: Országos Széchényi Könyvtár Budapest (Národná Széchényiho knižnica Budapešť), originálny rozmer: 67 x 47 cm, v mierke: 1:17 700, <https://maps.hungaricana.hu/en/OSZKTerkeptar/474/?list=eyJxdWVyeSI6ICJUcmVuY3NcdTAwZTluIn0>.



Obr. 4. Pohľad na hrad a mesto Trenčín od Váhu (horný obrázok) a pôdorys (dolný obrázok) v roku 1706. Jezuitský kostol a kolégium sú na tomto obrázku označené písmenom P a nachádzajú sa vpravo, v blízkosti mestskej brány. Zdroj: Hadtörténeti Intézet és Múzeum Budapest (Vojenský historický ústav a múzeum Budapešť), originálny rozmer: 50 x 70,5 cm, https://maps.hungaricana.hu/hu/search/results/?list=eyJxdWVyeSI6ICJ0cmVuY3NlbiAxNzA2In0&per_page=20

Povodeň na Váhu v Trenčíne dňa 18. novembra 1704

Príčiny tejto povodne nevieme bližšie vysvetliť, nakoľko ani počasie, ktoré na dennej báze zaznamenával do denníka jej zapisovateľ, nenasvedčovalo tomu, že by sa povodeň mohla kvôli zrážkam vyskytnúť. V Trenčíne dva týždne pred touto povodňou ani žiadne nezaznamenali. Striedali sa tu jasné, oblačné a zamračené dni, avšak bez dažďa či snehu. Možno teda predpokladať, že výdatnejšie zrážky zasiahli oblasť na hornom toku Váhu a jeho prítokoch.

V Trenčíne bolo zamračené v dňoch 10., 11., 12. a 17. novembra. Dňa 18. novembra je v denníku uvedený nasledovný záznam: „*Oblačno a trochu chladno. Váh veľmi stúpol pri mlynoch. V noci okolo 12-tej hodiny sa jeden mlyn majúci pod sebou zlé člny alebo lode („naves seu logye“) potopil, rozlámal na kúsky a odplával po Váhu. Utopilo sa s ním aj jedno dievča bez pochýb tiež veľmi obtiažkané obilím*“. Ani v ďalších dňoch sa autor zápisov vôbec nezmieňuje o stave hladiny na Váhu, v záznamoch sú iba tieto dve správy, týkajúce sa rieky Váh, a to 21. novembra: „*Zamračene, trochu chladno. Váh (je) dostatočne dobrý pre mlyny*“ a 22. novembra: „*Ráno sneh s dažďom. Trochu chladno. Váh (je) dobrý pre mlyny*“.

Výskyt ľadových javov na Váhu v Trenčíne v zime 1704/1705 (v dňoch od 11. decembra 1704 do 25. februára 1705)

Zima 1704/1705 sa vyznačovala chladným počasím, čo zrejme spôsobovali častejšie sa vyskytujúce anticyklonálne situácie. Napr. v januári 1705 prevažovali v Trenčíne dni s jasnou oblohou (celkom v 19,5 dňoch) pred zamračenými a oblačnými dňami (celkom v 11,5 dňoch; z toho v štyroch prípadoch to bolo i so snežením), v tomto mesiaci zároveň zapisovateľ v diáriu označil celkom 23 dní ako chladných, 4 dni trochu chladné, 3 dni mierne a len 1 januárový deň označil ako mierne teplý. Takéto chladné počasie malo vplyv aj na hladinu Váhu, kde sa počas tejto zimy vyskytli viaceré ľadové úkazy, a to od čiastočného ľadového zámrzu na Váhu v dňoch 11., 12. a 21. decembra 1704, cez úplný ľadový zámrz v dňoch 7.-10. januára 1705, až po rozpad tejto ľadovej pokrývky na jej konci. V denníku je dňa 6. februára 1705 zaznamenaný očakávaný ľadochod na Váhu, avšak reálne mohol prísť aj neskôr, nakoniec sa vyskytla i ľadová zátarasa spojená s pravdepodobne i menšou ľadovou povodňou v dňoch 24.-25. februára 1705.

Priebeh tejto zimy bol pomerne dobre zachytený v jezuitskom denníku a na jeho základe môžeme urobiť nasledovnú rekonštrukciu. Po krátkom teplejšom období na začiatku decembra 1704 sa 8. decembra počasie ochladilo, v dňoch 9. a 10. decembra bol zaznamenaný v Trenčíne silný mráz. Nasledujúce dva dni sa na Váhu vyskytol čiastočný zámrz, o čom sú v denníku nasledujúce informácie, dňa 11. decembra: „*Chladno, oblačno. Mlyny zablokované ľadom. Všeobecný výrub dreva v predmestí až po Šiance. Mnohé hrubé trámy, ktoré môžu byť použité na most, boli uložené na bezpečnejšie miesto od Váhu*“ a dňa 12. decembra: „*Jasno, chladno. Pracovalo sa pri mlynoch, zablokovaných ľadom, aby mohli mliesť*“. V nasledujúcich dňoch sa oteplilo, 13. decembra bol zaznamenaný miernejší mráz, 15. decembra už bolo teplo a v ostatné dni až do 19. decembra mierne teplo. Dňa 20. decembra sa opäť ochladilo a pri jasnej oblohe bolo trochu chladno a 21. decembra je uvedený nasledovný denníkový záznam: „*Silný mráz. Mlyny zablokované*“. Predpokladáme, že tento čiastočný ľadový zámrz na Váhu mohol pokračovať aj v ďalších dňoch, keďže počasie pretrvávalo prevažne jasné a chladné do konca tohto kalendárneho roka a v prvých štyroch dňoch januára bolo vystriedané snežením, ale stále s chladným počasím. Ďalej pre pokračujúce chladné a opäť jasné počasie došlo potom v januári 1705 k vytvoreniu úplného zámrzu na rieke Váh. Podľa záznamov bolo dňa 7. januára: „*Chladno, jasno. Váh sa zastavil*“ a veľmi podobná opakujúca sa správa i 10. januára: „*Jasno, chladno. Váh sa zastavil*“. Takéto chladné a väčšinou i jasné počasie prevažovalo i v ďalších dňoch, a to až do začiatku februára, preto predpokladáme, že po celú túto dobu bol Váh v Trenčíne zamrznutý. Dňa 6. februára je

uverejnený nasledovný zápis, týkajúci sa buď už v tom čase existujúceho ľadochodu na Váhu alebo pravdepodobnejšie len v jeho očakávaní, že by sa mohol v najbližších dňoch dostaviť: „*Mierny mráz. Na strelnici (delostreleckej batérii) vnútri, v meste, sa pracovalo. Vonku začali mešťania rozoberať mosty kvôli strachu, aby ich ľad úplne neodplavil. Iné nič. Obvyklá blokáda. Zajatí kuruci boli kvôli nejakému sprisahaniu vložení do kladiv*“. Chladné počasie pretrvávalo ďalej až do 13. februára, keď prišlo sneženie v ďalších troch nasledujúcich dňoch. Dňa 17. februára sa objavuje v denníkových záznamoch nasledujúca informácia: „*Zamračene, mierne teplo. Vietor topí sneh. Celú noc teply vietor roztápal sneh*“ a v nasledujúci deň 18. februára: „*Teplo, sneh sa topil a ľad na Váhu bol značne oslabený*“. Predpokladáme teda, že ľadová pokrývka na Váhu sa zrejme začala postupne rozpúšťať až v tomto čase, napomohlo k tomu aj teplé počasie a jasný deň dňa 19. februára. V diáriu možno nájsť ku 20. februáru nasledujúci záznam: „*Jasno, teplo. S moravskými poslami prišlo z Moravy jedno dievča, slúžka chirurga Jána, ktorá odišla na Moravu pred 6 týždňami. Prišla ráno. Okolo pol deviatej hodiny prekročila ľad. Čo priniesla, nevedno. Medzitým bola privedená k Profosovi a svojmu pánovi priniesla nejakú tel'aciu, cibuľu a maslo, z čoho si vojací vzali desatinu*“. Podľa tejto informácie sa Váh v daný deň dal teda stále ešte prejsť z jedného brehu na druhý pešo (suchou nohou) po pevnom ľade. Po ďalších dvoch miernych a oblačných dňoch nastalo oteplenie. V záznamoch sú uvedené nasledovné poznámky, a to ku 23. februáru: „*Oblačno a mierne teplo. Ľad na Váhu veľmi zoslabol*“, ku 24. februáru: „*Zamračené, mierne teplo. Voda vo Váhu sa vyliala na ľad, ale zatiaľ so sebou nevzala tri delá pripevnené k batérii*“. Podľa týchto správ predpokladáme, že 24. februára sa mohla na Váhu niekde pod Trenčínom vytvoriť ľadová zátarasa, v dôsledku ktorej vznikla pravdepodobne i menšia ľadová povodeň v Trenčíne (poznámka: z uverejnených správ v Diáriu nie je celkom isté, či veľká voda vo Váhu vyšla zo svojho koryta na breh, preto hovoríme v tomto prípade iba o pravdepodobnej ľadovej povodni), ktorá kulminovala v tomto meste v nasledujúci deň, a to 25. februára s nasledujúcim denníkovým záznamom: „*Oblačno, mierne. Veľká voda vo Váhu tiekla ponad ľad, ale ľad sa zatiaľ neroztopil*“.

Vzhľadom na to, že posledné tri februárové dni boli chladnejšie a v denníkových záznamoch sa už ďalšie správy o ľade v tejto zime na Váhu nenachádzajú, predpokladáme, že zvyšný ľad sa udržal minimálne do konca februára a pravdepodobne sa postupne rozpustil až v teplejších dňoch na začiatku marca 1705, pričom zrejme nespôsobil žiadne problémy, keďže zapisovateľ tomuto javu už nevenoval ďalšiu pozornosť na stránkach diária.

Jarná povodeň na Váhu v Trenčíne dňoch 21. – 30. marca 1705

Od 10. marca až do 29. marca 1705 sa v zápisoch Diária objavuje opakované konštatovanie o teplých a väčšinou i jasných dňoch v Trenčíne, len minimálne sa tu objavili dni s oblačnosťou, resp. zamračením, a aj to bolo vždy bez zrážok. Iba na konci mesiaca (29.-30. marca) bolo trochu chladnejšie počasie. V tomto období sa viac krát objavila v denníkových záznamoch správa o veľkej vode na Váhu, čo môžeme v týchto dňoch vďaka teplejšiemu počasiu pripísať rýchlejšiemu topeniu snehu, naakumulovaného počas zimy vo vyšších polohách v povodí Váhu. Tu prinášame jednotlivé správy z diária o povodňovej situácii v Trenčíne, a to: 21. marca: „*Oblačno, mierne teplo. Niektorí naši vybehli spod hradu cez Váh zbierať bylinky, ľudovo režuchy, boli však kubranskými kurucmi vyhnani, no vrátili sa všetci zdraví. Váh je veľký (rozvodnený)*“, 25. marca: „*Mierne teplo, jasno. Váh (je) stále veľký*“, 27. marca: „*Zamračene, mierne teplo. Váh bol veľký*“, 28. marca: „*Pekné počasie. Váh bol veľký*“, 30. marca: „*Jasno, vietor trochu chladný, južný. Váh dosť dobrý (veľký)*“ a 31. marca: „*Zamračene, trochu chladno. Váh primeraný*“.

Presný dátum kulminácie tejto jarnej povodne, vzniknutej z topenia snehovej pokrývky v horských oblastiach Karpát v povodí Váhu, sa z uvedených zápisov nedá jednoznačne určiť, vieme len, že 31. marca už bolo po nej a Váh sa vrátil do bežného stavu.

Letná povodeň na Váhu v Trenčíne dňa 25. júla 1705

Po prerušení záznamov (od 27. mája až do 20. júla 1705) z dôvodu ochorenia zapisovateľa na skorbut sa v diáriu nachádza ďalšia zmienka o povodni dňa 25. júla 1705, a to: „*Oblačno, trochu chladno. Dobytok bol vypustený na pašu cez dolnú bránu. Váh stúpol a pasienkov za mostami už takmer niet. Vyháňať dobytok ďaleko nie je bezpečné*“. Predpokladáme, že táto povodeň mohla byť reakciou na daždivejšie dni, ktoré boli v dňoch 21. a 22. júla, pričom 23. júla bolo v Trenčíne podľa záznamov: „*Oblačno a trochu chladno*“. Po zrážkach, ktoré mohli byť frontálneho charakteru a zasiahnutť mohli aj vyššie položené oblasti v povodí Váhu, sa kulminácia tejto menšej a krátkotrvajúcej povodňovej vlny prejavila v Trenčíne 25. júla 1705, viac pozornosti už jej zapisovateľ v diáriu nevenoval.

Veľká voda na Váhu v Trenčíne dňa 16. októbra 1705

16. októbra 1705 sa vyskytla na Váhu v Trenčíne veľká voda, v tento deň sa objavil v diáriu nasledovný záznam: „*Jasno, teplo. Váh (je) veľký*“. Viac sa o nej v záznamoch autor nezmieňuje. Čo sa týka počasia, tak pred touto zvýšenou hladinou na Váhu v Trenčíne boli v októbri zrážky iba v dvoch dňoch, a to 9. a 13. októbra a tesne pred touto udalosťou dňa 15. októbra bolo v Trenčíne zamračené. Nepredpokladáme, že by táto veľká voda prerástla do povodne.

Stúpajúca voda na Váhu v Trenčíne dňa 16. decembra 1705

V Diáriu sa objavuje ešte jedna zmienka o stúpajúcej vode na Váhu v Trenčíne, a to dňa 16. decembra: „*Zamračene, mierne teplo. Váh začal stúpať*“. Ďalšie informácie o tejto situácii na Váhu sa už v denníkových záznamoch nenachádzajú, preto išlo len o menšiu reakciu zrejme na predchádzajúce zrážky v povodí (v Trenčíne bol dňa 3. decembra zaznamenaný sneh, v dňoch 4. a 6. decembra sneženie, 12. decembra zamračené, 13. decembra daždivo, 15. decembra daždivo) a povodeň pravdepodobne v tomto prípade nenastala.

ZÁVER

Obdobie začiatku 18. storočia, ktoré sme študovali v tomto príspevku, patrí k tzv. malej dobe ľadovej, ktorá sa vyznačovala výskytom chladnejších zím, čo dokazuje aj niekoľko informácií nájdených v Diáriu trenčianskeho konviktu z obdobia 1701-1705. Začiatok tohto skúmaného obdobia (1701-1702), v ktorom vykonával záznamy Ján Garajský, sice nie je zachytený žiadnou hydrologickou zmienkou, na druhej strane vo svojich zápisoch priniesol tento autor cenné informácie o dennom stave počasia, ktoré vyhodnotíme v ďalšom príspevku. Nasledujúci autor zápisov v denníku (1702-1705) Juraj Košetič spočiatku taktiež nevenoval pozornosť hydrologickým záznamom, k nim sa dopracoval až postupne, a to približne od začiatku roka 1704, keď si začal všímať výskyt ľadových javov na Váhu v Trenčíne a zvýšený stav hladiny na tejto rieke. Zachytil tak viaceré pre nás doposiaľ neznáme prípady, ktoré sa tu vyskytli v rokoch 1704 a 1705.

Zo spracovaných výsledkov vyplýva, že v tomto dvojročnom období sa vyskytla spolu 7 krát veľká voda na Váhu v Trenčíne, z toho predpokladáme, že v piatich prípadoch mohlo íť o povodeň, keď voda z Váhu vystúpila zo svojho koryta a zaplavila brehy. Všetky zaznamenané povodne však radíme k menším, z toho v jednom prípade mohlo íť o ľadovú povodeň. Významné sú aj denníkové záznamy o výskyti ľadových javov na rieke Váh v Trenčíne, v zime 1703/1704 tu bol zaznamenaný ľadochod v januári 1704. V zime 1704/1705 sa tu vyskytli viaceré ľadové javy, a to od čiastočného po úplný zámrz a zaznamenaný bol aj rozpad ľadovej pokrývky, kedy sa na rieke objavil ľadochod, ľadová zátarasa i s pravdepodobnou ľadovou povodňou. Ľadové javy počas tejto zimy trvali pomerne dlhú dobu, vyskytli sa už v decembri 1704 a pravdepodobne kontinuálne trvali minimálne do

konca februára (zrejme až do začiatku marca) 1705. Toto zimné obdobie bolo charakteristické prevažne chladným počasím, čo korešponduje s charakterom tuhých zím obdobia tzv. malej doby ľadovej. Po preštudovaní zvyšnej časti diária (1706-1710), ktorý máme k dispozícii, vyhodnotíme tieto výsledky v nasledujúcom príspevku.

Poděkovanie

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LITERATÚRA

- Bernát, L. (2013): Životopisný slovník pedagógov Jezuitského gymnázia v Trenčíne v rokoch 1649-1773. Eko-konzult Bratislava, 380pp.
- Bernát, L. (2020): Noviciát frátorov Spoločnosti Ježišovej v Trenčíne v rokoch 1655-1773. Trenčianske múzeum v Trenčíne, 302pp.
- Brázdil, R., Kiss, A. (2001): Daily weather observations at Košice, Slovakia, in the period 1677-1681. Meteorologický časopis 4, 4, 3-14.
- Brázdil, R., Kundzewicz, Z.W. (2006): Historical hydrology – Editorial. In: Hydrological Sciences Journal, 51, 5, 733-738.
- Brázdil, R., Kundzewicz, Z.W., Benito, G., Demarée, G., Macdonald, N., Roald, L.A. (2012): Historical floods in Europe in the past millennium. In: Kundzewicz, Z.W. (ed.) (2012): Changes in flood risk in Europe. IAHS Special Publication 10, IAHS Press, Wallingford, 121-166.
- Horváthová, B (2003): Povodeň to nie je len veľká voda. Bratislava: VEDA, 232pp.
- Hudaček, M. (2012): Spoločnosť Ježišova a 450 rokov jej pôsobenia na Slovensku. In: Hudaček, M. (ed.) (2012): Jezuiti na Slovensku v minulosti aj v súčasnosti. Dobrá kniha Trnava, 13-47.
- Kiss, A. (2019): Floods and Long-Term Water-Level Changes in Medieval Hungary. Springer, 895pp.
- Melo, M., Bernáthová, D. (2013): Historické povodne v povodí Slanej od konca 18. storočia do začiatku 20. storočia. In: Acta Hydrologica Slovaca, 14, 2, 291–298.
- Melo, M., Melová, K., Bernáthová, D., Dujšíková, C. (2014a): Využitie historických prameňov pri štúdiu klímy a hydrometeorologických extrémov na Slovensku. Studia Scientifica Facultatis Paedagogicae Universitas Catholica Ružomberok, 13, 3, 55-68.
- Melo, M., Pekárová, P., Miklánek, P., Melová, K., Dujšíková, C. (2014b): Use of historical sources in a study of the 1895 floods on the Danube River and its tributaries. Geographica Pannonica 18, 4, 108-116.
- Melo, M., Pišút, P., Melová, K., Viglaš, P. (2014c): Zaniknuté značky dunajskej povodne z roku 1775 v Bratislave. Acta Hydrologica Slovaca, 15, 2, 308-319.
- Melo, M., Pišút, P., Melová, K., Viglaš, P., Damborská, I., Bada, M. (2019): Dôsledky extrémnych prejavov počasia v zime 1783/84 na mestá strednej Európy po erupcii vulkánu Lakagigar. In: Bada, M., Duchoňová, D. a kol. (2019): Pohromy, katastrofy a nešťastia v dejinách našich miest. Igor Ilíš – RádioPrint, Bratislava, Historický ústav SAV, 137-182.
- Miklánek, P., Pekárová, P., Halmová, D. (2013): Historická povodeň z roku 1813 vo svetle povodňových značiek. Časť I.: Povodie Váhu. In: Acta Hydrologica Slovaca, 14, 2, 299-307.
- Pekárová, P., Miklánek, P. (2012): Historické povodňové značky v Bratislave v oblasti Vydrickej brány a Zuckermannu. In: Procc: Vplyv vodných stavieb na tvorbu a ochranu územia. Vyd. STU Bratislava, 114-127.
- Pekárová, P., Škoda, P., Majerčáková, O., Miklánek, P. (2011): Významné povodne na území Slovenska v minulosti. In: Acta Hydrologica Slovaca, 12, 1, 65-73.
- Pišút, P., Procházka, J., Matečný, I., Bandura, P. (2016): Vývoj koryta Váhu pri Leopoldove v 17. - 20. storočí a odozva rieky na zásahy človeka. Univerzita Komenského v Bratislave, 272pp.
- Šišmiš, M. (Ed.) (1993): Trenčín. Vlastivedná monografia I. Bratislava: Alfa, 384pp.
- Udiás, A. (2015): Jesuit Contribution to Science. A History. Springer, 277pp.

Section III: Climate Change and Variability

CHANGES IN THE MAXIMUM DAILY PRECIPITATION TOTALS IN SLOVAKIA

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ABSTRACT

This article is focused on the analysis of new record values of maximum daily precipitation totals in Slovakia recorded in the period 2001 – 2021. The analysis is constructed as a simple comparison between the record values measured in the periods 2001 – 2021 and 1951 – 2000. Our research was carried out on the annual and seasonal time series of maximum daily precipitation totals obtained from more than 450 precipitation stations. The paper presents the results of the analysis for those months, in which the changes were most significant. The increase in the values of the analyzed precipitation characteristics during the winter season (XII – II) is particularly noteworthy. A similar development was also detected in other seasons, but it was only limited to individual months and was not present throughout the season. The increase in the winter precipitation totals is associated with a significant increase in the average winter air temperature. A warmer atmosphere not only results in a proportional change in the total amount of the solid, liquid and mixed precipitation, but can modify the nature of winter precipitation. Changes in maximum daily precipitation totals were more pronounced in the more continental climate of eastern Slovakia.

Keywords: daily precipitation totals, extreme precipitation, climate change

INTRODUCTION

Man induced climate change is noticeably warming the atmosphere and this warming process is still accelerating during the 21st century. In a warmer environment, the atmosphere may contain more water vapor (IPCC 2022). A warmer atmosphere not only results in a proportional change in the total amount of solid, liquid and mixed precipitation but can also significantly change the nature, intensity and abundance of winter precipitation (Markovič et al., 2020). Warmer winter condition can result in higher daily precipitation totals, which are usually not characteristic for traditional winter climate in Central Europe. Europe and adjacent areas of Atlantic Ocean registered during the second decade of the 21st century weakened and often absent west-east transmission of moist air masses. This change in the traditionally predominant atmospheric circulation might have directly affected results of this analysis. Perhaps the most noticeable is the decline in more homogeneous longer-lasting large-scale stratiform precipitation. This type of precipitation, which originates in the North Atlantic Ocean, is the main source of precipitation in the traditional climate conditions of inland Europe. It is therefore very important to properly examine the changes in maximum daily precipitation totals in order to better understand changing weather extremes. This article presents an analysis of daily rainfall totals in annual, seasonal and monthly time steps for meteorological stations in Slovakia in the years 1951 – 2020.

METHODS AND DATA

Maximum daily precipitation totals (1D_max) were analyzed at 491 precipitation stations with complete, homogeneous, and consistent daily precipitation sets over the 70-year period

1951 – 2020. (Fig. 1.). For historical reasons, the daily amount of atmospheric precipitation is measured as a 24-hour total from 7:00 a.m. to 7:00 a.m. the following day at Slovak precipitation stations. So it's not really a "true" daily total. This paper presents an analysis of new record values of the maximum daily precipitation totals in Slovakia recorded in the period 2001 – 2020 with focus on the comparison with previous record values from the period 1951 – 2000. Data were evaluated using geostatistical analysis and spatially interpolated using the Inverse distance weighting (IDW) method. IDW is a type of deterministic method for multivariate interpolation with a known scattered set of points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points (Achilleos, 2011).

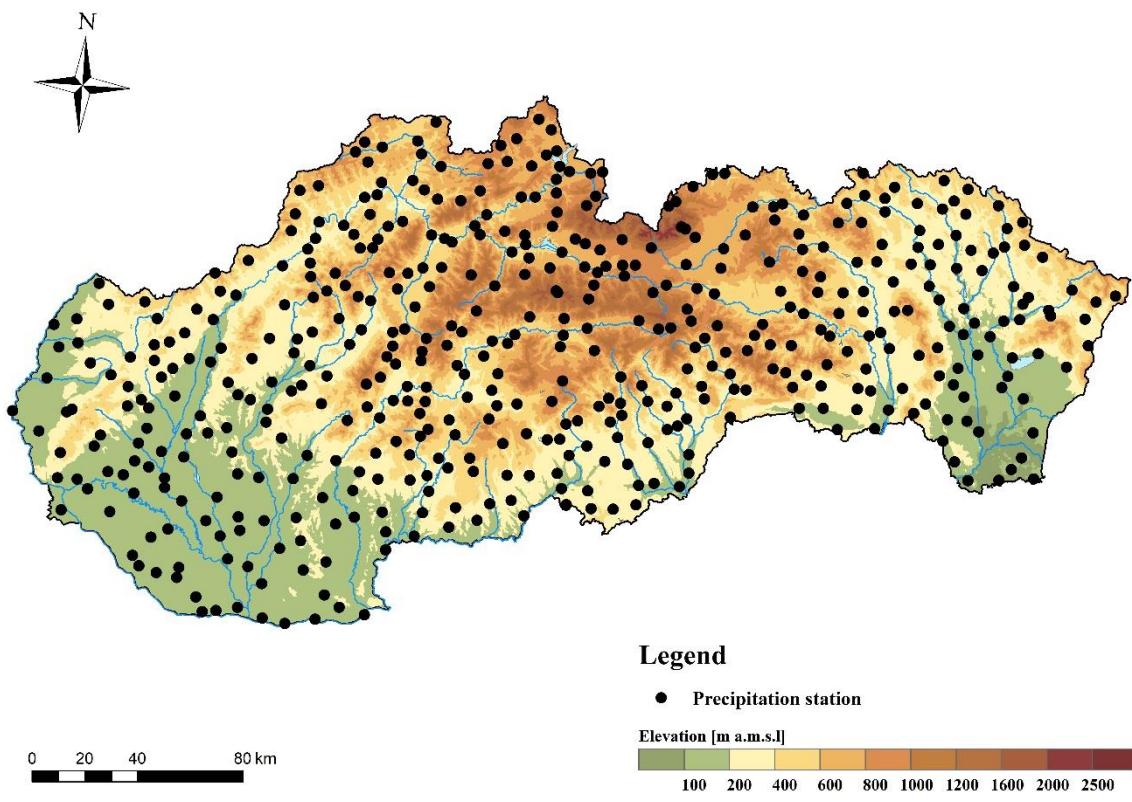


Fig. 4. Network of precipitation stations used in the analysis.

RESULTS AND DISCUSSION

The analysis was performed on annual, seasonal and monthly time series of daily precipitation totals. This article presents the results of the spatial geostatistical analysis for those months and seasons in which the most significant changes were detected. Most significant changes in seasonal values, exceeding 60 percent of previous 1D_max, were detected during spring (central part of Slovakia) (Fig. 2A, 2C; Fig. 3A.) and autumn (west part of Slovakia) (Fig. 2B, 2D; Fig. 3B.). The origin of these changes differs significantly between the two seasons. The increase in 1D_max values during spring is almost exclusively related to the intensive convective storms and showers. The change in autumn maxima is, on the other hand, caused by a change in the nature of the atmospheric circulation. These changes lead to the recurrence of circulation systems originating in the Mediterranean region, which may cause widespread and prolonged stratiform precipitation during September.

If we focus on individual months, then the most remarkable increase in 1d Max values is recorded during the winter months of January (I) and February (II) and in May (V), September (IX) and November (XI) (Fig. 3). April (IV) and October (X) are the months with the smallest recorded change.

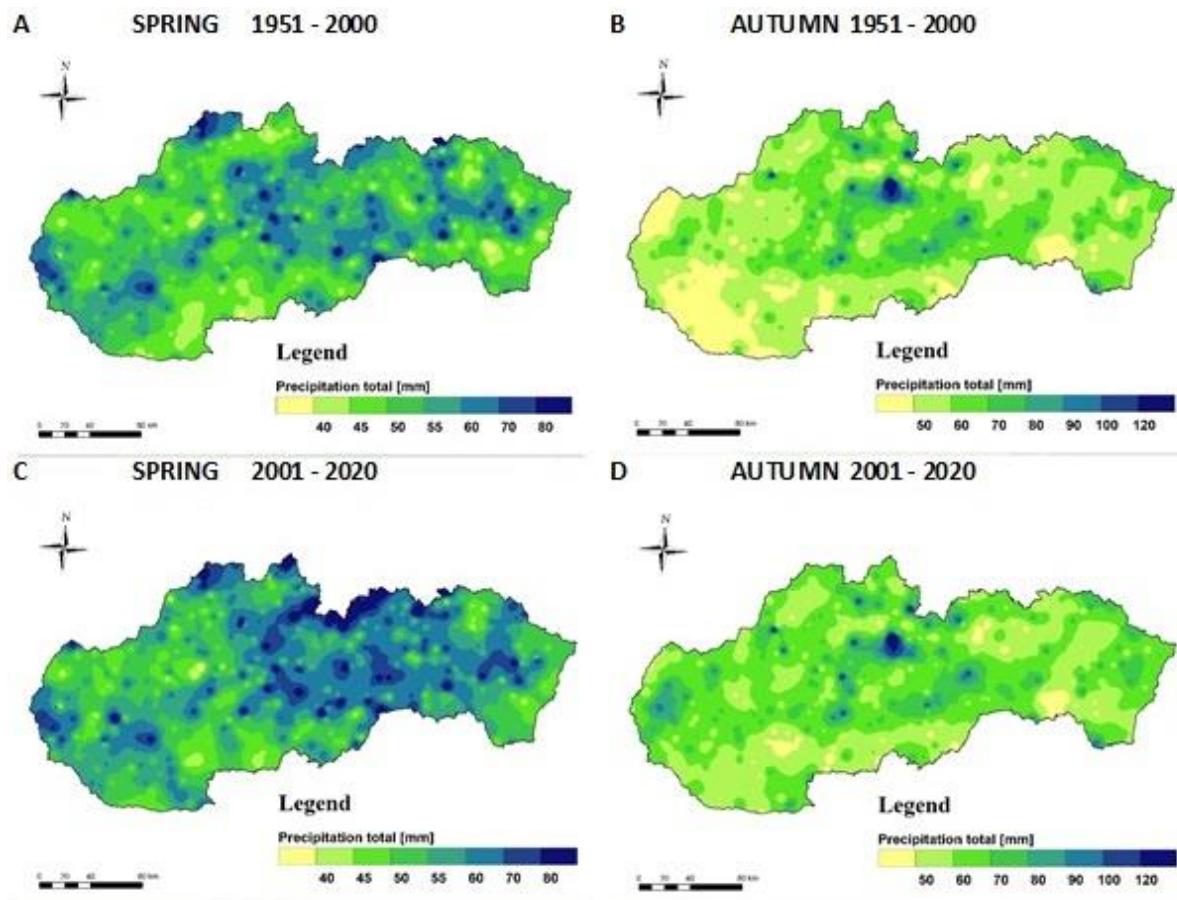


Fig. 2. Spatial distribution of maximum annual and seasonal values of daily precipitation totals in spring and autumn [mm] during periods 1951 – 2000 and 2001 – 2020 in Slovakia and relative change [%] between the period 2001 – 2020 and 1951 – 2000.

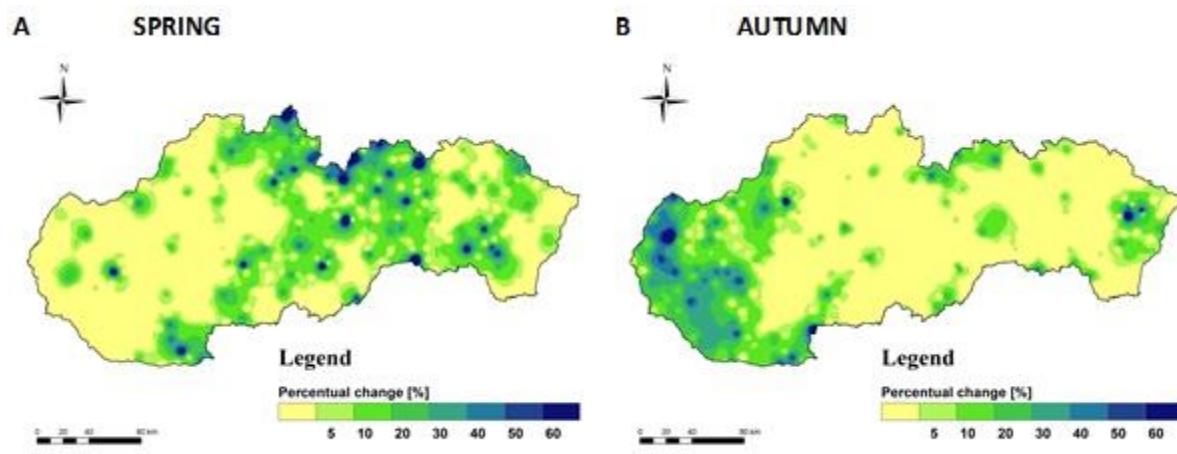


Fig. 3. The relative change [%] in maximum seasonal values of daily precipitation totals during spring (A) and autumn (B) [mm] between the periods 2001 – 2020 and 1951 – 2000 in Slovakia.

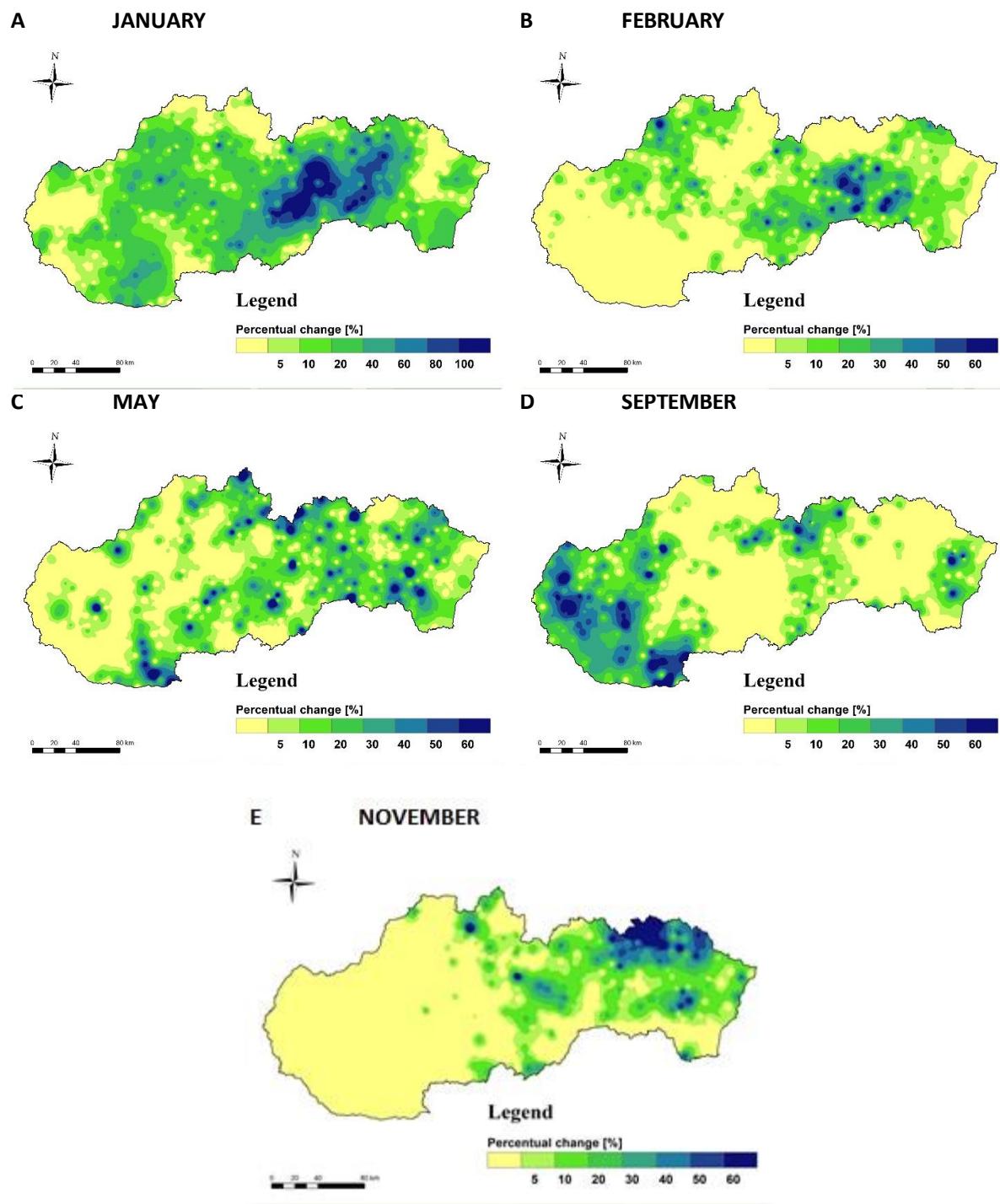


Fig. 4. The relative change [%] in maximum seasonal values of daily precipitation totals during January (A), February (B), May (C), September (D) and November (E) [mm] between the periods 2001 – 2020 and 1951 – 2000 in Slovakia.

When comparing the two selected periods 2001 – 2020 and 1951 – 2000, absolutely the most significant changes were recorded in January (Table 2). The record value of the maximum January daily precipitation total increased at more than 72% of the 491 stations included in the analysis. The average maximum value for the whole set increased by 24% from 29,5 mm to 36,6 mm (Tab. 2.). Changes in record values were in some cases very significant, for example a 220% increase was recorded at the Hrabišice station (from 16,7 mm to 53,4 mm).

The extreme west, northwest and north of Slovakia was relatively less affected by the change in 1d_max detected in January. The lack of changes detected in the extreme west, northwest and north of Slovakia is related to the more oceanic climate in this part of Slovakia. In general, the most significant factor influencing this change was a significant increase in the long-term average monthly January air temperature. This fact results in the frequent occurrence of exceptionally warm January.

Table 1. Average annual and seasonal values of maximum daily precipitation totals for the periods 1951 – 2000 (row 1) and 2001 – 2020 (row 2), with the relative change (row 3) the highest recorded relative change (row 4) and the percentage of stations with new record value (row 5)

	YEAR	WHY	CHY	III - V	VI - VIII	IX - XI	XII - II
AVER MAX							
1951 - 2000	85.1	83.9	55.8	54.5	82.4	60.1	43.5
[mm]							
AVER MAX							
2001 - 2020	90.4	89.6	57	59.6	87.9	64.3	45.7
[mm]							
DELTA							
[%]	6	7	2	9	7	7	5
MAX DELTA							
[%]	130	129	174	137	130	114	129
NEW MAX							
[%]	34	35	19	40	36	37	33

Table 2. Average monthly values of the maximum daily precipitation totals for the periods 1951 – 2000 (row 1) and 2001 – 2020 (row 2), with the relative change (row 3) the highest recorded relative change (row 4) and the percentage of stations with new record value (row 5)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
AVER MAX												
1951 - 2000	29,5	32,7	34,1	45,8	50,5	66,6	72	65,4	54	51,7	41,5	41
[mm]												
AVER MAX												
2001 - 2020	36,6	35,7	36,4	46,8	56,9	70,8	77,4	72	59,9	52,9	44,4	42,5
[mm]												
DELTA												
[%]	24	9	7	2	13	6	7	10	11	2	7	3
MAX DELTA												
[%]	220	90	115	69	160	117	142	173	134	65	115	129
NEW MAX												
[%]	72	45	35	18	49	33	38	41	43	21	34	23

CONCLUSIONS

Changing climatic conditions constantly modify record values and have potential to extremify intensity and total amount of precipitation. It is therefore essential to provide revised and actual extreme values of precipitation totals. These changed extreme daily precipitation totals (1D_max) significantly modify traditional climatological knowledge and shows, that even winter precipitation can, in this new conditions, exceed 50 mm. This paper presents an

analysis of new record values of 1D_max in Slovakia recorded in the period 2001 – 2020 with focus on the comparison with previous record values from the period 1951 – 2000. The increase in the winter 1D_max is particularly noteworthy. A similar development, in a form of a significant increase, was also detected in other seasons. In these cases, it was limited only to individual months and was not present throughout the season. The most significant changes were recorded in January. The record value of the maximum January daily precipitation total increased at more than 72% of the 491 stations included in the analysis and the average maximum value for the whole set included in the analysis increased by 24% from 29,5 mm to 36,6 mm.

