DOI: 10.31577/ahs-2022-0023.02.0031

ACTA HYDROLOGICA SLOVACA

Volume 23, No. 2, 2022, 273–281

Spatial and temporal variability of Aridity Index in lowland areas of Slovakia

Viera RATTAYOVÁ*, Marcel GARAJ, Kamila HLAVČOVÁ

Changes in precipitation and temperature caused by global warming are reasons for the increasing occurrence of hydrological extremes such as floods or droughts. The aridity index is a significant indicator of local climate changes and is often used for quantifying the long-term climate conditions of a given location. In addition, the values of the aridity index are indicators of the water conditions of the area and their potential tendency to change in humidity. Therefore, understanding the spatio-temporal patterns of the aridity index is a crucial goal for agricultural and water management of watersheds.
This research investigates the spatial and temporal variations of the aridity indices at 27 climatological stations situated in the lowland areas of Slovakia. The stations were divided into three main lowland areas according to their spatial location. The United Nations Environmental Program (UNEP) method was used, and 40 years climatological measurements data from the Slovak Hydrometeorological Institute (SHMI) was considered for calculating the monthly and yearly mean values of the aridity index and assessing its spatial and temporal patterns.
Trends in the monthly and yearly spatial mean values of the aridity index showed significant variability between selected areas. The annual mean of the aridity index of stations situated in the Juhoslovenská kotlina lowland indicates increasing trends in the aridity index in winter months and in July. In the case of other lowlands, there were no trends in the monthly and yearly values. Other significant differences were observed in the seasonal variability of the mean monthly values of the aridity index in selected areas.

KEY WORDS: Aridity Index, Drought Assessment, Reference Evapotranspiration

Introduction

The aridity index is an often used index for characterising the long-term climatic conditions of a region. For example, studies of the aridity index have shown that under conditions of increasing concentrations of CO_2, the aridity values will increase (Greve et al., 2019).
Changes in the aridity index offer information about the impact of climate change and related climate variables on the availability of water. This index is also used as an indicator of climate change in many studies, where the trends of hydrological variables are investigated(Arora, 2002), and is used as an indicator of climate change (Huo et al., 2013; Kafle and Bruins, 2009). It has also been used for the determination of changes in crop yields (Bannayan et al., 2010; Ranjan et al., 2012).
Research of Tomlain and Škvarenina (2007) realized on 31 meteorological stations in Slovakia showed high variability of aridity index in selected stations. They divided the station into samples according to vertical vegetational zones. The aridity index calculated according to the Budyko method was moved in intervals 1.4–0.4, where *AI* value constantly decreases with the increasing altitude of stations. In the Region of central Europe, SPI and SPEI indexes are more frequently used to evaluate the drought. Vido et al. (2019) evaluated drought in the Horne Pozitavie region of Slovakia using the SPEI index. The results showed increasing humid conditions in winter and drier conditions in spring and summer, with a negative trend of SPEI in April, which can have consecutive impacts on agricultural yields. Study of Řehoř et al. (2021) shows gridded soil-drought values from the SoilClim model for the 1961–2019 period in four lowlands in central Europe at altitudes of below 400 m a.s.l.. In the winter half-year, linear trends in soil drought decrease progressively but are statistically insignificant for all four regions. Increasing annual temperature, increasing frequency of anticyclonic circulation types, and decreases in cyclonic types are probably the main drivers of the changing frequency and intensity of soil-drought episodes and their distribution over the year.
To calculation of aridity index, it is necessary to define the difference between incoming moisture totals and potential outgoing moisture. Several methods have been developed for describing and estimating moisture deficit, that use different input parameters to estimate the aridity

index. Thornthwaite (1948) calculated the values of the aridity index as the difference between reference evapotranspiration and precipitation divided by reference evapotranspiration. UNEP (1997) suggested using the ratio of total precipitation to the mean atmospheric evaporative demand (expressed as potential evapotranspiration). Calculating the aridity index according to the UNEP (1997) method requires determining the potential evapotranspiration from the measured climatological data that represents moisture losses. This method was originally developed for evaluations of the aridity index on a global scale and for its application. The Thornthwaite method was used for the calculation of potential evapotranspiration. The authors mention a more sophisticated method for estimating the evaporation rate, such as „calculating evapotranspiration rates for different crop types or calculating the soil moisture deficit in relation to precipitation and evapotranspiration". However, this method was not used in the study because it requires many inputs that are not available worldwide.
The aridity index calculated by this method does not consider the effect of seasonal variations in climatological inputs. The climate of an area can be categorized into five classes (Şarlak and Mahmood Agha, 2018):

- Humid →$AI \geq 0.65$
- Drought sub-humid →$0.5 \leq AI < 0.65$
- Semi-arid →$0.2 \leq AI < 0.5$
- Arid areas →$0.05 \leq AI < 0.2$
- Hyper-arid →$AI < 0.05$

