

# IDŐJÁRÁS

*Quarterly Journal of the HungaroMet Hungarian Meteorological Service  
Vol. 130, No. 2, April – June, 2026, pp. 101–115*

## **Two decades of increasing aridity and temperature trends in the Nagykunság region, Hungary (2005–2024)**

**Krisztina Varga, Seren Zedan, Gergő Asbolt\*, Loujaine Seddik,  
István Csízi, Géza Tuba, György Zsigrai, and József Zsembeli**

*Hungarian University of Agriculture and Life Sciences, National Research Centre for Climate and  
Regional Land Management, Karcag, Kisújszállási út 166, H-5300, Hungary*

*\*Corresponding author E-mail: [Asbolt.Gergo@uni-mate.hu](mailto:Asbolt.Gergo@uni-mate.hu)*

*(Manuscript received in final form on August 26, 2025)*

**Abstract**— To better understand the impacts of global and regional climate change, it is essential to conduct investigations at the local level as well, particularly in climatically sensitive areas. The aim of our study is to present the climatic characteristics of the Nagykunság region based on annual data recorded at the Karcag meteorological station (HungaroMet 55405) between 2005 and 2024. Our analysis focuses on the long-term trends of key meteorological variables such as temperature, precipitation, evaporation, sunshine duration, wind speed, and air pressure. For data processing, we used the built-in statistical tools of Microsoft Excel, especially linear regression, moving averages, and trendline fitting. During the examined period, we identified a significant increase in temperature (+0.097 °C/year), a slight decrease in precipitation (−9.72 mm/year), and a rise in the number of sunshine hours (+18.95 hours/year). Our results highlight not only the ongoing climatic changes but also the urgent need for regional adaptation measures, particularly in agricultural management and water resource planning. The methodology demonstrates that accessible statistical tools can provide valuable insights to support local climate resilience strategies.

**Key-words:** Nagykunság region, weather data, long-term analysis, extreme weather

## 1. Introduction

The study of climate change impacts has become one of the most complex and urgent scientific and societal challenges of recent decades (*Intergovernmental Panel on Climate Change (IPCC)*, 2023). Numerous studies have documented changes in global climate systems, highlighting the rise in average temperatures, the reorganization of precipitation patterns, and the increasing frequency of extreme weather events (*Alexander et al.*, 2006; *Coumou & Rahmstorf*, 2012; *Fischer and Knutti*, 2015). While global and continental-scale climate models are indispensable for large-scale forecasting, identifying local and regional trends is essential for developing effective adaptation strategies (*Giorgi*, 2006; *Lelieveld et al.*, 2012; *Seneviratne et al.*, 2012).

Hungary is located on the continental fringe of the temperate zone, where the alternating influence of western European, Atlantic, and eastern European air masses prevails (*Péczely*, 1979; *Bartholy and Pongrácz*, 2010). These atmospheric characteristics, combined with the country's diverse topography – especially in the flat regions of the Great Hungarian Plain – result in significant microclimatic variations. In the Great Hungarian Plain, changes in temperature and precipitation patterns are particularly pronounced, directly affecting agricultural production, water management, and the condition of ecosystems (*Spinoni et al.*, 2015).

In recent decades, rising summer temperatures and decreasing precipitation have already been documented in the Great Hungarian Plain. The observed climatic trends in this region show significant deviations compared to other parts of the country, particularly between the Trans-Tisza and Transdanubia regions. This highlights the necessity of locally focused trend analyses, which enable the identification of region-specific impacts and their integration into climate-related decision-making processes (*Bartholy et al.*, 2015; *Szabó et al.*, 2019).

Nagykunság is an agroecologically significant region located in the central part of the Trans-Tisza region, characterized by flat terrain and a continental climate that gives rise to distinct climatic features (*Biró and Kovács*, 2024). In this area – particularly in Karcag – arable crop production and extensive grassland management play a dominant role, while semi-natural habitats such as saline grasslands and loess steppes are highly sensitive to weather extremes (*Tölgyesi et al.*, 2020). The region's climatic conditions – especially the seasonal variability of precipitation, temperature extremes, and fluctuations in sunshine duration – directly influence site-specific growing conditions and agricultural productivity (*Pongrácz et al.*, 2011; *Kocsis and Schweitzer*, 2013). Therefore, the analysis of local meteorological trends is justified not only from a scientific standpoint but also for practical reasons, particularly to support the foundation of climate adaptation measures.