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REFERENCES

- Achilleos, G.,A. (2011): The Inverse Distance Weighted interpolation method and error propagation mechanism – creating a DEM from an analogue topographical map, *Journal of Spatial Science*, 56:2, 283-304.
- IPCC (2022): Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.
- Faško, P., Pecho, J., Markovič, L. (2019): Some aspects of changes in number of warmer-than-normal months in climatic conditions of Slovakia. EMS Annual Meeting 2019: 09–13 September 2019, DTU Lyngby, Copenhagen, Denmark. EMS Annual Meeting Abstracts, Vol. 16, p. 443.
- Markovič, L., Pecho, J., Faško, P. (2020): Zmeny v skupenskom zastúpení atmosférických zrážok v zime na území Slovenska. Meteorologické zprávy. ČHMÚ, 73-2020/1. ISSN: 0026-1173.
- Markovič, L., Faško, P., Bochniček, O., Pecho J. (2021): Extreme daily precipitation totals in Slovakia and changes in their record values. In: Botyanszká, L., Vitková, J. (eds.), 2021. Hydrological Processes in the Soil–Plant–Atmosphere System. IH SAS, E-Book, Bratislava, p. 317. ISBN:978-80-89139-50-7.
- Markovič, L., Faško, P., Pecho, J. (2021): Climatology of the extreme heavy precipitation events in Slovakia in the 1951–2020 period. In *Acta Hydrologica Slovaca*, vol. 22, no.2, pp. 294-303. 2644-6291 (printed until 2018). DOI: <https://doi.org/10.31577/ahs-2021-0022.02.0033>.

CHANGES OF REPRESENTATION OF CARABID LIFE FORMS AND FOOD GUILDS IN THE FORESTS IN HIGH TATRA DAMAGED BY WINDSTROM OF 2004

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ABSTRACT

Classification of the Carabid life forms sensitively reflects the enormously diversified relationships between the body form of these beetles and their mode of life. Thus they represent a suitable criterion for evaluation of the structure of Carabid assemblages and the role they play in different ecosystems, as well as degree of their naturalness or damaging by various factors. Evaluation of changes in the representation of life forms in the Carabid assemblages in the area of High Tatra destroyed in November 2004 by the extensive windstorms shows that in the destroyed plots and plots additionally damaged by fire by turn of July and August 2005 were extensively invaded by the myxophagous harpaloid geobionts. They invasion was stronger in the site additionally damaged by fire, but gradually it declined in all destroyed sites. Quantitatively the walking zoophagous epigeobionts started to dominate in these sites. In the intact reference site and in the damaged site with timber *in situ* the zoophagous walking epigeobionts also started to dominate above the zoophagous stratopbions living in litter a burying into soil. from this aspect the striking convergent run in all studied sites.

Keywords: Carabids, life forms, food guilds, High Tatra, windstorms

INTRODUCTION

The enormous ecological differentiation of Carabids is reflected by a wide variability of their body form and various proportions of individual body parts. They reflect adaptations to their environment and life strategy. Since the long time, the long and narrow pronotum and head of *Cyclus* spp. was known as adaptation to eat the interior of the mollusc shells. A similar "ychroid" body shape is also known in the East Asian species of the genus *Accoptolabrus*. Other example is the wide and flat body of *Abax* spp. and some species of the related genus *Pterostichus*, which makes easier movement in the forest litter (Thiele 1977). Basing on the detailed analysis of the variability of Carabid body shape, Sharova (1981) created a modern and complex system of life forms of Carabid adults and larvae. This system makes possible to classify the species of individual assemblages into different functional groups reflecting their major ecological niches, food relations and modes of movement and hiding. Thus this system gives a more detailed view into the structure Carabid assemblages and on this base it allows to interpret more clearly the changes of the assemblages exposed to various disturbance or, on contrary, evaluate succession of their renaturation. The Sharova's system of life forms is relatively complex including 29 classes of imaginal life forms and 23 classes of larval life forms. It also distinguishes two types of the trophic relations of species – the zoophages and myxophages, but it classifies them into different groups of life forms, according the movement or hiding of the species. In order to simplify and to precise this aspect there are distinguished three more detailed trophic guilds (predators, myxophages and phytophages), which give a more forthright view on this aspect of the assemblage structure. The aim of this paper is to show the changes in representation of individual life forms and trophic guilds during succession of Carabid assemblages in the forests on the southern slopes of High Tatra damaged after the windstorm of November 2004.

METHODS AND DATA

The Carabids were pitfall trapped in six plots (intact reference plot at Vyšné Hágy, plot with fallen timber *in situ* Jamy near Tatranská Lomnica, two plots with extracted fallen timber (Danielov Dom a Vodný les) and two plots with extracted timber and additionally affected by extensive fire by turn of July and August 2005 (Tatranské zruby lower a Tatranské zruby upper). The plots were situated between Vyšné Hágy and Tatranská Lomnica at the altitudes of 1015 - 1235 m a.s.l. in 2007-2015. The details on these plots and abundance of individual species during the whole investigation period are given in the papers of Šustek & Vido (2013), Šustek et al. (2015, 2017) and Šustek (2021).

In each plot six plastic jars with opening of 9 cm filled with formalin traps were installed as traps. They were emptied approximately in one month intervals.

Among the large number of life forms of Carabids distinguished by Sharova (1981) only seven life forms (Table 1, second column) were recorded. The characteristics of trophic relations of species (Table 1, third column) was made according to monographs of Burmeister (1939) and Lindroth (1949, 1986).

Representation of each life form and trophic groups is presented qualitatively as number of species showing the respective properties and quantitatively and the cumulative dominance of such species given in percentage in order to eliminate the strong annual fluctuation of caught beetles.

Table 1. Survey of life forms and trophic relations of Carabids occurring in High Tatra in the area damaged by the windstorm of 2004 (ZSLS –zoophagous stratobionts living in litter and burying into soil, ZSL–zoophagous stratobionts living in litter, ZWE–zoophagous walking epigeobionts, ZSLC–zoophagous stratobionts living in litter and craks, MGH–myxophagous geobionts harpaloid, MSCH–myxophagous stratochortobionts, C–carnivores, M–myxophages, P–phytophages)

Species	Life form	Trophic relation
Agonum micans (Nicolai, 1822)	ZSLS	C
Agonum sexpunctatum (Linnaeus, 1758)	MGH	C
Amara aenea (De Geer, 1774)	MGH	P
Amara erratica (Dfuijtschmidt, 1812)	MGH	P
Amara eurynota (Panzer, 1797)	MGH	P
Amara familiaris (Panzer, 1797)	MGH	P
Amara lunicollis (Schodte, 1837)	MGH	P
Amara nitida (Sturm, 1825)	MGH	P
Amara ovata (Fabricius, 1792)	MGH	P
Anisodactylus binotatus (Fabricius, 1792)	MGH	M
Bembidion lampros (Herbst, 1784)	ZSLS	C
Calathus metalicus (Dejean 1828)	ZSL	C
Calathus micropterus (Duftschmidt, 1812)	ZSL	C
Carabus arvensis Herbst, 1787	ZWE	C
Carabus auronitens (Fabricius, 1792)	ZWE	C
C. arabus coriaceus Linnaeus, 1758	ZWE	C
Carabus glabratus Paykull, 1790	ZWE	C
Carabus hortensis Linnaeus, 1758	ZWE	C
Carabus linnei Dejean, 1826	ZWE	C
Carabus nemoralis O. F. Mueller, 1764	ZWE	C
Carabus violaceus Linnareus, 1758	ZWE	C

<i>Cychrus caraboides</i> (Linnaeus, 1758)	ZWE	C
<i>Europhilus gracilipes</i> (Duftschmidt, 1812)	ZSLS	C
<i>Harpalus affinis</i> (Schrank, 1784)	MSCH	M
<i>Harpalus distinguendus</i> (Duftschmidt, 1812)	MSCH	M
<i>Harpalus latus</i> (Linnaeus 1758)	MSCH	M
<i>Harpalus quadripunctatus</i> (Dejeasn, 1829)	MSCH	M
<i>Leistus piceus</i> (Frohlich, 1799)	ZSL	C
<i>Leistus terminatus</i> (Hellwig in Panzer, 1793)	ZSL	C
<i>Loricera caerulescens</i> (Linaeus, 1758)	ZSLS	C
<i>Microlestes maurus</i> (Sturm, 1827)	ZSLC	C
<i>Molops piceus</i> (Panzer, 1793)	ZSRLS	C
<i>N.otiophilus biguttatus</i> (Fabricius, 1779)	ZSRLS	C
<i>Notiophilus palustris</i> (Duftschmidt, 1812)	ZSRLS	C
<i>Poecilus cupreus</i> (Linaeus, 1758)	ZSLBS	C
<i>Poecilus versicolor</i> (Sturm, 1824)	ZSLBS	C
<i>P.seudophonus rufipes</i> (De Geer, 1774)	ZSLBS	C
<i>Pterostichus aethiops</i> (Panzer, 1797)	ZSLBS	C
<i>Pterostichus angustatus</i> (Duftschmidt, 1812)	ZSLBS	C
<i>Pterostichus burmeisteri</i> (Heer, 1801)	ZSLBS	C
<i>Pterostichus foveolatus</i> (Duftschmidt, 1812)	ZSLBS	C
<i>Pterostichus niger</i> (Schaller, 1783)	ZSLBS	C
<i>Pterostichus nigrita</i> (Fabricius, 1792)	ZSLBS	C
<i>Pterostichus oblongopunctatus</i> (Fabricius, 1787)	ZSLBS	C
<i>Pterostichus strenuus</i> (Panzer, 1797)	ZSL	C
<i>Pterostichus unctulatus</i> (Duftschmidt, 1812)	ZSRLS	C
<i>Trechus amplicollis</i> (Fairmar, 1859)	ZSL	C
<i>Trechus latus</i> (Putzeys, 1847)	ZSL	C
<i>Trechus striatulus</i> (Putzeys, 1847)	ZSL	C
<i>Trichotichnus laevicollis</i> (Duftschmidt, 1812)	MGH	M

RESULTS AND DISCUSSION

Life forms of Carabids

In the intact reference plot Vyšné Hágy (Fig. 1) zoophagous walking epigeobionts (mostly *Carabus* spp.) and zoophagous stratobionts living in litter and burying into soil (mostly *Pterostichus* spp.) predominated as qualitatively as quantitatively. Next trophic group were zhe zoophagous stratobionts living in liter, but in the second half of the investigation period they disappeared. The harpaloid geochortobionts were qualitatively represented by one (*Trichotichnus laevicollis*) or two species, but quantitatively their representation was negligible.

The structure of life forms with the timber *in situ* Jamy (Fig. 2) was very similar to that in the reference plot. The main difference was the more regular occurrence of the myxophagous harpaloid geochortobionts and the increasing tendency to increase of their quantitative representation in the second half of the investigation period. To certain degree the same tendency was also observable in the myxophagous stratochortobionts.

Quite different situation was observed in the damaged plots with extracted timber. Qualitatively, with some fluctuations, there was almost balanced representation of the harpaloid geochortobions, walking epigeic zoophages and of the zoophagous stratobionts

living in litter and burying into soil. Other life forms absented or were represented just occasionally.

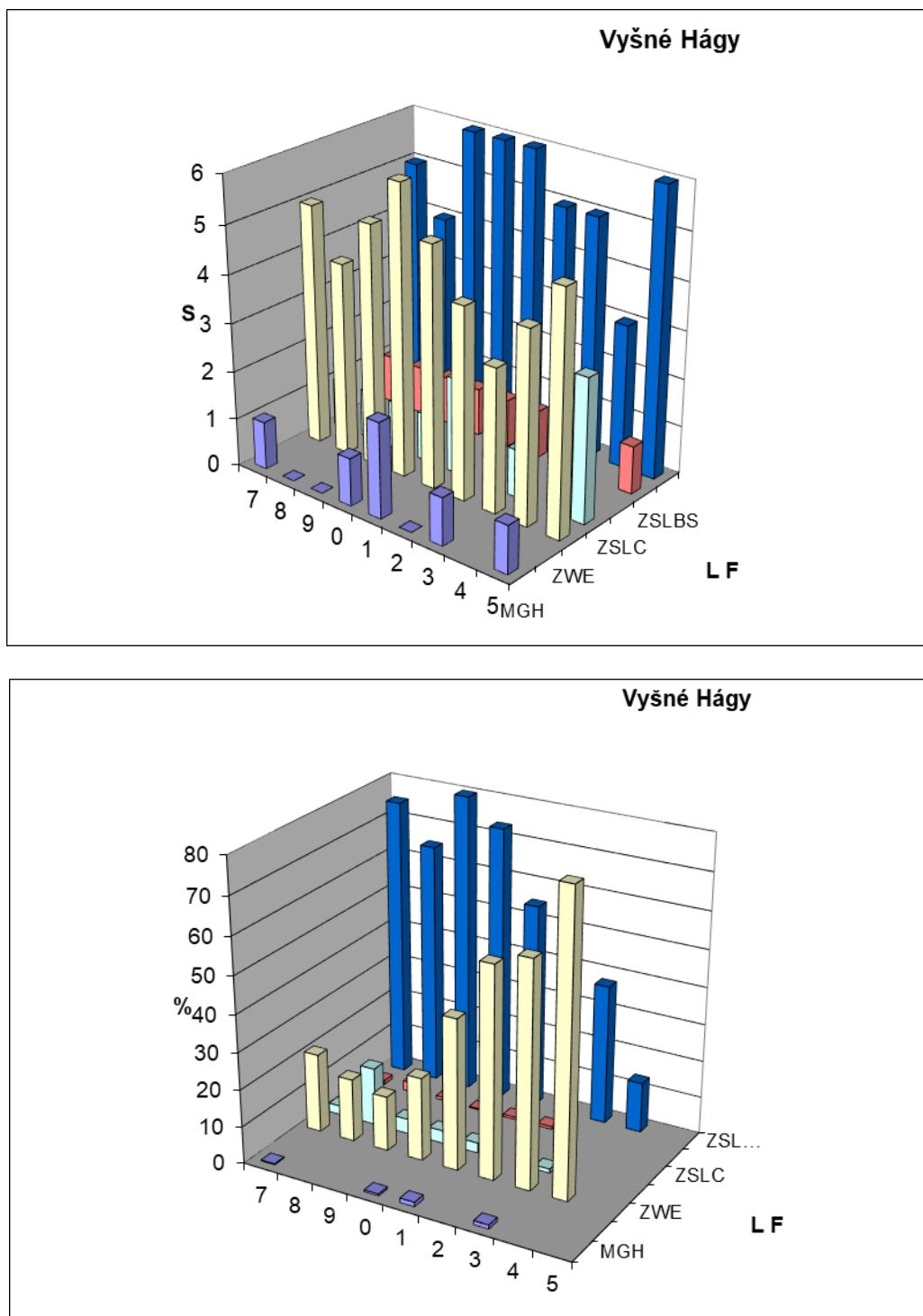


Fig. 1. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the intact reference plot near Vyšné Hágy in the years 2007 – 2015 (from years only the last digit presented at abscissa).

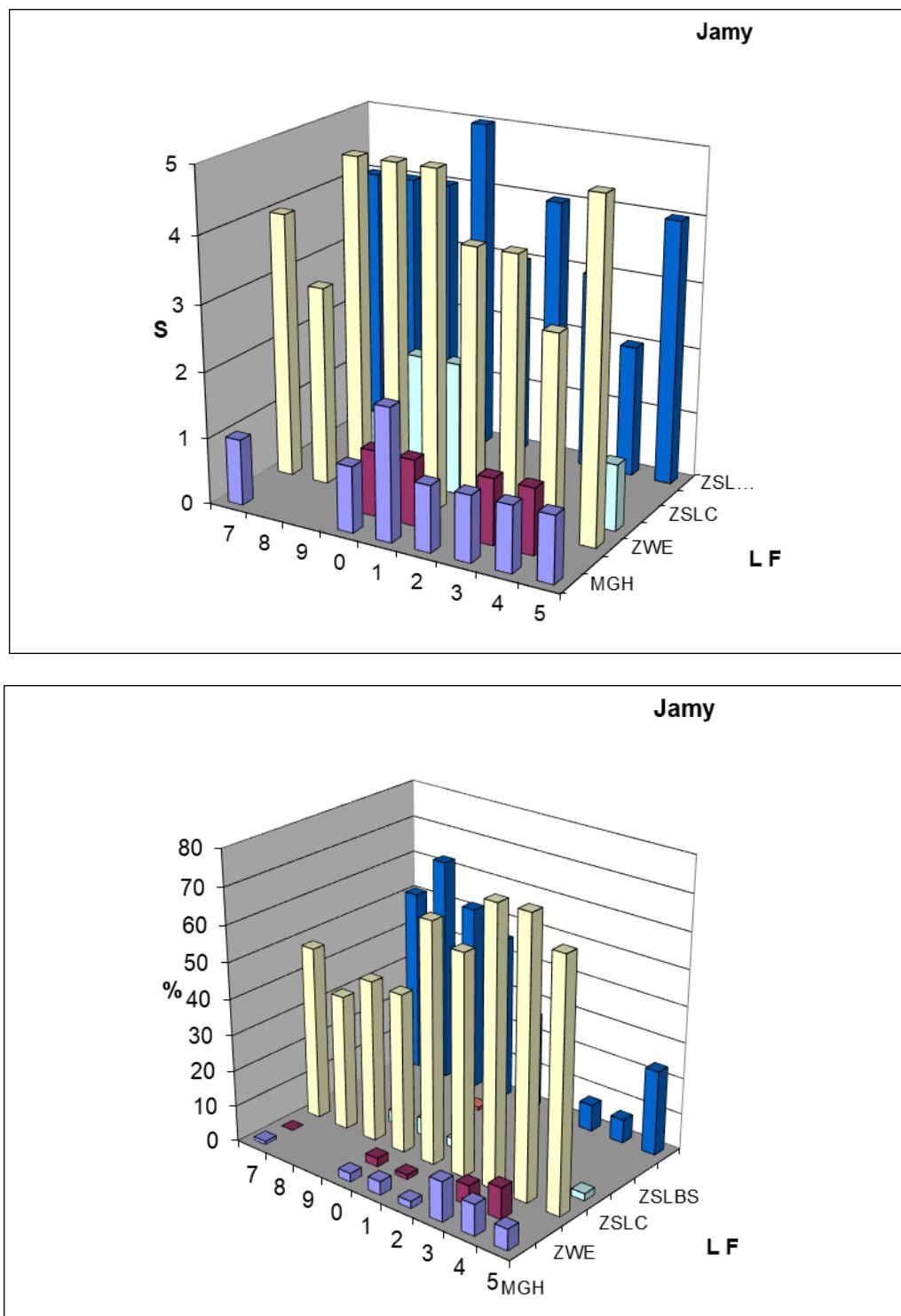


Fig. 2. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the plot with timber *in situ* in Jamy near Tatranská Lomnica in the years 2007-2015 (from years only the last digit presented at abscissa).

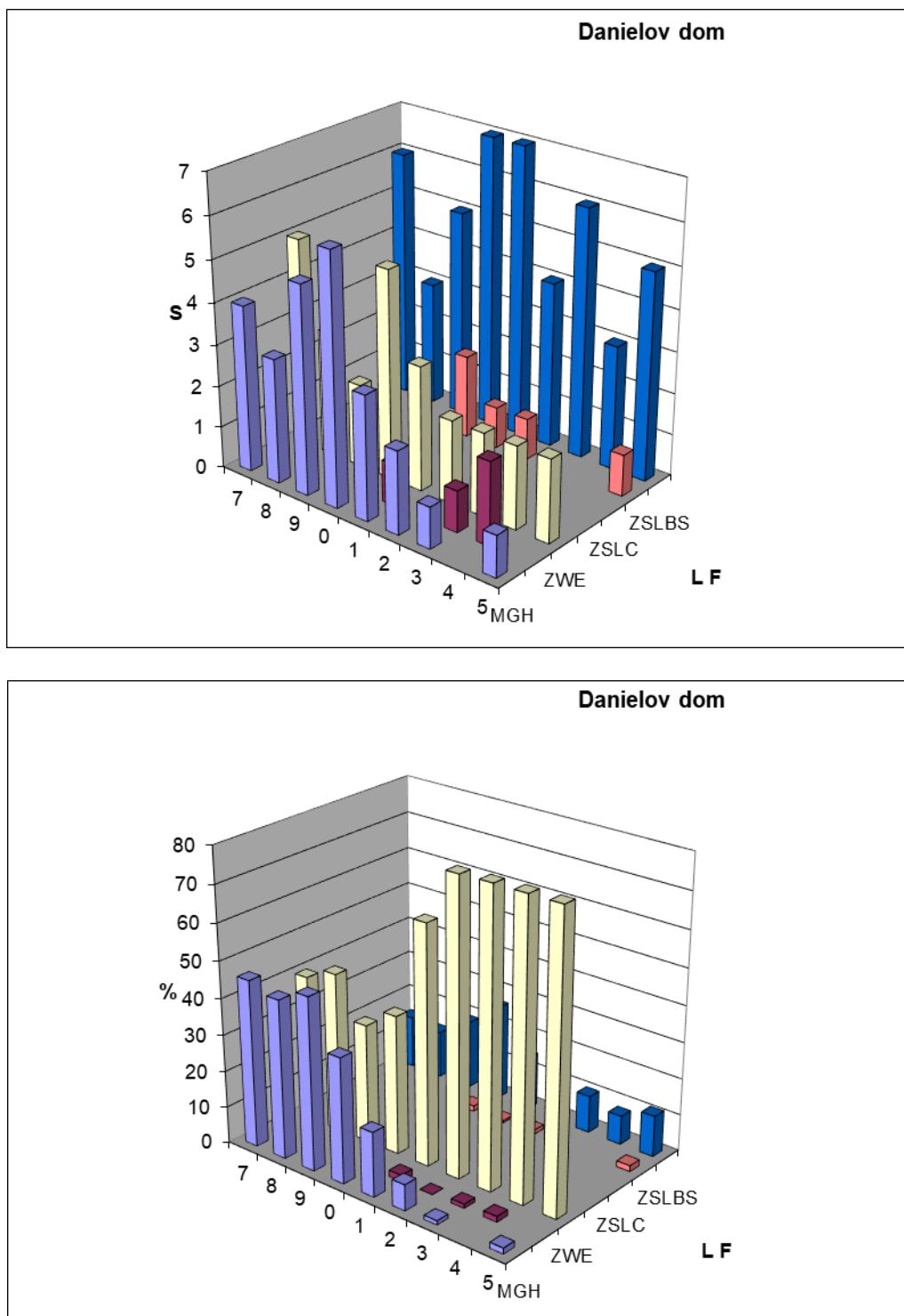


Fig. 3. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the plot with extracted timber at the Danielov dom near Tatranská Polianka in the years 2007-2015 (from years only the last digit presented at abscissa).

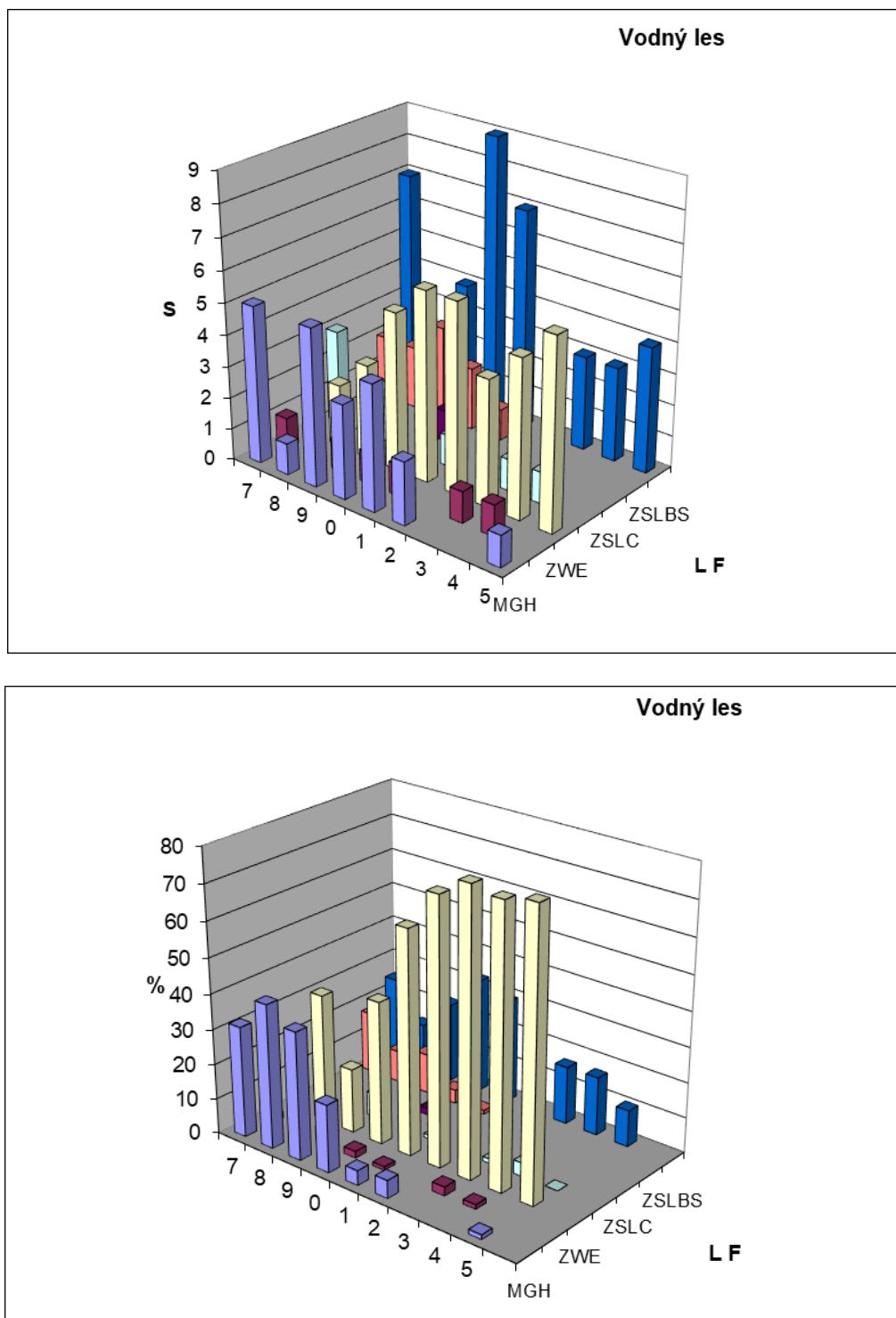


Fig. 4. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the plot with extracted timber Vodný les on the western margin of Nový Smokovec in the years 2007-2015 (from years only the last digit presented at abscissa).

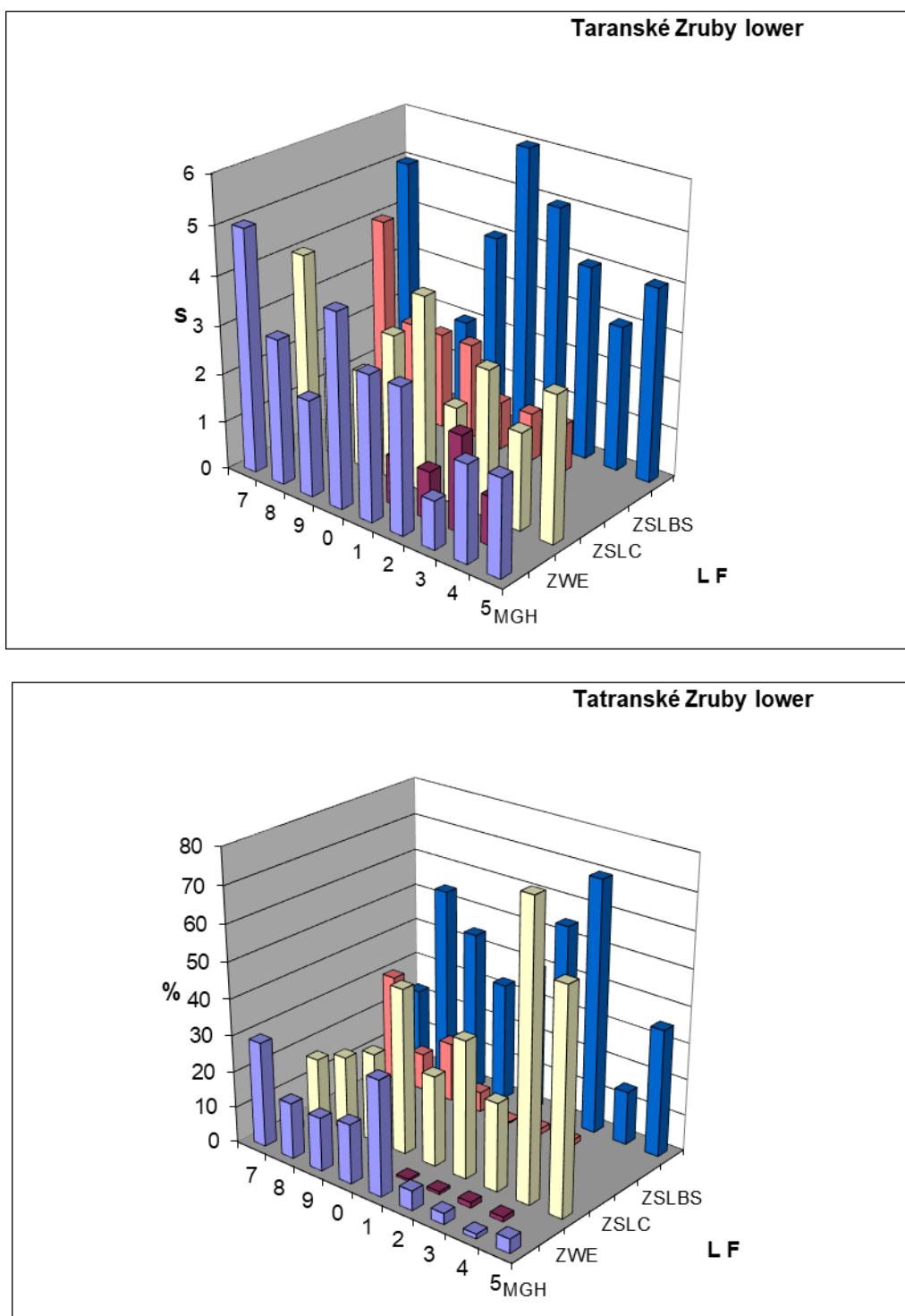


Fig. 5. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the burned plot with extracted timber near Tatranské Zruby at the railway station in the years 2007-2015 (from years only the last digit presented at abscissa).

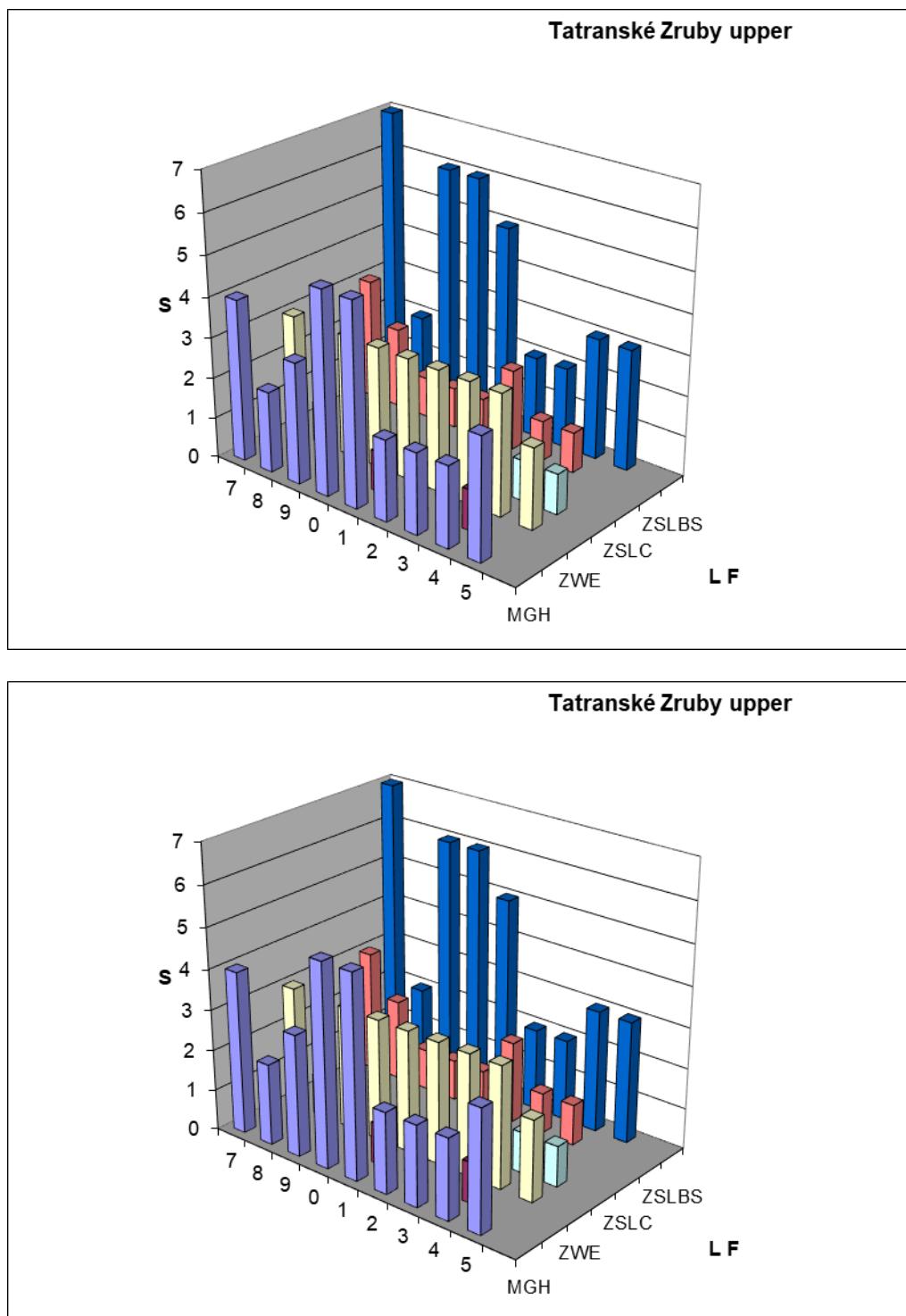


Fig. 6. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid life forms in the burned plot with extracted timber near Tatranské Zruby in the years 2007-2015 (from years only the last digit presented at abscissa).

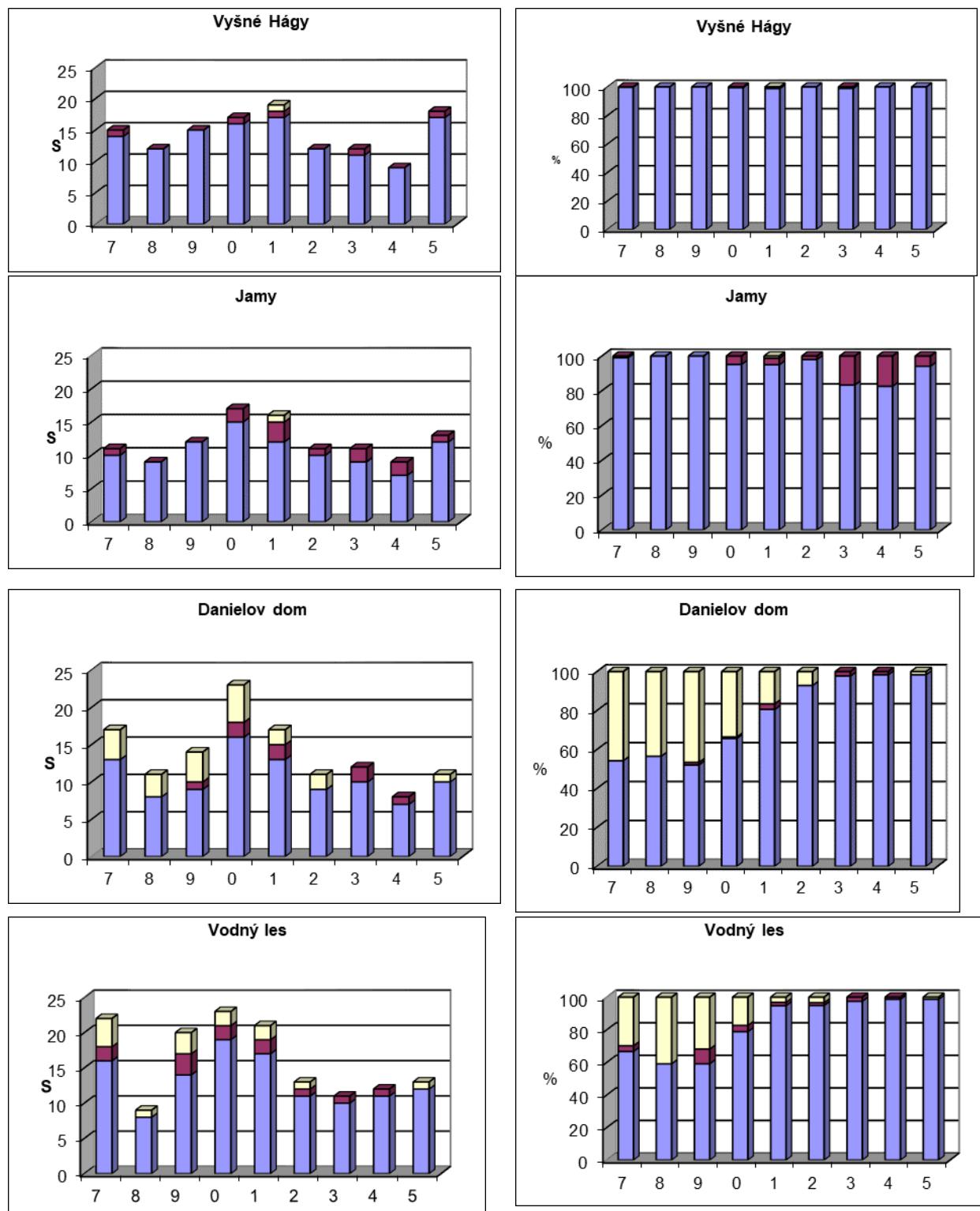


Fig. 7. Qualitative (S – number of species) and quantitative representation (%) - cumulative dominance of Carabid food guilds in four sites in High Tatras in 2007-2015 (only the last digit presented, yellow – phytophags, brown – myxophags, blue – carnivores).

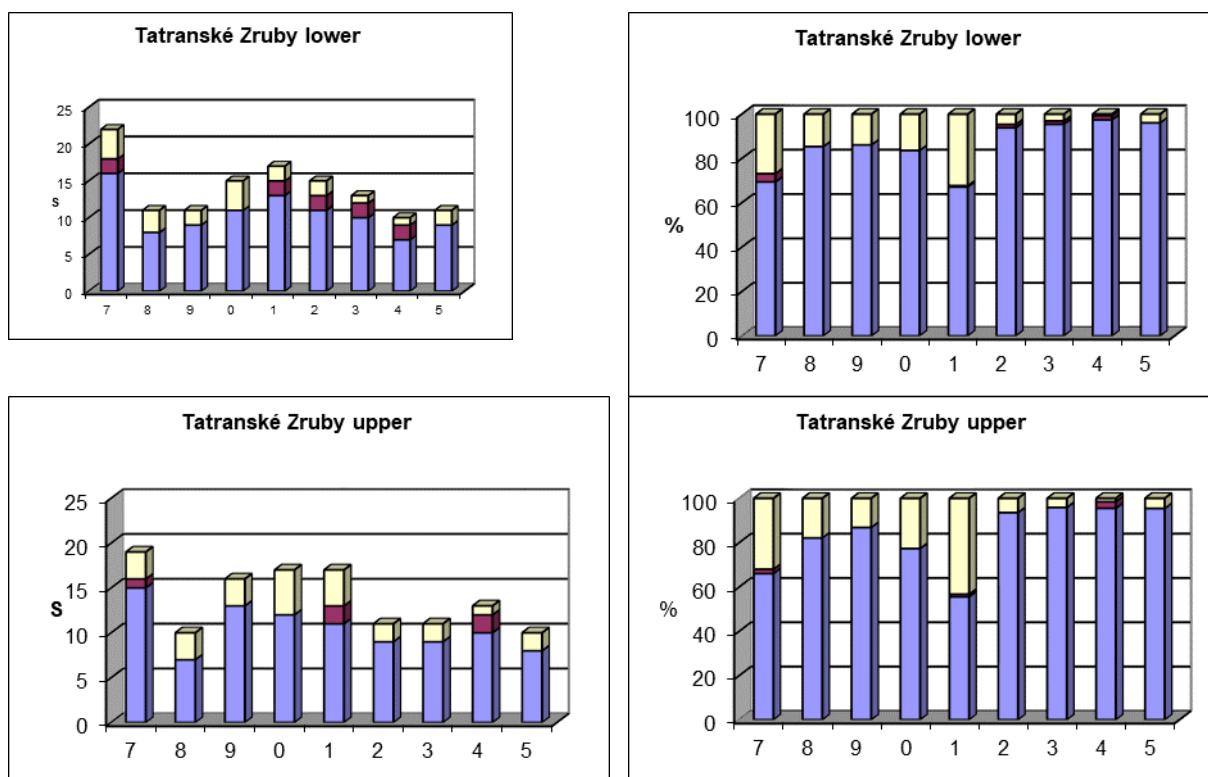


Fig. 8. Qualitative (S – number of species) and quantitative representation (% - cumulative dominance of Carabid food guilds in two sites in High Tatra in 2007-2015 (only the last digit presented, yellow – phytopgags, brown – myxophags, blue – carnivores).