For the calculation of the Aridity Index, a wide range of climatological variables measurements are necessary, especially for the estimation of reference evapotranspiration which is used instead of potential evapotranspiration. Reference evapotranspiration (ET_0) is a specific type of the potential value of evapotranspiration, which has been described as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m., a fixed surface resistance of 70 s m^{-1} and an albedo equal to 0.23, closely resembling an extensive surface of green grass" (Smith et al., 1990). FAO-56 Penman-Monteith equation for calculation of ET_0 (Eq.2) was utilized to calculate reference evapotranspiration. This method is commonly used as the benchmark method in research aimed at determining the water deficit of an area and evaluations of droughts (Ficklin et al., 2015).
Identification of the changes in the aridity index yields essential input for the management of watersheds and management of agricultural land. However, despite the many studies in various countries and regions on trends in the aridity index, only a few analyses are available for the Slovak Republic. This study aims to characterize temporal changes in the aridity index and determine the spatial distribution of AI values for identifying areas in the lowland regions of Slovakia the most endangered by aridity.

Materials and methods

Climatological data from 27 climatological stations of the maximum, minimum and mean air temperature, the wind speed at a 2 m height, actual water pressure, precipitation and duration of the sunsets in daily time step for the period from 1980 to 2019 was accessed from the Slovak Hydrometeorological Institute (SHMI). The 40-year period was considered to assess the spatial and temporal pattern of the aridity index. The list of 27 climatological stations (Fig. 1) was divided into three groups based on the lowland geomorphological units of Slovakia, i.e., a) Podunajská and Záhorská nížina lowland – the western part b) Juhoslovenská kotlina lowland – the central part and c) Východoslovenská nížina lowland – the eastern part. These three areas are the most important in terms of agricultural production in Slovakia; therefore, it is useful to get to know how they deal with water. Especially nowadays and recently when the impact of the soil drought, meteorological and hydrological drought is much stronger.

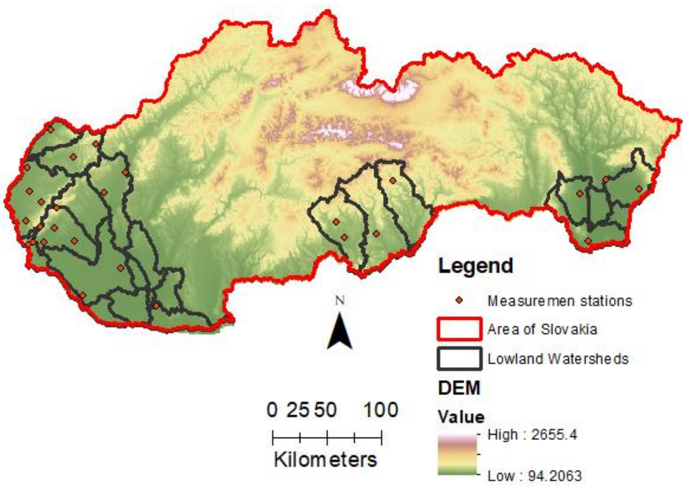

Fig. 1. Stations with measured meteorological data on selected lowland areas of Slovakia.

For calculating the aridity index (*AI*), the worldwide used UNEP (1997)method was selected. This method describes the aridity index as a deficiency of moisture under normal climatic conditions and is expressed as a ratio between total precipitation and potential evapotranspiration (Eq. 1, UNEP, 1997). According to Nastos et al. (2013), this method is suitable to use to appraise spatial patterns of aridity at a country or regional scale. The universal equation for calculating the Aridity Index is:

$$AI = \frac{P_i}{ET_{0_i}} \tag{1}$$

where

P_i –sum of precipitation for selected time step [mm i^{-1}]

ET_{0i} –sum of reference evapotranspiration for selected time step [mm i^{-1}]

The reference evapotranspiration in a daily step, which replaced potential evapotranspiration, was calculated using the FAO reference evapotranspiration equation for grass (Eq.2), according to the Penman–Monteith method (Allen et al., 1998). Replacement of the basic, low input required method for estimation of the potential evapotranspiration by a more sophistical method for calculating the reference evapotranspiration has been used in many studies (Koffi and Komla, 2015; Spinoni et al., 2015). This method provides better results for more specified regions, and, according to Sentelhas et al. (2010) and many other authors, is a universal standard for estimating *reference evapotranspiration*. The daily values of reference evapotranspiration were recalculated for monthly and yearly totals.

$$ET_0 = \frac{0.408 * \Delta * (R_N - G) + \Upsilon \frac{900}{T+273} * u_2 + (e_s - e_a)}{\Delta + \Upsilon * (1 + 0.34 * U_2)} \tag{2}$$

where

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

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

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

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

u_2 –wind speed at 2 m height [m s^{-1}];

e_s –saturation vapor pressure [kPa];

e_a –actual vapor pressure [kPa];

e_s - e_a –saturation vapor pressure deficit [kPa];

D –slope vapor pressure curve [kPa $°C^{-1}$];

Υ –psychrometric constant [kPa $°C^{-1}$].

Fig. 2 shows the seasonal distribution of the monthly values of the reference evapotranspiration, calculated by the Penman–Monteith equation.