A reliable foundation for meteorological trend analyses is provided by long-term, consistently recorded, and homogenized data series. The development of the

automatic station network of the Hungarian Meteorological Service (HungaroMet) enables the temporal analysis of daily-resolution, validated data (Izsák *et al.*, 2022). From these datasets, annual averages and totals can be calculated, yielding suitable indicators for examining trends in temperature and precipitation patterns, sunshine duration, and wind conditions (Izsák and Szentimrey, 2020).

In the town of Karcag (Jász-Nagykun-Szolnok County), the automatic meteorological station (code 55405) of HungaroMet has been recording daily meteorological data since 2005. Among the variables measured by the station are total precipitation, average, minimum, and maximum temperature, wind speed, sunshine duration, and global radiation. By aggregating these into annual datasets, a reliable time series can be constructed, enabling the examination of regional meteorological trends.

For the trend analysis, we used the built-in statistical tools of Microsoft Excel, particularly linear regression trendlines, moving averages, and the calculation of the coefficient of determination ( $R^2$ ). These straightforward methods are well-suited for examining the long-term direction, magnitude, and reliability of changes in meteorological variables. Therefore, the aim of this study is not to provide an in-depth statistical analysis through complex climate modelling, but rather to demonstrate that valuable insights into regional climate changes can be drawn using Excel-based tools.

In our study, we hypothesize that meteorological data recorded in Karcag between 2005 and 2024 reveal a gradual warming and drying trend, which may have significant agroecological implications for the Nagykovácsok region. The objective of our analysis is to assess the extent to which local weather trends reflect broader climatic changes characteristic of the Great Hungarian Plain and the Carpathian Basin, and to examine how these changes influence the ecological and agricultural stability of the region. Our findings aim to contribute to a deeper understanding of the region's climatic sensitivity and to provide a foundation for future ecological, agricultural, or climate adaptation studies.

## ***2. Materials and methods***

For our analysis, we used daily meteorological data from the automatic weather station located in Karcag (station code: 55405). The study covered the period from 2005 to 2024.

The daily meteorological variables measured by the station and included in the analysis are presented in *Table 1*.

Table 1. Meteorological variables used in the study

Variable name	Symbol	Unit	Description
Average daily temperature	$t$	°C	Daily average temperature
Minimum daily temperature	$tn$	°C	Lowest daily temperature
Maximum daily temperature	$tx$	°C	Highest daily temperature
Daily precipitation sum	$rau$	mm	Amount of daily precipitation
Potential evapotranspiration	$upe$	mm	Daily potential evapotranspiration
Sunshine duration	$ns$	hours	Number of sunshine hours per day
Global radiation	$sr$	J/cm <sup>2</sup>	Daily sum of global radiation
Relative humidity	$u$	%	Daily average relative humidity
Average wind speed	$f$	m/s	Daily average wind speed
Synoptic wind speed	$fs$	m/s	Daily average synoptic wind speed
Maximum wind gust	$fx$	m/s	Maximum wind speed per day
Soil temperature at 5 cm	$et5$	°C	Daily average soil temperature at 5 cm depth
Near-surface minimum temperature	$tsn24$	°C	Daily minimum near-surface temperature
Average air pressure	$p$	hPa	Station-level daily air pressure
Sea-level pressure	$p0$	hPa	Air pressure adjusted to sea level

Annual aggregates were calculated from daily values according to the nature of each variable. For precipitation and potential evapotranspiration, we calculated annual sums; for temperature and atmospheric parameters, we computed annual averages, minima, and maxima (Table 2).

Additionally, seasonal breakdowns were performed for spring, summer, autumn, and winter to identify seasonal variations. Furthermore, a section on extreme weather events (e.g., water-deficit and drought periods) was included, comparing these to the climatic water balance (CWB – Thornthwaite and Mather, 1955).

To assess temporal trends, we applied linear regression models using the statistical functions of Microsoft Excel. The slope of the regression line and the corresponding p-value were used to evaluate long-term changes in each variable.