Quantitatively there were three contradicting tendencies. One was the sudden decline of the representation of the harpaloid geochortobionts in the year 2001. This decline was stronger in the plots with extracted timber, while in those additionally damaged by fire more moderate. The second tendency was the simultaneous increase of quantitative representation of the zoophagous walking epigeobionts in all damaged sites, which was common with the reference site and the site with timber *in situ*.

The third tendency were strong fluctuations in representation of the zoophagous stratobionts living in litter and burying into soil. But in spite of the fluctuations, there was observable a trend to decline of their quantitative representation.

Other live forms were quantitatively represented only negligibly.

The described changes show that the species having the same trophical relationships can play quite different functions in the ecosystems according to their different size and mobility.

The observed changes were in contradiction to the trend observed along an idealized urbanisation gradient in Bratislava and Brno, where the zoophagous walking epigeobionts and zoophagous stratobionts disappeared in direction to the city centre and were replaced there by the myxophagous harpaloid geochotobionts and myxophagous stratobionts (Šustek 1992). In this sense the idealized urbanisation gradient represented a model of degradation of a Carabid assemblage, while the trends observed in High Tatra represent a complicated, but unambiguous tendency to the ecosystem restoration.

Trophic relations of Carabids

Number of species (Fig. 7) in each study plot ranged from 7 to 22. In the intact reference plot at Vyšné Hágy only one myxophagous species, *Trichotichbus laevicollis*, occurred in each year and only one phytophagous species in the year 2011. Quantitatively almost all individuals were carnivorous. The situation in the plot Jamy with timber *in situ* was

qualitatively very similar to the intact plot, but quantitatively the representation of myxophagous species (as matter of fact only *Trichotichnus laevicolis*) moderately increased in the years 2010 and 2014.

In all damaged sites, with extracted timber as well as in those additionally damaged by fire, about 1-3 myxophagous and 2-5 phytophagous species occurred in the whole investigation period, but with the obvious tendency to a moderate decline of their number in the second half of the investigation period. Quantitatively the phytophagous and myxophagous species represented 30-40% of all individuals. This proportion was almost stable in the first three years of the investigation, in the fourth and fifth year (2010-2011) it declined in the plots with extracted timber, but in the plots additionally damaged by fire in temporary increased. Since 2012 proportion of all myxophagous and phytophagous species strongly declined or the phytophagous species disappeared.

CONCLUSIONS

The largest changes in structure of life forms of Carabids indicate that the restoration of the damaged communities is disproportional. In more or less natural forests different zoophagous forms of Carabids are balanced. In High Tatra, however, only the zoophagous walking epigeobionts (as matter of fact only two species *Carabus violaceus* and *C. glabratus*) increase their abundance, while the zoophagous stratobionts living in litter show considerable annual fluctuations or even in the intact reference plot and in the plot with timber *in situ* their representations declines. This indicates two possible causes of such development – the large walking epigeobionts are favored by their mobility in colonizing the damaged site or, more probably there also exist a predation pressure of the larger epigeobionts on the zoophagous stratobionts and their larvae, which are small or medium sized.

The process of restoration is also indicated by decline of myxophagous geochortobions and myxophagous stratochortobionts, which mostly do not belong to the forest species.

Comparison of analysis of changes in structure of carabid life forms and of the trophic guilds show that they give principally similar results, but the analysis of life forms allows to obtain more accurate results and deeper interpretations. From this reason the analysis of representation life forms in Carabid assemblages is methodically suitable

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REFERENCES

- Burmeister, F. (1939): Biologie, Ökologie und Verbreitung der europäischen Käfer auf systematischer Grundlage. I. Band; Adephaga I, Familiengruppe: Caraboidea. Hans Goecke Verlag, Krefeld. 307 pp.
- Lindroth, C. H. (1949): Die Fennoskandischen Carabidae I. Spezieller Teil. Wettergren & Kerbers Förlag, Göteborg. 710 pp.
- Lindroth, C. H. (1986): The Carabidae (Coleoptera) of Fennoscandia and Denmark. Fauna Entomologica Scandinavica, Vol. 15, part 2, E. J. Brill – Scandinavia Science & press Ltd., 497 p.
- Sharova, I. Ch. (1981): Zhiznenye formy zhuzhelits, Nauka, Moskva, 360 p.
- Šustek, Z. (1992): Changes in the representation of Carabid life forms along an urbanization gradient (Coleoptera, Carabidae). Biológia (Bratislava), 47: 417-430.
- Šustek, Z. (2021): Changes in vertical distribution of some Carabid beetles: consequence of climate warming or temporary species expansion and population fluctuation.

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Interdisciplinary Approach in Current Hydrological Research*

- Šustek Z., Vido J. (2013): Vegetation state and extreme drought as factors determining differentiation and succession of Carabidae communities in forests damaged by a windstorm in the High Tatra Mts" Biologia, 68 (6): 1198–1210.
- Šustek, Z., Vido, J., Škvareninová, J., Škvarenina, J., Šurda P. (2017): Drought impact on ground beetle assemblages (Coleoptera, Carabidae) in Norway spruce forests with different management after windstorm damage - A case study from Tatra Mts. (Slovakia). Journal of Hydrology and Hydromechanics, 65(4): 333-342.
- Thiele, H. U. (1977): Carabid beetles in their environment. Springer-Verlag, Berlin – Heidelberg – New York. 369 p.

EVALUATION OF MULTI-MODEL HINDCASTS OF OVERLAND PRECIPITATION FOR GEORGIA

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ABSTRACT

This study evaluates the ability of several Regional Climate Models (RCMs) to simulate rainfall patterns in the South Caucasus region. In total, 8 RCM simulations were assessed against the CRU observational database over different domains, among them two from the Coordinated Regional Climate Downscaling Experiment (CORDEX). Seasonal climatology, annual rainfall cycles and interannual variability in RCM outputs were estimated for 8 homogeneous sub-regions against several observational datasets. Different metrics covering monthly and seasonal to annual time scales are analyzed over the region of interest. The results confirm the distinct capabilities of climate models in capturing the local features of the climatic conditions of the South Caucasus region. At the same time, the analysis shows significant deviations in individual models depending on the sub-region and season; however, the ensemble mean is in better agreement with observations than individual models. Overall, the analysis presented here demonstrates that the multi-model ensemble means adequately simulates rainfall in the South Caucasus and, therefore, it can be used to assess future climate predictions for the region. This work promotes the selection of RCM runs with reasonable performance in the South Caucasus region, from which, for the first time, a high-resolution bias-adjusted climate database can be generated for future risk assessment and impact studies.

Keywords: Gridded data, hindcast, reanalysis, regional climate models (RCMs)

INTRODUCTION

Assessing the anticipated climate variations and change on a regional scale is highly important. The primary tool for projecting climate is global climate models (GCMs), the output of which requires to be downscaled on a finer scale for the impact study, for which regional climate models (RCM) are used. Modelling of climate predictions contains many uncertainties, arising from several sources, such as incomplete model formulations, future emission scenarios, and many other factors (Northrop and Chandler, 2014). Model errors are probably the most viable to characterize, and potentially remedy to reduce the uncertainty. Thus, Climate model evaluation is a necessary step for model development and improvements for assessing and correcting model biases (IPCC, Climate change 1995; IPCC, Climate change 2001, IPCC, Climate change 2007).

Design and distribution of global climate model simulations of the past, current, and future climate by Coupled Model Inter-comparison Project (CMIP) is coordinated and has a long history of evaluating the fidelity in simulating the present-day climate of multiple GCMs as a fundamental step in estimating the uncertainty in future climate projections. Systematic multi-model RCM experimentations and observation-based evaluations are much less mature than those for GCM studies. GCMs operate all over the world, and this makes their comparison or evaluation more accessible. RCMs are focused on a specific geographical area, thus all regions are not equally explored and evaluated (Meehl et al, 2007; Reichler and Kim, 2008; Gleckler et al, 2008; Reichler and Kim, 2008; Nikulin et al, 2012).

The CORDEX program was established as the first activity of the Task Force on Regional Climate Downscaling established by the World Climate Research Program (WCRP).

Common experimental designs in CORDEX are advantageous for many practical purposes including model evaluations, uncertainty assessments, and constructing multi-model ensembles (ENS) (Russo et al, 2019; Ozturk et al, 2017; Deitch et al, 2017). The Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative has made a huge number of regional climate predictions available in various domains worldwide. This information is critical for the design of adaptation strategies and policymaking. The challenge is to assess potential multi-domain inconsistency while overlapping regions and to develop appropriate ensemble methods that try to make the most of all available information (Zittis, 2018; Zittis et al, 2019).

There are a big number of simulations in Europe, the Mediterranean area, Africa and North America (CORDEX domains), with numerous RCMs, different resolutions and experiments. Several leading scientific institutes and communities are involved in the effort to develop regional climate and earth system science in the mentioned regions (Lionello and Scarascia, 2018; Almazroui et al, 2016). Within the framework of these activities, the effectiveness of separate RCMs has been studied. Uncertainties in regional climate simulation, within the multi-models, multi-domains and resolution systems were estimated (Almazroui et al, 2016; Almazroui, 2019). Also, uncertainties in the so-called reference data, i.e. in gridded observations or analyses data were investigated. The evaluation criteria and suitable metrics for ensembles have been determined. The value of the EURO-CORDEX ensemble is shown via the number of peer-reviewed studies and its use in the development of climate services. Evaluations of the EUR-44 and EUR-11 ensembles also show the benefits of higher resolution. The added value of regional downscaling concerning scale, uncertainty, processes, and phenomena was investigated in several papers. However, significant challenges remain. Further development of scientific understanding aims to explore issues such as local-regional phenomena at convection-permitting scales and the impacts of land cover changes on regional climate across spatial and temporal scales. For the solution to these tasks flagship pilot study (FPS) was initiated (Bucchignani et al, 2016; Bucchignani et al, 2016).

This work is focused on the hindcast evaluation of precipitation patterns over the South Caucasus region, which is highly variable both in space and in time. The territory is unfortunately not fully covered with EURO and MED CORDEX domains, where lots of RCM simulations are available and rainfall across both domains is well investigated. Only CAS (Central Asia) and MENA (the Middle East and North Africa) - CORDEX domains overlap our target area. Several simulations became available in recent years in these domains, also some study results are presented in scientific papers focusing on different geographical areas inside of the domain (Bucchignani et al, 2018; Ozturk et al, 2018; Spinoni et al, 2020). However even the main climate parameters – temperature and precipitation are not evaluated for the South Caucasus region. This first demonstration case study focuses on hindcast evaluation in the multi-model, multi-domain ensemble of annual rainfall cycles, seasonal climatology, and interannual variability (Zittis and Hadjinicolaou, 2017).

This study evaluates the 6 RCM simulations over the Georgia using Regional Climate Model Evaluation System (RCMES). We include in this research 2 RCMs' (RegCM v 4.7.0 and WRF-ARW v3.9.1.1) simulations over the domain centered to Georgia performed by us and 6 simulations over MENA and CAS domains. Such a choice has resulted in the fact that the evolutionary simulations are available only for these models on ESGF (Earth System Grid Federation)-CORDEX archive.

Section (a) provides details of the experimental design including the evaluation domain, RCMs, and reference datasets; sections (b) and (c) – reference data and models used in the study; section (d) provides details of the Regional Climate Model Evaluation System (RCMES) used in the model evaluation; section (e) - climate description of country; sections (f) and (g) presents the evaluation of RCM skill in simulating the targeted variables and

examines the uncertainties in model evaluation related with reference data; results are summarized in section (h).

METHODS AND DATA

Evaluation Domain

In the study, we have used several data archives, most of which are available from the federative ESGF infrastructure, including the Coordinated Regional Climate Downscaling Experiment (CORDEX). We downloaded 7 CORDEX simulations over Central Asia (CAS) and the Middle East and North Africa (MENA) domains, covering South Caucasus territory (Fig.1. a,b). Two of our simulations with the same boundaries and with different configurations over the domain centered to the South Caucasus region and with the 15 km resolution from two RCMs - RegCM4 and WRF have also been evaluated (Fig.1. c).

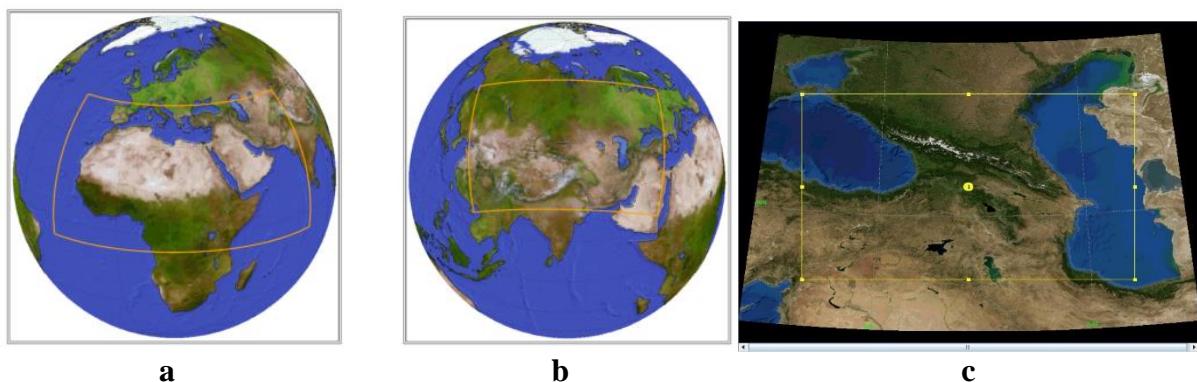


Fig. 1. a, b – CORDEX Middle East and North Africa (MENA) and Central Asia (CAS) domains; c- Caucasus domain (CAU).

All RCMs are forced with ERA-Interim - reanalysis of the global atmosphere dataset. The ERA-Interim atmospheric model and reanalysis system uses cycle 31r2 of ECMWF's Integrated Forecast System (IFS), configured for the spatial resolution - T255 spherical-harmonic representation for the basic dynamical fields and a reduced Gaussian grid with approximately uniform 79 km spacing for surface and other grid-point fields.

For the reference data, we used global gridded observations (CRU) and TRMM precipitation monthly data.

Reference data

For validation of individual models, also for the ensemble the gridded global data set of the Climate Research Unit (CRU) latest version TS 4.03, was released on 15 May 2019, covering the period 1901-2018 Coverage: all land areas (excluding Antarctica) at 0.5° resolution for 6 variables were used. These monthly observational data sets are based on statistical interpolation methods (ADW - Angular Distance Weighting technique), which are gridded time series and represent one of the most comprehensive observational data sets available (Harris et al., 2014).

TRMM has provided critical precipitation measurements in the tropical and subtropical regions of our planet, since its launch in 1997. The Precipitation Radar (PR) looked through the precipitation column and provided new insights into tropical storm structure and intensification.

The TRMM Microwave Imager (TMI) measured microwave energy emitted by the Earth and its atmosphere to quantify the water vapour, the cloud water, and the rainfall intensity in the atmosphere. The most relevant TRMM-related products for climate research are TMPA

(Multi-satellite Precipitation Analysis) 3B43 monthly precipitation averages available in 0.25° spatial resolution, covering 50°N to 50°S from 1998-present (Kim et al., 2018].

Climate models used in the study

All RCMs used in this study are hydrostatic atmospheric circulation models aimed to run over limited areas. The RCM names, responsible institutions for their simulations, resolutions, simulation periods and domains are presented in table 1.

The **ALARO-0 model** is a configuration of the ALADIN model that is developed, maintained and used operationally by the 16 countries of the ALADIN consortium. The dynamical core of the ALADIN model 120 is based on a spectral-spatial discretization and a semi-implicit semi-Lagrangian time-stepping algorithm. The ALARO-0 configuration is based on the physics parameterization scheme 3MT (Modular Multiscale Microphysics and Transport), which handles convection, turbulence and microphysics.

REMO is a three-dimensional atmosphere model developed at the Max Planck Institute for Meteorology in Hamburg, Germany and currently maintained at the Climate Service Center Germany (GERICS) in Hamburg. The physical packages originate from the global circulation model ECHAM4, although many updates have been introduced. The vertical atmospheric levels are represented in a hybrid sigma pressure coordinate system. Horizontally, REMO has a spherical Arakawa C grid.

RCA4. Since 1997 the Rossby Centre has developed an international standing in the field of regional climate modelling with the development of the atmospheric model RCA, at SMHI. RCA is based upon the numerical weather prediction (NWP) model HIRLAM. The RCA4 dynamical core is a two-time-level, semi-Lagrangian, semi-implicit scheme with six-order horizontal diffusion applied to the prognostic variables.

HadRM3P is a limited-area regional climate model widely used worldwide as part of the PRECIS (Providing Regional Climates for Impacts Studies) system, which was developed at the Hadley Centre of the United Kingdom Met Office. The model has 0.44 x 0.44 degrees' resolution with a rotated pole to achieve approx. 50 km x 50 km resolution on 19 levels over the Central Asia domain (CAS-44 domain) representing the period from 1990 to 2011.

RegCM4. Regional Climate Model RegCM is developed at ICTP (International Center for Theoretical Physics). It uses the radiation scheme of the NCAR CCM3, the cloud scattering and absorption parameterization, whereby the optical properties of the cloud droplets are expressed

in terms of the cloud liquid water content and an effective droplet radius. The soil hydrology calculations include predictive equations for the water content of the soil layers. Simulations with two different versions of the model RegCM v.4.3 and RegCM v4.7.0 over all three domains are evaluated in this paper. RegCM v.4.3 was run at the Boğaziçi University, Turkey, over CAS and MENA, with 0.440 X 0.440 resolution. The Georgian team of researchers performed a simulation over the Caucasus domain with RegCM v 4.7.0.

WRF-ARW v3.9.1.1. Weather Research and Forecasting model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs (<http://www.wrf-model.org>). It is a non-hydrostatic model, with several available dynamic cores as well as many different choices for physical parameterizations suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. The dynamic cores in WRF include a fully mass- and scalar-conserving flux from the mass coordinate version. The physics package includes microphysics, cumulus parameterization, planetary boundary layer (PBL), land surface models (LSM) and longwave and shortwave radiation. The Georgian team performed a simulation with WRF over the Caucasus domain.

Table 1. Summary of data used in the study

Dataset/version	Time Range	Resolution	Domain
Observation & reanalysis			
CRUvTS 4.03	1901-2018	0.5° X 0.5°	Global
TRMM	1/1998 - 6/2013	0.25° X 0.25°	Tropics/Mid-latitudes
ERA-Interim	1979- to the near present	79 km	Global
Climate models			
ALARO-0 (RMIB-UGent)	1980-2017	0.22° X 0.22°	CAS
REMO (HZG-GERICS)	1979-2017	0.22° X 0.22°	CAS
RegCM v 4-3 (BOUN)	1979-2005	0.44° X 0.44°	CAS
HadRM3P (MOHC)	1990-2011	0.44° X 0.44°	CAS
RCA4 (SMHI)	1980-2010	0.22° X 0.22°	MENA
RCA4 (SMHI)	1980-2010	0.44° X 0.44°	MENA
RegCM v 4 (BOUN)	1980-2010	0.44° X 0.44°	MENA
RegCM v 4.7.0	1985-2015	0.15° X 0.15°	CAU
WRF-ARWv3.9.1.1	1985-2015	0.15° X 0.15°	CAU

The Regional Climate Model Evaluation System (RCMES)

RCMES is an enabling tool for NASA for evaluating climate models on regional and continental scales using observational datasets from a variety of sources. RCMES provides a framework for performing systematic evaluations of climate simulations, such as those from the CORDEX, using in situ observations, as well as satellite and reanalysis data products.

RCMES is composed of two main components, the Regional Climate Model Evaluation Database (RCMED) and the Regional Climate Model Evaluation Toolkit (RCMET). RCMED brings together massive amounts of observational and model data, but also deals with a wide variety of sources and formats of data, necessitating significant investments in computer and personnel resources to transfer, decode, (re)format, (re)archive, and analyze the data.

RCMET includes a software suite for calculating statistical metrics used in model evaluations and visualizations. RCMET includes a Python OSS library for common climate model evaluation tasks as well as a set of user-friendly interfaces for quickly configuring a model evaluation task. Model-evaluation metrics and visualization generally vary widely according to users and targets; RCMET includes the capability to incorporate user-defined metrics as well as pathways to extract partially processed data (e.g., both model and reference data regridded onto a common grid) so that users can do their own specific data processing and visualizations (Gibson et al., 2019; Lucas-Picher et al., 2017; Lee et al., 2018).

Country climatology

Georgia, due to its geographical location, is under the influence of the circulation of temperate and subtropical latitudes. Atmospheric precipitation on the country territory almost all year is conditioned by cyclonic activities. However, precipitation associated with intra-mass processes occurred quite often mainly in the warm period of the year in eastern Georgia, and throughout the year in the western part of the country.

In the formation of the climate of Georgia, mainly zonal circulation takes place. Sometimes it destroys the meridian circulation, during which there is an intrusion of colder air masses from the north, and warmer - from the south. In such cases, special significance obtains to the Greater and Lesser Caucasus (South Georgian highlands) ranges. High-mountainous system of the Caucasus prevents a direct invasion of cold air masses from the north. Therefore, even arctic invasions in Georgia are mitigated as a result of their transformation over the Black and Caspian Seas. During the propagation of air masses from the West to Likhi ridge (submeridional range connecting the Greater and Lesser Caucasus, dividing the country climatically, watershed of the Black and Caspian Seas), they feel forced ascent and is accompanied by intense rainfall. Because of the foehn effect in eastern Georgia, such processes are often continued without precipitation. This type is the most frequent circulation process in Georgia, so it significantly affects the distribution of precipitation on the country's territory (Fig. 2.).

Synoptic processes through which air masses are distributed on the territory of the Caucasus, and in particular, Georgia, are grouped into the following types: western, eastern, two-sided, anticyclonic and wave disturbances developed in the southern regions of the Caucasus. Convective processes also participate in the formation of weather and are more pronounced in the warm period of the year.

Due to the country's climate regime, the territory was divided into eight sub-regions to examine the simulation performance across the experiments on different sub-regions. These regions mostly cover Georgia's territory but also include some neighbouring parts, according to the factors of local climate formation. In Fig. 2. the location and names of sub-regions are presented, where R01, R02 and R03 are respectively western, central and eastern parts of the Greater Caucasus mountains, R04 - Kolkheti lowlands, R05 - central part including Likhi range, R06 - Adjara Black Sea coastal zone with adjacent mountains, R07 - Lesser Caucasus mountains, R08 - eastern country plane territory.

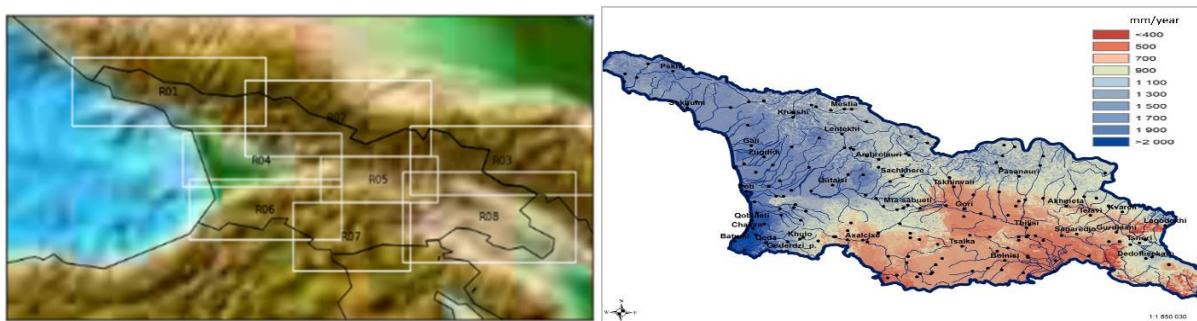


Fig. 2. Study (Caucasus) domain: the colour contours represent the terrain elevation and the numbered boxes with white boundaries indicate the eight sub-regions in which the area-mean time series are evaluated (left); annual precipitation climatology (right).

RESULTS AND DISCUSSION

The analysis focuses on how the model simulates surface climate (precipitation) in response to the large-scale forcing imposed by the ERA-Interim reanalysis and by local topographical

features. The study presented here is performed over the interior domain to eliminate the buffer zone where the direct effect of the lateral boundary conditions is maximum.

Evaluation metrics

Different metrics have been used to represent the performance of climate models in simulating climatic conditions. Besides computing the mean bias (MBE) (1) and root mean square error (RMSE) (2), the degree of statistical similarity between two climatic fields was quantified in the form of normalized Taylor diagrams.

$$MBE = \frac{1}{N} \sum_{k=1}^N (P_k - O_k) \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{k=1}^N (P_k - O_k)^2}{N}} \quad (2)$$

where:

P is prediction, and

O is observation.

This can be considered as the combination of different measures such as the centered (or bias removed) RMSE - CRMSE (3), spatial standard deviation (STD) (4) and spatial correlation (R) (5).

$$CRMSE = \sqrt{\delta_p^2 + \delta_o^2 - 2\delta_p\delta_o R} \quad (3)$$

where:

δ_p is the prediction variance or standard deviation (STD),

δ_o is the observation variance or standard deviation (STD), and

R is a correlation coefficient.

$$\delta_p^2 = \frac{1}{N} \sum_{k=1}^N (P_k - \bar{P})^2 \quad (4a)$$

$$\delta_o^2 = \frac{1}{N} \sum_{k=1}^N (O_k - \bar{O})^2 \quad (4b)$$

$$R = \frac{\frac{1}{N} \sum_{k=1}^N (P_k - \bar{P})(O_k - \bar{O})}{\delta_p \delta_o} \quad (5)$$

The Taylor diagrams reported in the present study are based on 16-year annual and seasonal means in grid points. The spatial distribution of mean precipitation and the annual cycle of mean monthly precipitation are also presented.

Uncertainties assessment

The accuracy of reference data is among the most important concerns in model evaluation. All observations and/or analyses include errors of unknown/estimated magnitudes; e.g., analyses based on surface station data are directly affected by local station density. This is especially true for the Caucasus region in which station density varies substantially according to region. Uncertainties in model evaluation originating from reference data are examined using two different reference datasets. In addition to CRU, the Tropical Rainfall Measuring Mission (TRMM) was selected for 1998-2005, overlapping with the period when the model evaluation was performed.

All RCMs yield higher spatial correlations with the CRU than TRMM. The standardized deviations and RMSE are smaller in absolute values against CRU, but the same normalized

metrics are closer to remote-sensing data, forasmuch as the spatial variability of the TRMM is larger than in situ gridded data (CRU). So normalization by bigger quantities produces reduced differences between modelled and reference data (in this case TRMM) (Fig. 3).

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Fig. 4 shows the spatial distribution of mean annual precipitation biases averaged over the entire period compared to the CRU and TRMM datasets. In all seasons (not shown) precipitation bias against CRU data mostly ranges between ± 2.4 mm/day over the most of domain, except in summer, when the deviation increases up to ± 3.2 mm/day. Differences between models and TRMM data range between ± 2.0 mm/day in the cold period of the year (NDJFM - November to March) and for annual biases. During the warm period (AMJJASO - April to October) differences are higher (± 2.4 mm/day). Finally, including a longer comparison period, a better fit was obtained with CRU, although there are some systematically occurred features in the spatial distribution of these differences. Relative to CRU it is a noticeable wet bias over the Caucasus throughout the year, more apparent in the western part in the winter season, shifting to the east in the summer months. Dry bias is the most evident in summer over the plain territory, with the greatest underestimation on the Black Sea coastal area and adjacent lowlands. As for TRMM, deviations in spatial features are almost the same, but contrary to CRU, for all simulations, dry bias occurred again over lowlands and plain territory and was especially clearly expressed over the west country coastal zone and lowland territory.

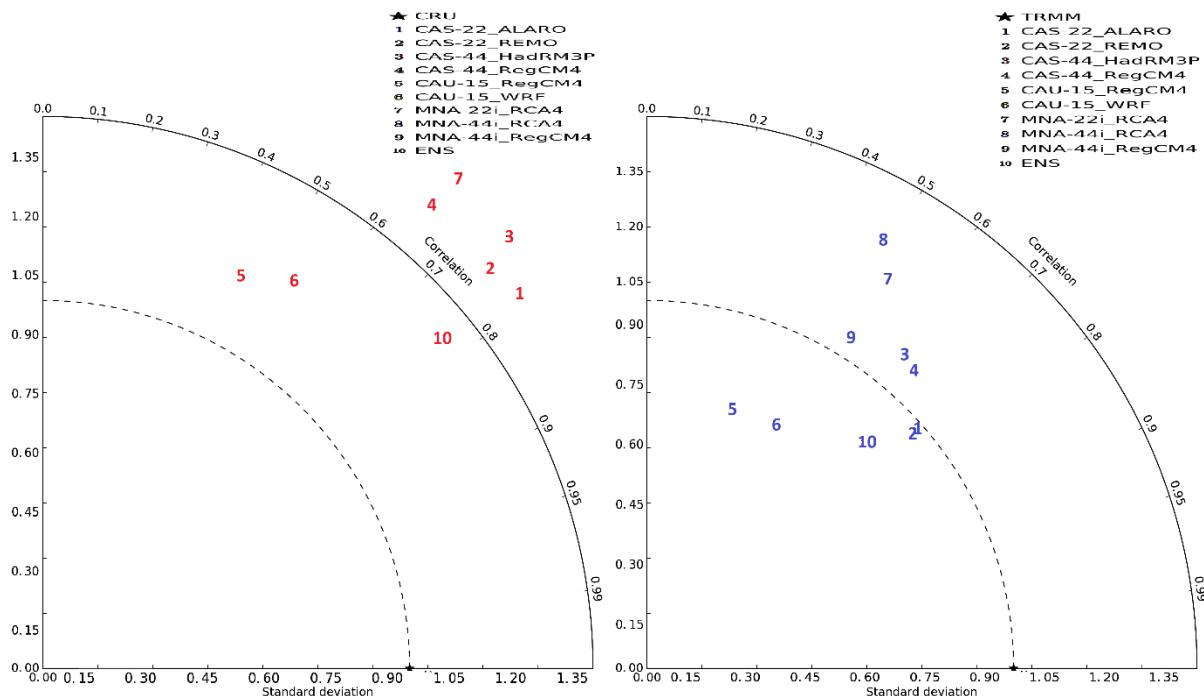


Fig. 3. Evaluation of the simulated precipitation climatology over the land using two different reference datasets: CRU (left) and TRMM (right) indicate the model ensemble evaluated against different reference data.

It is dominant throughout the entire year, with precipitation overestimation depicted over the Greater Caucasus most explicitly seen in summer. Therefore, the evaluation of models against

two observation datasets demonstrates the spatial features of precipitation biases and bias pattern is comparable with the terrain profile.

The differences between precipitation evaluations based on the two observation datasets may have resulted from the difference in the observational platform and methodologies. This examination shows that quality control and cross-examination of reference datasets are important for model evaluations.

Evaluation results

In this study, a multi-year evaluation of overland precipitation against the CRU dataset is carried out from 1990 to 2005. As already mentioned, the most noticeable feature is the general moisture shift over the Greater and Lesser Caucasus (western part) mountains and dry bias in the Black Sea coastal area and adjacent Kolkheti lowlands (Fig. 4). The spatial patterns of wet biases for all simulations are similar, with the largest magnitudes being located over Geater Caucasus range. However, overestimation in the HaDRM3P and RegCM4 coarser resolution simulations is generally larger and extended over the West Georgia lowlands. The dry bias over the lowlands and plains of the territory is found in all simulations except RegCM4 with 0.44^0 resolution integrated into MENA (the Middle East and North Africa) domain. It seems that coarser resolution simulations (0.44^0) generate the greatest wet biases and MENA-RegCM4 is an outlier among six RCMs in the sense that it overestimates precipitation over almost the entire study territory, whereas finer resolution runs (0.22^0 , 0.15^0) are the main producers of mentioned underestimation over lowland areas.

All RCMs calculations except for the local simulations performed for the Caucasus region, seem to overestimate the precipitation over the high mountain regions and underestimate the low heights, resulting in the least deviated ENS results relative to observations in the ± 1 mm/day range.

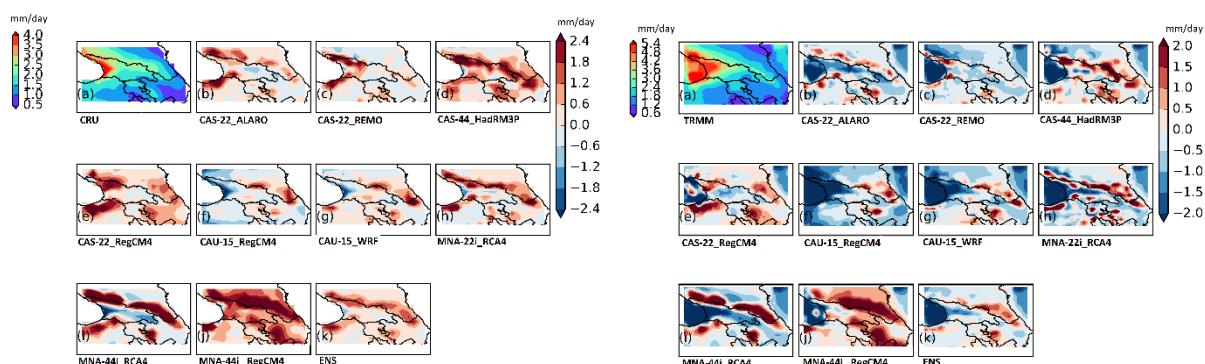


Fig. 4. Annual-mean surface precipitation mm) from the CRU (a) (left), and TRMM (a) analysis (right). The biases (mm) from the reference data for (b)–(j) the individual models and (k) the multi-model ensemble (ENS).

Overall, all models simulate the spatial variations in the annual mean precipitation over Georgia (R02, R03, R05, R07, R08) with the spatial pattern correlation coefficients between 0.5 and 0.8 and standardized deviations (the spatial standard deviation of the simulated atmospheric precipitation normalized by that of the observed data) of 1.1–1.65 concerning CRU data, except RCA4 and RegCM4, integrated for MENA domain on 0.44^0 grid, with much higher STD up to 1.6–2.4 (Fig. 3). Fig. 3 also shows that the multi-model ensemble mean (ENS) along with ALARO yields the smallest RMSE. Investigation of those metrics by regions also reveals considerable differences, i.e. correlation is much lower (0.2–0.5) in the

West part of the country (R01, R04, R06), especially in the Black Sea adjacent lowlands (R01), where the greatest RMSE (up to 4) and STD (up to 2.7) is obtained.

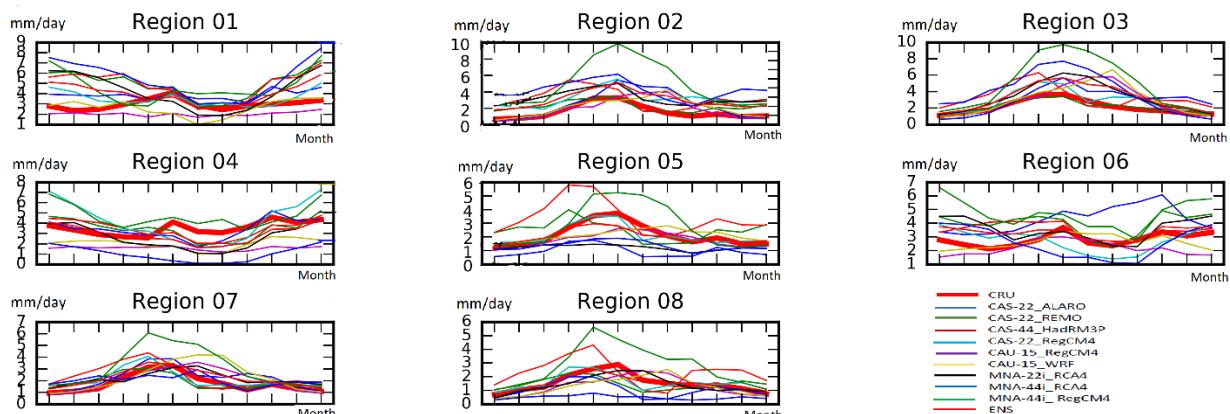


Fig. 5. Simulated and observed (CRU, thick red) precipitation annual cycle (mm) for eight sub-regions. The thin red line indicates the multi-model ensemble precipitation.

A comparison of the simulated annual cycle against the CRU analysis for the sub-regions shows that the multi-model ensemble agrees relatively well with the observed climatology in these regions, except for region R01. However, it should be noted that there are significant differences between the selected nine simulations having not identical annual cycles and variability ranges in monthly mean precipitation averaged over sub-regions, with differences up to 6-7 mm/day for separate models. Accordingly, model biases vary noticeably according to regions and seasons (Fig. 4). Fig. 5 shows the time dependence of model deviations since precipitation offsets are not constant over time. They have a more or less clear annual cycle: there is one RCMs (MNA-RegCM4) with a constant negative precipitation bias throughout the entire year, for the other five models precipitation is mostly underestimated in summer (up to 3-4 mm/day), whilst overestimated to a varying extent in the rest of the year resulting ensemble simulations overall slightly positive bias. Therefore, the seasonal variation in the magnitude of the bias in area-average precipitation means that the ENS simulation has a more extreme annual cycle than the annual cycle of the observations. In the cold period (NDJFM), all regions of the study territory have a wet bias. This appears to be the largest over the western and central part of the Caucasus mountains. A dry bias in area-mean precipitation is greatest during autumn and especially in summer. In these seasons, dry biases extend over entire low-elevation regions including the Greater Caucasus western part. This can be related to the simulation of cold-season snowpack in high-elevation regions and/or the lack of resolutions both in model simulations and the CRU data, suitable for representing the large orographic variations and associated variations in atmospheric precipitation in the mountainous region. As well as in modifying synoptic systems entering the domain enhancing the role of the large-scale frontal processes while diminishing the locally induced intra-mass precipitation that is mostly related to extreme rainfall events.

Fig. 6 presents the normalized biases and interannual variability in terms of the percentage of the temporal standard deviations of the CRU data over the 16 years of the simulated atmospheric precipitation in the eight sub-regions during each season. The scaled model bias shows that the wet bias over the Caucasus mountains is common for nearly all models (except RCMs integrated over the Caucasus) and is more distinct in the cold period of the year (NDJFM) over the western mountainous part, whereas getting sharper in the east and south Caucasus in the warm period (AMJJASO).