The Penman-Monteith method (Allen et al., 1998) requires input data of the air temperature, relative air humidity (or vapour pressure), wind speed, and solar net radiation. The dataset of the solar net radiation is not accessible in the SHMI database; and it is necessary to calculate it according to one of the available methods. The daily values of the solar net radiation were calculated according to the FAO-56 methodology(Allen et al., 1998), which is part of the methodology for estimation of reference evapotranspiration by the FAO method, where the most important input is the duration of the sunset (eq.3).

$$R_n = [(1-\alpha) * R_s] - \left[\sigma * \left[\frac{T_{max,K} + T_{min,K}}{2}\right] * \left(0.34 - 0.14\sqrt{e_a}\right) * \left(1.35 * \frac{R_s}{R_{s0}} - 0.35\right)\right] \tag{3}$$

where

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

α –albedo or canopy reflection coefficient,

σ – Stefan-Boltzmann constant [4.903 10-9 MJ K^{-4} m^{-2} day^{-1}];

R_s – the incoming solar radiation [MJ m^{-2} day^{-1}];

R_{s0} – clear-sky solar radiation [MJ m^{-2} day^{-1}];

$T_{max,K}$ – maximum absolute temperature during a 24-hour period [K = °C + 273.16];

$T_{min,K}$ – minimum absolute temperature during a 24-hour period [K = °C + 273.16].

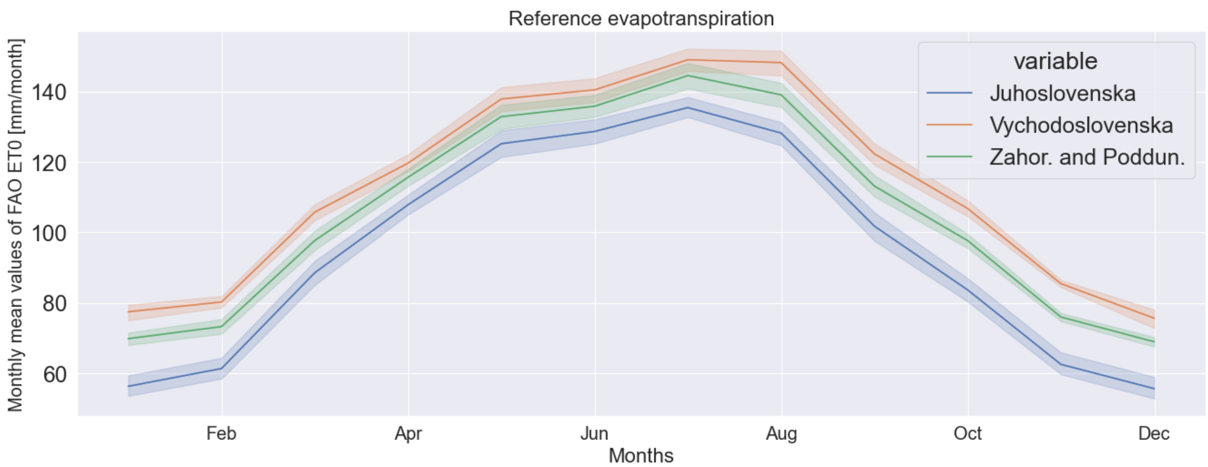

Fig. 2. Seasonal distribution of the monthly values of the reference evapotranspiration-areal mean value (the dark line is the median of the values, light border around the median is variance of the value).

Unfortunately, sunset duration data is unavailable in a length equal to length of the other climatologic data used. We cannot estimate this value from the value of any other accessible variable; therefore, the missing solar net radiation results were supplemented by reanalyzing the remote sensing data from the ERA5 dataset of the hourly data of net radiation on a single level, produced by Copernicus (2022). The values of the reanalyzed remote sensing data were calibrated by a simple linear model with net radiation derived from the measured data, with a Pearson correlation coefficient of 0.69, i.e., a moderate degree of correlation. The missing values of the calculated time series were replaced with data from these calibrated ERA5 net radiation datasets.

Mann-Kendall's non-parametric test was used for evaluating the monotonic tendencies of the aridity indices over time (Bevan and Kendall, 1971; Mann, 1945). This method for testing the trends was also recommended by the World Meteorological Organization (2009). The nature of the test is a correlation between the data ranks and sequences of a time series (Wang et al., 2020). For the calculation of the slope, the Theil–Sen (TS) method was applied (Sen, 1968; Theil, 1992).

Results

The results of the seasonal distribution show a different course of the mean monthly values of the aridity index in selected areas (Fig.3). The most significant difference in the seasonal distribution is in the case of stations in