Table 2. Annual totals calculated on the basis of daily meteorological data for the years under study (Karcag, 2005–2024)

Year	<i>t</i> (°C)	<i>tn</i> (°C)	<i>tx</i> (°C)	<i>rau</i> (mm)	<i>upe</i> (mm)	<i>ns</i> (h)	<i>sr</i> (J/cm <sup>2</sup> )	<i>u</i> (%)	<i>f</i> (m/s)	<i>fs</i> (m/s)	<i>fx</i> (m/s)	<i>et5</i> (°C)	<i>tsn24</i> (°C)	<i>p</i> (hPa)	<i>p0</i> (hPa)
2005	9.8	-23.3	35.2	702.5	901.9	3046	511614.3	76.9	1.9	1.9	20.6	11.5	-11.6	1006.7	1017.6
2006	10.6	-16.5	34.3	585.3	981.5	2962	509486.9	76.1	1.9	1.9	21.9	11.8	-13.7	1007.5	1018.4
2007	12.0	-7.5	40.0	552.6	1289.5	3009	547125.8	68.8	2.4	2.4	25.1	13.0	-6.4	1006.1	1016.9
2008	11.4	-13.8	37.7	574.9	1048.5	3096	516925.2	74.1	2.3	2.3	24.9	12.3	-9.4	1006.4	1017.2
2009	11.6	-20.5	35.2	556.1	1216.2	2914	515396.6	70.9	2.2	2.2	22.7	12.4	-13.1	1004.7	1015.5
2010	10.4	-17.9	34.8	890.1	798.5	2846	488422.8	80.6	2.1	2.1	21.0	11.7	-11.0	1003.6	1014.4
2011	11.1	-13.9	37.6	385.7	1146.0	3070	487753.4	72.3	2.0	2.0	22.9	11.8	-7.6	1008.3	1019.2
2012	11.5	-21.2	38.8	344.8	1292.1	3154	521339.6	70.1	2.3	2.3	20.2	12.0	-13.1	1006.0	1016.8
2013	11.6	-13.5	37.7	574.2	1092.8	3001	464846.1	75.6	2.2	2.2	20.8	11.7	-9.3	1005.2	1016.0
2014	12.2	-11.9	35.4	630.0	991.8	2984	516984.6	77.5	2.0	2.0	24.5	13.1	-10.8	1005.5	1016.3
2015	12.1	-11.0	38.2	408.7	1160.5	2891	526305.1	73.9	2.2	2.2	25.1	12.8	-10.8	1008.2	1019.0
2016	11.2	-13.7	33.8	591.7	1013.9	3001	526893.0	75.9	2.0	2.0	20.2	12.2	-11.9	1006.6	1017.4
2017	11.2	-18.0	38.6	527.0	1159.3	3000	540046.9	72.9	2.3	2.3	22.0	12.2	-5.9	1006.9	1017.7
2018	12.4	-12.7	34.5	556.9	1178.7	3027	531891.6	74.4	1.9	1.9	19.3	12.9	-9.7	1006.2	1017.0
2019	12.5	-11.3	37.4	484.5	1152.3	3044	530244.8	72.8	2.2	2.2	28.6	12.9	-9.0	1005.6	1016.4
2020	11.7	-7.8	36.5	649.5	993.2	2848	507500.1	76.0	2.1	2.0	22.7	12.6	-9.1	1007.2	1018.1
2021	11.2	-12.6	37.5	397.8	1120.0	2983	523278.1	73.4	2.1	2.1	25.6	14.2	-10.1	1006.5	1017.3
2022	12.1	-14.1	39.4	342.0	1310.0	3000	521948.6	69.2	2.2	2.2	26.0	14.8	-11.0	1007.3	1018.1
2023	12.7	-8.8	37.9	572.3	1145.1	2512	408014.1	75.1	2.4	2.4	24.2	14.5	-8.9	1005.3	1016.1
2024	13.4	-9.5	39.5	357.1	1324.4	2896	495684.3	73.1	2.2	2.1	21.6	17.1	-7.6	1006.2	1017.0

Climatic variables were analyzed over time using linear trend analysis, which involved the following methodological steps: trends were estimated by fitting a linear regression line to the annual time series data. The slope ( $\beta$ ) of the fitted line expresses the average annual change in the variable (e.g., mm/year or °C/year).

The strength of the linear fit was expressed using the coefficient of determination ( $R^2$ ), indicating the percentage of total variance explained by the linear model. Trends were visualized in graphs, displaying the regression line along with its slope ( $\beta$ ), p-value, and  $R^2$ . The temporal changes were statistically analyzed using linear regression in Excel (LINEST and TREND functions), and the results were validated with non-parametric methods. For this, the Mann-Kendall trend test (*McLeod, 2022*) and Sen's slope estimator (*Pohlert, 2023*) were applied using the latest version of the R programming language (R 4.5.1, 2025-06-13 ucrt). The Kendall package (version 2.2.1) and the trend package (version 1.1.6) were used for robust trend analysis, suitable for data that may not meet normal distribution assumptions. This approach confirmed the direction and statistical significance of the results obtained in Excel.