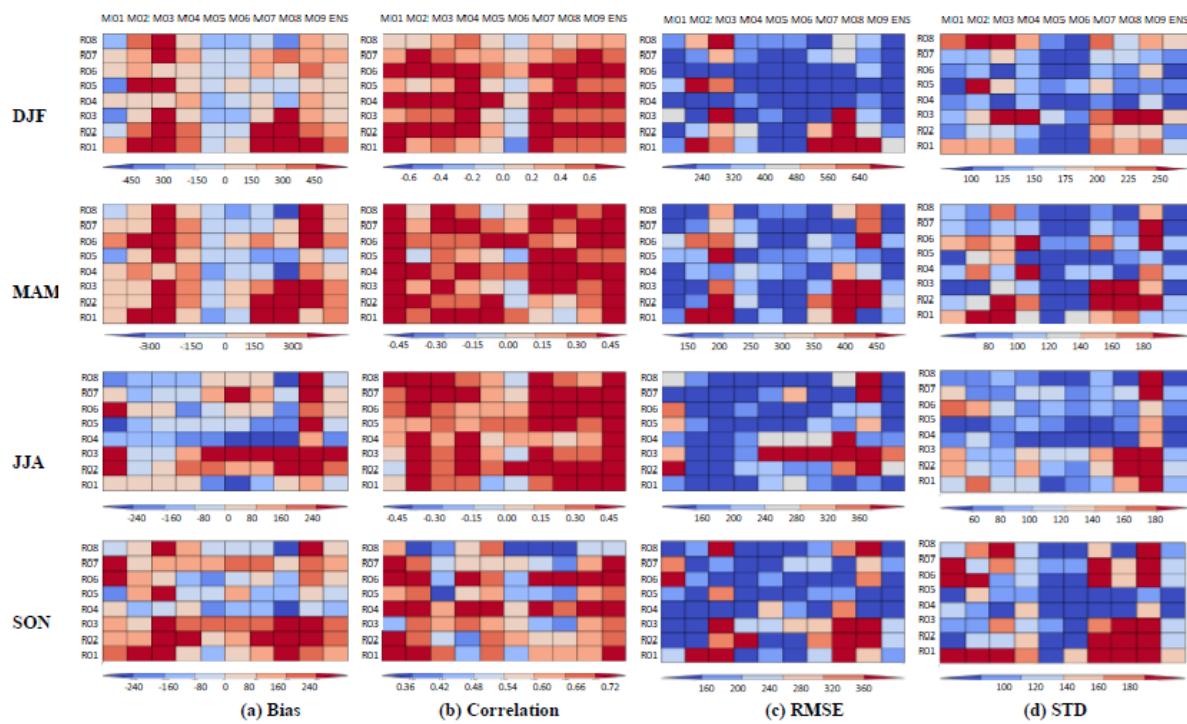


Fig. 6. Regional (a) bias, (b) temporal correlation coefficients, (c) root mean square error and (d) temporal standard deviation of simulated average seasonal precipitation relative to CRU observations. Seasons are defined as follows: winter-DJF (December–February), spring-MAM (March–May), summer-JJA (June–August) and autumn-SON (September–November). Regions are represented on the vertical axis, and models - on the horizontal axis. The bias, standard deviation, and RMSE are normalized by the standard deviation of the CRU data.

The dry biases generated by CAU-15 are less strong during the almost entire year (by 50%–150% of the observed interannual variability) and ENS underestimation over the mountainous region R01 in summer, is the only exception. As for dry bias on the intermountain area (R04, R05, R08) negative deviations are systematic for most of the models (except MNA-RegCM4 and CAS-HaDRM3P) in the warm period (AMJJASO), getting especially evident for west Georgia lowlands (R04) in summer months.

The model's skill in simulating the interannual variability of the seasonal precipitation is further examined using RMSE and the temporal correlation coefficients between the simulated and CRU data. The resulting RMSE (Fig. 6) exceeds the interannual variability of the CRU data regardless of the models and seasons (i.e., normalized RMSE>100%), especially during winter, when the normalized RMSE for the multi-model ensemble is not less than 240% while for separate RCMs is well above 400% mostly for regions belonging to Greater Caucasus range (R01, R02, R03). As for ENS, it yields the smallest RMSE in spring (MAM). Like the bias, it reveals systematic behaviour in terms of regional distribution, i.e. throughout the year RMSE is the greatest over the Greater Caucasus range, enhancing in the western part in the cold period and the East in the warm period of the year. Additionally, for annual and cold period means because of mostly underestimation is evident, ENS RMSE is greater than for separate models that are ALARO and RCMs integrated over the Caucasus domain, having a generally negative bias.

The spread of bias fields mostly ranges between –240% and +240%, however, MNA-RegCM4 and CAS-HaDRM3P (overestimation) models are exceeding these limits in the winter-spring period almost all over the country. Other models are beyond these ranges over the Greater Caucasus regions. Underestimation greater than these limits is common not for any specific model but the lowland and plain territory (R01, R08) in summer-autumn seasons.

CAS-HaDRM3P in the cold period of the year and MNA-RegCM4 in the warm period typically show a strong wet bias when compared to the CRU observational dataset. In general, RegCM4 and WRF, integrated over CAS and Caucasus domains, performs among the best climate models: i.e., producing close to zero mean annual bias due to the least biased performance during the period from November to March. Hence, higher resolution simulations (RegCM4, WRF) are expected to decrease the mean bias fields, and actually, the standard deviation of bias averaged over the region in each season is smaller in the case of RegCM4 and WRF compared to the ensemble (Fig. 5). The wide range of the spread in seasonal biases can be directly attributed to the different topography and parameterizations implemented in the evaluated climate models.

The model biases also vary systematically according to region. For spring, the most noticeable systematic biases are the wet bias over the almost entire territory with relatively smaller dryness revealed in the central mountainous part (R05 Likhi range). For autumn, the most systematic biases are again the wet bias in the mountainous regions including East Georgia plains (R08), whilst dry bias is enlarged relative to spring and covers also West Georgia lowlands. In winter, wet bias is evident relative to other seasons as shown in Fig. 6. As for summer, dry bias gets dominant compared to other seasons and it varies closely with orography. This feature of orography dependence bias is noticeable during the whole year but most evident in summer. The evaluation of the temporal standard deviation, a surrogate for the interannual variability, shows that all models perform reasonably well in simulating the interannual variability of spring precipitation for all sub-regions. Most of RCMs overestimate the interannual variability of the cold season precipitation; overestimation is greatest for the models integrated over the MENA domain. For all seasons finest resolution simulations, integrated over the Caucasus domain have the least STD. Correlation coefficients between the simulated and CRU time series (Fig. 6) also show that climate models examined in this study generally perform better in simulating the phase of the interannual variation in the overland precipitation during autumn (SON) than in other seasons. As for separate simulations, the poorest correlation was found for the WRF model integrated with the Caucasus domain. An overview of seasonal means approved that degree of matching with observation varies by region and depends on the season. In contrary to annual correlations, west Georgia regions (R01, R04, R06) were found as almost not correlated with observations, whilst the same regions 04 and 06 have the highest scores for winter and autumn seasonal means.

CONCLUSIONS

In the present study, six climate models have been evaluated over a 16-year reference period (1990–2005) against CRU observational dataset, while the TRMM data have been used for comparison. This study aims to provide useful information on the general capabilities of given models in reproducing climatic conditions over the South Caucasus region. This article does not attempt to identify the physics and dynamics of the model responsible for the differences in RCM performance. In general, the annual precipitation cycle averaged over the study region is relatively well represented by ensemble modelling. According to the spatial distribution of seasonal precipitation, models performing well for annual precipitation do not necessarily perform well in separate seasons. The model performance varies widely and, often systematically, according to regions and seasons. These characteristics in model errors make it difficult to design a set of model weightings that can be universally applied to the construction of a multi-model ensemble.

According to the findings reported in the present work, the following considerations can be made: (i) there is not a single model outperforming the other ones in all aspects, but it is also important to note that all models have their strengths and weaknesses; (ii) higher resolution

simulations may more adequately resolve over-land precipitation variations in the region; (iii) but due to the amplification of biases or the increased internal variability on small scales induced by strong local surface heterogeneities within the regional domain, higher resolution simulations not necessarily reduce the uncertainties; (iv) domain of model integration might have a significant impact; (v) model performances are also influenced by observational uncertainties and (vi) it is fundamental to test whether an RCMs can reproduce the mean climatology and temporal variability over a region using finer scale observations from different sources.

REFERENCES

- Almazroui M. (2019): Temperature Changes over the CORDEX-MENA Domain in the 21st Century Using CMIP5 Data Downscaled with RegCM4: A Focus on the Arabian Peninsula. *Advances in Meteorology*. DOI: 10.1155/2019/5395676.
- Almazroui M., Islam M. N., Al-Khalaf A. K., Saeed, F. (2016): Best convective parameterization scheme within RegCM4 to downscale CMIP5 multi-model data for the CORDEX-MENA/Arab domain. *Theoretical and Applied Climatology*, 124(3–4), 807–823. DOI: 10.1007/s00704-015-1463-5.
- Almazroui M., Islam M.N., Al-Khalaf A.K., Saeed F., Dambul R., Rahman M. A. (2016): Simulation of temperature and precipitation climatology for the CORDEX-MENA/Arab domain using RegCM4. *Arab J Geosci*, 9(1), 13. DOI: 10.1007/s12517-015-2045-7.
- Bucchignani E., Cattaneo L., Panitz H. J., Mercogliano, P. (2016): Sensitivity analysis with the regional climate model COSMO-CLM over the CORDEX-MENA domain. *Meteorology and Atmospheric Physics*, 128(1), 73–95. DOI: 10.1007/s00703-015-0403-3.
- Bucchignani E., Mercogliano P., Panitz H. J., Montesarchio M. (2018): Climate change projections for the Middle East–North Africa domain with COSMO-CLM at different spatial resolutions. *Advances in Climate Change Research*, 9(1), 66–80. DOI: 10.1016/j.accre.2018.01.004.
- Bucchignani E., Mercogliano P., Rianna G., Panitz H. J. (2016): Analysis of ERA-Interim-driven COSMO-CLM simulations over Middle East – North Africa domain at different spatial resolutions. *International Journal of Climatology*, 36(9), 3346–3369. DOI: 10.1002/joc.4559.
- Deitch M.J., Sapundjieff M.J., Feirer S.T. (2017): Characterizing precipitation variability and trends in the world's Mediterranean-climate areas. *Water* 9:259. <https://doi.org/10.3390/w9040259>.
- Gibson P. B., Waliser D. E., Lee H., Tian B., Massoud E. (2019): Climate Model Evaluation in the Presence of Observational Uncertainty: Precipitation Indices over the Contiguous United States, *J. Hydrometeor*. 20 (7): 1339–1357. <https://doi.org/10.1175/JHM-D-18-0230.1>.
- Gleckler P., Taylor K., Doutriaux C. (2008): Performance metrics for climate models. *J.Geophys. Res.* 113. DOI: 10.1029/2007JD008972.
- Harris I., Jones P.D., Osborn T.J., Lister D.H. (2014): Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. <https://doi.org/10.1002/joc.3711>.
- IPCC, Climate change (1995): the science of climate change. Intergovernmental Panel on Climate Change, WMO, p. 572.
- IPCC, Climate change (2001): the scientific basis. Intergovernmental Panel on Climate Change, WMO, p. 881.
- IPCC, Climate change (2007): synthesis report. Intergovernmental Panel on Climate Change, WMO, p. 73.
- Kim J., Guan B., Waliser D.E., Ferraro R. D., Case J. L., Iguchi T., Kemp E., Putman W., Wang W., Wu D., Tian B. (2018): Winter precipitation characteristics in western US related to atmospheric river landfalls: observations and model evaluations. *Clim Dyn* 50, 231–248. <https://doi.org/10.1007/s00382-017-3601-5>.
- Lee H., Goodman A., McGibbney L., Waliser D. E., Kim J., Loikith P. C., Gibson P. B., Massoud E. C. (2018): Regional Climate Model Evaluation System powered by Apache Open Climate Workbench v1.3.0: an enabling tool for facilitating regional climate studies, *Geosci. Model Dev.*, 11, 4435–4449. <https://doi.org/10.5194/gmd-11-4435-2018>.
- Lionello P, Scarascia L. (2018): The relation between climate change in the Mediterranean region and global warming. *Reg Environ Chang*, 18(5):1481–1493. <https://doi.org/10.1007/s10113-018-1290-1>.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Lucas-Picher, R. Laprise, K. Winger. (2017): Evidence of added value in North American regional climate model hindcast simulations using ever-increasing horizontal resolutions. *Climate Dyn.*, 48, 2611–2633. <https://doi.org/10.1007/s00382-016-3227-z>.
- Meehl G., Covey C., Delworth T., Stouffer R., Latif M., McAvaney B., Mitchell J. (2007): The WCRP CMIP3 multi-model dataset: a new era in climate change research. *Bull. Am. Meteorol. Soc.* 88:1383–1394.
- Nikulin G., Jones C., Samuelsson P., Giorgi F., Sylla M., Asrar G., Buchner M., Cerezo-Mota R. (2012): Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. *J.Clim.* DOI:10.1174/JCLI-D-11-00375.
- Northrop P., Chandler R. (2014): Quantifying Sources of Uncertainty in Projections of Future Climate. *J. Clim.*, 27 (2014), pp. 8793-8808. DOI: <https://doi.org/10.1175/JCLI-D-14-00265.1>.
- Ozturk T., Turp M.T., Türkeş M., Levent Kurnaz M. (2017): Projected changes in temperature and precipitation climatology of Central Asia CORDEX Region 8 by using RegCM4.3.5. *Atmospheric Research*, Volume 183, 1 January, Pages 296-307. <https://doi.org/10.1016/j.atmosres.2016.09.008>.
- Ozturk T., Turp M. T., Türkeş M., Kurnaz M. L. (2018): Future projections of temperature and precipitation climatology for CORDEX-MENA domain using RegCM4.4. *Atmospheric Research*, 206, 87–107. DOI: 10.1016/j.atmosres.2018.02.009.
- Reichler T., Kim J. (2008): Uncertainties in the climate mean state of global observations, reanalyses and the GFDL climate model. *J.Geophys. Res.* 113:D05106. DOI: 10.1029/2007JD009278.
- Reichler T., Kim J. (2008): How well do coupled models simulate today's climate? *Bull. Am.Meteorol. Soc.* 89:303–311.
- Russo E., Kirchner I., Pfahl S., Schaap M., and Cubasch U. (2019): Sensitivity studies with the regional climate model COSMO-CLM 5.0 over the CORDEX Central Asia Domain, *Geosci. Model Dev.*, 12, 5229–5249. <https://doi.org/10.5194/gmd-12-5229-2019>.
- Spinoni J., Barbosa P., Buccignani E., Cassano J., Cavazos T., Christensen J. H., Christensen O. B., Coppola E., Evans J., Geyer B., Giorgi F., Hadjinicolaou P., Jacob D., Katzfey J., Koenigk T., Laprise R., Lennard C. J., Kurnaz M. L., Delei L., Llopis J., McCormick N., Naumann G., Nikulin G., Ozturk T., Panitz H.-J., Porfirio da Rocha R., Rockler B., Solman S.A., Syktus J., Tangang F., Tiechmann C., Vautard R., Vogt J.V., Winger K., Zittis G., Dosio A. (2020): Future Global Meteorological Drought Hot Spots: A Study Based on CORDEX Data. *Journal of Climate*, 33(9), 3635–3661. DOI: 10.1175/jcli-d-19-0084.1.
- Zittis G. (2018): Observed rainfall trends and precipitation uncertainty in the vicinity of the Mediterranean, Middle East and North Africa. *Theor Appl Climatol*, 134:1207. <https://doi.org/10.1007/s00704-017-2333-0>.
- Zittis G., Hadjinicolaou P. (2017): The effect of radiation parameterization schemes on surface temperature in regional climate simulations over the MENA-CORDEX domain. *International Journal of Climatology*, 37(10). DOI: 10.1002/joc.4959.
- Zittis G., Hadjinicolaou P., Klangidou, M., Proestos Y., Lelieveld J. (2019): A multi-model, multi-scenario, and multi-domain analysis of regional climate projections for the Mediterranean. *Reg Environ Change* 19, 2621–2635. <https://doi.org/10.1007/s10113-019-01565-w>.

EXAMINING THE PAST AND CURRENT DISTRIBUTION OF THE PALLAS'S CAT IN SOUTHERN AND CENTRAL MONGOLIA

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ABSTRACT

Mongolia is considered the stronghold of the Pallas's cat population (*Otocolobus manul* Pallas, 1776) and is thought to be widely distributed across Mongolia's mountain steppes. However, the species ecology and regional distribution remain poorly known. In June 2018, we performed an interview-based survey to estimate the current distribution pattern of the Pallas's cat in the Gobi Gurvansaikhan National Park, Southern Mongolia, and assessed how the population's distribution has changed over the last 30 years. We used the multi-season site-occupancy framework to assess factors affecting the probability of use by Pallas's cat while controlling for imperfect detection. The distribution of Pallas's cat was positively correlated with ruggedness. Furthermore, detection probability was greater for herders that spent more time or visited a larger area of the mountains. Our results indicate that the distribution of the Pallas's cat in the Gobi Gurvansaikhan National Park has shrunk by 15% over the last 30 years. These results highlight the importance of monitoring the elusive species in order to inform conservation and management efforts in Mongolia. Since June 2022, we have been conducting this research to estimate the distribution of Pallas's cat in Central Mongolia.

Keywords: *Otocolobus manul*, Pallas's cat, distribution, occupancy, habitat change

INTRODUCTION

The Pallas's cat (*Otocolobus manul*), also known as the manul, is a small-sized felid native to the grasslands and mountain steppes of central Asia. Pallas's cat primarily occurs in Mongolia and China (Batsaikhan et al., 2014; Ross et al., 2020). The Pallas's cat is listed as *Least Concern* in the IUCN Red List and the main threats to the species are habitat loss and fragmentation due to increasing human and livestock populations, infrastructure development, mining, illegal hunting, killing by herding dogs, accidental capture when trapping for other animals, decreasing prey numbers largely due to poisoning, and climate change (Clark et al., 2006; Ross et al., 2019, Ross et al. 2020). Another threat is the lack of basic information about the species regional distribution, abundance, and population trends for most of the range (Ross et al., 2019, 2020).

Assessing the distribution of Pallas's cat is challenging due to low population densities, their elusive behavior, and the remoteness of their habitat (Munkhtsog et al., 2004; Ross, 2009; Ross et al., 2010a, 2012., Barashkova et al., 2017). Occupancy modelling (Mackenzie et al., 2003; Mackenzie et al., 2017) has been used to estimate species occurrence, distribution, and habitat selection for a variety of species (Cabeza et al., 2004; Smith et al., 2007., Ruell et al., 2009).

The probability of occupancy has been proposed as a useful technique to assess the distribution of the Pallas's cat and how it changes over time (Ross et al. 2019). Similarly, for species that are difficult to detect, such as the Pallas's cat, the use of interview data in an occupancy framework has the potential to provide a cost-effective alternative to large-scale field surveys (Caruso et al., 2017; Taubmann et al., 2017). Local people living in areas adjoining or overlapping with wildlife habitats represent a source of potentially valuable information on the occurrence of species and potential threats (Lunney et al., 2009; Pillay et al., 2011; Zeller et al., 2011; Taubmann et al., 2017; Ghoshal et al., 2017). This study aimed to examine (1) the current distribution of the Pallas's cat in the Gobi Gurvansaikhan National Park in southern Mongolia and in the Hustai National Park in Central Mongolia and how this has changed during the last 30 years and (2) the factors affecting the distribution of the Pallas' cat in both national park by using a multi-season site-occupancy model. A detailed understanding of how the distribution of the Pallas cat changes over time and the factors that affect these changes are important for the conservation of this elusive and shy cat.

METHODS AND DATA

We conducted a household survey between June and July from all known households in the Gobi Gurvansaikhan National Park in Southern Mongolia. The Gobi Gurvansaikhan National Park ($27,000 \text{ km}^2$) was established in 1993 and is the largest national park in Mongolia; elevation ranged from 1000 m to 3000 m in altitude and the park's landscape vary from alpine meadows to sandy deserts but is dominated by desert, semi desert, and steppe (Donald & Sabine, 2006). The climate is continental and temperature extremes from 40° C to minus 40° C . The national park is rich in wildlife and is also an area that is used by nomadic herders and their livestock for thousands of years. Our study area comprised of $4,500 \text{ km}^2$ of the core zone of the national park, called the Zuunsaihan and Dundsaihan mountains. We asked about the sightings of Pallas's cat in two different time periods (1980-1990 and 2008-2018), considering direct pugmark and sighting as a detection. For data analysis, we used PRESENCE v. 2.12.25 (Hines, 2006) to run multi-season occupancy models (D. I. Mackenzie et al., 2003) to estimate the probability of occupancy, detection, and local extinction and colonization. We created maps with the probability of occupancy for the Pallas's cat from the two time periods using QGIS v. 3.6.2.

Since June 2022, we started a household survey in Hustain Nuruu National Park in Central Mongolia and the same methodology of data collection was used to estimate the detection of Pallas's cat. The Hustain Nuruu National Park (570 km^2) is a large conservation area established in 2003. The national park consists of a mountain and upland steppe (van Dierendonck & Vries, 1996), and the climate is characterised by long cold winters (lowest temperature of -40° C), and short temperate summer (reaches up to $+40^\circ \text{ C}$). In total, 54 interviewees were interviewed, and this research is going to continue through June 2023 in the national park.



Fig. 3. Captured Pallas cat in camera trap in Central and Southern Mongolia.

RESULTS

In the Zuunsaikhan and Dundsaihan Mountains of the Gobi Gurvansaikhan National Park, we conducted 130 independent interviews in total. The age ranges of the interviewees who participated in the household interviews were 18 to 83. 93 of the interviewees were living in the area before 1990. Most interviewees were males ($n=84$, 65%) and most of the interviewees were herders ($n=112$, 86%). Overall, we had 72 and 78 detections of the Pallas's cat from the past (around 1990) and current periods (around 2018), respectively.

Detection probability was best explained by the model that included number of years residing in the area and area of coverage as covariates and site use was best explained by the model that included ruggedness as a covariate (

Table 3, AIC weight=0.997). Detection probability was negatively related to the number of years residing in the area ($\beta = -0.18 \pm \text{SE } 0.12$) and positively related to the area of coverage by an interviewee ($\beta = 2.3 \pm \text{SE } 0.17$). The probability of site use by the Pallas's cat was positively related to ruggedness ($\beta = 1.58 \pm \text{SE } 0.61$, Fig. 4). The impact of gender on detection probability was negligible ($\beta = -0.05 \pm \text{SE } 0.18$). Our results thus suggest that the distribution of the Pallas's cat has decreased in the last 30 years and that the probability of local extinction was 0.21 and the probability of local colonization was 0.6 between the two time periods.

Table 3. Summary of multi-season (past and current) model selection of detection probability and site use probability by the Pallas's cat in the Gobi Gurvansaikhan National Park in southern Mongolia where detection probability and site use probability was modeled in two steps

	AIC	DAIC	AIC weight	Model Likelihood	No. of parameters	-2 LogL
Step 1: Modeling detection probability						
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{area of coverage} + \text{years in area})$	765.52	0	0.3623	1	6	753.52
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{area of coverage})$	765.71	0.19	0.3295	0.9094	5	755.71
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{area of coverage} + \text{years in area} + \text{gender})$	767.19	1.67	0.1572	0.4339	7	753.19
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{years in area} + \text{gender})$	767.27	1.75	0.151	0.4169	6	755.27
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\cdot)$	1177.58	412.06	0	0	4	1169.58
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{years in area})$	1178.35	412.83	0	0	5	1168.35
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{gender})$	1179.58	414.06	0	0	5	1169.58
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{gender} + \text{years in area})$	1180.35	414.83	0	0	6	1168.35
Step 2: Modeling site use						
$\psi(\text{ruggedness}), \gamma(\cdot), \varepsilon(\cdot), p(\text{years in area} + \text{area of coverage})$	754.07	0	0.9967	1	7	740.07
$\psi(\cdot), \gamma(\cdot), \varepsilon(\cdot), p(\text{years in area} + \text{area of coverage})$	765.52	11.45	0.0033	0.0033	6	753.52

The interviewees reported having detected Pallas's cats in 28 grid cells around 1990, and in 19 sampling units around 2018 resulting in naïve occupancy estimates of $\Psi_{\text{past}} = 0.39$ and $\Psi_{\text{current}} = 0.27$.

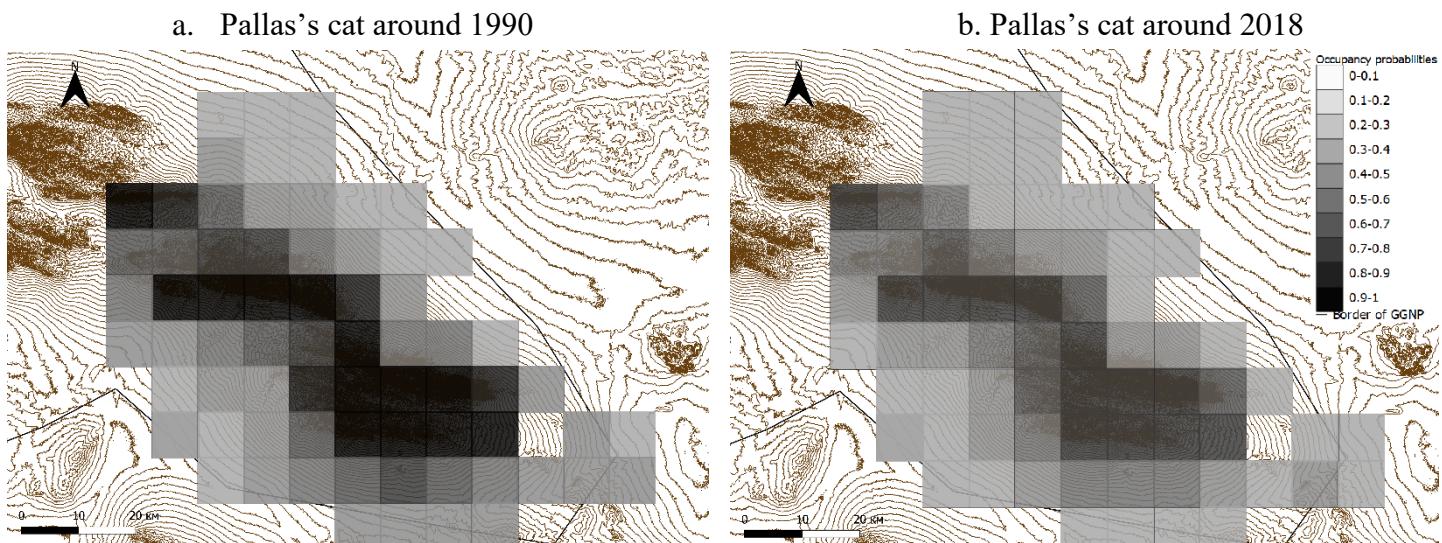
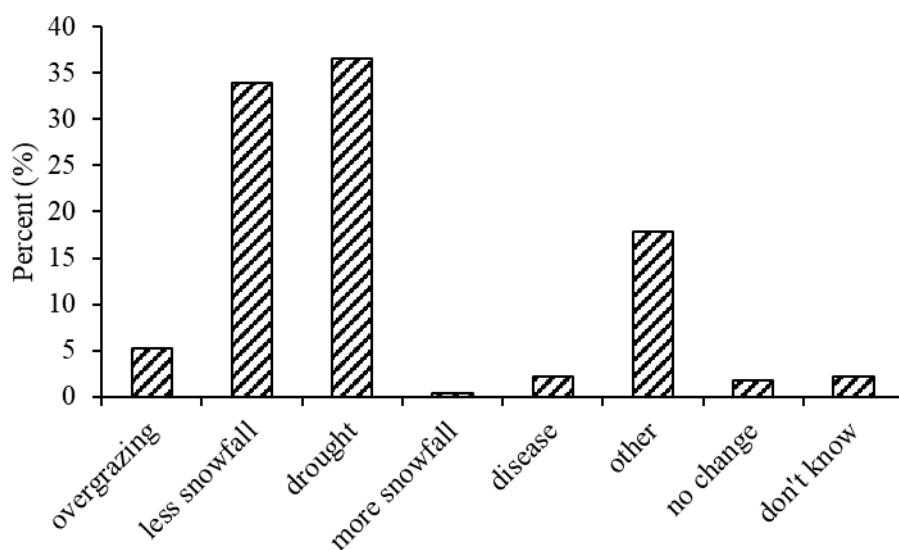


Fig. 4. Estimated site use probabilities for the Pallas's cat in the Zuunsaikhan and Dundsaihan Mountains of the Gobi Gurvansaikhan National Park 1980–1990 and 2008–2018 based on the top model (thin brown lines are elevation contours and the thin black line is the border of the national park).

The table also includes differences in AIC (Akaike information criteria) values between each model and the best fitting model ($\ominus i$), the model likelihood, and number of model parameters ψ Site use probability, γ colonization probability, ε extinction probability, p detection probability

Herders generally agreed that there had been an overall habitat change in the Zuunsaikhan and Dundsakhan mountains of Gobi Gurvan Saikhan National Park over the past 10 years. Most of the herders reported that (37%, n = 48) the rate of the drought was increasing and 34% (n = 44) thought that snowfall was lessening. Other changes that several herders (18%, n=23) reported were a decline in the number of wildlife, an increase in livestock and tourism, and lastly a lack of vegetation (Table 4).

Table 4. Habitat changes in the Zuunsaikhan and Dundsakhan mountains over the last 10 years



DISCUSSION AND CONCLUSION

This study showed that the distribution of the Pallas's cat in the Gobi Gurvansaikhan National Park was associated with more rugged areas of this mountain region. The results are similar to earlier studies that show that the Pallas's cat generally occurs in fragmented areas and more disruptive cover, such as rocky areas and ravines, and avoids open areas without suitable cover (Ross, 2009). The site use was higher in the Bayan Uul, Ulaan Khad, Guriin Tolgoi, and the Tsagaan Ovoo Mountains where the probability of site use was > 0.80. Site use in the Shar Sarhia, Bayan Bag, Ikh Khundii, Chuluut, and Kharuut Ovoo, in contrast, was lower (< 0.30). The difference in site use between these geographic areas was explained by the topography and openness of the areas with the former areas being more rugged and mountainous than the latter areas. In addition, our study also confirms the occurrence of the Pallas's cat distribution in an area that was not part of the known distribution range as shown in previous Red List assessments (Ross et al., 2020) and showed that the population has been present there for a long time.

Our results suggest that with a higher probability of local extinction than that of local colonization, the Pallas's cat's distribution in the Zuunsaikhan and Dundsakhan Mountains has shrunk by 15% during the last 30 years. Although we do not have information to explain the causes of this decrease, we suggest that it might be related to increasing livestock numbers and associated decreases in prey species such as pikas and small rodents. This appears to be a common conservation challenge for the Pallas's cat throughout the range (Ross et al., 2019).

The livestock numbers in the national park increased from 27,500 in 1990 to 76,000 in 2018 (“National Statistical Office of Mongolia,” 2018).

Herders in southern Mongolia move between camp sites less frequently today as compared to 30 years ago and this has likely resulted in increased grazing pressure around herder camps and watering holes, which, in turn, has affected grassland quality (Pringle & Landsberg, 2004). We suspect the influences of increasing livestock numbers and more sedentary behavior of the herders may also have negatively impacted pikas and small rodents’ populations in the Gobi Gurvansaikhan National Park.

A further potential threat to the Pallas’s cat is climate change (Barashkova et al., 2019). In the South Gobi, the annual average temperature has risen by 2.4°, despite an annual precipitation decline of 20 mm and a sharp rise in the frequency of droughts over the last decade (*General basic report of GZB in Omnogobi province*, 2004). Our results suggest that with less snow fall, and drought are the major habitat changes in the national park, which may be negatively influencing the prey and shrinking the distribution of the Pallas’s cat.

In summary, our study has shown that the Pallas’s cat is associated with rugged areas and that the site use of the Pallas’s cat in the Gobi Gurvansaikhan National Park appears to have decreased during the last 30 years. We assume that this is related to increasing grazing pressure in the area and potentially other factors such as small mammal control measures. We, however, recognize that more research is needed to understand these processes and that the potential impacts of wider socio-economic and cultural factors on the distribution of the Pallas’s cat need further investigation. Moreover, these results highlight the importance of monitoring this elusive species to inform local and regional conservation and management efforts.

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REFERENCES

- Akaike, H. (2013): Information theory as an extension of the maximum likelihood principle. In Second International Symposium on Information Theory.
- Barashkova, A. N., Kirilyuk, V. E., Smelansky, I. E. (2017): Significance of Protected Areas for the Pallas’s cat (*Otocolobus Manul: Felidae*) conservation in Russia. *Nature Conservation Research*, 2 (Suppl. 1), 113–124.
- Barashkova, A., Smelansky, I. (2011): Pallas’s cat in the Altai Republic, Russia. *Cat News*, 54, 1027–2992.
- Barashkova, A., Smelansky, I., Kirilyuk, V., Naidenko, S., Antonevich, A., Gritsina, M., Zhumabai Uulu, K., Koshkin, M., Nasanbat, B., Baatargal, O., Grachev, A., & Lissovsky, A. (2019): Distribution and status of the manul in Central Asia and adjacent areas (pp. 14–23).
- Batsaikhan, N., Samiya, R., Shar, S., Lkhagvasuren, D., King, S. R. B. (2014): A field guide to the mammals of Mongolia (2nd edition). Munkhiin Useg.
- Cabeza, M., Araújo, M. B., Wilson, R. J., Thomas, C. D., Cowley, M. J. R., Moilanen, A. (2004): Combining probabilities of occurrence with spatial reserve design. *Journal of Applied Ecology*, 41(2), 252–262.
- Caruso, N., Vidal, E. L., Guerisoli, M., Lucherini, M. (2017): Carnivore occurrence: Do interview-based surveys procedure unreliable results? *Oryx*, 2, 240–245.
- Clark, E. L., Dualmtseren, S., Baillie, J. E. M., Batsaikhan, N., Samiya, R., Stubbe, M. (2006): Mongolian Red List of Mammals.
- Donald, J. B., & Sabine, M. S. (2006): Rangelands of Gobi Gurvansaikhan National Conservation Park, Mongolia. 22, 4. https://doi.org/10.2458/azu_rangelands_v22i4_bedunah
- General basic report of GZB in Omnogobi province, 2004.
- Ghoshal, A., Bhatnagar, Y. V., Pandav, B., Sharma, K., Mishra, C., Raghunath, R., & Suryawanshi, K. R. (2017): Assessing changes in distribution of the Endangered snow leopard *Panthera uncia* and its wild

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Interdisciplinary Approach in Current Hydrological Research

- prey over 2 decades in the Indian Himalaya through interview-based occupancy surveys. *Oryx*, 4, 620–632.
- Hines, J. E. (2006): Software to estimate patch occupancy and related parameters. United States Geological Survey, Patuxent Wildlife Research Center, Laurel, USA.
- Lunney, D., Crowther, M. S., Shannon, I., Bryant, J. V. (2009): Combining a map-based public survey with an estimation of site occupancy to determine the recent and changing distribution of the koala in New South Wales. *Wildlife Research*, 3, 262–273.
- Mackenzie, D. I., Nichols, J. D., Hines, J. E., Knutson, M. G., Franklin, A. B. (2003): Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecological Society of America*, 8, 2200–2207.
- Mackenzie, D. I., Royle, J. A. (2005): Designing occupancy studies: General advice and allocating survey effort. *Journal of Applied Ecology*, 42(6), 1105–1114.
- Mackenzie, D., Nichols, J., Royle, J., Pollock, K., Bailey, L., Hines, J. (2017): *Occupancy Estimation and Modeling* (2nd Edition).
- Munkhtsog, B., Ross, S., Brown, M. (2004): Home range characteristics and conservation of Pallas' cat in Mongolia. 10pp. <http://www.savemanul.org/articles/doc/>
- Murdoch, J. D., Munkhzul, T., Reading, R. P. (2006): Pallas' Cat ecology and Conservation in the Semi-desert Steppes of Mongolia. *Cat News*, 45, 19–19.
- Pillay, R., Johnsingh, A. J. T., Raghunath, R., Madhusudan, M. D. (2011): Patterns of spatiotemporal change in large mammal distribution and abundance in the southern Western Ghats, India. *Biological Conservation*, 144(5), 1567–1576.
- Pringle, H. J. R., Landsberg, J. (2004): Predicting the distribution of livestock grazing pressure in rangelands. *Austral Ecology*, 29(1), 31–39. <https://doi.org/10.1111/j.1442-9993.2004.01363.x>
- Ross, S. (2009). Providing an ecological basis for the conservation of the Pallas's cat (*Otocolobus manul*). [PhD thesis]. University of Bristol, UK.
- Ross, S., Barashkova, A., Dhendup, T., Munkhtsog, Smelansky, I., Barclay, D., Moqanaki, E. (2020): *Otocolobus manul* (errata version published in 2020). The IUCN Red List of Threatened Species. <https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T15640A180145377.en>
- Ross, S., Barashkova, A., Farhadinia, M. S., Appeal, A., Riordan, P., Sanderson, J., Munkhtsog, B. (2016): *Otocolobus manul*. The IUCN Red List of Threatened Species.
- Ross, S., Kamnitzer, R., Munkhtsog, B., Harris, S. (2010a): Den-site selection is critical for Pallas's cats (*Otocolobus manul*). *Canadian Journal of Zoology*, 9, 905–913.
- Ross, S., Moqanaki, E. M., Barashkova, A., Dhendup, T., Smelansky, I., Naidenko, S., Antonevich, A., Samelius, G. (2019): Past, present and future threats and conservation needs of Pallas's cats. *Cat News Special Issue*, 13, 46–51.
- Ross, S., Munkhtsog, B., Harris, S. (2012): Determinants of mesocarnivore range use: Relative effects of prey and habitat properties on Pallas's cat home-range size. *Journal of Mammalogy*, 5, 1292–1300.
- Ruell, E. W., Riley, S. P. D., Douglas, M. R., Pollinger, J. P., Crooks, K. R. (2009): Estimating Bobcat Population Sizes and Densities in a Fragmented Urban Landscape Using Noninvasive Capture–Recapture Sampling. *Journal of Mammalogy*, 1, 129–135.
- Smith, J. B., Jenks, J. A., Klaver, R. W. (2007): Evaluating Detection Probabilities for American Marten in the Black Hills, South Dakota. *Journal of Wildlife Management*, 7, 2412.
- Taubmann, J., Sharma, K., Zhumabai Uulu, K., E. Hines, J., Mishra, C. (2017): Status assessment of the Endangered snow leopard *Panthera uncia* and other large mammals in the Kyrgyz Alay, using community knowledge corrected for imperfect detection. *Oryx*, 2, 1–11.
- van Dierendonck, M. C., Vries, M. F. W. de. (1996): Ungulate Reintroductions: Experiences with the Takhi or Przewalski Horse (*Equus ferus przewalskii*) in Mongolia. *Conservation Biology*, 10(3), 728–740.
- Zeller, K. A., Nijhawan, S., Salom-Perez, R., Potosme, S. H., Hines, J. E. (2011): Integrating occupancy modeling and interview data for corridor identification: A case study for jaguars in Nicaragua. *Biological Conservation*, 2, 892–901.

GEOGRAPHIC STRUCTURE OF FOREST CARABID ASSEMBLAGES AS A BIOINDICATIVE CRITERION CLIMATIC CHANGES

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ABSTRACT

Two sites in the Vtáčnik Mts. and two sites in the Čierna hora Mts. were selected in order to monitor the response of Carabid assemblages to the longterm climatic fluctuations. One of the sites in the Vtáčnik Mts. is also influenced by the undermining, while one of the sites in the Čierna hora Mts. is damaged by the heavy metals pollution from the Krompachy smelting plant. The Carabid assemblages consist of 39 species of differently sized geographic ranges. The size of geographic range reflects, to certain degree, the ecological tolerance and adaptability of species. Larger ranges are correlated with higher tolerance and dispersal power and vice versa. Due to, the assemblages in the undermined site and in the heavy metal polluted site showed a larger proportion of transpalaeartic and eurosiberian species, while the assemblages in two more natural sites were dominatated by European and Central European species. This was particularly characteristic for the assemblage from the forest Za Gočalovou. Because of a relatively low altitude of all sites, there were missing the Carpathian endemic species, except *Pterostichus foveolatus*. The biogeographic criteria have been shown to be a suitable supplementary bioindicative criterion of environmental changes.

Keywords: Carabid beetles, biogeography, ecological tolerance, climatic changes, undermining, heavy metals load

INTRODUCTION

The climatic changes and various anthropogenic interventions in ecosystems have potentially a deep influence on their composition, as well as on the geographic and altitudinal distribution of plants and animals. The size of areas of geographic distribution of animal and plant species is a result of complex factors like dispersal power of species, their ability to tolerate or use conditions in the newly colonized territories ans presence or absence of geographical barriers (de Latin 1967, Călinescu 1969, Bănărescu 1973, Udvardy 1978). In the last decades also the passive introduction by traffic plays a significant role in spreading of living organisms.

The earlier studies of Carabid assemblages in the strongly anthropogenically affected suburban ecosystem, parks and gardens in big European cities (e.g. Kiel, Warsaw, Madrid, Brno, Bratislava) have shown that the species having a large area of geographic distribution mostly predominate in such habitats (e.g. Czechowski 1981, Klausnitzer & Richter 1980, Holecová et al. 2012, Šustek 1980 and 2012).