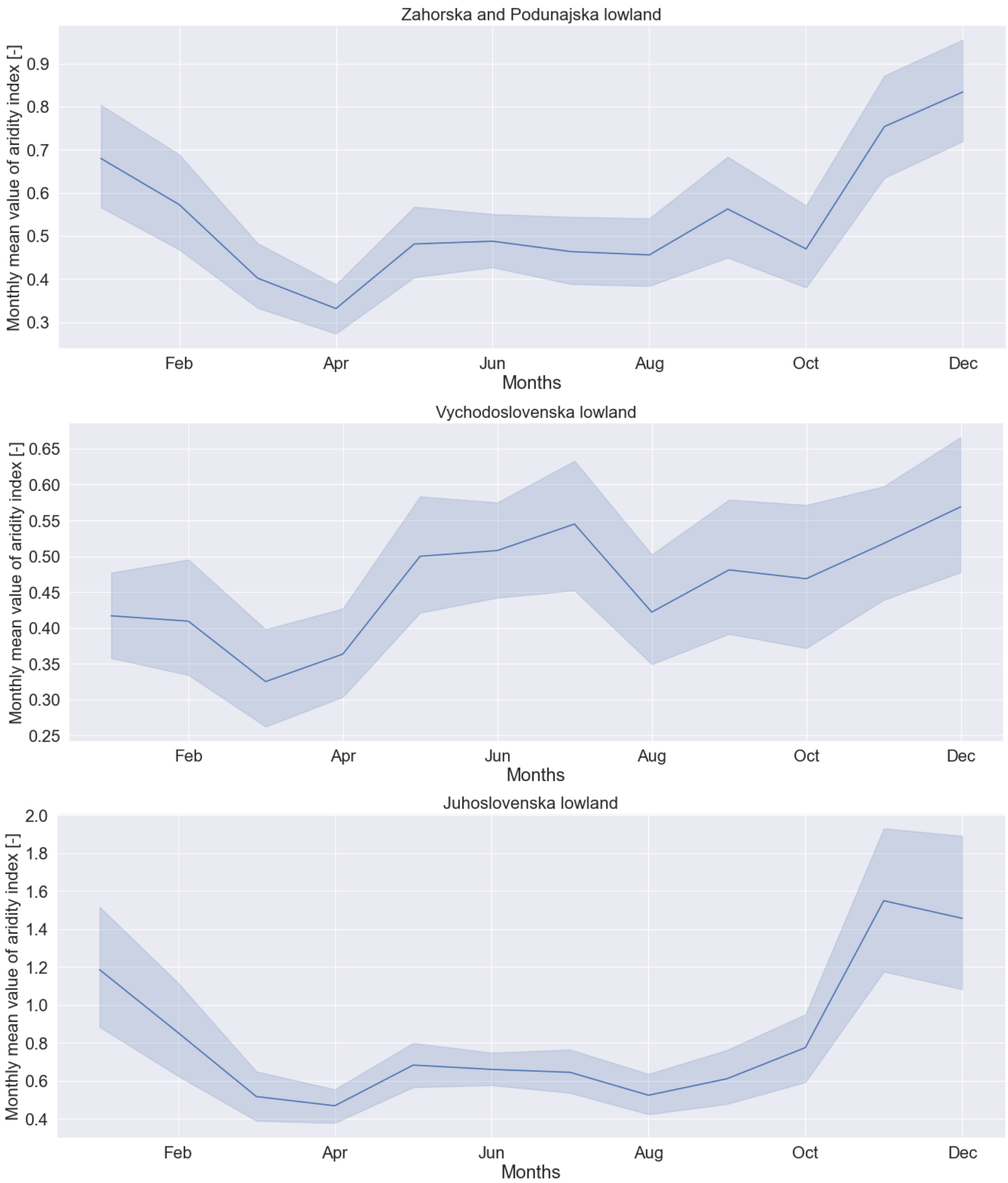

Fig. 3. Seasonal distribution of the mean monthly aridity index for selected areas (the dark line is median of the values, light border around the median is the variance of the values).

the Východoslovenská nížina lowland, where the mean monthly value of the aridity index is at its maximum in the summer months.

The seasonal distribution of the *AI* in the Záhorská and Podunajská nížina lowlands (Fig. 3) shows humid condition in the winter months and only becoming to semi-arid in April. The highest range of values appears in December. The seasonal distribution of *AI* in the stations in the Východoslovenská nížina lowland show a very similar course of AI; however, it is essential to point out that the values are higher than in other areas, and the Juhoslovenská kotlina lowland remains a dry humid area during all the months on average.

Moreover, the notable seasonal distribution of *AI* (Fig. 3) is for the Východoslovenská nížina lowland. At the end of the winter and in the early spring, the values of *AI* decrease below 0.5, which means that the area belongs to a semi-arid zone. This could be crucial for farmers in the spring season when vegetation and crops most demand water. It could increase costs for farmers to maintain healthy and vital plants. Another interesting fact is that the range of values is broad during all the months. This phenomenon is determined by the variability of the meteorological elements in the continental climate conditions representing the eastern part of Slovakia.

The linear regression with the trendline equation was derived from the yearly and monthly data (Fig. 4). To determine the significance of the trends, the Mann-Kendall trend test and the Thein-Sen slope were used. According to the results of the trends of the yearly values of AI, an increasing trend was identified by the Mann-Kendall test and the Thein-Sen slope on the monthly and yearly values in the case of the Juhoslovenská kotlina lowland. The trend analyses of the aridity index in the Juhoslovenská kotlina lowland with a significant level of α=0.05 showed a *p*-value of 0.0071 with a slope of 0.0059 for the yearly values and a *p*-value of 0.0000068 with a slope of 0.00066 for the monthly values.