### 3. Results

The trend analysis covered all available meteorological variables (*Table 3*). Using annual averages, totals, and extremes derived from daily values, we calculated the parameters of linear regression models along with their significance levels. The variables were evaluated by grouping them according to their nature. Seasonal analyses revealed additional details, while the 5-year moving averages smoothed out natural interannual fluctuations and highlighted more pronounced long-term changes.

Based on the trend parameters of the examined variables, it is advisable to clearly distinguish between significant ( $p < 0.05$ ), nearly significant ( $0.05 \leq p < 0.1$ ), and non-significant ( $p \geq 0.1$ ) trends. Notably, the strongest correlations were observed for average temperature ( $t$ ), minimum temperature ( $tn$ ), and soil temperature ( $et5$ ), where the coefficient of determination ( $R^2$ ) exceeded 0.25. Seasonal breakdowns revealed the most pronounced temperature increases during spring and summer, especially in the case of maximum temperature ( $tx$ ). This trend coincides with a decrease in spring precipitation sums, resulting in an increased evapotranspiration deficit. During summer, the combined effect of rising temperatures and increasing sunshine hours may critically contribute to water stress in vegetation. In contrast, autumn showed a slight increase in precipitation, while winter saw a rise in minimum temperature ( $tn$ ), which reduces the number of frost days.

Table 3. Trends of meteorological variables based on Excel and R statistical analysis (2005–2024)

Variable	$\beta$ (slope) (Excel)	R <sup>2</sup> (Excel)	p-value (Excel)	Trend direction	Significance	MK p-value (R)	Sen's slope (R)	Note
<i>t</i> (avg temp)	+0.097 °C/year	0.47	0.01	increasing	significant	0.0022	+0.093 °C/year	warming trend
<i>tn</i> (min temp)	+0.40 °C/year	0.29	0.03	increasing	significant	0.0179	+0.43 °C/year	milder winters
<i>tx</i> (max temp)	+0.103 °C/year	0.10	0.12	increasing	not significant	0.183	+0.13 °C/year	summer warming
<i>rau</i> (precip.)	-9.72 mm/year	0.18	0.08	decreasing	near-significant	0.0743	-9.63 mm/year	precipitation deficit
<i>upe</i> (PET)	+9.23 mm/year	0.15	0.06	increasing	near-significant	0.0904	+8.89 mm/year	intensifying evapotranspiration
<i>ns</i> (sunshine)	-9.18 hours/year	0.17	0.073	decreasing	near-significant	0.0729	-9.63 hours/year	cloudier periods
<i>sr</i> (radiation)	-1079.2 J/cm <sup>2</sup> /year	0.043	0.44	decreasing	not significant	0.871	+266.5 J/cm <sup>2</sup> /year	weak trend
<i>u</i> (humidity)	-0.059 %/year	0.01	0.22	decreasing	not significant	0.1614	-0.054 %/year	decreasing humidity
<i>f</i> (avg wind)	+0.003 m/s/year	0.02	0.33	stable	not significant	0.3095	+0.003 m/s/year	slight increase
<i>fs</i> (syn. wind)	+0.0027 m/s/year	0.01	0.35	stable	not significant	0.3276	+0.002 m/s/year	no major change
<i>fx</i> (max gust)	+0.099 m/s/year	0.06	0.14	increasing	not significant	0.2102	+0.092 m/s/year	slight increase in gusts
<i>et5</i> (soil temp 5 cm)	+0.172 °C/year	0.55	0.02	increasing	significant	0.0027	+0.169 °C/year	near-surface warming
<i>tsn24</i> (min near-surface temp)	+0.116 °C/year	0.10	0.11	increasing	not significant	0.1416	+0.12 °C/year	increasing ground-level temp
<i>p</i> (air pressure)	+0.011 hPa/year	0.00	0.45	stable	not significant	0.6054	+0.009 hPa/year	nearly unchanged pressure
<i>p0</i> (sea-level pressure)	+0.0072 hPa/year	0.00	0.47	stable	not significant	0.4834	+0.0068 hPa/year	nearly unchanged pressure