There arises the question, whether these rules can be generalized to the differently disturbed forest stands in free landscape.

The aim of this contribution is an attempt to show how the geographic distribution of the Carabid species is correlated with their tolerance to various disturbances (changed hydrological regime due to undermining and heavy metal load) in middle altitudes and how it can be taken as a supplementary bioindicative criterion for assessment of ecosystem naturalness or processes of their degradation spontaneous or managed restoration in condition of the changing climate.

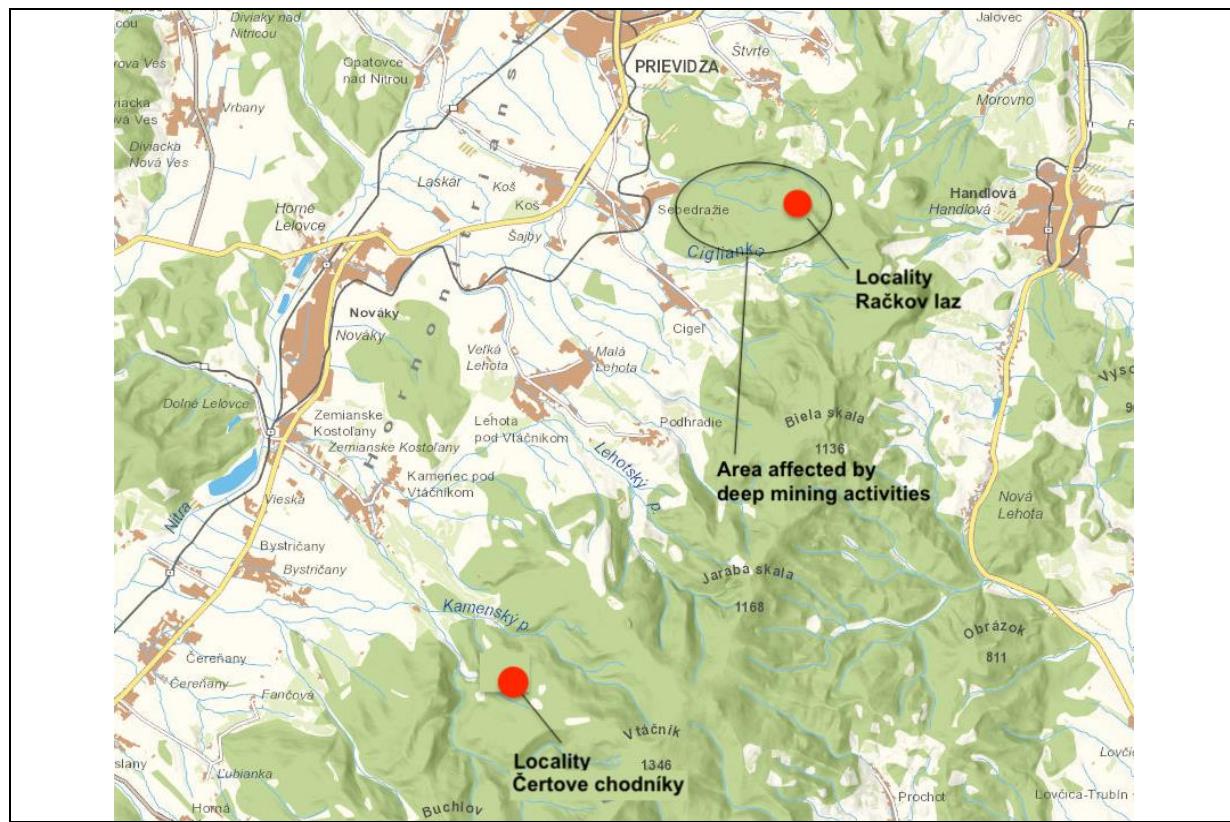


Fig. 1. Position of two study plots in the Vtáčnik Mts. near to Prievidza.

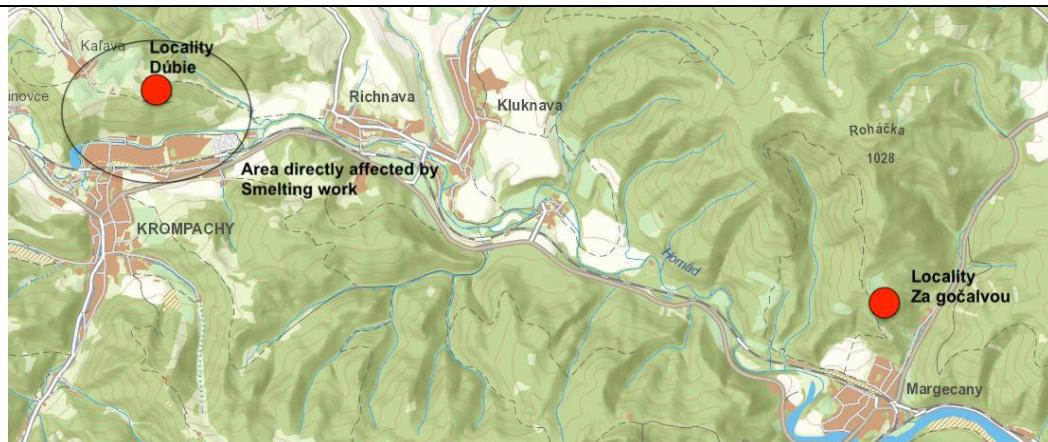


Fig. 2. Position of two study plots in the Čierna hora Mts. near to Krompachy and Prievidza.

MATERIAL AND METHODS

The Carabids were pitfall-trapped using the plastic jars of 0.5 l with opening of 9 cm and filled with 4% formol. In each plot (Fig 1 and 2), traps were exposed from late May to early November and emptied in 1-2-month intervals. In three plots six the traps were installed in a line in mutual distances of about 5-6 m. But in Dúbie near Krompachy, 11 traps were installed in a line passing through the predominantly grassy and shrubby vegetation in the southern part of the hill to a closed oak-hornbeam stand on the northern slope. The southern part was more exposed to the earlier heavy metals load. In this study material from all traps was pooled.

Table 1. Survey of Carabid species occurring in four plots in the Vtáčnik Mts. and Čierna hora Mts. in 2019 - 2021 (Č. – Čertove chodníky, R. – Račkov laz, and their geographic distribution (TP – transpalaearctic, ES – Eurosiberian, WP – westpalaearctic, E – European, WE – Westeuropean, CE – Central European, CA – Carpathic, CM – Circummediterranean)

Species	Distribution type
<i>Abax ovalis</i> (Duftschmidt, 1812)	EC
<i>Abax paralelopipedus</i> (Piller et Mieterpacher, 1783)	E
<i>Abax parallelus</i> (Duftschmidt, 1812)	E
<i>Amara bifrons</i> (Gyllenhal, 1810)	WP
<i>Amara ingenua</i> (Duftschmidt, 1812)	TP
<i>Amara littorea</i> C. G. Thomson, 1857	ES
<i>Aptinus bombarda</i> (Illiger, 1800)	EC
<i>Calathus fuscipes</i> (Goeze, 1777)	WP
<i>Carabus arvensis</i> Herbst, 1784	TP
<i>Carabus auronitens</i> Fabricius, 1792	WE
<i>Carabus convexus</i> Fabricius, 1775	WP
<i>Carabus coriaceus</i> Linnaeus, 1758	E
<i>Carabus hortensis</i> Linnaeus, 1758	E
<i>Carabus intricatus</i> Linnaeus, 1762	E
<i>Carabus linnei</i> Panzer, 1810	EC
<i>Carabus nemoralis</i> D. F. Müller, 1764	E
<i>Carabus scheidleri</i> Panzer, 1799	EC
<i>Carabus violaceus</i> Linnaeus, 1758	E
<i>Cychrus attenuatus</i> (Fabricius, 1792)	EC
<i>Cychrus caraboides</i> (Linnaeus, 1758)	EC
<i>Cymindis axilaris</i> (Fabricius, 1794)	CM
<i>Cymindis humeralis</i> (Fouecroy, 1785)	CM
<i>Harpalus distinguendus</i> (Duftschmidt, 1812)	TP
<i>Leistus rufomarginatus</i> (Duftschmidt, 1812)	EC
<i>Molops piceus</i> (Panzer, 1793)	EC
<i>Nebria brevicollis</i> (Fabricius, 1792)	E
<i>Ophonus nitidulus</i> Stephen, 1828	ES
<i>Platynus assimilis</i> (Paykull, 1790)	ES
<i>Poecilus cupreus</i> (Linnaeus, 1758)	TP
<i>Poecilus virens</i> (G. F. Müller, 17785)	TP
<i>Pterostichus aethiops</i> (Panzer, 1797)	E
<i>Pterostichus burmeisteri</i> Heer, 1841	EC
<i>Pterostichus foveolatus</i> (Duftschmidt, 1812)	CA
<i>Pterostichus melas</i> (Creutzer, 1799)	WP
<i>Pterostichus niger</i> (Schuller, 1783)	TP
<i>Pterostichus oblongopunctatus</i> (Fabricius, 1787)	TP
<i>Pterostichus unctulatus</i> (Duftschmidt, 1812)	EC
<i>Synuchus vivalis</i> (Illiger, 1798)	TP
<i>Trichotichnus laevicollis</i> (Duftschmidt, 1812)	EC

The Carabids were identified using the key by Hůrka (1996). Their geographical ranges (Tab. 1) were typified into the following categories arranged decreasingly according to their size: Transpalaearctic (distributed in the Palaearctis except its southern and northern parts), Eurosiberian (similar, but reaching just West Siberia), European (almost whole Europe, except Caucasus and Mediterranean area), West Palaearctic (almost Europe and Northwest Africa), Central European (limited to the Central European mountain ranges Carpathian (limited to higher elevation of Carpathians), West European (reaching from France to Central Europe, inclusively of the Carpathian), Circummediterranean expansive (distributed around

the major part Mediterranean sea and reaching northerly to Central Europe). The data on distribution of species were taken from the monographs by Habermann (1968), Turin (1981), Kryzhanovskij et al. (1995) and Hůrka (1996).

Their qualitative representation is expressed by number of species recorded in each site and year, while quantitative representation is expressed as absolute number of individuals caught and as percents as cumulative dominance (relative abundance) in percentage of all species having the same distribution type. The data of their quantitative representation were take from the earlier paper of the authors (Šustek et al., 2021).

STUDY SITE SPECIFICATION

Two study plots are situated in the northwest part of the Vtáčnik Mts. in the Prievidza district (Fig. 1). The plot in Račkov laz (619 m a.s.l.) is located in the area affected by deep mining activities of the brown coal mine Cígel'. Typical damage forms are deep geological cracks and landslides, which were inducted by the mining activities. These damages caused surface water and groundwater deficits. In contrast, the plot Čertove chodníky (590 m a.s.l.) is situated in the intact area and simulates natural reference conditions. Both plots are highly afforested (70%-90%). Prevailing forest types are mixed beech forests on cambisoils.

Two other plots are situated in the southwest parts of the Čierna hora Mts. in the Gelnica district (Fig. 2). Among them the plot at Dúbie near Krompachy (540 m a.s.l.) represents a highly damaged forest by heavy metal deposition from the smelting work in Krompachy. Its southern part is discontinuous, consisting of patches of grassy and shrubby vegetation. Its northern part is almost continuous, consisting of resistant tree species like willows, birches and Scots pine. The plot Za Gočalovou near Margecany (578 m a.s.l.) represents a reference continuous European beech forest subjected just indirect to atmospheric depositions of heavy metals from the Krompachy smelting work. The composition of the Carabid as such in this site is characterized by a rich species specter and co-occurrence of several species of the genus *Carabus* (Šustek et al., 2021).

RESULTS AND DISCUSSION

In all plots altogether 3,425 individuals of 39 species were collected (Tab. 1). In individual plots and years, number of individuals fluctuated between 51 and 856 and that of species fluctuated between 10 and 23.

Among many types of geographical distribution of Carabid beetles (Habermann 1968) only eight types were recorded in the four studied sites (Tab. 1). Among them the Transpalaearctic, European and Central European species were present in almost all sites and years (Fig. 3). In individual sites, these distribution types are represented by 1 - 9 species. The striking difference in number of Transpalaearctic species is between the site Dúbie and other better preserved sites. Most stable is number of European species and Central European species. The Eurosiberian and West European species occur approximately in half of sites. The Circummediterranean species (*Cymindis humeralis* and *Cymindis axilaris*) occurred only in one site (Čertove chodníky), similarly as the Carpathian species, *Pterostichus foveolatus*, only in Račkov Laz.

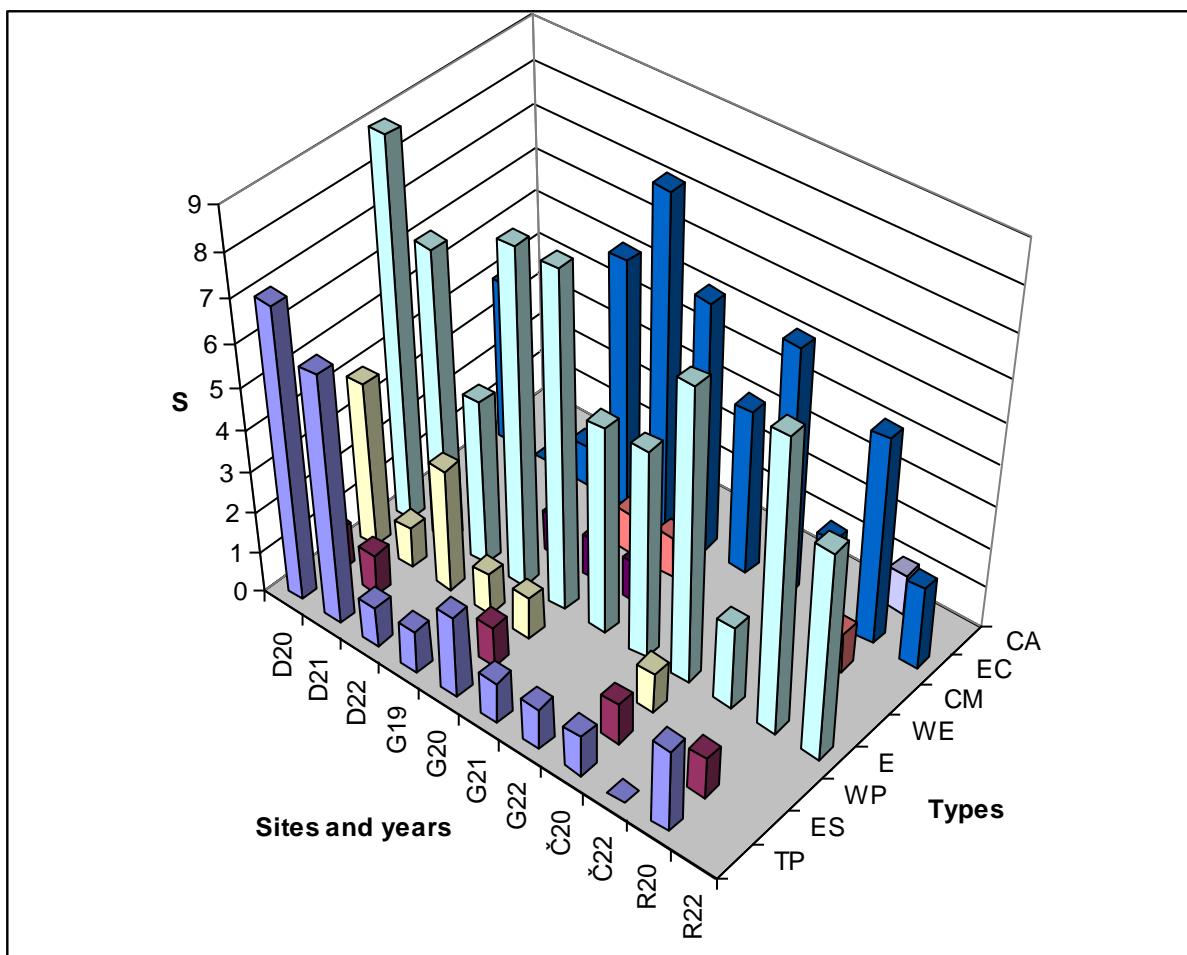


Fig. 3. Numbers of species (S) representing each type of geographic histration in the sites Dúbie in 2020-2022 (D20-D22), Za Gočálovou in 2019-32002 (G19-G22), Čertove chodníky in 2020 and 2022 (Č20 and Č22) and Račkov Laz in 2020 and 2022 (R20 and R22), for abbreviations of distribution types see Table 1).

Very large differences were observed in the absolute numbers of individuals belonging to some of the distribution type (Fig. 4). Two Transpalaearctic species (*Pterostichus niger* and *P. oblongopunctatus*) occurred abundantly in the site Dúbie in 2020, but in the 2021 a 2022 their number dropped strongly. In 2022 they absented in Čertove chodníky and Račkov laz. The typical European forest species *Abax paralelopipedus* and *A. parallelus* oocured in large numbers in the most natural site Za Gočálovou in 2019 and 2020, but in 2021 and 2022 their number considerably declined in this locality. Relatively stable among the localities was representation of the Central European species (mostly *Pterostichus burmeisteri*, *P. unctulatus* and *Cydrus tenuatus*), but large differences within one locality were observed in individual year. Cumulative numbers of individuals of other distriburion types of species were did not exceed about 10 or they absented at all, especially in the years 2021 and 2022 (Čertove chodníky and Račkov laz).

However, these differences reflected the strong between-year fluctuations of species abundance.

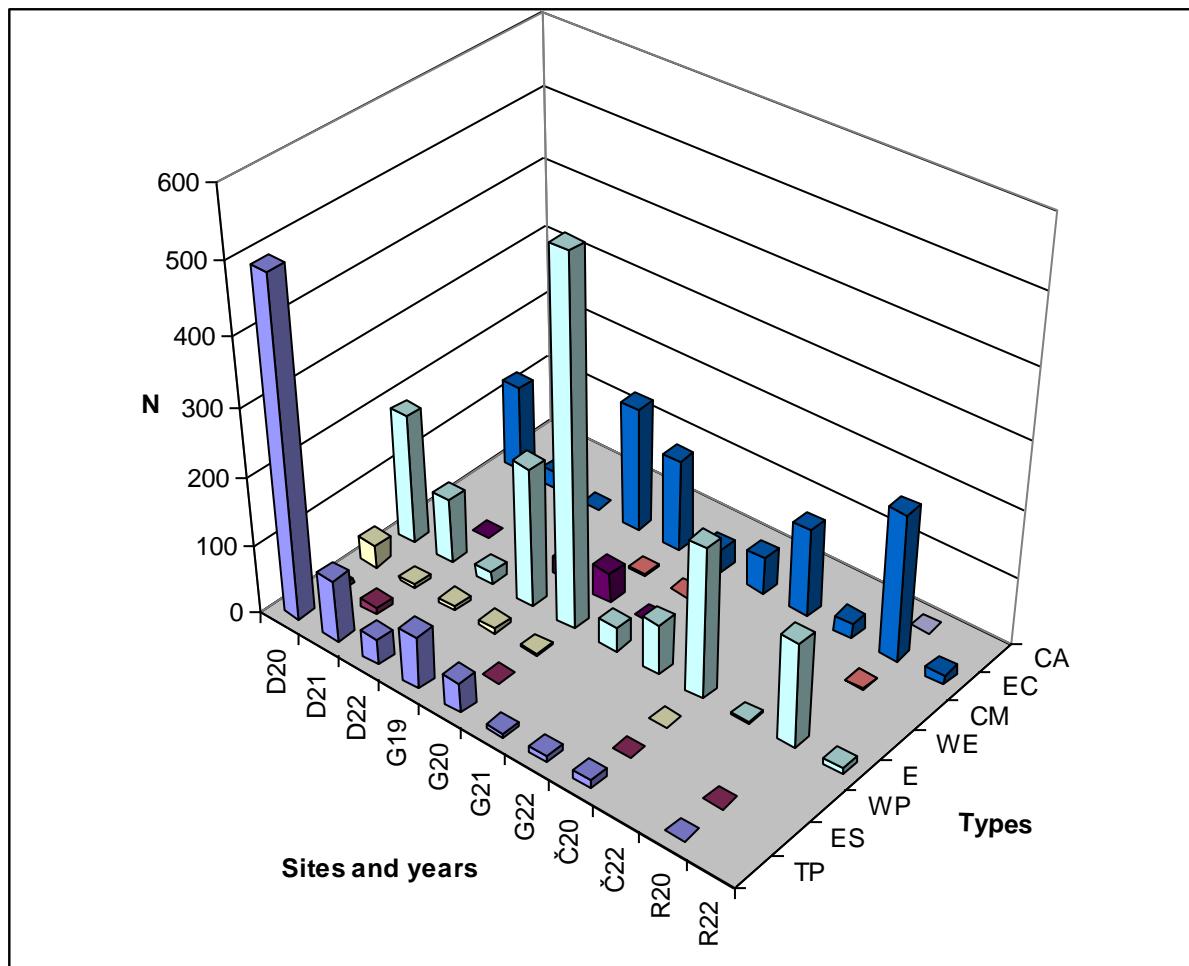


Fig. 4. Cumulative numbers of individuals (N) representing each type of geographic distribution in the sites Dúbie in 2020-2022 (D20-D22), Za Gočálovou in 2019-32002 (G19-G22), Čertové chodníky in 2020 and 2022 (Č20 and Č22) and Račkov Laz in 2020 and 2022 (R20 and R22), for abbreviations of distribution types see Table 1).

While the large fluctuations in absolute cumulative abundance of species belonging to individual types of distribution (Fig. 4) were observed, the cumulative dominance of species was balanced (Fig. 5). The Transpalaearctic species occur almost in the same level during individual years in the sites Dúbie and Za Gočálovou. A similarly balanced representation is observed also in the European and Central European species, which form the dominant part of the assemblages investigated. In contrast, the cumulative dominance of species of other types of geographic distribution is very low.

The relatively balanced cumulative dominance of individual types of geographic distribution shows that in spite of the between-year fluctuations the proportion of their representation is stable. Striking differences were observed only in Transpalaearctic species due to invasion of the hygrophilous lowland species *Pterostichus niger*, which in last years invades even the mountain ecosystems in High Tatras.

The high cumulative dominance of Transpalaearctic, European and Central Europeans species in the studied localities reflects their position in middle altitudes, where the lowland forest species (Transpalaearctic and European) co-occur with the Central European species having optimum in just in middle altitudes and being less expansive. There are accompanied by a low number of species having smaller distribution areas (West European, West Palaearctic, Circummediterranean and Carpathic).

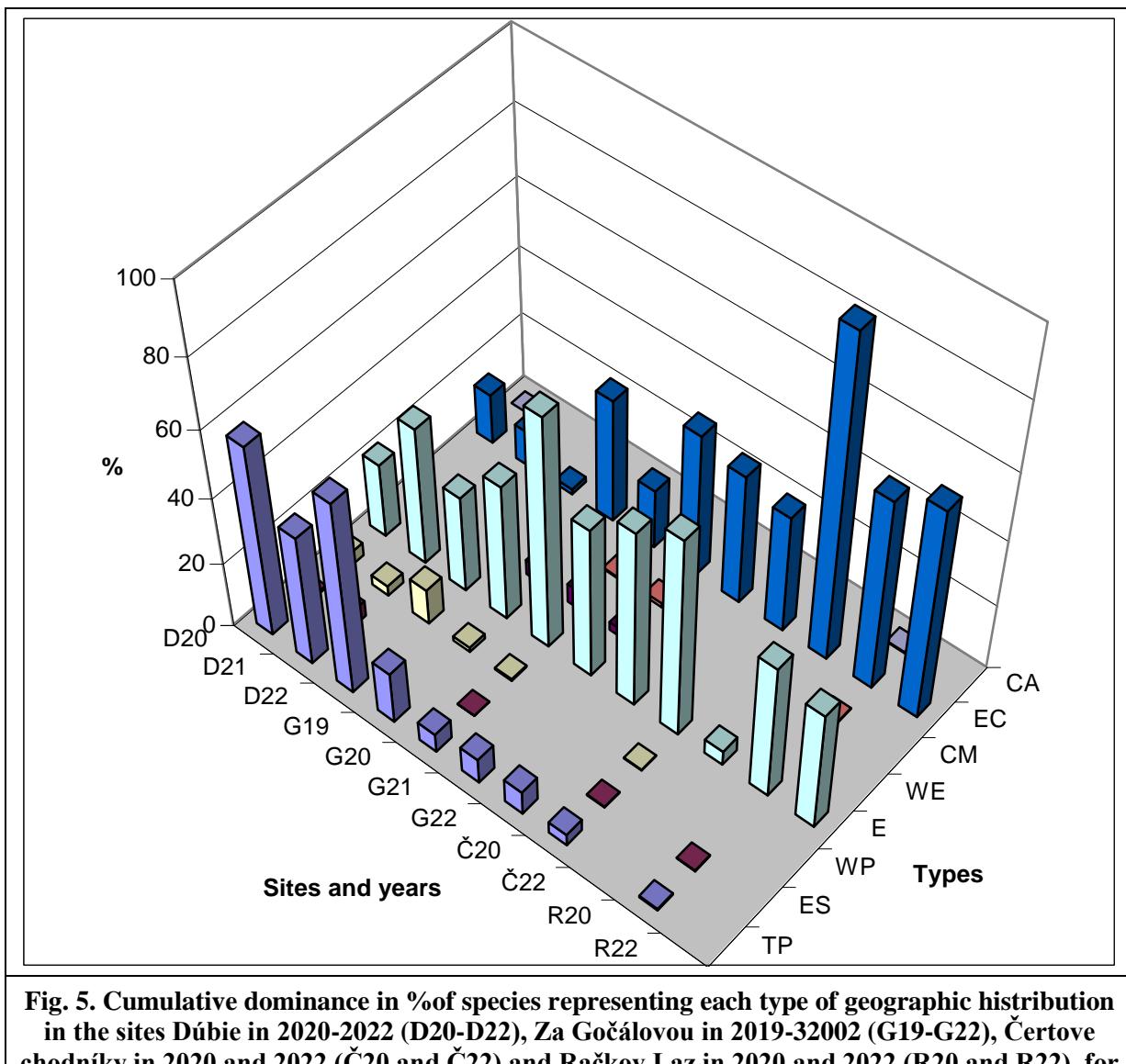


Fig. 5. Cumulative dominance in % of species representing each type of geographic distribution in the sites Dúbie in 2020-2022 (D20-D22), Za Gočálovou in 2019-32002 (G19-G22), Čertove chodníky in 2020 and 2022 (Č20 and Č22) and Račkov Laz in 2020 and 2022 (R20 and R22), for abbreviations of distribution types see Table 1)

CONCLUSIONS

In spite of the fact that two of the studied Carabid assemblages originate from intentionally chosen disturbed forest ecosystems (Dúbie and Čertove chodníky), all assemblages studied show a similar chorological structure that can be considered as characteristic of relatively natural broadleaved forests in middle altitudes. Three dominant types of geographic distribution (Transpalaearctic, European and Central European) are accompanied by the types with much smaller areas. Their representation shows considerable annual fluctuations in absolute cumulative numbers of individuals, but the relatively representation of individual types of distribution changes little.

The chorological structure of Carabid assemblages can be considered as a supplementary bioindicative criterion in the free landscape forests, similarly as in the urban ecosystem.

Acknowledgements

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REFERENCES

- Bănărescu, P. (1973): Biogeografia. Editura științifică, București, 302 p.
- Călinescu, R. (1969): Biogeografia României. Editura științifică, București, 410 p.
- Czechowski, W. (1981): Carabids (Coleoptera, Carabidae) of Warszaw and Mazovia. *Memorabilia zoologica*, 34: 119-144.
- Habermann, H. (1968): Eesti jooksiklased. Valgus, Tartu, 592 p.
- Hůrka, K. (1996): Carabidae of the Czech and Slovak Republics. Kabourek, Zlín, 565 p.
- Holecová, M., Christophoryová, J., Mrva, M., Roháčová, M., Stašov, S., Štrichelová, J., Šustek, Z., Tirjaková, E., Tuf, I. H., Vďačný, P. Zlinská J. (2012): Biodiversity of soil micro- and macrofauna in oak-hornbeam forest ecosystem on the territory of Bratislava. Comenius University in Bratislava, Bratislava, 144 p.
- Klausnitzer, B., Richter, K. (1980): Quantitative und qualitative Aspekte der Carabidenfauna der Stadt Leipzig. *Wissenschaftliche Zeitschrift der Universität Leipzig. Mathematisch-naturwissenschaftliche Reihe*, 29: 567-573.
- Kryzhanovskij, O. L., Belousov, I. A., Kabak, I. I., Kataev, B. M., Makarov, K. V., Shilenkov, V. G. (1995): A Checklist of the Ground-Beetles of Russia and Adjacent Lands (Insecta, Coleoptera, Carabidae), Pensoft, Moscow – Sofia, 275 p.
- Latin, G. de. (1967): Grundriss der Zoogeographie. G. Fischer Verlag, Stuttgart, 602 p.
- Šustek, Z. (1980): Některé souvislosti geografického rozšíření strěvlíkovitých (Col. Carabidae) a jejich schopnosti pronikat do ekosystémů urbanizované krajiny. *Zprávy Geografického ústavu ČSAV Brno*, 18: 30-40.
- Šustek, Z. (2012): Changes in Carabid communities (Insecta, Coleoptera) along an urbanisation gradient in Madrid (Spain). *Oltenia, Studii și comunicări. Științele naturii*. 28 (2): 73 – 92.
- Šustek, Z., Vido, J., Nalevanková, P. (2021): Founding of a monitoring network of impact of climatic changes on forest carabid assemblages in Slovakia: evaluation of their initial state
- Turin, H. (1981): Provisional Checklist of the European ground-Beetles (Coleoptera, Cicindelidae & Carabidae), Amsterdam, 249 p.
- Udvardy, M. D. F (1978): Zoogeografia dynamiczna ze szczególnym uwzględnieniem zwierzą lądowych. Państwowe wydawnictwo naukowe, Warszawa, 460 p.

GLACIAL BASINS DEGRADATION DYNAMICS RESEARCH IN THE AUTONOMOUS REPUBLIC OF ABKHAZIA

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ABSTRACT

The article discusses the dynamics of degradation of the glacial basins of the Autonomous Republic of Abkhazia. Glaciers are present in large numbers in the territory of Abkhazia. Due to ongoing climate change, the research and monitoring of glaciers are of particular importance, since changes in the size of glaciers are one of the best natural indicators of climatic conditions. Changes in glaciers in mountainous areas lead to changes in landscapes, the formation of new lakes and sea level rise issues of the Black Sea coastline and the activation of destructive natural phenomena. Up-to-date data on the state of glacial systems are needed to reduce risks and adapt to the consequences of ongoing changes. Due to the absence of local glaciologists in Abkhazia and taking into account the current political situation, studying the current state of glaciers in the Autonomous Republic of Abkhazia is possible only through high-resolution satellite remote sensing (SRS). The glacial basins' characteristics (glaciers number, area) representing the initial state of the 1960' (field surveys data) and then the years 2010, 2015 and 2020 (the SRS-based data) are compared. A comparison of the results from the initial state until 2010 with 2010 until 2020 showed that climate change speed is non-linear, making glacial basin degradation more intense in the following period than in the previous one. This also proves the main thesis of the IPCC 6th report that the main problem is not climate change, but its speed.

Keywords: climate change, number of glaciers, glaciated area, satellite remote sensing

INTRODUCTION

Glaciers are one of the most sensitive and reliable indicators of climate change. They can be considered an open database, a natural archive in which the past of the environment is preserved and the current state is reflected. The above allows for studying the climatic condition and their evolution in time. Currently, the scientific study of glaciers is of great importance to study the impact of climate change. The study of glaciers is important for determining changes in freshwater stored in glaciers and surface and groundwater.

Glaciers are most vulnerable to the effects of ongoing climate change, so their degradation is a visible reflection of the rate of climate change. Ongoing climate change is adversely affecting the cryosphere, especially glaciers (IPCC Technical Paper 2008; IPCC Special Report, 2018). This will have dire consequences for the world by landscape degradation, reduced glacial runoff, and an increase in the frequency and magnitude of natural glaciation events. These consequences pose a serious threat to the sustainable development of the region and hence, the glacier study is considered one of the priority activities.

Glaciers are present in large numbers in Georgia, namely in the Autonomous Republic of Abkhazia. They have a significant impact on the environment there. In particular, they greatly affect the water regime of rivers, regional climatic conditions, degradation of unique landscapes, and sea level rise issues of the Black Sea coastline.

Due to the absence of local glaciologists and taking into account the current political situation, studying the current state of glaciers in the Autonomous Republic of Abkhazia is only possible through high-resolution satellite remote sensing.

The impact of current climate change on glaciers and its consequences can be researched in several ways. One of the important issues to do this is to study the degradation dynamics of the glaciers which is possible by comparing the data from different years over a longer period.

METHODS AND DATA

The highest glaciers in Europe are well-developed in the Great Caucasus Range in the northern part of Georgia. Scientific studies of glaciers in Georgia began in 1860 in the former Russian Empire (Khatisyan, 1864, Statkovsky 1866, Abikh, 1870, Podozersky, 1911) and continued throughout the 70ies in the Soviet Union (Maruashvili, 1936, 1956; Tsomaia and Drobishev, 1970; Tsomaia, 1975), were mainly based on field glaciological surveys. The results of a 100-year study of glaciers located on the territory of Georgia were summarized and published in 1975 in the form of the catalogue (Katalog Lednikov SSSR, 1975, hereinafter, the Catalogue). Glaciers of the Autonomous Republic of Abkhazia are included there as part of West Georgia's glaciers (Katalog Lednikov SSSR, 1975). Due to the importance of the Catalogue, the World Glaciers Inventarization (WGI) includes its formatted digital version (WGMS and NSIDC World glacier inventory, 1989).

The study area is located in the Autonomous Republic of Abkhaz and contains glaciated basins of rivers Bzipi, Kelasuri, and Kodori. The basins are in the north-western part of the Greater Caucasus, where the altitude of the highest peaks reaches 3500 m a. s. l. and more. The Catalogue registers 136 glaciers in Abkhazia and provides their main characteristics (morphological type, exposure, length, area, minimum and maximum height, firn line height and area of ablation).

At present, the contours, areas and other characteristics of glaciers have changed significantly due to their retreat and melting.

The Catalogue was created 60 years ago while the study of glaciers with satellite observations of the Earth started only a few decades ago. This difference in time creates a prerequisite for studying the evolution of glaciers and the effects of climate change on the state of glaciers. We compare selected characteristics of the glaciers, namely the number of glaciers and their areas, taken from the Catalogue and derived from SRS for the years 2010, 2015 and 2020. The data derived from SRS are denoted as SRS 1 (the year 2010), SRS 2 (the year 2015) and SRS 3 (the year 2020).

The use of high-resolution satellite remote sensing (SRS) makes it possible to study glaciers over large areas with the necessary resolution and accuracy in conditions of limited material, human resources and time. The reliability and high quality of the results are achieved by the combination of satellite remote sensing data, historical data, various catalogue data, and expert knowledge.

Previous studies proved the efficiency of technological approaches for scientific studies of glacier degradation as best practices (A. Kääb et. al., 2002; Khalsa et. al., 2004; Bolch, Kamp, 2005; Pelli, P., Gareth Rees, W. 2010), as well as the methods developed by the authors (Kordzakhia et. al., 2019; Kordzakhia et. al., 2022) are used.

Various high-resolution satellites images were used for research, in particular, data obtained by Landsat satellites (resolution 15-30 m), data from open sources of satellite databases of the National Aeronautics and Space Administration (NASA) of the USA and Global Land Ice Project "Measurements from Space" (GLIMS). Satellite data processing is carried out using various GIS applications. Effective software is Google Earth, which offers satellite images of

high spatial resolution (0.5-0.8 m). All of the above makes it possible to determine the contours of glaciers with good accuracy.

The necessity of using various sources of SRS data as well as catalogue information resulted in some problems:

The first one is the identification of glaciers, mostly small ones, in the SRS imagery.

To determine the location of glaciers of the Autonomous Republic of Abkhazia on satellite images, i.e. to identify them, maps/diagrams (Figs. 1,2) available in the Catalogue are used. This makes it possible with a high degree of reliability to determine the locations of glaciers in the study area.

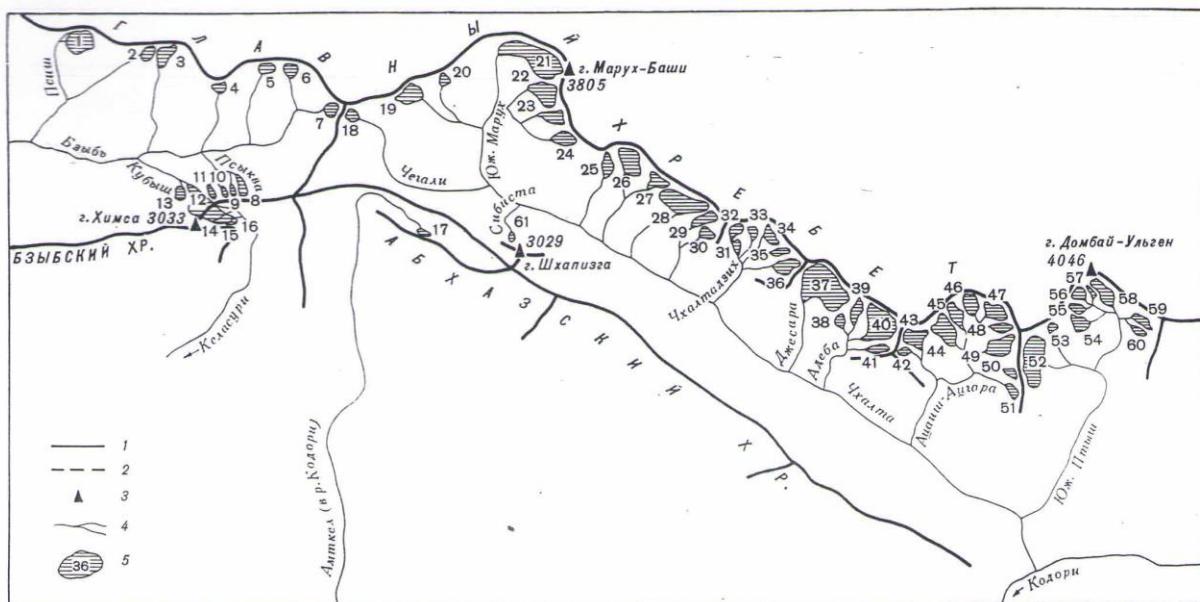


Fig. 1. The layout scheme of the glaciation basins of the rivers Bzibi, Kelasuri and Kodori-Amtkeli, Chkhalti basins locations. 1 – watersheds, 2 – ice sheds, 3 – peaks, 4 – rivers, 5 – glaciers with their number.

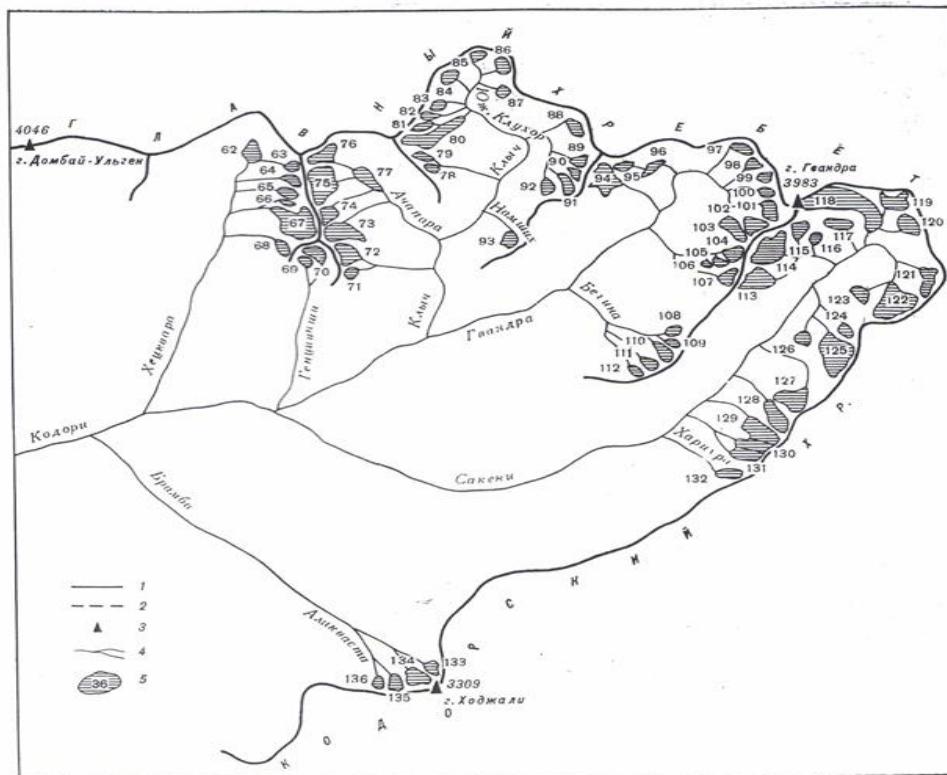


Fig. 2. Layout scheme of glaciers in the upper reaches of the River Kodori River and corresponding river basins. 1 – watersheds, 2 – ice sheds, 3 – peaks, 4 – rivers, 5 – glaciers with their number.