The trend analyses of the monthly mean values for each month separately show the significant increasing trends of *AI* in the winter months- from December to February and in July (Table 1), in the station in the Juhoslovenská kotlina lowland. In the winter months of January and February, this phenomenon could be caused by a combination of an increasing precipitation trend and a decreasing trend of ET_0, the same situation occurs in July. In December, the increasing value of *AI* is probably caused by actual and previous months with decreasing

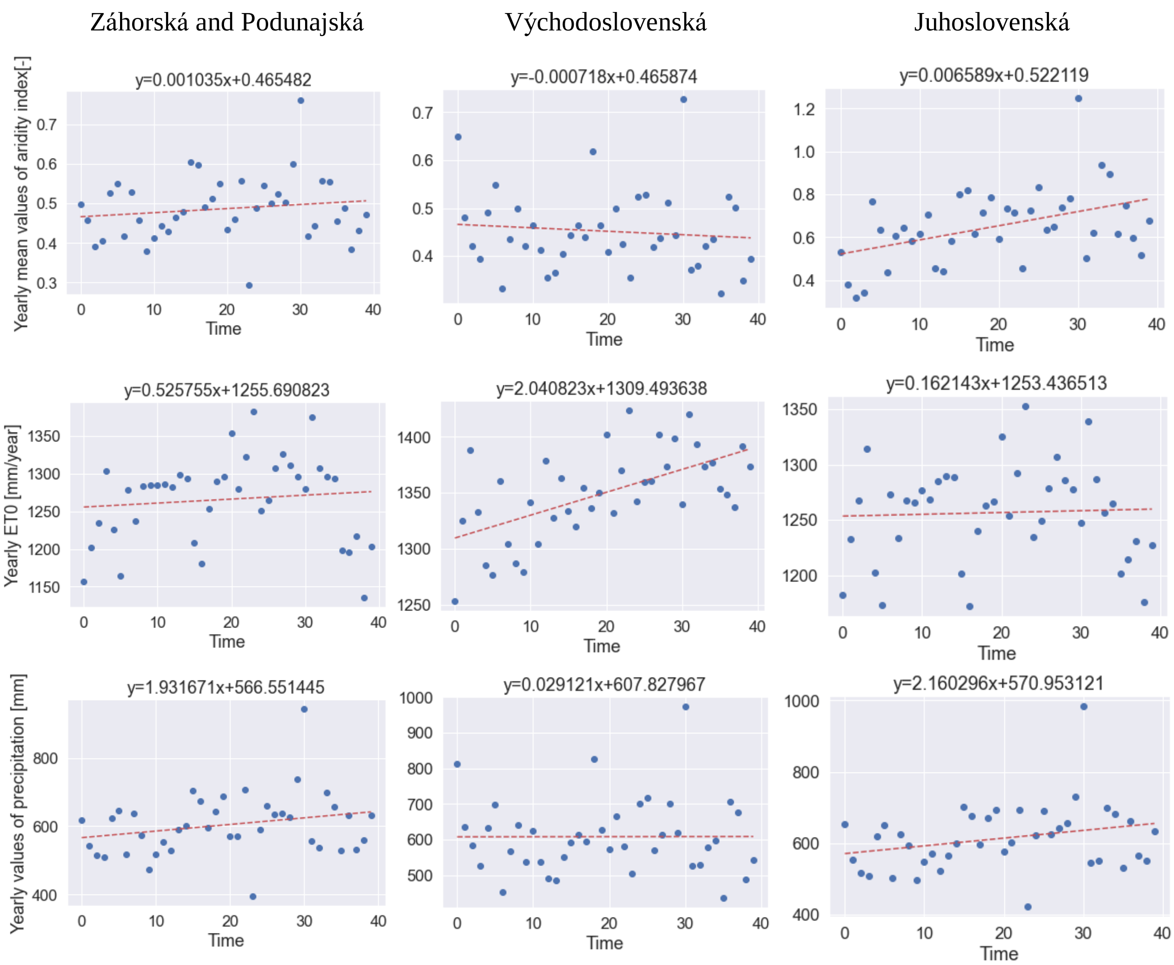

Fig. 4. Trends in the yearly mean aridity index and yearly sum of the reference evapotranspiration and precipitation for stations in selected areas – Linear regression.

value of ET_0, which continues to February. There is no trend in the monthly and yearly data in the spring and autumn months.

There were no recognized trends in the aridity index and precipitation in other areas. There is only a decreasing trend of ET_0, which is not significant enough to result in changes in the trends of the aridity index.

Another unexpected result is the difference between the seasonal distribution of the mean monthly precipitation and the seasonal distribution of the mean monthly aridity index values for the Juhoslovenská kotlina lowland. While the maximum monthly precipitation is concentrated in the summer months, i.e., from May to July (Fig. 5), the values of the aridity index are minimal in these months, with the maximum in the winter months, where the precipitation is in its minimal values. This impact is different in other selected areas, where the impact of the distribution of the monthly values of precipitation is discernible in the distribution of the monthly values of AI.