### 3.1 Temperature trends

The temperature data show a clear warming trend in the annual average temperatures recorded in Karcag ( $t$ ;  $\beta = +0.097$  °C/year;  $R^2 = 0.47$ ), indicating a significant linear relationship over time (Fig. 1). The Mann–Kendall trend test confirms this tendency ( $\tau = 0.507$ ,  $p = 0.0022$ ), and the Sen’s slope estimate (+0.1 °C/year) is consistent with the regression-based slope. The increase in minimum temperatures ( $tn$ ;  $\beta = +0.40$  °C/year;  $R^2 = 0.29$ ) suggests that night-time cooling is becoming progressively milder. According to the Mann–Kendall test ( $\tau = 0.389$ ,  $p = 0.0179$ ), this trend is statistically significant, and the Sen’s slope estimation indicates an increase of +0.43 °C/year. The rise in maximum temperature ( $tx$ ;  $\beta = +0.103$  °C/year;  $R^2 = 0.10$ ) is particularly pronounced during the summer months, which may indicate an increase in the number of heatwave days. Despite a visible tendency, the Mann–Kendall test ( $\tau = 0.222$ ,  $p = 0.183$ ) suggests a non-significant trend, though the Sen’s slope estimate remains positive (+0.13 °C/year). The near-surface minimum temperature ( $tsn24$ ) shows a slight increasing trend based on linear regression ( $\beta = +0.116$  °C/year;  $R^2 = 0.10$ ), although this trend is not statistically significant ( $p = 0.11$ ). The Mann–Kendall test, however, yields a near-significant positive trend ( $\tau = 0.277$ ,  $p = 0.097$ ), and the Sen’s slope estimation suggests a warming rate of +0.15 °C/year. The soil temperature at 5 cm depth ( $et5$ ) also displays a clear increasing trend ( $\beta = +0.172$  °C/year;  $R^2 = 0.55$ ) with statistical significance ( $p = 0.02$ ). This warming is further confirmed by a highly significant Mann–Kendall trend ( $\tau = 0.564$ ,  $p = 0.0006$ ), and the Sen’s slope indicates a warming rate of +0.14 °C/year. Average ( $t$ ) and maximum ( $tx$ ) temperatures increase most intensely during the summer months (June–August). In the winter months (December–February), significant increases are observed in the minimum temperature ( $tn$ ) and near-surface minimum temperature ( $tsn24$ ). Moving averages of the temperature variables reveal a clear upward trend, with the most marked increases observed for the soil temperature ( $et5$ ) and minimum temperature.

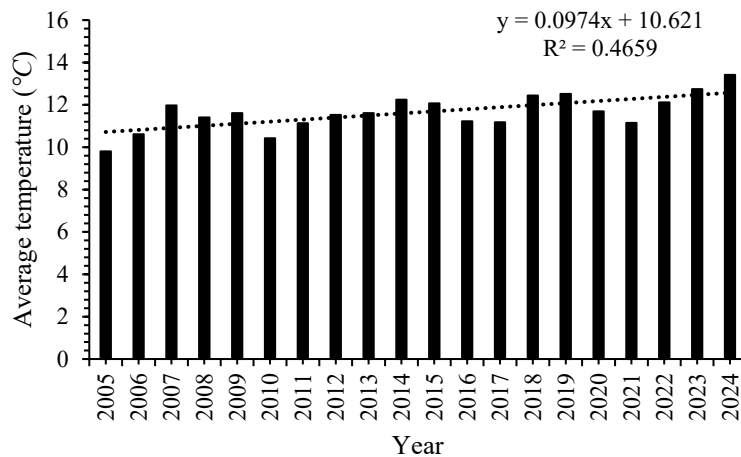


Fig. 1. Trend of annual mean temperature ( $t$ ) in Karcag, 2005–2024.

### 3.2 Precipitation and evapotranspiration

The annual precipitation total (*rau*) shows a slight decreasing trend ( $\beta = -9.72$  mm/year;  $R^2 = 0.18$ ), although due to natural variability, this trend is not pronounced every year. According to the Mann–Kendall test, this trend is near-significant ( $\tau = -0.295$ ,  $p = 0.074$ ), with a Sen’s slope estimate of  $-9.63$  mm/year. In parallel, the potential evaporation (*upe*) is increasing ( $\beta = +9.23$  mm/year;  $R^2 = 0.15$ ), indicating enhanced evaporative losses, which is an important implication in terms of drought sensitivity (Fig. 2). The Mann–Kendall test indicates a near-significant upward trend ( $\tau = 0.263$ ,  $p = 0.112$ ), and the Sen’s slope estimate is  $+9.53$  mm/year. This dual effect intensifies the evaporation deficit, potentially leading to long-term water supply challenges in the region. Spring precipitation totals (March–May) exhibit the most pronounced decrease, while autumn values show a slight increase. The moving average of precipitation (*rau*) reveals a gradual decline, whereas potential evaporation (*upe*) follows an upward trend.