The second problem is inaccuracies in determining the initial state of glaciers, mainly the areas of small glaciers in the catalogue. The solution to this issue was found in the refinement of data on the area of glaciers according to topographic maps of the 1960s. The solution turned out to be effective and made it possible to clarify the initial states of the glacier area with high reliability.

The third problem, the most difficult one, is related to the use of archival data. It appeared when the contours of some glaciers were used in the SRS data, namely from the open sources of satellite databases of NASA and GLIMS. Significant inaccuracies and gaps, especially in the vicinity of neighbouring glaciers were found. A lot of analytical work had to be carried out to clarify glaciers' contours.

RESULTS AND DISCUSSION

The results are summarised in Table 2 and document an increase in the number of glaciers caused by the division of medium and large glaciers into smaller ones and the decrease in glaciers area. Fig. 3 presents a striking example of the melting of Abkhazian glaciers №117–120 Green pins indicate glaciers, yellow pins show snowfields (area < 0.1 km²) and red pins – fully melted glaciers.

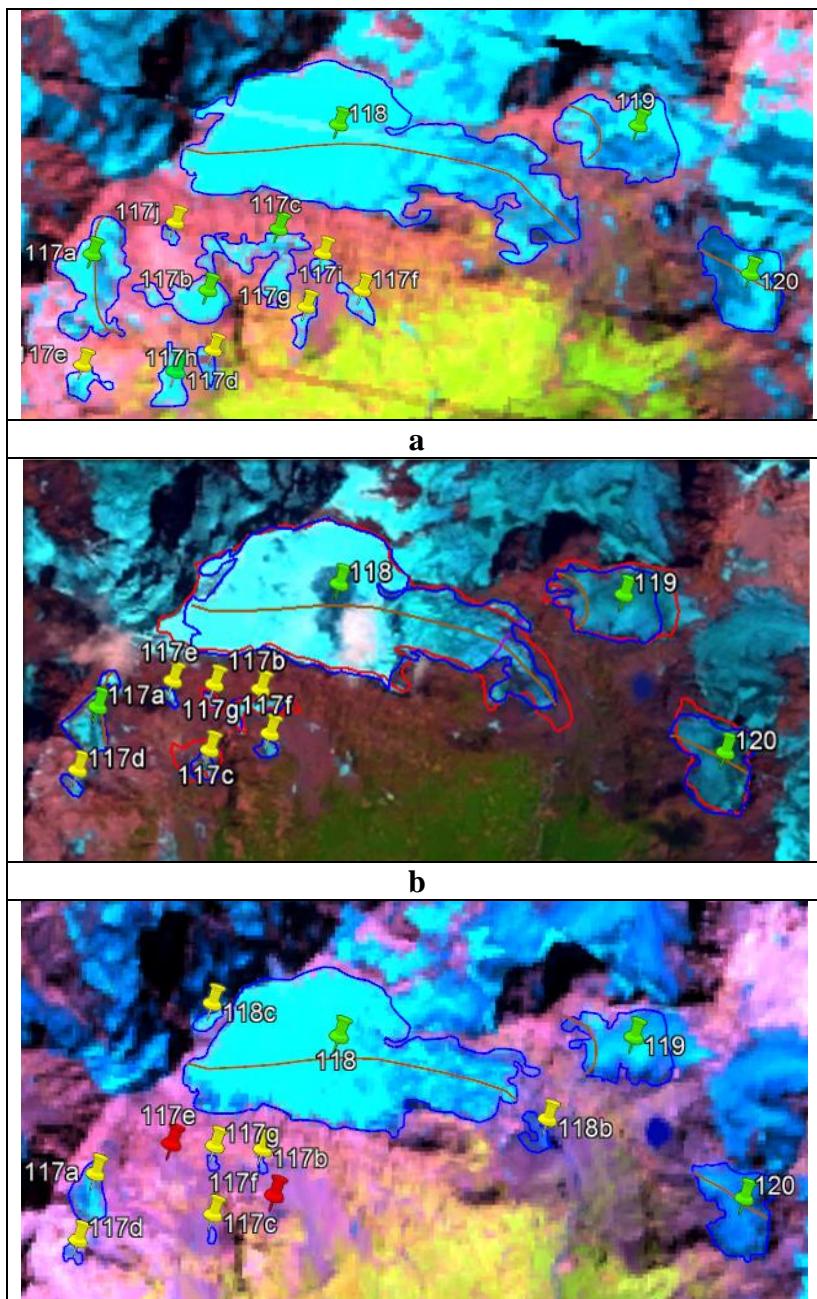


Fig. 3. The glaciers №117–120 are shown on satellite images at subsequent times: a - contours according to the image of the Landsat 7 ETM+ sensor on August 23, 2010, and the combined Landsat 5 TM sensor on August 30, b - contours according to the image of the Landsat 7 ETM+ sensor on September 6, 2015, c - contours according to the image of the Landsat 8 OLI sensor on September 11, 2020. Green pins indicate glaciers, yellow pins - snowfields (area < 0.1 km²) red pins – fully melted glaciers.

Based on the processing of the images (Fig.3) we received Table 1 indicating the values of the areas of glaciers №117 - 120 according to the catalogue, SRS 1, SRS 2 and SRS 3.

Table 1. Identification codes of glaciers №117–120 of the Kodori river basin, area values according to the catalogue, SRS 1, SRS 2 and SRS 3. Small glaciers are marked in green, medium - in grey, large glaciers - in blue, snowfields - in yellow and disappeared glaciers in red

№ According to the scheme from the catalogue	Name or/and № of the glacier according to the catalogue	ID According to WGI	According to the catalogue	Area (km ²)		
				SRS 1	SRS 2	SRS 3
117	119b	SU5T09104117	1.3	0.3	0.1	0.1
				0.02	0.01	0.01
				0.03	0.01	0.01
				0.2	0.01	0.01
				0.01	0.01	0.01
				0.2	0.05	0.01
				0.02	0.02	0.0
				0.1	0.0	0.0
				0.04	0.0	0.0
				0.04	0.0	0.0
				0.03	0.0	0.0
				0.03	0.0	0.0
				0.02	0.0	0.0
				0.01	0.0	0.0
118	Sakeni, 120a	SU5T09104118	2.8	2.2	2.0	1.8
						0.04
						0.02
119	120b	SU5T09104119	0.6	0.4	0.4	0.3
120	120c	SU5T09104120	0.6	0.3	0.3	0.3

It would be mentioned that depending on the area, glaciers are divided into three grades: small glaciers (0.1 to 0.5 km²), medium glaciers (0.5 to 2.0 km²), and large glaciers (2.0 km² and more). Glacial formations of less than 0.1 km² are considered snowfields.

Summarizing the data from Table 1 we can create Table 2 presenting the distribution of the area and number of glaciers of the Autonomous Republic of Abkhazias' glacial basins.

As mentioned above the data received from the SRS (SRS 1, SRS 2 and SRS 3) were compared with each other and the initial data. The time gaps between the initial, intermediate (2 states) and final states are accordingly about 50, 55 and 60 years. Thus, the dynamics of changes in the areas of glaciers included in glacial basins will be presented based on three time periods, which effectively characterize the details of glacier degradation dynamics (Table 2). Changes in the number of glaciers are not very representative, but generally indicate the trend of glacier degradation. So, the according to the catalogue, the number of glaciers in Abkhazia was 136. In about 50 years (by 2010), the total number of glaciers became 164, which means that the number of glaciers increased by 20.6%. This increase occurred after the melting of large and especially medium glaciers causes the creation of additional small glaciers to existing ones. This increase occurred at the expense of an increase in the number of small glaciers. The number of medium and large glaciers has decreased.

By 2015, the number of glaciers has become 135 or decreased by 18 % in 5 years. By 2020, the number of glaciers has become 121, which means that in another 5 years it has decreased by 10 %. Compared to catalogue data, the number of glaciers decreased by 15 or 11 % by 2020.

Table 2. Distribution of the area and number of glaciers of the Autonomous Republic of Abkhazias' glacial basins according to the gradation. The data from the catalogue (cat.), SRS data - SRS 1, SRS 2 and SRS 3 data

Autonomous Republic of Abkhazias' glaciers										
Glacial Basins			Glacial number				Glacial area (km ²)			
Nº	Name and Glacier Nº	Gradation:	Cat.	SRS 1	SRS 2	SRS 3	Cat.	SRS 1	SRS 2	SRS 3
1	Bzibi 1–13	Small	8	12	9	9	2,3	2,5	2,3	1,8
		Medium	5	3	1	1	4,8	2,4	0,8	0,8
		Large	0	0	0	0	0	0	0	0
		Subtotal	13	15	10	10	7,1	4,9	3,1	2,6
2	Kelasuri 14–16	Small	2	1	0	0	0,7	0,1	0	0
		Medium	1	1	1	1	0,8	0,8	0,7	0,6
		Large	0	0	0	0	0	0	0	0
		Subtotal	3	2	1	1	1,5	0,9	0,7	0,6
3	Kodori 17–136	Small	78	122	105	96	21,4	24,0	20,3	18,0
		Medium	38	22	17	12	37,9	18,5	16,1	11
		Large	4	3	2	2	11,6	7,9	5,6	5,1
		Subtotal	120	147	124	110	70,9	50,4	42	34,1
4	Total		136	164	135	121	79,5	56,2	45,8	37,3

The impact of climate change on the glaciers number of glaciers in the Autonomous Republic of Abkhazia is reflected in the increase in the number of small glaciers, the decrease in the number of medium glaciers from 38 to 12, and the decrease in the number of large glaciers from 4 to 2 due to the degradation of glaciers.

More important is the analysis of glaciers area in these periods. Areas covered by glaciers during 50 years (by 2010) decreased by 29 %, after 5 years (by 2015) the decrease was equal to 19 %, and after another 5 years (by 2020), it decreased by 19 %. Compared to the catalogue data, the area of glaciers decreased during 55 years (until 2015) by 42.4%, and during 60 years (until 2020) by 53.1%. It can be concluded that the area occupied by glaciers on the territory of the Autonomous Republic of Abkhazia territory is less than half compared to the area 60 years ago.

CONCLUSIONS

Up-to-date data on the state of glacial systems are needed to reduce risks and adapt to the consequences of ongoing changes. Due to the absence of a local glaciological school in Abkhazia and taking into account the current political situation, studying the current state of glaciers in the Autonomous Republic of Abkhazia is carried out by high-resolution SRS.

Processing of the satellite images, using several data archives and the QA/QC procedures gave the possibility to receive the dynamic picture of the degradation of the Autonomous Republic of Abkhazias' glacial basins for 60 years from the issue of the initial conditions of these glacial basins (catalogue data).

The impact of climate change on the glaciers number of glaciers in the Autonomous Republic of Abkhazia is reflected in the increase in the number of small glaciers, the decrease in the

number of medium glaciers and the decrease in the number of large glaciers due to the degradation of glaciers.

The analysis of glacier areas showed that the area occupied by glaciers on the territory of the Autonomous Republic of Abkhazia territory is less than half compared to the area 60 years ago.

The reduction speed of glacier areas shows that during 50 years (1950-2010) this speed makes 0.6 % annually while during the second period (2010-2020) this decrease is 3.7 % annually. These numbers clearly show that the glaciers' areas decrease is more intensive in the second period i.e. glacial basin degradation is nonlinear.

Acknowledgements

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REFERENCES

- Abikh, G.V. (1870): *Iccledovanie nastoiacshchikh i drevnikh lednikov Kavkaza. Otdel 1. Opisanie nine sushchectvuiuchego Devdorakskogo lednika i sledov deistvia prerhnikh lednikov v doline Tereka. Otdel 2. O sledakh prerhnikh lednikov v dolinakh rek Assi, Narti-dona i Shasni.* G. Abikh; Per. F. Fon-Koshkul. Tiflis (42 p.) (in Russian).
- Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (2008): Technical Paper of the Intergovernmental Panel on Climate Change. Climate Change and Water. IPCC Secretariat, Geneva, Switzerland. 210 p.
- Bolch, T., Kamp, U. (2005): Glacier Mapping in High Mountains Using DEMs, Landsat and ASTER Data, 8th International Symposium on High Moutain Remote Sensing Cartography, La Paz, Bolivia, 22 March 2005.
- Kääb, A., Huggel, C., Paul, F., Wessels, R., Raup, B., Kieffer, H., Kargel, J. (2002): Glacier Monitoring from Aster Imagery: accuracy and Applications, Proceedings of EARSeL-LISSLIG-Workshop Observing our Cryosphere from Space, Bern, March 11 – 13.
- Katalog Lednikov SSSR (1975): T. 9, vip. 1, ch. 2-6, L.: Gidrometeoizdat (in Russian).
- Khalsa, S.J.S., Dyurgerov, M.B., Khromova, T., Raup, B.H., Barry R.G. (2004): Space-Based Mapping of Glacier ChangesUsing ASTER and GIS Tools, IEEE Transactions on geoscience and remote sensing, vol. 42, No. 10, 2177.
- Khatisyan, G.S. (1864): Kratkii ocherk deistvii dvukh komissii dlia issledovaniia Kazbekskikh lednikov v 1862 i 1863 gg. Tiflis: Zap. KORGO, 6(2), 220–230 (in Russian).
- Kordzakhia, G., Shengelia, L., Tvauri, G., Dzadzamia, M. (2019): The climate change impact on the glaciers of Georgia. Journal-World Science, DOI: https://doi.org/10.31435/rsglobal_ws, 1, 4(44), 29-34.
- Kordzakhia, G.I., Shengelia, L.D., Tvauri, G. A., Dzadzamia, M. (2022): East Georgia Glacial Basins Degradation Dynamics Under the Impact of Modern Climate Change. Bulletin of the Georgian National Academy of Sciences. ISSN – 0132 – 1447. Georgia, Tb., Vol. 16, №1, pp. 32-39.
- Maruashvili, L I., Oledenie Kavkaza (1936): Priroda, 5, 52–61 (in Russian).
- Maruashvili, L I. (1956): Tselesoobraznost peresmotra suthetsvuuthikh predstavlenii o paleograficheskix usloviyah Lednikovogo vremeni na Kavkaze, Tbilisi, izd. An GSSR, 124 (in Russian).
- Pellika, P., Gareth Rees, W. (2010): Remote sensing of glaciers: techniques for topographic, spatial and thematic mapping of glaciers (pp. 330).
- Podozerskii, K.I. (1911): *Ledniki Kavkazskogo khreba.* Tiflis: Zapiski Kavkazskogo otdela Imperatorskogo pusskogo geograficheskogo obchestva, T.21; vip. 1; Tiflis, 200 s (in Russian).
- Statkovskii B.I. (1866): Kratkaia zapiska o deictviakh v 1865 ekspeditsii dlaia issledovanii prichin proiskhojdzenia periodicheskogo Kazbekskogo zavala. Zap. KORGO, kn.7, vip.1, c.1-28 (in Russian).
- Tignor, M., Poloczanska, E., Mintenbeck, K., Alegre, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., Weyer, N.M. (2018): The Ocean and Cryosphere in a Changing Climate. A Special Report Working Group II Technical Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. 755 p.

Electronic book
Interdisciplinary Approach in Current Hydrological Research

- Tsomaia, V. Sh., Drobishev, O. A. (1970): Resultati glatsiologicheskikh nabliudenii na lednikakh Kavkaza. Trudy ZakNIGMI, 45(51), 141–146. (in Russian).
- Tsomaia, V. Sh. (1975): Ledniki Kavkaza 1963–1973, Tbilisi, 322 p. (in Russian).
- WGMS and NSIDC World glacier inventory (1989): Compiled and made available by the World Glacier Monitoring Service, Zurich, Switzerland, and the National Snow and Ice Data Center, Boulder CO, USA. Digital media. 1989, updated 2012.

LANDSCAPE USE CHANGES IN THE CITY OF DEBRECEN IN THE LIGHT OF DEVELOPMENT PROJECTS

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ABSTRACT

In the study we evaluate the planning documents the city of Debrecen for the period 2014-2020 and the development projects implemented in the city by their landscape-shaping properties. Its aim is to reveal what role the natural environment plays in Debrecen's strategic documents and what priorities and characteristics of green space consumption the development projects have. These are realized through statistical content analysis and the classification and analysis of projects. The precise area occupation illustrated according to the landscape character and the mathematical results of the content analysis serve to verify the assumption that the strategic documents, and thus the developments realized in the city area, treated the natural and landscape environment as an asset to be utilized and shaped during the examined period.

Keywords: landscape use, EU projects, green infrastructure, natural environment, climate change

INTRODUCTION

One of the most important points of connection between society and nature is the permanent place of residence created by man, i.e. settlements, where his environmental and landscape-shaping activity grows from an individual level to a global factor through social organization. The study belongs to a little-studied area of settlement development in Hungary.

The settlement environment is a frontier area both geographically and scientifically, and from the point of view of nature conservation, it is one of the most significant elements of social geography, the knowledge of which is essential for effective nature and landscape protection, especially in the production- and growth-oriented economic and social system of the 20th century. City of Debrecen is the settlement that, with its long-term goals, aims to be the economic, social and cultural motor and center region of the eastern part of the country and the Carpathian Basin as a counterweight to Budapest. Strategic planning, as a means of establishing the settlement's seven-year development activities, is especially exposed to economic development interests and long-term visions of settlement marketing in the investigated settlement. Among the methodologies used to find this, the unique statistical content analysis related to the analysis of the projects and the classification and statistical evaluation of the realized projects appear in a system of criteria. In this way, not only the strategic landscape use of Debrecen and the independent evaluation of realized projects, but also the exploration of the system of relationships between them is realized. With strategy and project analysis based on aspects of the natural and landscape environment, settlement and area development from an ecological perspective can be placed in a nature conservation framework, as human ecology and the area of settlement geography closest to the natural environment. (Orosz et al., 2019) examined the specific implemented projects of EU development cycles at the regional level to see how they relate to the natural features of the region. As the first step of the work, the projects were examined based on two aspects: 1. Projects supporting and protecting natural capital, 2. Projects based on and exploiting natural capital. Projects that support and protect natural capital strengthen the regulatory and maintenance function of ecosystem services, while projects based on and exploiting natural

capital make use of the supply and cultural services of ecosystem services. The distribution of selected projects and the amount of resources used were proportional to all projects and resources. They then drew conclusions from this. In an other publication (Orosz et al., 2018) examined civil organisatons projects with the same method focusing on the role of these NGOs in small regional developement.

The involvement of the natural environment constitutes a significant and essential issue when looking at the development of Debrecen. Changes in landscape use are also a significant factor in terms of the effects of climate change. With the increase in the extent of the artificial surfaces, the increase in the average temperature and the decrease in the amount of precipitation can prevail as a stronger effect on the settlement. Based on the ALADIN-Climate climate model (Internet 1), precipitation in the Debrecen area is expected to decrease by 25-50 mm compared to the 1961-1990 average. And the average temperature will be 1.5-2 °C higher.

METHODS AND DATA

We examined Debrecen's landscape use trends with a complex evaluation, which starts with the evaluation of strategic documents, because these are the ones that provide a framework for development projects that directly shape the settlement environment. Our aim was to reveal the emphasis placed on the parts and elements relating to the natural and landscape environment, as well as what priorities and ideas they contain regarding the future vision of the city. We evaluated the strategies according to four economic and natural aspects on a five-point scale, based on the depth, scope and weight of the document. By averaging these data, we obtained a set of values, which interpretation ranges represented the distribution between the aspects. In the first part of the investigation of the development projects, the trends underlying the changes in the surface cover can be shown in a detailed breakdown, while in the second part we specifically limited ourselves to the occupation of land and the transformation of the landscape. The examination of the development documentation was carried out using the methods of content analysis, supplemented by statistical analysis. Regardless of the systematization of the extracted information and the drawing of conclusions, content analysis is a research method in which the "hidden" information material in the text is read according to a predetermined system of criteria, thereby scientifically verifying the practical interpretation of the text material (Antal, 1976.). Since the methods for analyzing the form and content of the texts can be freely interpreted rather than having to be implemented according to a fixed form and set of rules, during the investigation we tried to use these methods in the proportion that best suits the topic of the research. The method we have created contains both an exploratory and inferential part of the work, so it can be considered a qualitative research method due to the classification based on quality, while the data processing with statistics and the quantifiable nature of the number of words and the scope can also be considered a quantitative research method. In this, we relied on the scope of individual subsections and chapter sections relative to each other and to the entire document, the frequency of individual terms and their synonyms, as well as the detailed explanation of the various subject areas, and we used this in such a way that the table created from the results of the text analytics was created using statistical methodology (calculating the average and the average of the average) added.

With the help of content analysis and statistical analysis, the previously established orientation was also mathematically supported. The projects required for the analysis were retrieved from the "Térképtér" official database of completed projects, in accordance with the development documents, filtered for the European Union budget cycle between 2014 and 2020 (Internet 2). In the course of the research, the queried projects were first divided into

groups of aspects and characteristics, the involvement of the natural environment, the legal form of the supported person, and the place of implementation were examined basically according to the number of projects and the amount of support.

Table 1. Process of the first round of project analysis

	data collection from “Térképtér”	
Filtering	projects implemented in Debrecen in the period 2014-2020	
	projects relevant to the natural environment	
Projects using nature (negative impact)	health industry, availability improvement, industrial capacity expansion, other	
Projects based on nature (use ecosystem-services)	water management, horticulture, animal husbandry, other crop production, tourism, greening of interior areas, soil conservation, forest management	
Projects protecting nature	natural disadvantage affected areas, afforestation, climate protection, gene preservation	
Division	Natural involvement: Direct / Indirect Location: Outdoor area (natural?) / Indoor area (inhabited?) Supported: Legal entity / Individual	

After the location-based query of the projects, temporal filtering followed, so the analysis also includes those grants that were awarded before 2014, but were already implemented in the period under review. We also screened those that, were called to Debrecen through the aided person, but did not actually take place within the city's administrative area. From the total of 6,378 projects queried, after the preliminary screenings, 640 projects that could also be evaluated from the point of view of the natural environment were further examined.

After that, we created three criteria groups (Orosz, 2020) from the point of view of the natural environment:

- projects using nature
- projects based on nature
- projects protecting nature

Within these, we created character groups based on the names and descriptions of the projects. The data grouped in this way were evaluated in terms of direct and indirect involvement in terms of the natural environment based on the place of implementation and the legal form of the supported person. In terms of location, in the case of those carried out in the outer area, it was shown how many and with what support they were carried out in natural areas, and in built-up areas in the interior. These data were used to filter the projects that we later dealt with specifically in terms of landscape involvement through the grouping and statistical illustration of the data (Table 2).

In the second stage of the analysis, we further evaluated the projects that are directly involved with the natural environment, that make use of it, and are based on its resources. Among these, those that took place outside areas and in uninhabited inside areas. Due to the demonstrability and map illustration of the territory reservation, several aspects were applied. Thus, from the point of view of landscape use, a total of 38 projects with demonstrable land use, precisely demarcated on site, green fields, and a grant amount of over HUF fifty million form the basis of the report. First of all, we examined whether the implementation of the investment was accompanied by a change in the cultivation branch and surface coverage.

Table 2. Process of landscape use project analysis

Projects that use and are based on the natural environment				
Direct involvement				
Valuable land reservation				
Green field investment				
Funding amount over HUF 50 million				
Precisely identifiable location				
Non-inhabited inner area	Outer area			
Definition of land use classes (Table 3)				
Did the cultivation branch changed?				
Yes	No			
Before the change				
After the change				
Land use in m ²				
<1500	1500 – 5000	5000<		

If the implementation was accompanied by a change in the field of cultivation, we examined what field of cultivation the area was in before and after the change. If there was no change in land cover, we examined what the cultivation branch was like at the time of implementation, and most importantly, what the real function of the area was before implementation. This helped us when typing the exact area reservation. At the same time, the area of Debrecen was divided into use-based landscape categories, which are necessary for the map illustration of the projects. They were demarcated on the basis of their surface coverage, with the combined evaluation of MePAR and Google Earth overlays. (Internet 3; Internet 4) The exact area reservation was demonstrated through project descriptions and map measurements.

Table 3. Landscape use categories specified for the sample area

Class	Name	Property
I.	Nature conservation	Practical function: primarily the preservation of the natural environment, protective area, the role of the buffer zone.
II.	With arable land	Fields of homogeneous, intensive field cultures
III.	Forest roast mixed	Forest management, mosaic animal husbandry, garden management, plantations.
IV.	Enclosed garden	Partially residential function, gardening, animal husbandry
V.	Industrial	Non-inhabited industrial investment target area (inner area) surrounded by a residential area

RESULTS AND DISCUSSION

In relation to the content analysis, it can be said that the most significant documents, and the ones that most determine the vision of the settlement, can without exception be classified into the economic and social approach group. Debrecen's Local Community Development Strategy 2014-2020 has achieved a more natural orientation, but it is also typical that it deals with the natural environment from a human approach and objective examination, rather than from the point of view of nature and landscape protection. The red line indicates the equilibrium zero value between the emphasis of natural and economic aspects. It can be seen

that in the documents defining the development direction, the development of the economy (mostly the health industry, machinery industry, agricultural and research development fields) is considered important not only during the definition of the future visions, but also during the approach of the entire document. The distribution between the two groups of views is illustrated by the scatter diagram in Figure 1.

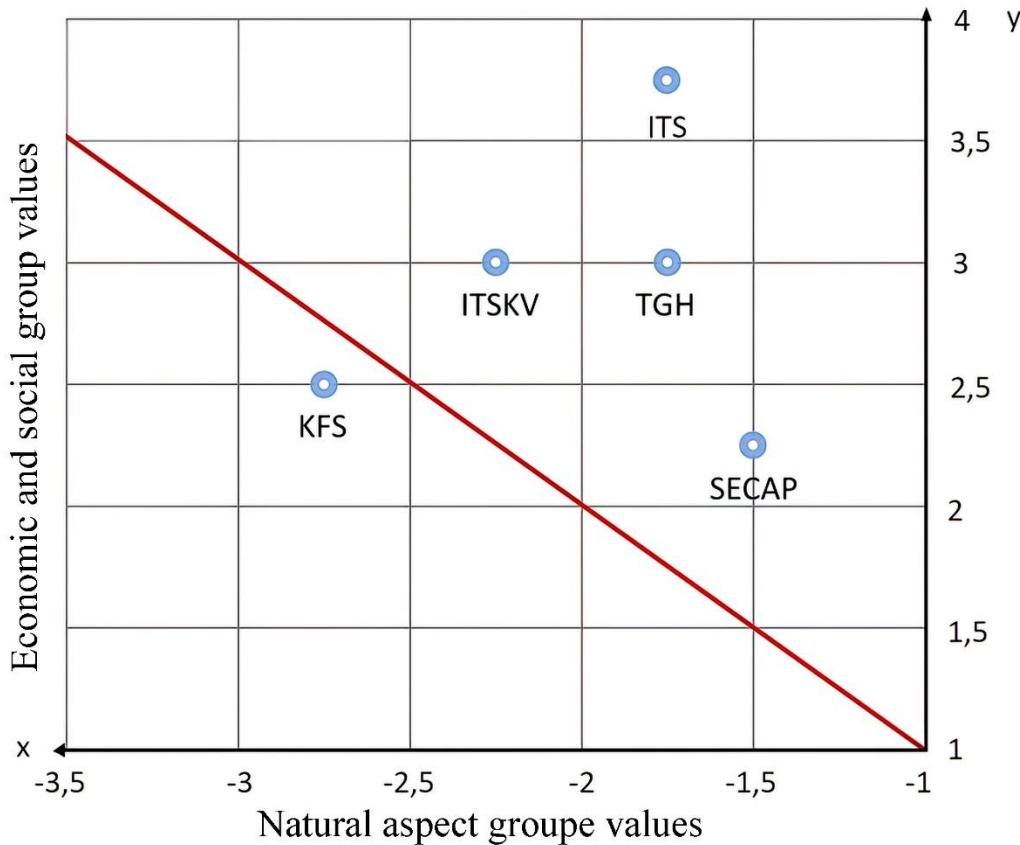


Fig. 1. Scatter plot of analyzed documents.

During the examination of the projects, it was revealed that the number of projects and the amount of support per project show an inverse proportionality, which became visible not only among characteristic groups, but also among the larger criteria groups, as shown by the pair of diagrams in Figure 2, on the basis of which it can be stated that the largest support projects that make use of the natural environment have the highest amount, while they are only second in terms of number. The biggest contrast can be observed in projects supporting the natural environment. At the same time, direct proportionality can be observed when examining the nature of the beneficiaries. The larger the grant amount per project within the criteria group, the larger the proportion of legal entities. According to their place of implementation, the projects that took advantage of the natural environment affected the interior areas, only an extremely small number, showing a value of barely 1-2%, were implemented outside. This can be explained by the fact that the areas designated as action areas, on which these projects were implemented, are usually classified as internal areas, but mainly reclaimed areas and industrial plots that perform natural functions.

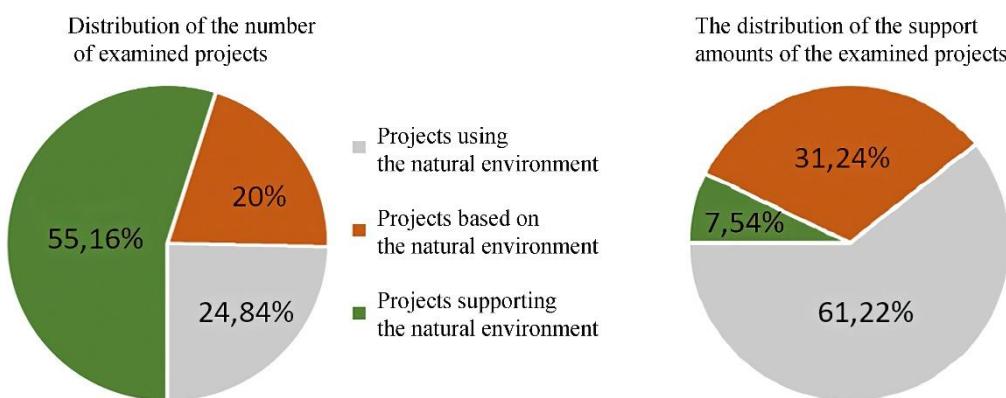


Fig. 2. The distribution of the projects of the examined criteria groups according to the number of units and the amount of support.

Among the developments, investments related to industrial capacity expansion and logistics developments achieved an outstanding value, accounting for 77.5% of the total amount within the entire criterion group. Projects based on natural resources show a more diverse picture. Here, only tourism and greening programs are implemented in the interior area of the city. At the same time, these represent the highest values according to the investment amount. The rest of the projects were mainly implemented in the outskirts, which can be explained by the agricultural nature. It should be emphasized that the developments related to the improvement of water management were mostly realized in the outskirts, on the edges of the industrial areas. The landscape use analysis revealed that in the mentioned period, Debrecen lost about 33.66 ha of natural functional area. This data does not include investments that do not receive European Union support, but at the same time have multiples of this value in themselves. Figure 3 illustrates the functional distribution of the areas directly affected by the developments. The change in the cultivation branch was typical in the case of outer areas and forest areas, mainly due to road construction, tourism investment and logistics activities. Figure 4 shows the realization of the projects divided into three categories based on square meter land use on a map with landscape use classes. It is obvious that the reservation of green space affected by the investments mainly affects the agricultural landscape areas of the western industrial park, including the newly built southern part of it. The intensive expansion of the industrial areas wedged in from the southeast is also significant, which is growing in the direction of the closed garden areas of the suburbs. In the Nagyerdő, interventions (Internet 5) related to tourism and healthcare resulted in the occupation of land and appeared as a landscape-transforming element. (Orosz, 2020) examined the development projects of Hungary's areas with high natural capital using the same method. As a result, he found that 4.3% of EU development projects implemented between 2007-2013 support the local natural environment and 1.5% are based on the use of ecosystem services provided by the local natural environment. Debrecen was not included in the investigated areas.

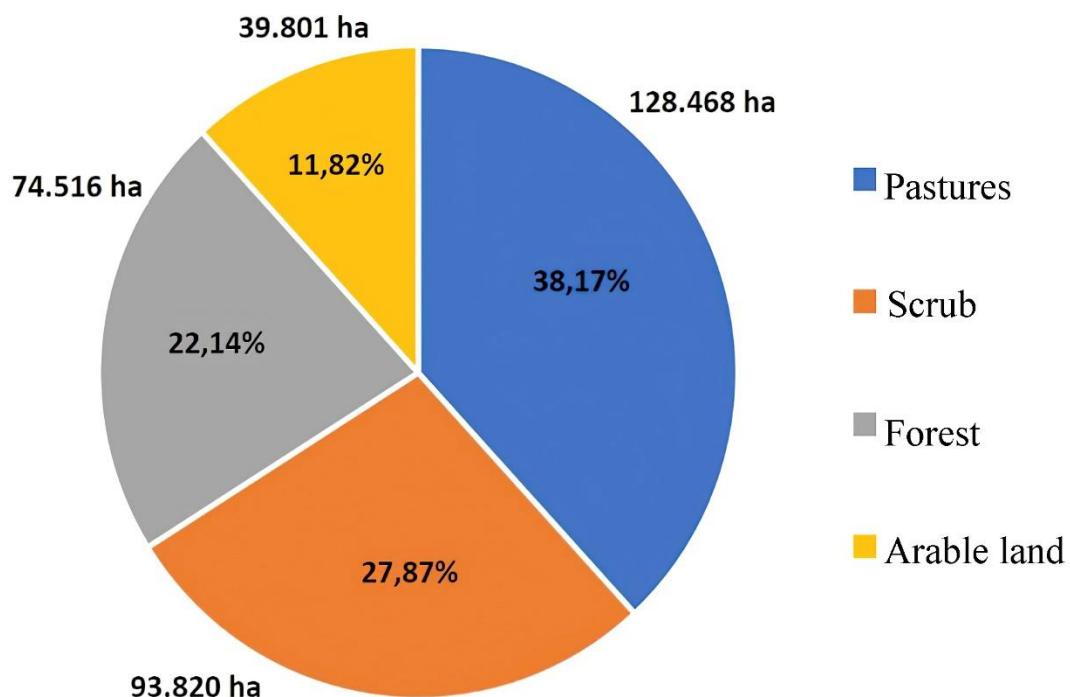


Fig. 3. The extent of the land occupation is according to the territorial functions before the implementation of the developments.

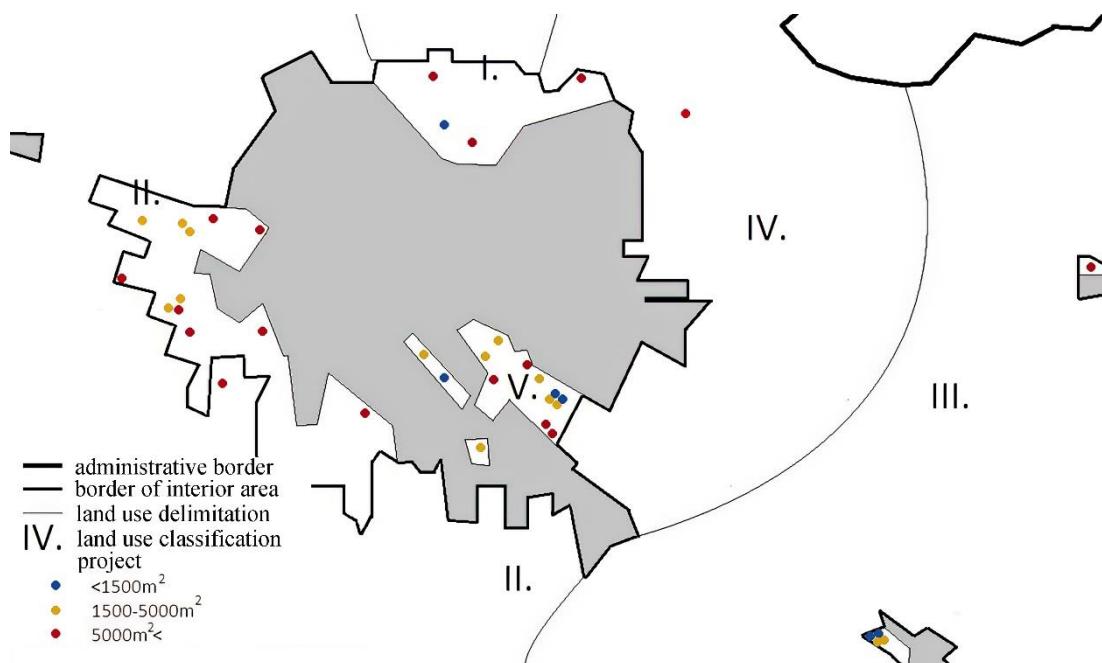


Fig. 4. Map illustration of realized projects.

CONCLUSIONS

In order to slow down the observed trends and reduce the effects of climate change, it can be recommended to rehabilitate the already existing green areas in the interior, especially their afforestation. It is important that the created green spaces are not isolated from each other, but

participate in the urban fabric as a connected network, whose maintenance and continuous upkeep is also an essential element. This is also served by the mosaic spatial structure, as the achievement of an optimal settlement image target state. It is highly recommended to convert the existing covered areas into natural cover where the use of the area does not necessarily justify the use of the cover. It is also necessary to continuously ensure the permanent vegetation cover and management of uninhabited fallow areas, lawns and shrubs, which strengthens the role of the buffer zone. All of this directly serves the local mitigation of the effects of climate change. It is necessary that the included green infrastructure elements maintain their ecological relations with the external areas of the settlement (INNOVA, 2014). These reduce the potential location and inclusion of the settlement's green surfaces, border vegetation, cemeteries and fragmented areas with less natural cover, and their involvement in the ecological relationship system, thereby increasing the complexity and resilience of the settlement's green infrastructure. In relation to economic priorities, observing the trends, it may be justified to slow down the declaration as inland areas, and to widen the economic development action areas in the direction of brownfield areas. A change in the direction of the proposals and the demonstrated trends is only possible if the natural environment appears more effectively, with a greater emphasis and specifically from a nature conservation point of view, in settlement development strategies and planning documents.

REFERENCES

- Antal, L., (1976): *A tartalomelemzés alapjai*. Budapest, Magvető Kiadó.
- Cívis Local Opportunities in Debrecen (CLLD) Local Community Development Strategy of Debrecen 2014-2020, 2016
- INNOVA (2014): Urban Development Concept and Integrated Urban Development Strategy of the County City of Debrecen 2014-2020. Euro-Régió Ház Közhasznú Nonprofit Kft. and INNOVA Észak- Alföld Regionális Fejlesztési és Innovációs Ügynökség Nonprofit Kft., Debrecen. p 87.
- Orosz, Gy. (2020): Examination of spatial use of natural potentials and territorial cohesion, Doctoral (PhD) Thesis Statements, DOI: 10.14751/SZIE.2020.019, 39-44.
- Orosz, Gy., Barczi, A., Szalai, D. (2018): The functioning of landscape ecology potentials in territorial cohesion with an outlook on the role of nature conservation ngo's, Annals of Faculty of Engineering Hunedoara - International Journal of Engineering 16: 4, 45-50.
- Orosz, Gy.; Barczi, A. (2019): Természeti adottságok szerepe a területfejlesztésben a komplex programmal fejlesztendő magyarországi járások esetében, TÁJÖKOLÓGIAI LAPOK / JOURNAL OF LANDSCAPE ECOLOGY (1589-4673): 17 2 209-218
- Urban Development Concept of the City of Debrecen County 1979/2020. (XII. 28.) Mayor's decision annex, Debrecen. p. 53.
- Resources from the Internet:
- Internet 1: <https://nater.mbfesz.gov.hu/hu/node/133> [downloaded: 2022. 09. 13.]
- Internet 2: Pályázat.gov.hu, Pályázatkereső: https://www.palyazat.gov.hu/tamogatott_projektkereso [downloaded: 2022. 06. 18.]
- Internet 3: Google Earth pro
- Internet 4: Hungarian State Treasury, Agricultural Parcel Identification System – MePAR portál: <https://mepar.mvh.allamkincstar.gov.hu/#/> [downloaded: 2022. 07. 30.]
- Internet 5: Social urban rehabilitation Preliminary Action Area Plan of Nagysándortelep – Vulkán telep, <http://srvcom.debrecen.hu/testulet/Dokumentumok/K%C3%B6zgy%C5%91%C1%91%C3%A9s/2011.03.31/2/EATTDbNSTelep20110329.html> [downloaded: 2022. 07. 30.]