The pie charts (Fig. 6) below represent the fraction of each month allocated to a category of *AI* in the selected areas. Fig. 6 shows the highest frequency of months in the hyper-arid category (2.5%) and in the humid category of area in the stations of Juhoslovenská kotlina lowland with a fraction of 45.5% (Fig. 6). This area has the largethest ratio of months with edge categories of aridity index. Recognition of the spatial variability of the drought risk is significant for its management. On the other hand, the most considerable portion of the month adjunct to an area of semi-arid and dry sub-humid regions occurs in the stations in the Východoslovenská kotlina lowland, where is the highest fraction of months assigned like arid regions at the same time.

The range of the mean long-term values of the aridity index over the Slovak lowland stations is from 0.39 to 1.00 (Fig.7). The highest mean long-term values of the aridity index were estimated at the two stations of the Juhoslovenská kotlina lowland, i.e., Revúca and Malinec (0.99 and 1.0). The lowest value of the long-term aridity index was identified at the Gabčíkovo climatological station, where a value represents a semi-arida semi-arid climatic region.

In general, if we consider every area studied as a homogenous part, then we can assume that the climate of the central part of Slovakia in the Juhoslovenská kotlina lowland is categorized as a humid region according to the long-term mean value of the aridity index of 0.65. The Podunajská, Záhorská (*AI*=0.49) and Východoslovenská nížina lowland (*AI*=0.45) belong to semi-arid regions with a higher drought risk.

Table 1. Results from the Mann-Kendall trend analyses of the monthly values for each month separately (red-significant trend α=0.05, yellow-low significant trend α=0.1)

Zahorská and Podunajská lowland	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AI												
P												
ET_0				↑		↑						

Juhoslovenská lowland	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AI	↑	↑					↑					↑
P	↑	↑					↑	↑				
ET_0	↓	↓							↓	↓	↓	↓

Vychodoslovenská lowland	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AI												
P												
ET_0				↑		↑	↑	↑			↑	

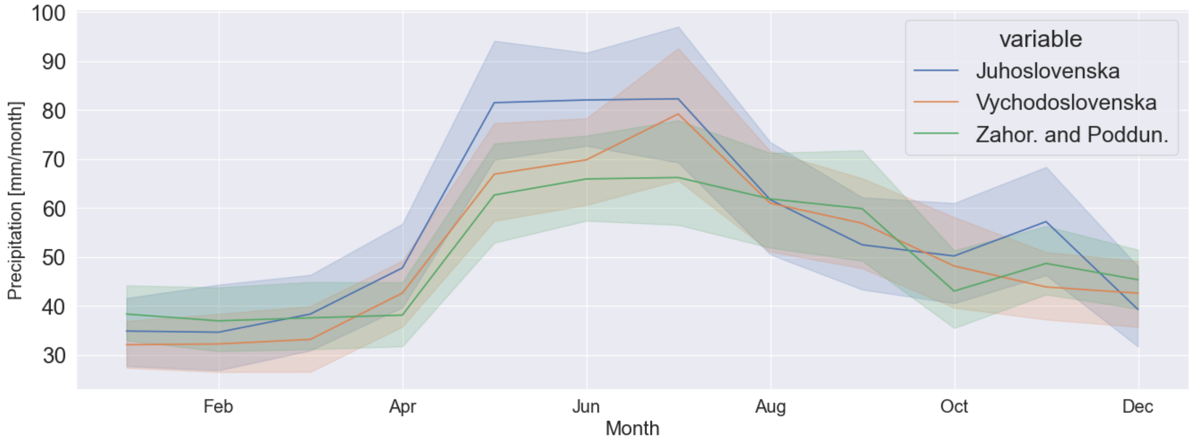

Fig. 5. *Seasonal distribution of the long-term total monthly precipitation.*

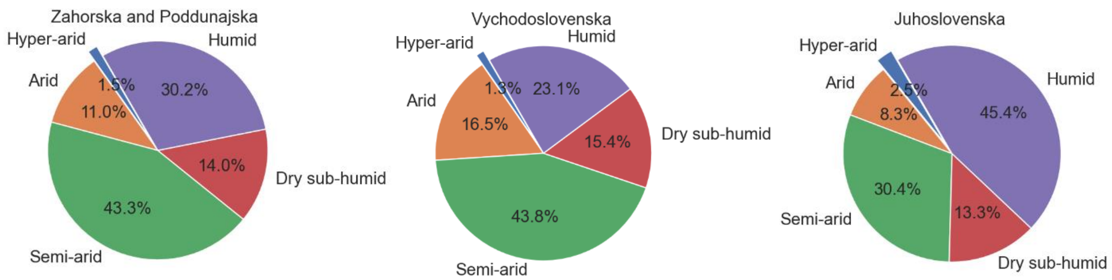

Fig. 6. *Categorization of the months according the mean value of aridity index.*