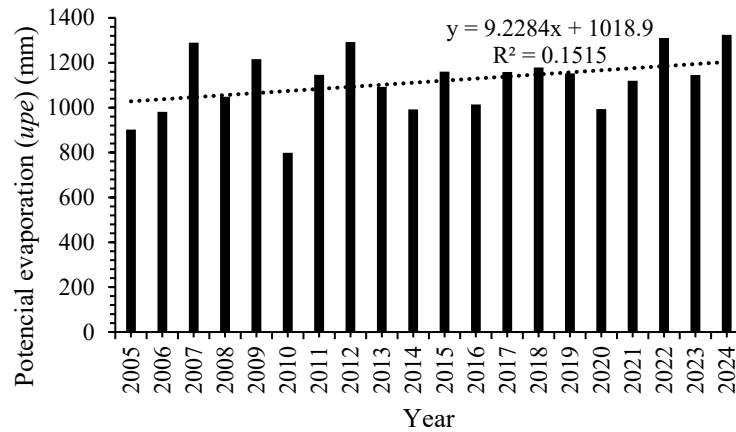


Fig. 2. Trend of annual potential evaporation (*upe*) in Karcag (2005–2024).

### 3.3 Sunshine and radiation

The number of sunshine hours (*ns*) shows a slight decreasing trend ( $\beta = -9.18$  hours/year;  $R^2 = 0.17$ ), which may indicate more frequent periods of cloudiness or changes in atmospheric composition. This is supported by a Mann–Kendall trend ( $\tau = -0.265$ ,  $p = 0.111$ ), with a Sen’s slope of  $-4.49$  hours/year, close to near-significance. The annual total of global radiation (*sr*) also exhibits a slight decreasing trend ( $\beta = -1079.2$  J/cm<sup>2</sup>/year) with relatively low explanatory power ( $R^2 = 0.04$ ), which could be partly related to changes in cloud cover or aerosol levels (e.g., dust, pollen). No significant trend is observed ( $p = 0.87$ ), and the Sen’s slope estimate is statistically insignificant.

### 3.4 Wind conditions

Both the synoptic wind speed ( $f_s$ ) and the average wind speed ( $f$ ) show minimal increases ( $f_s$ :  $\beta = +0.0027$  m/s/year;  $f$ :  $\beta = +0.003$  m/s/year), but these trends are statistically weak ( $R^2 < 0.02$ ). No significant trend is supported by the Mann–Kendall test of wind speed ( $p = 0.77$ ), and the Sen’s slope estimate is zero. The maximum wind gust speed ( $f_x$ ) exhibits an increasing tendency ( $\beta = +0.099$  m/s/year), which may amplify extreme fluctuations in the wind climate. A weak upward tendency (Sen’s slope =  $+0.08$  m/s/year) is not confirmed by Mann–Kendall ( $p = 0.44$ ). Maximum gusts ( $f_x$ ) tend to be stronger during the spring months, while they are weaker in winter.

### 3.5 Air pressure and relative humidity

Instrument-level ( $p$ ) and sea-level ( $p_0$ ) air pressure changes show weak but positive trends ( $p$ :  $\beta = +0.011$  hPa/year;  $p_0$ :  $\beta = +0.007$  hPa/year), but based on the coefficients of determination, these are not considered significant changes ( $R^2 < 0.01$ ). The Mann–Kendall test of sea-level shows no trend ( $p = 0.97$ ), the Sen’s slope is near zero. Relative humidity ( $u$ ) exhibits a slight decline ( $\beta = -0.06$  %/year;  $R^2 = 0.015$ ), which may indicate increasing aridity, especially during the summer months. A decreasing tendency is observed, though the Mann–Kendall ( $p = 0.53$ ) does not confirm statistical significance, while the Sen’s slope is  $-0.08$  %/year. Relative humidity decreases moderately in spring and summer, while it remains stable in autumn and winter. Moving averages show minimal variation in air pressure values, and no significant seasonal trends are observed.

Based on daily maximum temperatures, heatwave days exceeding  $35$  °C were examined for the period 2005–2024 (*Table 4*). Annual data show an increasing trend both in the number and duration of heatwaves. The longest heatwave was recorded in 2022, lasting 11 consecutive days. Both the number of heatwaves and the maximum temperatures have increased year by year, indicating more frequent heat stress conditions during summers.