SUMMER AND TROPICAL DAYS IN SLOVAKIA

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ABSTRACT

The occurrence of summer, but especially tropical days, acquires importance especially in the context of climate change and its effects on humans. Not only is the number of these days increasing, but more significantly, the series of consecutive high temperature days is also increasing. More often, not only station but also national air temperature records are broken. In this contribution, we have processed both the number and the period of summer and tropical days with regard to the character of the territory of Slovakia. We have selected meteorological stations with continuous observation since at least 1951, respectively one station since 1901. There have also been early onsets of summer days in the past, but their duration of consecutive days did not last long. Tropical days occurred even less often. The task was to find out whether the beginnings of these days occur more often now than in the past, and whether series of consecutive days are more frequent. We have highlighted the periods with the longest periods, which, however, do not always have to correspond with the number of such days in a given month or season. The importance of the occurrence of periods with high air temperatures in connection with periods without precipitation causes the drying effect of the land, which results in losses in the harvest as well as the forest ecosystem.

Keywords: summer, tropical days, climate change, consecutive days

INTRODUCTION

The average temperatures in Europe this summer were the highest on record. The extreme heat also led to increased drought risks. August 2022 was generally much drier than average in much of western and parts of east Europe. In fact, many parts of Europe have seen below average precipitation for several years in a row now. The summer of 2022 was the warmest in Slovakia since at least 1931 with a temperature deviation of +3.1 °C from the average of 1931-1960, +3.6 °C from 1951 - 1980, +3.7 °C from 1961-1990, +2.6 °C from 1981 - 2010, or +1.9 °C from 1991 - 2020. Individual months were quite warm. June was the third warmest with a deviation of +2.3 °C from the temperature values of 1991 - 2020, next month July was seventh with a deviation of +1.3 °C and August as third with a deviation of +2.0 °C at least since 1931. If we were to compare with previous periods, the deviations would be even more significant in positive numbers. Drought has threatened much of Europe - the summer of 2022 is likely to be the "worst in 500 years", according to a recent assessment by the European Commission's Joint Research Centre. Since both drought and long periods with high temperatures affect people, their activities and crops, we decided to process periods of consecutive summer and tropical days. Climatic conditions, including summer and tropical days, were processed in various older studies (Petrovič, 1968; Petrovič, 1972; Petrovič, 1966; Petrovič, 1960; Konček, 1979).

METHODS

Summer and tropical temperatures were the basis for processing. In climatology, we consider a summer day to be a day when the maximum temperature during the day rose to at least 25 °C. The same applies to a tropical day. This means that a tropical day is a day when the maximum air temperature rose to at least 30 °C during the day. The territory of Slovakia is

very fragmented, it contains lowlands, valleys, hills and mountains. All this affects the occurrence of characteristic days such as summer, tropical, but also others, e.g. icy, frosty, or days with a tropical night. In order to cover the territory of Slovakia and show the differences in the occurrence of summer and tropical days, we have selected meteorological stations of professional importance with a continuous series of observations since at least 1951 (Fig. 1). To illustrate and emphasize climate change, we have highlighted one of the named stations with its historical data since 1901. This is the meteorological station Hurbanovo, included in the protected international meteorological network of stations with great importance. To clarify the behavior of the time series of individual stations, we constructed graphs of monthly values together with decadal averages. We also calculated differences between individual decades. Individual heat waves cause problems for humans and animals, and as long as they do not last long, they can be avoided by using air conditioning, drinking water, etc. Stable weather in summer brings with it longer periods of warm (summer or even tropical) days. Sometimes there are periods of summer, lasting quite a long time, but nevertheless there are no consecutive tropical days of longer duration. Conversely, shorter periods of summer and tropical days sometimes occur simultaneously. Since this has not been considered so far, we decided to process the occurrence of periods of summer and tropical days and point out their occurrence in a time series at individual meteorological stations in each year. Such a detailed graphic representation will provide quick and clear information about the character of the summer and the statistics, in turn, their significance from the point of view of occurrence, respectively duration. In the statistical processing and evaluation of the observed material, we mainly focused on the number of days with characteristic temperatures and subsequently their occurrence in comparison with the average occurrence of such days during the year (especially the summer half-year). It was the average cumulative frequency of the given year compared with the cumulative average frequency for the period 1991 - 2020. This showed us in which temperature stage the given summer half-year occurs. But, what was most significant from a historical point of view was that we found periods of consecutive summer and tropical days for each year, and from these we determined the longest periods of consecutive summer and tropical days. Thus, in connection with other meteorological (climatological) characteristics of the given period, we can better define the climate of this period, as well as the causes that caused it or the consequences resulting from it. For example, in agriculture, water management, forestry, transport or in impact on the human organism.

RESULTS

For an objective assessment of the occurrence of summer and tropical days, we selected for processing meteorological (climatological) stations with continuous observation since at least 1951 (Fig. 1). At the same time, we took into account the coverage of the territory of Slovakia in order to highlight the differences in their occurrence in different parts and altitudes of Slovakia.

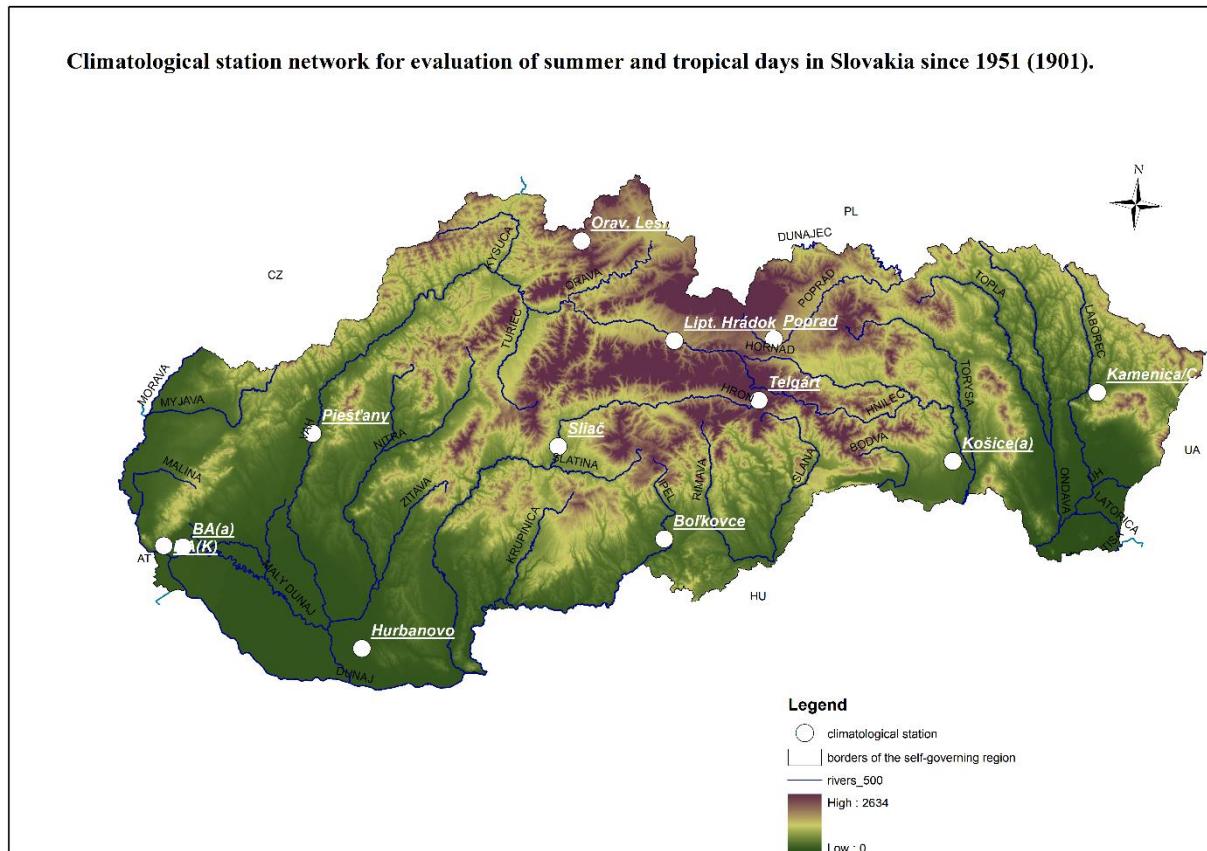


Fig. 1. Station network for evaluation of summer and tropical days in Slovakia since 1951 (1991).

We tried to simplify the increase with decadal averages, which show continuous growth at all stations. We expressed the inter-decadal increase in Table 1. We found some illogical differences during processing in the initial decades (Boľkovce, moved from Lučenec) as well as in Bratislava. Nevertheless, after 1981, the differences between decades are positive for all stations. If we were to generalize it to the entire territory of Slovakia, we recorded the greatest rise between the decades 2011 - 2020 and 2001 - 2010. With the exception of the colder (higher-lying) areas of northern and central Slovakia, the differences between the last two decades reached a double-digit number (up to 15 days at the airport in Bratislava). It could also become a growing urban heat island. For example, in Hurbanovo (understood as a rural station) there was an increase of up to 11 days. The same was true in the eastern part of Slovakia in Kamenica nad Cirochou. Due to the lower frequency of tropical days compared to summer days, the magnitude of the change in the number of tropical days between decades is not that great. Considering the fact that the occurrence of a summer day may not result in the occurrence of a tropical day, the trends between decades may not have the same character. This means, for example, that with a positive change between decades in summer days, there may be a case of a negative tendency in tropical days (Table 2). In climatology, we use climatological standards (normal values) to express the climate. They are average (but also extreme) values of various meteorological elements and their characteristics for periods lasting 30 years. For the above stations, we therefore calculated normal values for summer and tropical days and compared the periods 1961 - 1990 and 1991 - 2020.

Table 1. Decade differences of summer days at selected meteorological stations

Decade differences (Summer days)	Bratislava, Koliba	Bratislava, airport	Piešťany	Hurbanovo	Oravská Lesná	Sliač	Bolíkovce	Poprad	Telgárt	Košice, airport	Kamenica nad Cirochou
(1961-1970)-(1951-1960)	3.0	-0.3	-0.7	-1.0	-0.7	3.6	13.9	6.2	1.9	2.9	4.5
(1971-1980)-(1961-1970)	-1.0	4.5	-1.2	-4.9	-4.3	-7.1	-0.6	-8.2	-2.2	-9.8	-6.1
(1981-1990)-(1971-1980)	7.9	4.8	4.4	4.1	5.1	9.3	3.7	9.1	0.8	9.8	2.1
(1991-2000)-(1981-1990)	6.0	1.5	10.5	10.3	6.7	7.2	9.5	3.6	6.5	8.5	15.0
(2001-2010)-(1991-2000)	6.6	0.2	2.6	3.9	5.9	5.1	6.2	6.7	1.4	5.2	3.8
(2011-2020)-(2001-2010)	10.2	15.0	10.2	11.8	9.7	15.4	14.3	9.3	5.6	10.8	13.9

Table 2. Decade differences of tropical days at selected meteorological stations.

Decade differences (Tropical days)	Bratislava,Koliba	Bratislava, airport	Piešťany	Hurbanovo	Oravská Lesná	Sliač	Bolíkovce	Poprad	Telgárt	Košice, airport	Kamenica nad Cirochou
(1961-1970)-(1951-1960)	4.1	4.0	2.9	5.6	-1.0	4.1	-3.3	0.7	-0.3	2.7	3.0
(1971-1980)-(1961-1970)	-1.1	-2.4	-2.1	-8.4	0.0	-3.8	-2.5	-1.0	0.0	-5.0	-4.0
(1981-1990)-(1971-1980)	5.0	7.4	3.4	6.7	0.2	5.4	4.8	0.4	0.0	3.9	2.0
(1991-2000)-(1981-1990)	2.4	-0.5	4.3	6.6	2.1	2.2	1.7	3.0	0.2	4.9	7.5
(2001-2010)-(1991-2000)	5.0	2.4	5.0	6.1	-0.5	5.6	8.1	-1.4	0.0	2.8	1.7
(2011-2020)-(2001-2010)	6.5	8.3	6.7	6.8	4.3	9.6	6.9	4.3	0.1	6.4	7.9

The comparison normal values express the climate change at the given station (Fig. 2 and Fig. 3). Absolute anomalies in the difference between the summer days of the normal values of the periods 1991-2020 and 1961-1990 (Mikulová et al., 2015) are observed in the summer months (Fig. 4) with the largest positive increase in August (on average +5 days), while the highest changes occurred in central and the largest in eastern Slovakia (especially in the extreme southeast, 6 - 7 days). We observe absolute anomalies in the difference of tropical days from the normal values of the periods 1991 - 2020 and 1961 - 1990 in the summer months with the largest positive increase in July (on average +4.3 days), especially in western Slovakia and central Slovakia (Fig. 5). On the contrary, in central and eastern Slovakia we observe larger increases in August (in the northern districts) +1.4 - 1.9 days and in the east +4.1 - 4.7 days.

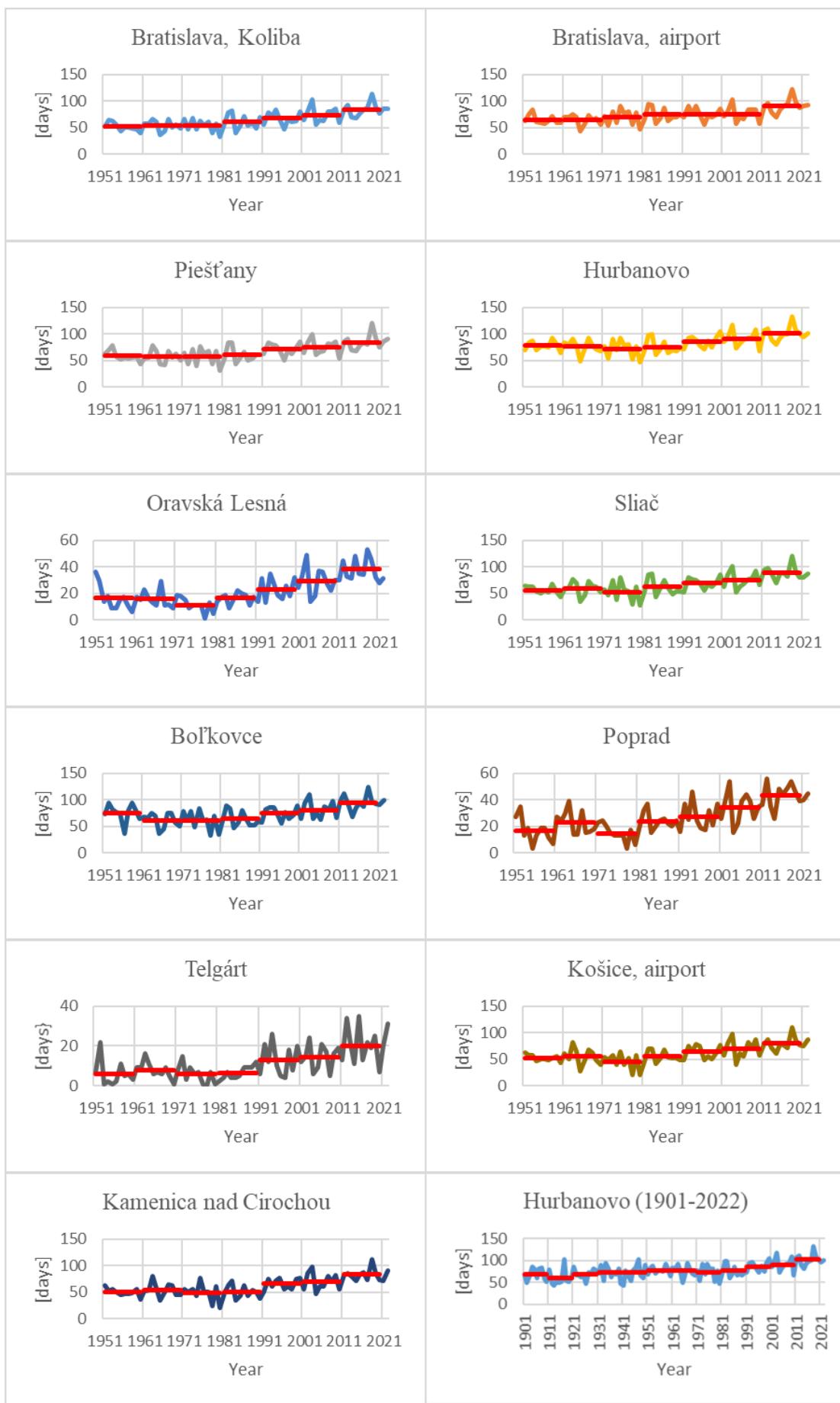


Fig. 2. Time series of summer days and decade averages.

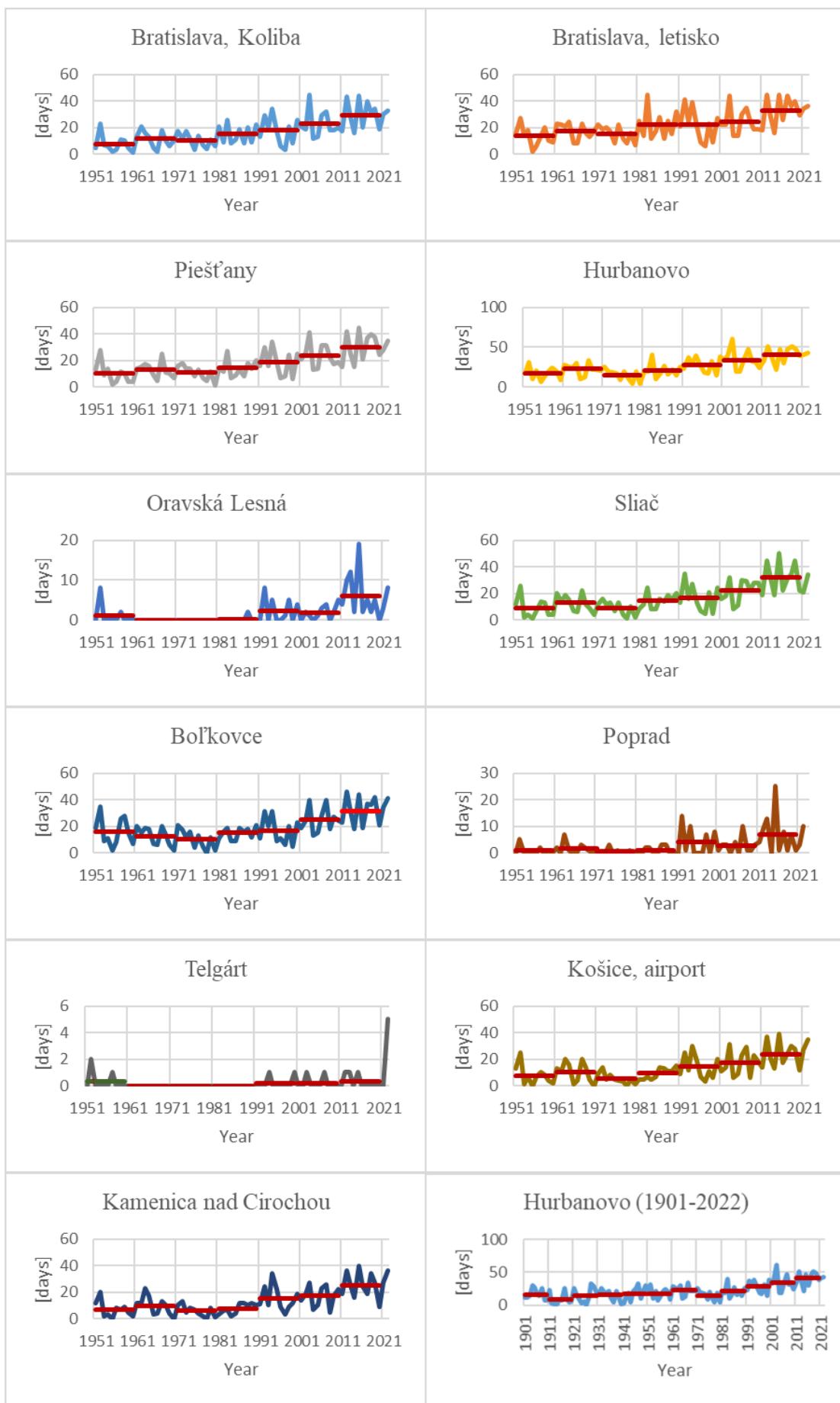


Fig. 3. Time series of tropical days and decade averages.

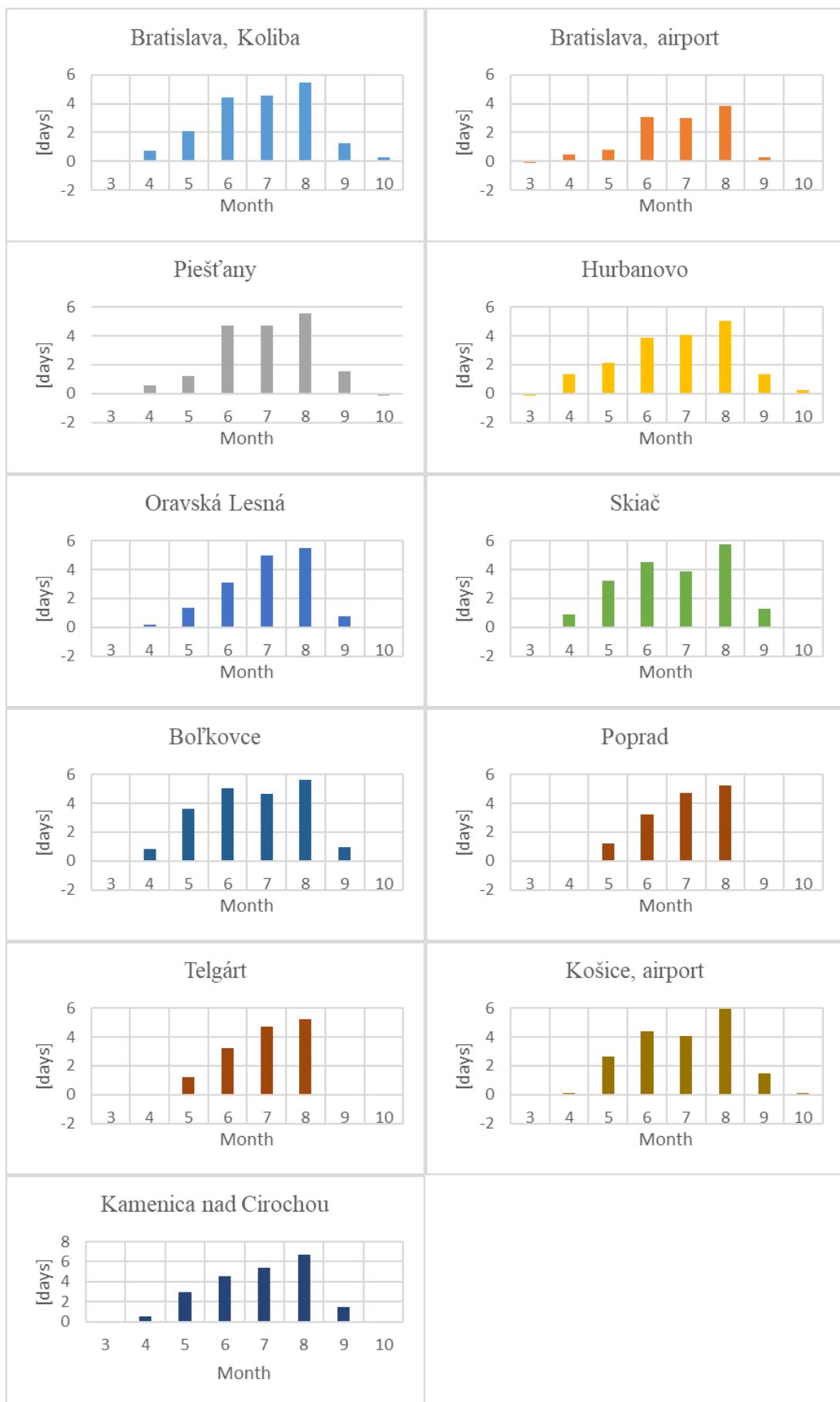


Fig. 4. Normal values comparison of summer days.

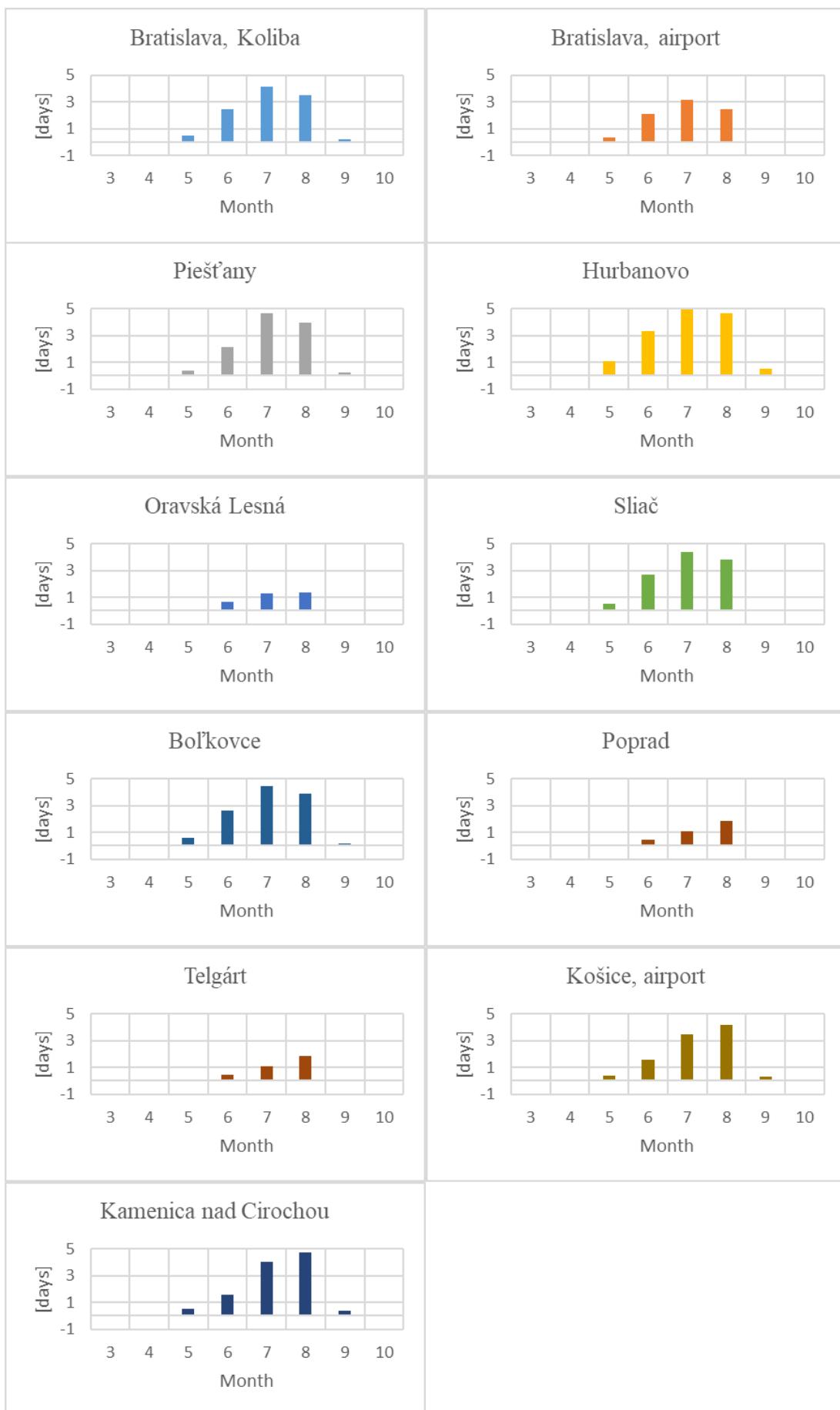


Fig. 5 Normal values comparison of tropical days.

The last but not the least task was to find out the simultaneous occurrence of summer and tropical days, to find the longest periods (consecutive days) in individual years (Table 3). Then determine the longest period ever, its beginning and end, the first and last day of occurrence of a summer day in a given year, as well as the historically earliest and latest occurrence of the first and last occurrence. The longest period of consecutive summer days occurred in Bol'kovce (south of central Slovakia) for 51 days. The beginning of the series occurred on June 15, 2021 and the end on August 4, 2021. The first summer day of this year (at that station) (2021) occurred on April 1 and the last on September 28. Historically, we recorded the first (earliest) summer day on March 21, 1974 (Hurbanovo and Bol'kovce) and the last (latest) on October 31, 2001 (Hurbanovo). We proceeded similarly for tropical days. The longest period of consecutive tropical days occurred in Kamenica nad Cirochou (extremely eastern Slovakia) for 22 days. The series began on July 21, 1994 and ended on August 11, 1994. The first tropical day in a given year (1994) occurred on May 18 and the last on September 14 (1994). Historically, we recorded the earliest occurrence of a tropical day on April 24, 1968 (Hurbanovo) and the last occurrence of a tropical day on September 30, 1932 (Hurbanovo). For all the stations mentioned above, we created graphs showing the occurrence of summer and tropical days. Of them, the separate or parallel occurrence of these days is noticeable. As an example, we present the time series from Hurbanovo for the period 1901 - 2022 (Fig. 6). The x-axis represents the period from the beginning of March (0) to the end of October (300) expressed in days instead of date and the y-axis represents the year of occurrence (duration) of summer and tropical days. From this figure (as well as from the others of the same meaning) an increase in the number as well as years with more frequent (longer consecutive days) periods of summer or tropical days is evident. In the case of the existence of longer consecutive days (especially tropical ones), critical situations occur (especially in connection with the lack of atmospheric precipitation). From Fig. 6 (at higher resolution) it is possible to define the significance of the duration of summer or tropical days or their simultaneous occurrence. After 1990, we observe an increasingly frequent parallel occurrence of tropical and summer days (most notably in the period 1991 - 2022). However, there were also years when a tropical day did not occur at all (e.g. from the recent past in Hurbanovo years 1986, 1997). Summer and tropical days most often occur in more northern and higher places, where previously their occurrence was less frequent, which ultimately gives new possibilities for changing the cultivation of agricultural crops as well as points to new possibilities for tourism, including the extension of the tourist season (in warm half a year).

Table 3. Consecutive summer and tropical days and added statistics (1951-2022)

Ind.	Station name	Char. day	Max period [days]	From	To	First occurrence	Last occurrence	First in records	Last in records
11813	Bratislava (K)	SD	34	11.7.1994	13.8.1994	15.5.1994	26.9.1994	7.4.2011	24.10.2019
		TD	18	22.7.1994	8.8.1994	26.6.1994	17.8.1994	29.4.2012	22.9.2003
11816	Bratislava, (a)	SD	34	18.6.1976	21.7.1976	4.4.1976	13.10.1976	24.3.1977	24.10.2019
		SD	34	11.7.1994	13.8.1994	15.5.1994	26.9.1994		
		TD	19	21.7.1994	8.8.1994	19.6.1994	12.9.1994	29.4.2012	22.9.2003
11826	Piešťany	SD	34	11.7.1994	13.8.1994	30.4.1994	26.9.1994	7.4.2011	24.10.2019
		TD	19	21.7.1994	8.8.1994	27.6.1994	10.8.1994	30.4.2012	22.9.2003
11858	Hurbanovo	SD	47	16.7.1992	31.8.1992	25.4.1992	28.9.1992	21.3.1974	31.10.2001
		TD	19	21.7.1994	8.8.1994	19.6.1994	2.9.1994	24.4.1968	30.9.1991
		TD	19	23.7.2018	10.8.2018	28.5.2018	13.9.2018		30.9.1932
11868	Orav. Lesná	SD	18	22.7.1994	8.8.1994	18.5.1994	2.9.1994	28.4.2012	15.10.2000
		TD	8	6.8.2015	13.8.2015	5.7.2015	1.9.2015	7.6.1998	1.9.2015
11874	Lipt. Hrádok	SD	24	17.7.2013	9.8.2013	26.4.2013	8.9.2013	21.4.2018	25.10.2019
		TD	10	25.7.1994	3.8.1994	27.6.1994	6.8.1994	8.5.2003	1.9.2015
11903	Sliač	SD	46	17.7.1992	31.8.1992	26.4.1992	12.9.1992	3.4.2017	18.10.1953
		TD	16	22.7.1994	6.8.1994	27.6.1994	8.8.1994	30.4.2012	19.9.1961
11927	Boľkovce	SD	51	15.6.2021	4.8.2021	1.4.2021	28.9.2021	21.3.1974	11.10.1995
		TD	18	22.7.1994	8.8.1994	26.6.1994	14.9.1994	30.4.2012	19.9.1961
11934	Poprad	SD	19	21.7.1994	8.8.1994	17.5.1994	14.9.1994	21.4.2018	24.10.2019
		TD	10	6.8.2015	15.8.2015	5.7.2015	1.9.2015	8.5.2003	1.9.2015
11938	Telgárt	SD	17	23.7.1994	8.8.1994	26.6.1994	11.8.1994	1.5.2012	19.9.1961
		TD	-	-	-	-	-	-	-
11968	Košice (L)	SD	38	19.7.2018	25.8.2018	12.4.2018	13.10.2018	22.3.1974	19.10.1961
		TD	18	22.7.1994	8.8.1994	27.6.1994	14.9.1994	1.5.2012	18.9.2015
11993	Kamenica /C	SD	37	20.7.2018	25.8.2018	12.4.2018	21.9.2018	6.4.1968	20.10.1961
		TD	22	21.7.1994	11.8.1994	18.5.1994	14.9.1994	1.5.2012	18.9.2015

Legend:

Ind. – international station number

SD – summer day and TD – tropical day

Bratislava (K) - Bratislava, Koliba

Bratislava, (a) - Bratislava, airport

Orav. Lesná - Oravská Lesná

Lipt. Hrádok - Liptovský Hrádok

Košice (a) - Košice, airport

Kamenica /C - Kamenica nad Cirochou

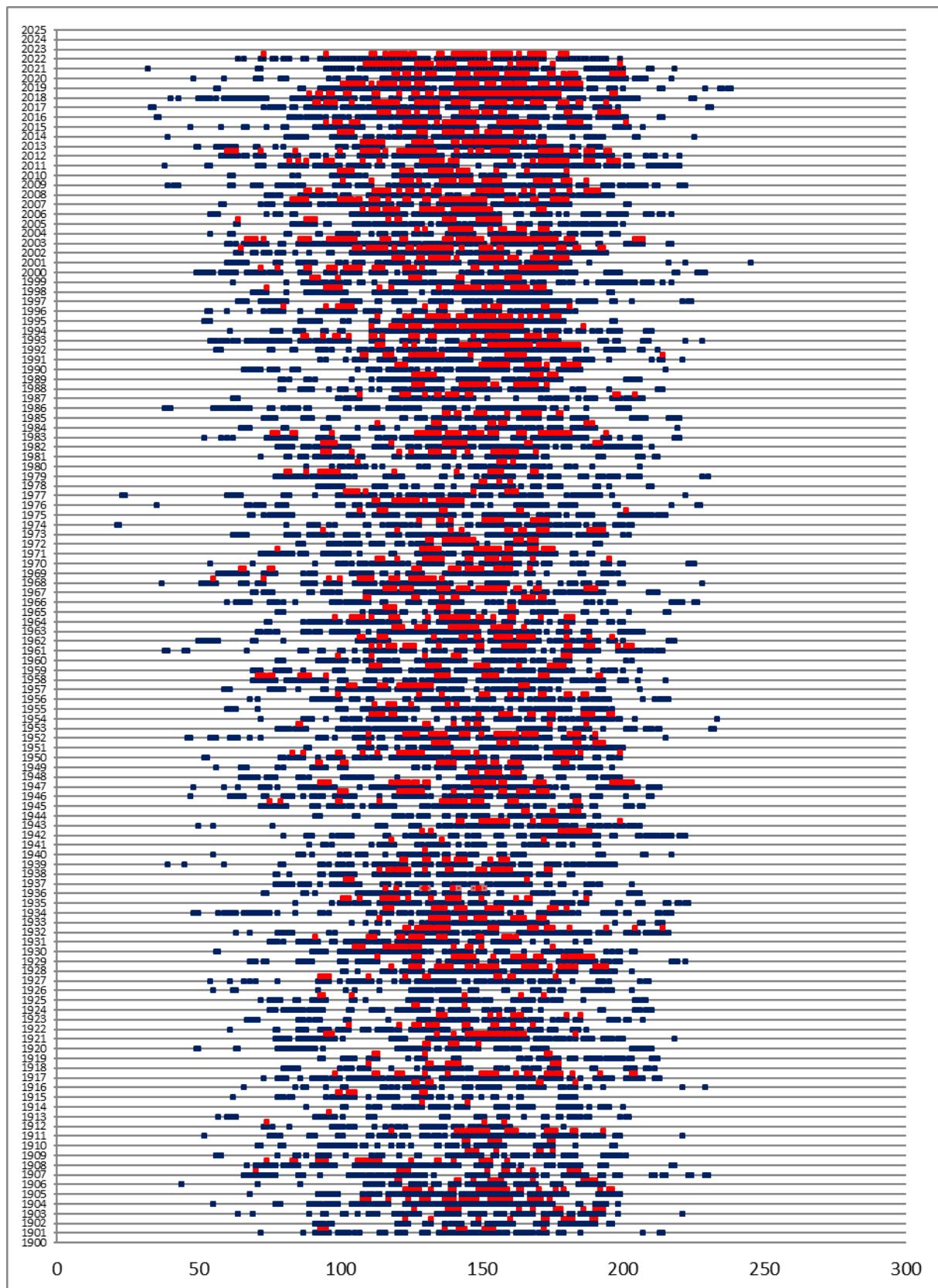


Fig. 6. Summer and tropical days (consecutive days) at Hurbanovo (1901-2022).

DISCUSSION

The processing of summer or tropical days (the same would be true for icy, frosty or tropical night days) is highly dependent on the quality of the measured data as well as on the invariance of the meteorological station surroundings. Currently, the problem of homogenization of daily, but especially extreme daily values, has not yet been comprehensively resolved. In order to eliminate possible errors as much as possible, we selected stations with professional staff. Nevertheless, we did not avoid a contradiction when evaluating the Boľkovce station, which had moved. Otherwise, the results at the other stations correspond to the trend resulting from the increase in air temperature, especially in recent decades. From the processing of data on summer and tropical days, it emerged that the growth of the average air temperature also leads to the occurrence of the longest consecutive summer or tropical days. The only thing that is certain is that the probability of the occurrence of such series has increased.

CONCLUSION

In the article, we mainly focused on expressing the trend in the number of summer and tropical days. We pointed out the differences between individual decades. We compared values from normal periods, classified as periods for determining climate change in 30 years. We found the longest periods of consecutive days (summer and tropical). We documented the statistics for when they occurred (first and last summer and tropical day). We found the historically first, last day of occurrence of a summer and tropical day at selected meteorological stations. The results can be used by farmers, foresters, tourism as well as for the general awareness of the population about climate change in the conditions of Slovakia.

REFERENCES

- Konček, M. (1979): Klíma a bioklíma Bratislav, SAV Bratislava, 32-37 s.
- Mikulová, K., Šťastný, P., Bochníček, O., Borsányi, P., Čepčeková, E., Ondruška, P. (2015): Klimatologické normálne teploty vzduchu na Slovensku za obdobie 1961 – 1990. NKP, 13-I/15, SHMÚ, Bratislava, 2015. 135 s. ISBN 978-80-88907-92-3.
- Petrovič, Š. (1960): Klimatické pomery Hurbanova, Hydrometeorologický ústav Praha, 74-78 s.
- Petrovič, Š. (1966): Klimatické pomery kraja (teplota vzduchu). Klimatické a fenologické pomery Východoslovenského kraja, Bratislava, Hydrometeorologický ústav ČSSR Praha, 36-38 s.
- Petrovič, Š. (1968): Klimatické pomery kraja (teplota vzduchu). Klimatické a fenologické pomery Západoslovenského kraja. Hydrometeorologický ústav ČSSR, Praha, 31-33 s.
- Petrovič, Š. (1972): Klimatické pomery kraja (teplota vzduchu). Klimatické a fenologické pomery Stredoslovenského kraja, Hydrometeorologický ústav Bratislava, 37-40 s.