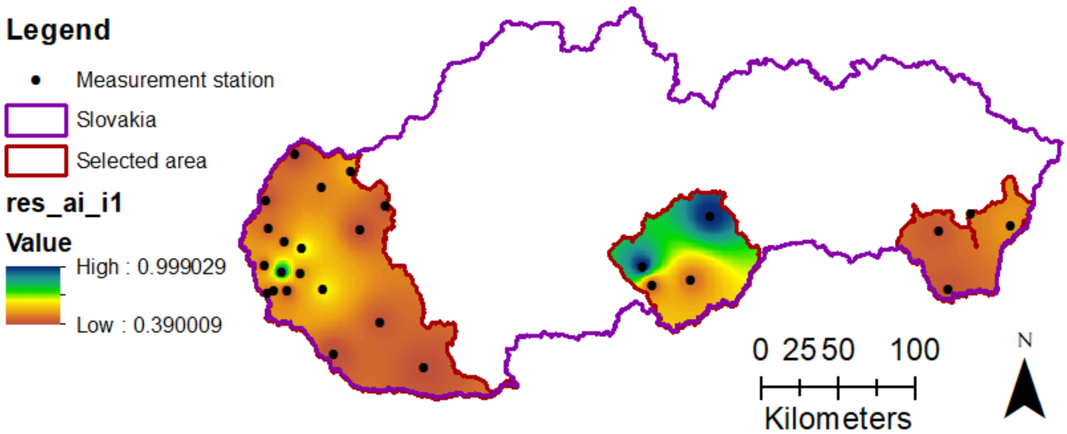

Fig. 7. *Spatial distribution of the mean long-term aridity index.*

Conclusion

The results show significant increasing trend in monthly values of *AI* (α=0.05) in the case of the Juhoslovenská kotlina Lowland, with the *p*-value $7*10^{-6}$ and Sen´s slope 0.0007 and *p*-value 0.007 and Sen´s slope 0.006 in yearly values. The seasonal distribution of the aridity index in the Juhoslovenská kotlina, Záhorská, and Podunajská nížina lowlands have two local minimums, the most significant in April (Juhosl. = 0.47, Zahor. and Pod. = 0.33) and the second local minimum in August (Juhosl. = 0.52, Záhor. and Pod. = 0.46). The maximum values of the aridity index were identified in the winter months in both areas, in November on Juhoslovenska nížina lowland (*AI*=1.55) and in December for Záhorská and Podunajská nížina lowland (*AI*=0.83). The third local minimum can be recognized in October in the case of the Záhorská and Podunajská nížina lowland. In the Vychodoslovenská nížina lowland, the monthly distribution of aridity index values is different from other areas, and the maximum values are recognized in the late spring and summer – in May (*AI*=0.49) and July (*AI*=0.54). The minimum *AI* values was detected in March (*AI*=0.32), with a second local minimum in August (*AI*=0.42). These differences could be caused by differences in the climate of these regions because in the eastern part of Slovakia the climatic characteristics are more continental than in the western part of Slovakia. In the long-term trends of AI, we can find the significant increasing trends in the Juhoslovenská kotlina Lowland in the yearly and monthly mean values. Detailed trend analyses for each month separately show the significant increasing trends of *AI* in the winter months, i.e., from December to February and in July. The differing yearly distribution of the monthly mean values of the aridity index than in the monthly distribution of precipitation in the Juhoslovenská kotlina lowland may imply that in this area, the precipitation does not have the same impact on the distribution of the mean aridity values, as in the case of the other selected areas. To interpretation of the relationship between these characteristics, it is necessary to carefully and consider all possibilities, because in some cases, the ostensible relationship could occur by changes in other related characteristics caused by climate change. Describing the relationship between climatic characteristics and the aridity index will be the goal of our following research.

Acknowledgement

"This publication is the result of the project implementation: „Scientific support of climate change adaptation in agriculture and mitigation of soil degradation" (ITMS2014+ 313011W580) supported by the Integrated Infrastructure Operational Programme funded by the ERDF; and was supported by the Slovak Research and Development Agency under Contract No. APVV-18-0347; and grant number VEGA 1/0782/21."

References

Allen, R. G., Pereira, L. S., Raes, D., Smith, M. W. B. (1998): Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. *Irrigation and Drainage*. https://doi.org/10.1016/j.eja.2010.12.001

Arora, V. K. (2002): The use of the aridity index to assess climate change effect on annual runoff. *Journal of Hydrology*, *265*(1–4). https://doi.org/10.1016/S0022-1694(02)00101-4

Bannayan, M., Sanjani, S., Alizadeh, A., Lotfabadi, S. S., Mohamadian, A. (2010): Association between climate indices, aridity index, and rainfed crop yield in northeast of Iran. *Field Crops Research*, *118*(2). https://doi.org/10.1016/j.fcr.2010.04.011

Bevan, J. M., Kendall, M. G. (1971): Rank Correlation Methods. *The Statistician*, *20*(3). https://doi.org/10.2307/2986801

Ficklin, D. L., Letsinger, S. L., Gholizadeh, H., Maxwell, J. T. (2015): Incorporation of the Penman-Monteith potential evapotranspiration method into a Palmer Drought Severity Index Tool. *Computers and Geosciences*, *85*. https://doi.org/10.1016/j.cageo.2015.09.013