Table 4. Heatwaves and their characteristics between 2005 and 2024

Year	Number of heatwave days	Number of heatwave events	Longest heatwave (days)	Annual maximum temperature (°C)
2005	2	0	2	35.2
2006	0	0	0	34.3
2007	11	1	7	40.0
2008	3	0	2	37.7
2009	1	0	1	35.2
2010	3	0	2	34.8
2011	6	1	4	37.6
2012	10	1	5	38.8
2013	4	0	2	37.7
2014	5	0	2	35.4
2015	8	1	4	38.2
2016	3	0	2	33.8
2017	7	1	4	38.6
2018	4	0	2	34.5
2019	9	1	5	37.4
2020	3	0	2	36.5
2021	6	1	4	37.5
2022	24	2	11	39.4
2023	5	0	2	37.9
2024	10	1	6	39.5

The annual values of the climatic water balance (*CWB*), calculated as the difference between precipitation and potential evapotranspiration, were negative in almost every studied year, indicating persistent moisture deficits (*Table 5*). Among the most extreme years were 2007 and 2022, with *CWB* values of  $-736.9$  mm and  $-968$  mm, respectively.

The annual number of water-deficit days exceeded 290 on multiple occasions, with the longest continuous period of water deficit lasting 65 days (in 2009). These data clearly underline the increasing drought sensitivity of the region.

Table 5. Climatic water balance (CWB) and water-deficit periods between 2005 and 2024

Year	Annual CWB (mm)	Number of water-deficit days	Longest water-deficit period (days)
2005	-199.4	289	28
2006	-396.2	294	36
2007	-736.9	301	41
2008	-473.6	301	34
2009	-660.1	300	65
2010	91.6	252	15
2011	-760.3	303	45
2012	-947.3	306	55
2013	-518.6	291	33
2014	-361.8	276	31
2015	-751.8	303	41
2016	-422.2	290	26
2017	-632.3	298	49
2018	-621.8	296	28
2019	-667.8	299	40
2020	-343.7	285	25
2021	-722.2	303	50
2022	-968.0	308	60
2023	-855.4	310	53
2024	-967.3	309	58

Overall, the results indicate that among the meteorological variables recorded in Karcag, temperature, evapotranspiration, and sunshine duration show significant increasing trends, while decreasing precipitation and relative humidity, along with the increasing number of water-deficit years, point toward climatic drying. The Mann–Kendall test and Sen’s slope estimator confirmed the statistical validity of the temperature trends detected by linear regression. We observed weaker but directionally consistent trends in precipitation and evapotranspiration. Trends with p-values below 0.05 were considered statistically significant. The Excel-based analyses effectively capture local signs of climate change and provide an important foundation for further agroclimatic studies.

#### 4. Discussion

The analysis of meteorological data recorded in Karcag reveals clear trends that are consistent with other national and international regional studies. The increasing trends in temperature variables – particularly average and minimum temperatures – corroborate observations across Hungary and Central Europe highlighting intensified warming over recent decades (*Bartholy et al.*, 2007; *Pongrácz et al.*, 2011).

The moderate but declining trend in precipitation, coupled with rising potential evapotranspiration, projects significant climatic and ecological challenges for the region. This is especially critical for agricultural production, as Nagykovács primarily relies on arable farming and livestock. The increasing frequency of years with high evapotranspiration potential fits well with the concept of a “desiccation spiral” (a process of gradual drought and increasing water scarcity) that has been confirmed by several studies for the Hungarian Great Plain (*Szalai and Szinell*, 2000; *Pongrácz et al.*, 2011).

The increase in sunshine hours alongside a slight decrease in global radiation may have a dual effect: while the former may support plant growth during the vegetation period, the latter may indicate changes in aerosol content and cloud cover in the climate system, as supported by other Hungarian research (*Lakatos et al.*, 2013).

Our results are in agreement with climate projections for the Carpathian Basin, particularly regarding rising temperatures and more extreme precipitation patterns (*Pongrácz et al.*, 2011; *Bartholy et al.*, 2015). Similar drying trends have been observed in other parts of the Hungarian Great Plain (e.g., Homokhátság, Békés-Csongrád region) (*Szabó et al.*, 2019), suggesting that the changes in Nagykovács fit into a broader regional climatic pattern.

The analysis of extreme temperature and water balance-based indicators further supports the observation that in the Nagykovács region, not only gradual warming but also an increased frequency of heat and moisture extremes have been observed over the past two decades. The rising number of days exceeding 35 °C and heatwaves, along with longer periods of water deficit, confirm estimates that the region is particularly vulnerable to the negative agricultural and ecological impacts of climate change (*Blanka et al.*, 2013; *Vadas and Rácz*, 2013).