VPLYV ZVOLENÝCH PARAMETROV NA VÝPOČET HODNOTY INDEXU SUCHA SPEI

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ABSTRACT

Sucho je pomerne zložitý pojem, na ktorý sa môžeme pozerať cez viaceré perspektívy: meteorologickú, hydrologickú, poľnohospodársku, socioekonomickú, či inú. Medzi najznámejšie a najčastejšie používané ukazovatele meteorologického sucha patrí index SPEI. SPEI predstavuje normalizovanú hodnotu záporného klimatického ukazovateľa zavlaženia D (D=zrážky – potenciálna evapotranspirácia). Spôsob výpočtu SPEI nie je jednoznačný a možno pri ňom meniť viaceré parametre v rôznych krokoch výpočtu. V tejto práci analyzujeme veľkosť zmeny indexu pri zmene týchto parametrov tým, že porovnáme veľkosť absolútnej odchylok indexov s rovnakými vstupnými údajmi, ale odlišným jedným parametrom vo výpočte. Porovnáme rady SPEI, ktoré sa líšia metódou výpočtu pot. evapotranspirácie (Hargreaves a Penman-Monteith); použitím rozdelením pravdepodobnosti hodnoty D (log-logistické, generalizované extremálne a Pearsonovo III rozdelenie) a použitím referenčným obdobím na základe ktorého sa normalizujú hodnoty indexu. Vstupnými údajmi sú meteorologické údaje zo stanici Beluša v období 1981-2019. Analýze sme podrobili 1, 3 a 6 mesačné indexy. Najväčšia zmena indexu sa vyskytla pri zmene referenčného obdobia (v priemere 0,2), ďalej pri zmene metódy výpočtu potenciálnej evapotranspirácie (0,13), kým najmenšiu zmenu priniesla zmena štatistikého rozdelenia (0,06).

Keywords: Meteorologické sucho, SPEI index, pravdepodobnostné rozdelenie, absolútne odchýlky

ÚVOD

Sucho je pomerne komplexný pojem. Neexistuje jednoznačná definícia ani fyzikálna veličina, ktorou by sa sucho dalo určiť a následne odmerať. Hlavnou príčinou jeho vzniku je deficit zrážok za určitú dobu vzhl'adom na klimatický priemer daného územia. Vyššia teplota vzduchu, intenzívnejšie slnečné žiarenie, nízka relatívna vlhkosť vzduchu, malá oblačnosť, či rýchlejšie prúdenie vzduchu zvyšuje mieru evapotranspirácie, čo môže značne prispieť k zintenzívneniu sucha. WMO vo svojej zbierke indexov a ukazovateľov sucha (Svoboda, Fuchs 2016) uvádzá 23 indexov sucha, ktoré vychádzajú z meteorologických, či klimatologických prvkov a charakteristík. Okrem toho môže byť sucho charakterizované aj z pohľadu hydrologickej, poľnohospodárskej, socioekonomickej, či iných charakteristík. Medzi jeden z najčastejšie používaných ukazovateľov meteorologického sucha patrí index SPEI (Standardized precipitation-evapotranspiration index). Ide o index, ktorý je zahrnutý aj v rámci monitoringu sucha Slovenského hydrometeorologického ústavu.

Jednou z výhod tohto indexu je to, že jeho hodnoty sú normalizované, vďaka čomu je možné porovnávať rôzne dlhé periody sucha. Zároveň ho možno použiť celosvetovo, keďže je index navrhnutý tak, aby sa prispôsobil podmienkam lokálnej klímy. Vďaka svojej celosvetovej popularite možno o tomto indexe nájsť množstvo literatúry-či už týkajúcej sa priameho použitia indexu na charakterizáciu sucha v rôznych klimatických oblastiach alebo aj literatúry týkajúcej sa samotnej metodiky výpočtu SPEI.

Medzi nevýhody tohto indexu v porovnaní s inými meteorologickými indexami sucha môžeme zaradiť jeho nezohľadňovanie typu povrchu a pôdy. Rôzne typy pôd rôzne

zadržiavajú, či prepúšťajú vodu a rovnako aj typ povrchu (a porastu na ňom) môže ovplyvniť výpar.

Ďalšou nevýhodou je nejednoznačnosť v metodike výpočtu indexu. Pri niektorých krokoch výpočtu SPEI je totiž možné modifikovať viaceré parametre výpočtu. Problematikou zmeny niektorých z modifikovateľných parametrov pri výpočte SPEI sa budeme zaoberať práve v tejto práci.

Jedným z takýchto modifikovateľných parametrov je spôsob výpočtu potenciálnej evapotranspirácie (PET), ktorá vstupuje do výpočtu SPEI. Samotní autori indexu pri zadefinovaní SPEI použili jednoduchú Thornthwaitovu metódu, pri ktorej sú vstupnými údajmi teplota vzduchu a zemepisná šírka (Vicente-Serrano, Beguería, López-Moreno 2010). Po ďalšej analýze navrhnutého indexu, autori uprednostnili použitie Penman-Monteith metódy (P.-M.). P.-M. metóda je zároveň odporúčaná aj Organizáciou pre výživu a poľnohospodárstvo spojených národov (FAO – Food and Agriculture Organization of the United Nations) ako štandardná metóda výpočtu PET (Allen, Pereira, et al. 1998). Ako vstupné údaje si však táto metóda vyžaduje aj prvky ako rýchlosť vetra, vlhkosť vzduchu, či slnečná radiácia, ktoré sa na mnohých meteorologických staniciach nemerajú, prípadne sa merajú s prístrojmi s nedostatočnou presnosťou. Preto v prípade nedostupnosti vstupných údajov autori odporúčajú použiť jednoduchšiu metódu Hargreaves, ktorá si vyžaduje iba teplotu vzduchu a zemepisnú šírku stanice. Výsledné hodnoty PET podľa metódy Hargreaves sú však porovnatelné ako pri metóde P.-M. (Beguería, Vicente-Serrano, et al. 2014).

Ďalším modifikovateľným parametrom je referenčné obdobie na základe ktorého sa v metodike výpočtu posudzuje, či pre danú situáciu ide o normálne alebo skôr extrémne vlhkostné podmienky. Odporúča sa, aby referenčné obdobie malo dĺžku minimálne 30 rokov, avšak nie je pevne stanovené. Index sucha napríklad pre jún 2018 teda možno počítať podľa distribučnej funkcie zostavenej pre obdobie 1988-2018, ale aj pre obdobie 1981-2011, či iné obdobie s ľubovoľnou dĺžkou. Týmto spôsobom index ocharakterizovaný ako extrémne suchý podľa jendého referenčného obdobia, môže byť napríklad mierne suchý podľa iného referenčného obdobia.

Zároveň je pri metodike výpočtu možné vybrať si štatistické rozdelenie, ktoré sa použije na zstrojenie distribučnej funkcie rozdielu zrážok a PET. Autori SPEI odporúčajú použiť log-logistické rozdelenie (Vicente-Serrano, Beguería, López-Moreno 2010), kým Stagge a kol. uprednostňujú generalizované extremálne rozdelenie – GEV (Stagge, Tallaksen, et al. 2015; 2016).

Okrem toho je možné určiť viacerými spôsobmi aj parametre zvoleného rozdelenia. Spôsob výpočtu parametrov rozdelenia môže ovplyvniť ich hodnoty a samým tým aj finálne SPEI. Parametre vyššie uvedených rozdelení možno počítať napríklad metódou nevychýlených pravdepodobnostne vážených momentov (unbiased probability weighted moments-ubPWM) alebo metódou maximálnej vieročnosti (maximum likelihood estimation-MLE).

Ďalšou nejednoznačnosťou pri výpočte SPEI je možnosť udeliť rôzne váhy jednotlivým mesiacom pri viacmesačných indexoch. S takýto modifikáciou indexu sme sa však v domácej ani zahraničnej literatúre často nestretali.

V tejto práci sme sa zamerali na parametre, ktoré môžu podľa nás najviac ovplyvniť výsledný index. Zaujímalo nás do akej miery ovplyvní volba spôsobu výpočtu PET, referenčného obdobia, či štatistického rozdelenia hodnoty D finálne hodnotu indexu SPEI. Analyzovali sme preto absolútne rozdiely medzi indexami, pri ktorých bol pozmenený vždy iba jeden z uvedených parametrov.

METHODS AND DATA

Pre štatistickú analýzu indexu SPEI sme si v tejto práci zvolili stanicu Beluša. Pracovali sme s dennými meteorologickými údajmi v období 1981-2019, ktoré nám poskytol Slovenský hydrometeorologický ústav. Beluša sa nachádza v okrese Púchov, na strednom Považí, v severnej časti Ilavskej kotliny v údolí rieky Váh. Meteorologická stanica Beluša sa nachádza v nadmorskej výške 254 m n.m., na $49,07^{\circ}$ severnej zemepisnej šírky a $18,32^{\circ}$ východnej zemepisnej dĺžky. V období 1981-2019 bola na tejto stanici v januári priemerná maximálna teplota vzduchu $1,62^{\circ}\text{C}$ a priemerná minimálna teplota vzduchu $-4,97^{\circ}\text{C}$, kým v júli bola priemerná maximálna teplota $26,38^{\circ}\text{C}$ a priemerná minimálna teplota $13,03^{\circ}\text{C}$. Priemerná suma atmosférických zrážok v teplom polroku (apríl-september) bola 408 mm a priemerná suma PET za teplý polrok 758 mm. Podľa Končekovej klimatickej klasifikácie (obdobie 1961-2010) sa Beluša radí do teplej oblasti s miernou zimou a dostatočnou vlhkosťou (okrsok T8) (SHMÚ 2015).

Metodika výpočtu indexov

Samotnú metodiku výpočtu SPEI ukážeme v nasledovných krococh:

1. Vstupným parametrom pre výpočet SPEI je veličina D - záporná hodnota klimatického ukazovateľa zavlaženia. Ide vlastne o rozdiel úhrnu atmosférických zrážok (R) a potenciálnej evapotranspirácie (PET) za zvolené obdobie pre ktoré počítame index (napr. 1 mesiac).
2. V ďalšom kroku sa na základe dostatočne dlhého referenčného obdobia hodnoty D zostaví distribučná funkcia hodnoty D. Tento krok pozostáva z voľby vhodnej distribučnej funkcie, ktorá dobre popisuje veličinu D a následného výpočtu parametrov tohto zvoleného rozdelenia.
3. Podľa stanovenej distribučnej funkcie sa potom pre konkrétnu hodnotu D pre ktoré počítame index určí pravdepodobnosť prekročenia tejto hodnoty: $P(x \geq D)$.
4. Aby bolo možné vzájomné porovnanie indexov v priestore a čase, index SPEI je normalizovaný. V ďalšom kroku sa teda vykoná normalizácia hodnoty P z predchádzajúceho kroku transformáciou distribučnej funkcie zvoleného štatistického rozdelenia na normálne rozdelenie so strednou hodnotou v 0 a štandardnou odchýlkou 1: $N(\mu=0; \sigma^2=1)$. Táto hodnota je finálnou hodnotou indexu SPEI.

Index SPEI teda poukazuje na to, či hodnota D (za zvolené časové obdobie) je pre daný bod v priestore bežne vyskytujúca sa alebo ide skôr o hodnoty nachádzajúce sa na chvostoch štatistického rozdelenia. Ako už bolo spomenuté, hodnoty indexu sú normalizované, pričom záporné hodnoty signalizujú suché obdobie, kým kladné hodnoty vlhké obdobie. Kategorizáciu vlhkostných období na základe hodnoty indexu SPEI uvádzame v Tabuľke 2.

Tabuľka 2. Kategorizácia vlhkostných období podľa hodnoty SPEI

HODNOTA INDEXU SPEI	OBDOBIE
$\geq 2,00$	extrémne vlhké
$1,50 \text{ AŽ } 1,99$	veľmi vlhké
$1,00 \text{ AŽ } 1,49$	stredne vlhké
$0,99 \text{ AŽ } 0$	mierne vlhké
$0 \text{ AŽ } -0,99$	mierne suché
$-1 \text{ AŽ } -1,49$	stredne suché
$-1,50 \text{ AŽ } -1,99$	veľmi suché
$\leq -2,00$	extrémne suché

Ako vstupné údaje pre výpočet sucha sme v tejto práci použili 30, 92 a 183 dňové sumy zrážok a PET pre každý deň v analyzovanom období 1981-2019 (retrográdne). Výsledkom boli 1, 3 a 6 mesačné hodnoty indexu pre každý deň v analyzovanom období (napr. 1 mesačný SPEI pre 30 január 1981 zahŕňa obdobie od 1.-30. januára 1981; SPEI pre 31. január zahŕňa 2.-31. január, atď.). Výhodou takého denného kroku vo výpočte (v porovnaní s klasickou 1 hodnotou indexu za mesiac) je väčšia štatistická vzorka a detailnejší a hladší časový priebeh indexu.

Ako bolo spomenuté v úvodnej časti, pri výpočte SPEI je možné niektoré parametre modifikovať. My sme v tejto práci použili 2 spôsoby výpočtu PET (P.-M. metódu a metódu Hargreaves), 5 referenčných období indexu (1981-2019, 1981-2000, 1981-2009, 2000-2019 a 1990-2019) a 3 rôzne štatistické rozdelenia hodnoty D (log-logistické, GEV a Pearsonovo III rozdelenie). Kombináciou uvedených modifikácií sme za tých istých vstupných podmienok získali sadu 14 indexov pre každú skúmanú dĺžku indexu (1, 3 a 6 mesačné obdobie). V Tabuľke 3 uvádzame skratky názvov jednotlivých modifikácií indexu, ako aj prehľad ich charakteristík.

Tabuľka 3. Skratky názvov modifikácií indexov a ich prislúchajúce charakteristiky (použité referenčné obdobie, metodika výpočtu PET a štatistické rozdelenie)

PET			
Ref.obdobie	Harg.	P.-M.	Rozdelenie
1981-2019	hl1	pl1	log-logistické
1981-2000	hl2	pl2	log-logistické
1981-2010	hl3	pl3	log-logistické
2000-2019	hl4	pl4	log-logistické
1990-2019	hl5	pl5	log-logistické
1981-2019	hp1	pp1	Pearson III
1981-2020	hg1	pg1	GEV

Pri výpočte parametrov pre všetky 3 analyzované štatistické rozdelenia sme postupovali metódou MLE. Pri viacmesačných indexoch mal každý mesiac rovnakú váhu.

Kedže sme na výpočet indexov v tejto práci používali relatívne krátke referenčné obdobia (20-40 rokov), je potrebné uvedomiť si, že rozdenie, ktoré bolo z tohto referenčného obdobia vytvorené nedokáže presne určiť extrémne hodnoty sucha a vlhka (napríklad udalosti vyskytujúce sa raz za 1000 rokov). Rozhodli sme sa preto indexy ohraničiť hodnotou ± 3 , tak ako to pri kratších referenčných obdobiach odporúča aj Stagge a kol. (Stagge, Tallaksen, et al. 2015; 2016). Hodnota SPEI ± 3 predstavuje udalosť s pravdepodobnosťou 0,14%, čiže udalosť, ktorá sa vyskytne približne raz za 741 rokov. Zároveň by sme chceli zdôrazniť, že hodnoty SPEI presahovali túto hodnotu najmä pri 20 ročných referenčných obdobiach. V niektorých prípadoch pri 20 ročnom referenčnom období sa vyskytlo až zhruba 2,5% hodnôt v časovom rade mimo interval ± 3 , pričom mnohé z týchto prípadov boli na úrovni výskytu raz za 100 000 rokov. Pri 40 ročných referenčných obdobiach sa hodnoty SPEI mimo interval ± 3 prakticky nevyskytovali (maximálne na úrovni stotiny percenta z celkového počtu prvkov v časovom rade). Tento fakt svedčí o tom, že 20 ročné referenčné obdobie pri indexoch SPEI môže byť nedostatočné na adekvátne ocharakterizovanie klímy. Napriek tomu sme sa po ohraničení indexov spomínanou hodnotou rozhodli pre porovnanie použiť aj tieto kratšie

referenčné obdobia. Vychádzali sme pritom z predpokladu, že mimo extrémnych oblastí môžu byť tieto indexy odhadnuté pomerne presne.

Výpočty indexu SPEI boli vykonané v prostredí programovacieho jazyka R za pomocí balíčka SCI (Gudmundsson, Stagge 2016).

Metodika určenia vplyvu zmeny zvoleného parametra na SPEI

Vplyv zmeny jednotlivého parametra na SPEI sme posudzovali na základe absolútnej hodnoty rozdielu medzi dvojicami indexov, pričom analyzovaná dvojica indexov sa vždy líšila iba v jednom posudzovanom parametri. Podľa toho, aký parameter sme analyzovali môžeme úlohu rozdeliť na 3 časti:

- Rozdiel indexov, ktoré sa líšia v štatistickom rozdelení
- Rozdiel indexov, ktoré sa líšia v referenčnom období použitom na výpočet parametrov rozdelenia
- Rozdiel indexov, ktoré sa líšia v použitej metóde výpočtu PET

Pre každú časť úlohy sme porovnávali relevantné dvojice indexov (Tabuľka 3), pričom sme určovali maximálnu a priemernú absolútну odchýlku a jej štandardnú odchýlku v časovom rade pre danú dvojicu.

Tabuľka 4. Priradenie čísel k skúmaným rozdielom dvojíc indexov pre časti úlohy a) Rozdiel indexov, ktoré sa líšia v štatistickom rozdelení; b) Rozdiel indexov, ktoré sa líšia v referenčnom období a c) Rozdiel indexov, ktoré sa líšia v použitej metóde výpočtu PET

úloha a)	rozdiel č.	dvojica vstupujúca do rozdielu	úloha b)	rozdiel č.	dvojica vstupujúca do rozdielu						
	1	hl1	hp1		1	hl1	hl2				
	2	hl1	hg1		2	hl1	hl3				
	3	hp1	hg1		3	hl1	hl4				
	4	pl1	pp1		4	hl1	hl5				
	5	pl1	pg1		5	hl2	hl3				
	6	pp1	pg1		6	hl2	hl4				
					7	hl2	hl5				
					8	hl3	hl4				
					9	hl3	hl5				
					10	hl4	hl5				
					11	pl1	pl2				
úloha c)	rozdiel č.	dvojica vstupujúca do rozdielu				12	pl1	pl3			
						13	pl1	pl4			
	1	hl1	pl1			14	pl1	pl5			
	2	hl2	pl2			15	pl2	pl3			
	3	hl3	pl3			16	pl2	pl4			
	4	hl4	pl4			17	pl2	pl5			
	5	hl5	pl5			18	pl3	pl4			
	6	hp1	pp1			19	pl3	pl5			
	7	hg1	pg1			20	pl4	pl5			

Časový rad pozostával zhruba z 14 000 absolútnych rozdielov (365 dní x 39 rokov=14235; pokial chýbala určitá hodnota v jednej z dvojíc, daný datum sme vynechali). Chceme upozorniť, že aj v prípade použitia kratšieho referenčného obdobia v metodike výpočtu indexu (napr. 20 ročné referenčné obdobie 2000-2019) sme indexy počítali pre celé analyzované obdobie 1981-2019. Referenčné obdobie bolo použité iba na zostavenie distribučnej funkcie (bod 2. pri popise metodiky výpočtu SPEI).

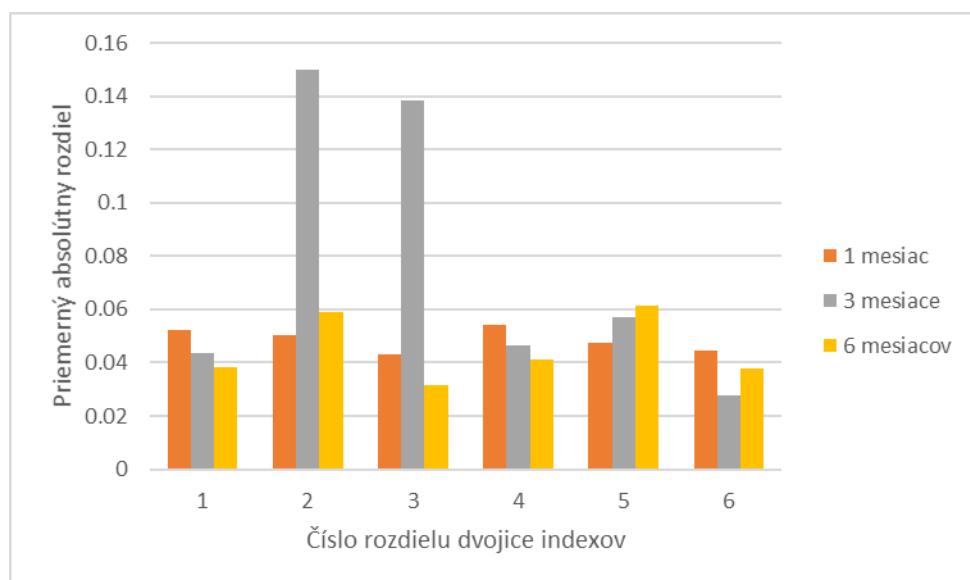
RESULTS

Rozdiel indexov, ktoré sa líšia v štatistickom rozdelení

Maximálne absolútne rozdiely medzi porovnávanými dvojicami boli pri jednomesačnom indexe od 0,5 (dvojica 5) po 1,24 (dvojica 6); pri trojmesačnom indexe od 0,6 (dvojica 6) po 1,39 (dvojica 4) a pri šesťmesačnom od 0,4 (dvojica 1) po 1,06 (dvojica 4) (tabuľka 4, časť a, oranžová časť).

Pri trojmesačných a šesťmesačných indexoch sme najväčší priemerný rozdiel zaznamenali medzi log-logistickým a GEV rozdelením, kým pri jednomesačných indexoch sa v priemere najviac líšili indexy s log-logistickým a Pearson III rozdelením. Naopak najmenší priemerný rozdiel bol pri jednomesačnom a šesťmesačnom indexe pre dvojicu s rozdeleniami GEV a Pearson III a pri trojmesačných indexoch pre dvojicu s GEV a log-logistickým rozdelením. Takáto analýza však nie je dostatočná na to, aby sme uzavreli, že indexy s určitými rozdeleniami sú si viac, či menej podobné, keďže rozdiel medzi dvojicami s najmenšími a najväčšími priemerným absolútnym rozdielmi je na úrovni 0,01 pri jednomesačných, 0,03 pri šesťmesačných a 0,11 pri trojmesačných indexoch. Domnievame sa preto, že uvedené poradie podobnosti indexov je skôr náhodné ako štatisticky významné, čomu nasvedčuje aj fakt, že poradie nie je jednotné pri inej dĺžke indexu.

V priemere boli absolútne rozdiely medzi indexami pri použití iného štatistického rozdelenia na úrovni 0,05 pri jednomesačnom indexe, 0,08 pri trojmesačnom a 0,04 pri šesťmesačnom indexe.



Graf 1. Priemerný absolútny rozdiel medzi dvojicami indexov s odlišným štatistickým rozdelením.

Tabuľka 5. Priemerný absolútny rozdiel medzi dvojicami indexov (zelená časť vyššie), štandardná odchýlka absolútneho rozdielu (zelená časť nižšie), priemerný absolútny rozdiel pre všetky dvojice indexov (boldom vyššie), priemer štandardnej odchýky medzi všetkými dvojicami (boldom nižšie), maximálny rozdiel, ktorý sa pri zmene daného prvku vyskytol (oranžová časť vľavo) a číslo rozdielu dvojice indexov pri ktorých sa tento maximálny rozdiel vyskytol (oranžová časť vpravo). Časť a) predstavuje rozdiely indexov, ktoré sa líšia v štatistickom rozdelení; časť b) indexy lísiace sa referenčným obdobím; časť c) indexy lísiace sa metodikou výpočtu PET. V časti b) sú uvedené iba rozdiely indexov s PET=P.-M. (rozdiely 11-20), výsledky indexov PET=Hargreaves (1-10) sú približne rovnaké a preto ich pre nedostatok priestoru vynechávame.

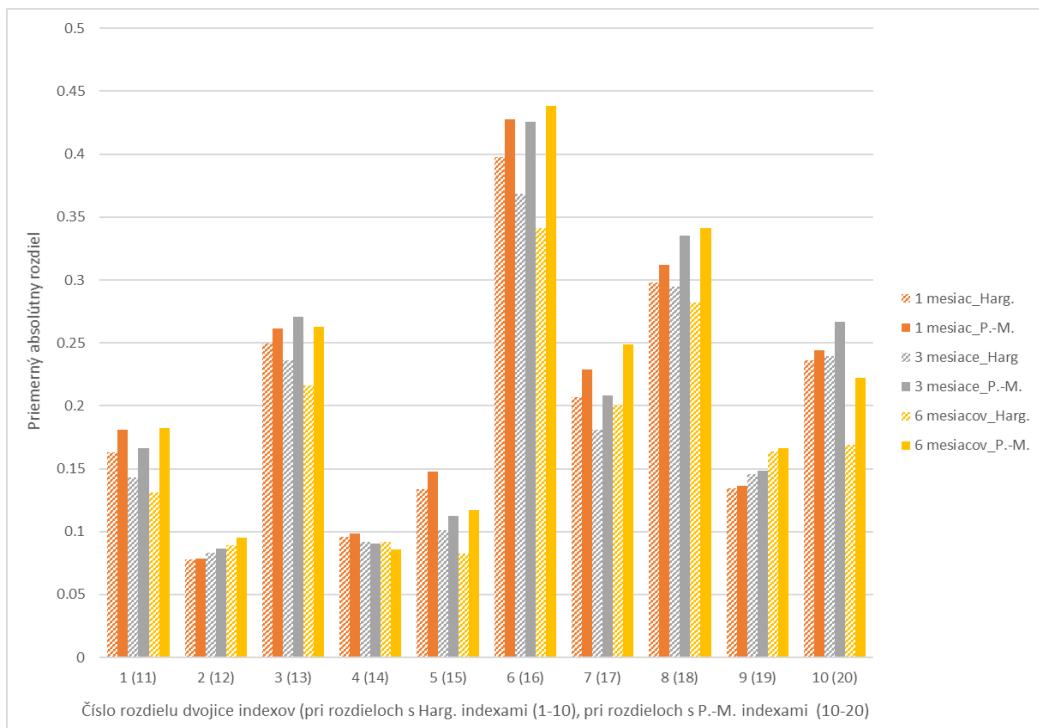
		číslo rozdielu indexov						priemer	maximum	č.rozdielu				
		1	2	3	4	5	6							
priemerný absolútny rozdiel	1 mesiac	0.05	0.05	0.04	0.05	0.05	0.04	0.05	1.24	6				
	3 mesiace	0.04	0.15	0.14	0.05	0.06	0.03	0.08	1.39	4				
	6 mesiacov	0.04	0.06	0.03	0.04	0.06	0.04	0.04	1.06	4				
štandardná odchýlka	1 mesiac	0.06	0.06	0.06	0.06	0.05	0.06	0.06						
	3 mesiace	0.04	0.12	0.11	0.05	0.07	0.04	0.07						
	6 mesiacov	0.04	0.07	0.04	0.05	0.07	0.05	0.05						
		číslo rozdielu indexov												
		11	12	13	14	15	16	17	18	19				
priemerný absolútny rozdiel	1 mesiac	0.18	0.08	0.26	0.10	0.15	0.43	0.23	0.31	0.14	0.24	0.21	3.11	6
	3 mesiace	0.17	0.09	0.27	0.09	0.11	0.43	0.21	0.34	0.15	0.27	0.21	2.43	16
	6 mesiacov	0.18	0.10	0.26	0.09	0.12	0.44	0.25	0.34	0.17	0.22	0.22	2.27	16
štandardná odchýlka	1 mesiac	0.19	0.09	0.27	0.09	0.16	0.39	0.23	0.31	0.13	0.27	0.21		
	3 mesiace	0.15	0.08	0.26	0.06	0.10	0.35	0.16	0.29	0.10	0.26	0.18		
	6 mesiacov	0.13	0.08	0.27	0.06	0.10	0.35	0.17	0.29	0.11	0.26	0.18		
		číslo rozdielu indexov							priemer	maximum	č.rozdielu			
		1	2	3	4	5	6	7	priemer	maximum	č.rozdielu			
priemerný absolútny rozdiel	1 mesiac	0.11	0.13	0.11	0.13	0.11	0.12	0.11	0.12	2.42	4			
	3 mesiace	0.12	0.14	0.13	0.16	0.12	0.13	0.01	0.12	2.15	4			
	6 mesiacov	0.15	0.17	0.16	0.19	0.14	0.15	0.15	0.16	2.05	4			
štandardná odchýlka	1 mesiac	0.10	0.15	0.11	0.17	0.11	0.11	0.10	0.12					
	3 mesiace	0.11	0.14	0.11	0.18	0.11	0.11	0.03	0.11					
	6 mesiacov	0.12	0.16	0.13	0.20	0.12	0.13	0.13	0.14					

Rozdiel indexov, ktoré sa líšia v referenčnom období

Pri porovnaní indexov s iným referenčným obdobím boli maximálne absolútne rozdiely pri jednomesačnom indexe od 1,13 (dvojica 2) po 3,11 (dvojica 6), pri trojmesačnom indexe od 0,43 (dvojica 14) po 2,43 (dvojica 16) a pri šesťmesačnom indexe od 0,87 (dvojica 2) po 2,27 (dvojica 16) (tabuľka 4, časť b, oranžová časť).

Absolútne rozdiely medzi indexami s iným referenčným obdobím boli v priemere 0,2 pre jednomesačné, trojmesačné aj šesťmesačné indexy. Logicky pri indexoch s úplne odlišnými referenčnými obdobiami bola priemerná absolútна odchýlka indexov vyššia než pri indexoch, ktorých referenčné obdobia sa čiastočne prekrývali. Rovnako sme pri týchto indexoch zaznamenali aj najvyššiu štandardnú odchýlku absolútnych rozdielov. Príkladom je dvojica 6 resp. 16 (rozdiel období 1981-2000 a 2000-2019), kde bola priemerná absolútna odchýlka indexov 0,4 pri všetkých 3 dĺžkach indexu (tabuľka 4, časť b, zelená časť). V prípade porovnania indexov s 30 ročným a 20 ročným referenčným obdobím so vzájomným 10

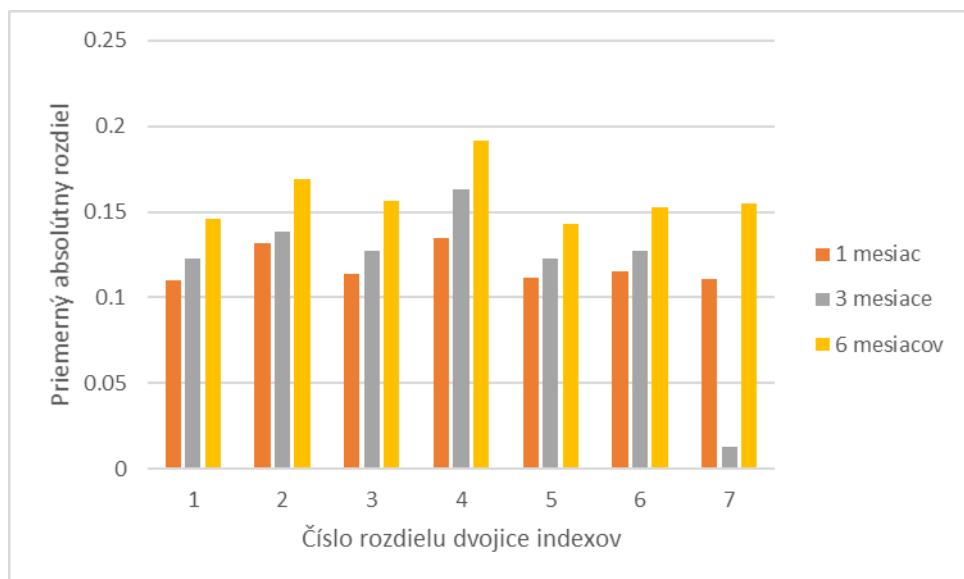
ročným prekryvom referenčných období (dvojice 7 a 8, resp. 17 a 18) sa indexy od seba líšili v priemere o hodnoty od 0,18 (dvojica 7 pri trojmesačnom indexe) po 0,34 (dvojica 18 pri šest' mesačnom indexe). Keď sme porovnali indexy s 30 ročným a 20 ročným referenčným obdobím, avšak s ich vzájomným 20 ročným prekryvom (dvojice 5, 9 a 10, resp. 15, 19 a 20) priemerné absolútne rozdiely sa pohybovali na úrovni od 0,08 (dvojica 5 pri šest' mesačnom indexe) po 0,27 (dvojica 20 pri trojmesačnom indexe). V prípade nahradenia 40 ročného referenčného obdobia 20 ročným výsekom z tohto obdobia by sa podľa tejto analýzy indexy s 20 ročným ref. obdobím líšili od pôvodných o 0,13 (dvojica 1 pri šest' mesačnom indexe) až 0,27 (dvojica 13 pri trojmesačnom indexe). V prípade nahradenia 40 ročného ref. obdobia 30 ročným výsekom z tohto obdobia sa indexy medzi sebou líšili v priemere o 0,08 (dvojica 2 pri jednomesačnom a trojmesačnom indexe) až 0,1 (dvojica 14 pri jednomesačnom a dvojica 12 pri šest' mesačnom indexe).



Graf 2. Priemerný absolútny rozdiel medzi dvojicami indexov s odlišným referenčným obdobím (ked'že pri rozdieloch 1 a 11, resp. 2 a 12., atď. sú všetky parametre rovnaké, akurát boli pri indexoch použité iné metódy výpočtu PET, uvádzame tieto hodnoty vedľa seba. K rozdielom indexov s PET=Harg. (nevýšrafovanej) patria čísla 1-10, kým pre rozdiely indexov s PET=P.M. (vyšrafovanej) patria čísla 11-20).

Rozdiel indexov, ktoré sa líšia v použitej metóde výpočtu PET

Pri indexoch, ktoré sa od seba líšili metódou výpočtu PET sme zaznamenali maximálny absolútny rozdiel 0,68 (dvojica 1) až 2,42 (dvojica 4) pre jednomesačné indexy, 0,2 (dvojica 7) až 2,15 (dvojica 4) pre trojmesačné indexy a 0,7 (dvojica 1) až 2,05 (dvojica 4) (tabuľka 4, časť c, oranžová časť). V priemere bol absolútny rozdiel medzi indexami s inou metódou výpočtu PET 0,12 pri jednomesačných a trojmesačných indexoch a 0,16 pri šest' mesačných indexoch. Jednoznačne vyššie priemerné absolútne odchýlky, ako aj vyššie štandardné odchýlky sa vyskytli pri porovnaní indexov s 20 ročným referenčným obdobím (dvojice 2 a 4). V týchto prípadoch bola priemerná odchýlka od 0,13 (dvojice 2 a 4 pri jednomesačnom indexe) po 0,19 (dvojica 4 pri šest' mesačnom indexe). Tento výsledok poukazuje na fakt, že pri použití 20 ročných referenčných období musíme počítať s väčšou nepresnosťou indexu.



Graf 3. Priemerný absolútny rozdiel medzi dvojicami indexov s odlišnou metódou výpočtu potenciálnej evapotranspirácie.

DISCUSSION AND CONCLUSIONS

V tejto práci sme analyzovali ako sa zmení hodnota indexu SPEI pri zmene štatistického rozdelenia rozdielu zrážok a PET, zmene referenčného obdobia indexu, či zmene metodiky výpočtu PET vstupujúcej do indexu. Absolútne odchýlky medzi indexami, ktoré sa líšili iba v skúmanom parametri poukazujú, že zmena indexu pri zmene jedného z uvedených parametrov môže byť väčšia než 0,5, čím sa podľa kategorizácie indexu SPEI (Tabuľka 2) môže dané obdobie preradiť do inej vlhkostnej kategórie.

Zo skúmaných parametrov sme najväčšie zmeny indexu sponzorovali pri zmene referenčného obdobia indexu (najmä pri kratších referenčných obdobiach a referenčných obdobiach, ktoré nemajú vzájomný prekryv rokov). Priemerná absolútna odchýlka pri zmene referenčného obdobia sa pohybovala na úrovni 0,2. Pri zmene metódy výpočtu PET boli hodnoty priemernej absolútnej odchýlky 0,13. Najmenšiu zmenu priniesla zmena štatistického rozdelenia rozdielu zrážok a PET: 0,06.

Napriek malej zmeni indexu pri zmene použitého štatistického rozdelenia je pri zmene tohto prvku potrebná hlbšia analýza vhodnosti jednotlivých štatistických rozdelení. Pri štúdiu literatúry sme sa totiž stretli napríklad s tvrdením, že pri použití GEV rozdelenia sa vyskytol väčší počet prípadov, kedy model nedokázal na základe vstupných podmienok vypočítať parametre zvoleného rozdelenia v porovaní s log-logistickým rozdelením, kedy sa takéto prípady vyskytli iba zriedkavo, prípadne sa nevyskytli vôbec (Vicente-Serrano, Beguería 2016). Okrem toho, niektorí autori uvádzajú, že pri použití GEV rozdelenia sa extrémne hodnoty indexov s nereálne vysokými návratovými hodnotami indexov vyskytujú častejšie než pri použití log-logistického rozdelenia (Vicente-Serrano, Beguería 2016).

Rovnakú analýzu rozdielov medzi indexami sme výkonali aj pre stanice Košice-letisko a Kráľová pri Senci. Výsledky týkajúce sa týchto dvoch staníc sa zhodujú s našimi výsledkami na stanici Beluša. Pri všetkých troch stanicach bolo rovnaké poradie vplyvu zmeny parametrov na veľkosť indexu a tiež aj približne rovnaké hodnoty priemerných absolútnych odchýlok pri všetkých 3 častiach úlohy (a, b a c).

Naša analýza tiež ukázala, že použitie 20 ročného referenčného obdobia viedie k väčšej nepresnosti indexu, najmä v oblasti extrémnych hodnôt. Odporučame preto používať dlhšie referenčné obdobie.

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REFERENCES

- Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998): Crop evapotranspiration-Guidelines for computing crop water requirements. *FAO Irrigation and drainage paper* [online]. p. 300. Available from: <http://www.fao.org/3/X0490E/X0490E00.htm>.
- Beguería, S., Vicente-Serrano, S.M., Reig, F., Latorre, B. (2014): Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *International Journal of Climatology* [online]. 1 August 2014. Vol. 34, no. 10, p. 3001–3023. Available from: <http://doi.wiley.com/10.1002/joc.3887>
- Gudmundsson, L., Stagge, J.H. (2016): *SCI: Standardized Climate Indices Such as SPI, SRI or SPEI* [online]. package version 1.0-2. Available from: <https://cran.r-project.org/package=SCI>.
- SHMÚ (2015): *Klimatický atlas Slovenska*. Bratislava: Slovenský hydrometeorologický ústav. ISBN 978-80-88907-90-9.
- Stagge, J.H., Tallaksen, L.M., Gudmundsson, L., Van Loon, A.F., Stahl, K. (2015): Candidate Distributions for Climatological Drought Indices (SPI and SPEI). *International Journal of Climatology* [online]. Available from: <https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/joc.4267>.
- Stagge, J.H., Tallaksen, L.M., Gudmundsson, L., Van Loon, A.F., Stahl, K. (2016): Response to comment on “Candidate Distributions for Climatological Drought Indices (SPI and SPEI).” *International Journal of Climatology*. Vol. 36, no. 4, p. 2132–2138. DOI 10.1002/joc.4564.
- Svoboda, M.D., Fuchs, B.A. (2016): *Handbook of drought indicators and indices*. Geneva: World Meteorological Organization. ISBN 978-92-63-11173-9.
- Vicente-Serrano, S.M., Beguería, S. (2016): Comment on ‘Candidate distributions for climatological drought indices (SPI and SPEI)’ by James H. Stagge et al. *International Journal of Climatology* [online]. 30 March 2016. Vol. 36, no. 4, p. 2120–2131. Available from: <http://doi.wiley.com/10.1002/joc.447>.
- Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I. (2010): A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate* [online]. Vol. 23, no. 7, p. 1696–1718. Available from: <https://journals.ametsoc.org/doi/pdf/10.1175/2009JCLI2909.1>.



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