Greve, P., Roderick, M. L., Ukkola, A. M., Wada, Y. (2019): The aridity Index under global warming. *Environmental Research Letters*, *14*(12). https://doi.org/10.1088/1748-9326/ab5046

Huo, Z., Dai, X., Feng, S., Kang, S., Huang, G. (2013): Effect of climate change on reference evapotranspiration and aridity index in arid region of China. *Journal of Hydrology*, *492*. https://doi.org/10.1016/j.jhydrol.2013.04.011

Kafle, H. K., Bruins, H. J. (2009): Climatic trends in Israel 1970-2002: Warmer and increasing aridity inland. *Climatic Change*, *96*(1). https://doi.org/10.1007/s10584-009-9578-2

Koffi, D., Komla, G. (2015): Trend analysis in reference evapotranspiration and aridity index in the context of climate change in Togo. *Journal of Water and Climate Change*, *6*(4). https://doi.org/10.2166/wcc.2015.111

Mann, H. B. (1945): Non-Parametric Test Against Trend. *Econometrica*, *13*(3).

Nastos, P. T., Politi, N., Kapsomenakis, J. (2013): Spatial and temporal variability of the Aridity Index in Greece. *Atmospheric Research*, *119*. https://doi.org/10.1016/j.atmosres.2011.06.017

Ranjan, K., ·P., Goyari, P., Mishra, R. K. (2012): Measuring Weather Impact on Crop Yield Using Aridity Index: Evidence from Odisha. In *Agricultural Economics Research Review* (Vol. 1, Issue 26).

Řehoř, J., Brázdil, R., Trnka, M., Lhotka, O., Balek, J., Možný, M., Štěpánek, P., Zahradníček, P., Mikulová, K., Turňa, M. (2021): Soil drought and circulation types in a longitudinal transect over central Europe. *International Journal of Climatology*, *41*(S1). https://doi.org/10.1002/joc.6883

Șarlak, N., Mahmood Agha, O. M. A. (2018): Spatial and temporal variations of aridity indices in Iraq. *Theoretical and Applied Climatology*, *133*(1–2), 89–99. https://doi.org/10.1007/s00704-017-2163-0

Sen, P. K. (1968): Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association*, *63*(324). https://doi.org/10.1080/01621459.1968.10480934

Sentelhas, P. C., Gillespie, T. J., Santos, E. A. (2010): Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. *Agricultural Water Management*, *97*(5). https://doi.org/10.1016/j.agwat.2009.12.001

Smith, M., Segeren, A., Santos Pereira, L., Perrier, A., Allen, R. (1990): *Report on the Expert Consultation on Procedures for Revision of FAO Guidelines for Prediction of Crop Water Requirements. Rome, Italy, 28–31 May 1990*. https://doi.org/10.3/JQUERY-UI.JS

Spinoni, J., Vogt, J., Naumann, G., Carrao, H., Barbosa, P. (2015). Towards identifying areas at climatological risk of desertification using the Köppen-Geiger classification and FAO aridity index. *International Journal of Climatology*, *35*(9). https://doi.org/10.1002/joc.4124

Theil, H. (1992): *A Rank-Invariant Method of Linear and Polynomial Regression Analysis*. https://doi.org/10.1007/978-94-011-2546-8_20

Thornthwaite, C. W. (1948): An Approach toward a Rational Classification of Climate. *Geographical Review*, *38*(1). https://doi.org/10.2307/210739

Tomlain, J., Škvarenina, J. (2007): K charakteristike vlhkostných pomerov vegetačných stupňov Západných Karpát – index sucha a relatívna evapotranspirácia. *Vyskot, I. (Ed): „Klima Lesa“*.

UNEP. (1997): World atlas of desertification 2ED. *United Nations Environment Programme*.

Vido, J., Nalevankova, P., Valach, J., Sustek, Z., Tadesse, T. (2019): Drought Analyses of the Horne Pozitavie Region (Slovakia) in the Period 1966–2013. *Hindawi Advances in Meteorology*. https://doi.org/https://doi.org/10.1155/2019/3576285

Wang, F., Shao, W., Yu, H., Kan, G., He, X., Zhang, D., Ren, M., Wang, G. (2020): Re-evaluation of the Power of the Mann-Kendall Test for Detecting Monotonic Trends in Hydrometeorological Time Series. *Frontiers in Earth Science*, *8*. https://doi.org/10.3389/feart.2020.00014

World Meteorological Organisation (WMO) (2009): Guide to Hydrological Practices: Volume II: Management of Water Resources and Application of Hydrological Practices (sixth edition). In *WMO Report No. 168: Vol. II* (Issue 168). https://doi.org/10.1080/02626667.2011.546602

Ing. Viera Rattayová (*corresponding author, e-mail: viera.rattayova@stuba.sk)
Prof. Ing. Kamila Hlavčová, PhD.
Department of Land and Water Resource Management
Faculty of Civil Engineering
Slovak University of Technology
Vazovova 5
812 43 Bratislava 1
Slovak Republic

Mgr. Marcel Garaj, PhD.
Department of the Climatological Service
Slovak Hydrometeorological Institute
Jeséniova 17
833 15 Bratislava
Slovak Republic