Moreover, the application of more robust statistical methods, such as the Mann–Kendall test and Sen’s slope estimator, is justified in this study, as they are less sensitive to data variability and non-normal time series distributions. These methods more accurately confirm the direction and significance of climatic changes (*Hirsh et al.*, 1982; *Helsel et al.*, 2002).

A methodological strength of the Excel-based analysis is its ability to efficiently review long time series with basic statistical tools. While it does not replace complex modeling or multivariate statistical analysis, it effectively

captures key trends and can provide a foundation for future research, especially aimed at supporting climate adaptation strategies.

## 5. Conclusions

Based on data from the Karcag climate station for the period 2005–2024, it can be concluded that the climate changes occurring in the Nagykovács region are clear and affect multiple variables. The gradual increase in temperature, the decrease in precipitation, the rise in evapotranspiration, and the increase in sunshine hours together indicate a drying climatic trend. Although not all variables show significant trends individually, the combined effects clearly outline the warming and drying pattern characteristic of the Great Hungarian Plain. Based on our results, it is recommended to pay increased attention in the region to irrigation strategies, crop selection, and soil protection. Our study also demonstrates that reliable, publishable results can be achieved using simple tools such as Excel, which can provide a solid basis for preparing more complex climate adaptation decisions.

## References

- Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadah, F., Tagipour, A., Kumar, K. R., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, B.D., Burni, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., and Vazquez-Aguirre, J.L., 2006: Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, 111(D5), D05109. <https://doi.org/10.1029/2005JD006290>
- Bartholy, J. and Pongrácz, R., 2010: Analysis of precipitation conditions for the Carpathian Basin based on extreme indices in the 20th century and climate simulations for 2050 and 2100. *Physics and Chemistry of the Earth*, 35(1–2), 43–51. <https://doi.org/10.1016/j.pce.2010.03.011>
- Bartholy, J., Pongrácz, R., and Gelybó, G., 2007: Regional climate change expected in Hungary for 2071–2100. *Applied Ecology and Environmental Research*, 5(1), 1–17. [https://doi.org/10.15666/aeer/0501\\_001017](https://doi.org/10.15666/aeer/0501_001017)
- Bartholy, J., Pongrácz, R., and Kis, A., 2015: Projected changes of extreme precipitation using multi-model approach. *Időjárás*, 119(2), 129–142.
- Biró, K. and Kovács, E., 2024: Agro-climatic analysis for agricultural adaptation in Hungary. *Periodica Polytechnica Social and Management Sciences*, 32(2), 141–147. <https://doi.org/10.3311/PPso.22482>
- Blanka, V. Mezősi, G., and Meyer, B., 2013: Projected changes in the drought hazard in Hungary due to climate change. *Időjárás*, 117(2), 219–237.
- Coumou, D. and Rahmstorf, S., 2012: A decade of weather extremes. *Nature Climate Change*, 2(7), 491–496. <https://doi.org/10.1038/nclimate1452>
- Fischer, E. M. and Knutti, R., 2015: Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. *Nature Climate Change*, 5(6), 560–564. <https://doi.org/10.1038/nclimate2617>
- Giorgi, F., 2006: Climate change hot-spots. *Geophysical Research Letters*, 33(8), L08707. <https://doi.org/10.1029/2006GL025734>

- Helsel, D.R. and Hirsch, R.M., 2002: Statistical methods in water resources. *U.S. Geological Survey Techniques of Water-Resources Investigations*, Elsevier, Vol. 49, Book 4, Chapter A3. <https://doi.org/10.3133/twri04A3>
- Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982: Techniques of trend analysis for monthly water quality data. *Water Resources Research*, 18(1), 107-121. <https://doi.org/10.1029/WR018i001p00107>
- IPCC, 2023: Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Izsák, B. and Szentimrey, T., 2020: To what extent does the detection of climate change in Hungary depend on the choice of statistical methods? *GEM - International Journal on Geomathematics*, 11(1), 17–32. <https://doi.org/10.1007/s13137-020-00154-y>
- Izsák, B., Szentimrey, T., Lakatos, M., Pongrácz, R., and Szentes, O., 2022: Creation of a representative climatological database for Hungary from 1870 to 2020. *Időjárás*, 126(1), 1–26. <https://doi.org/10.28974/idojaras.2022.1.1>
- Kocsis, K. and Schweitzer, F. (Eds.), 2013: Hungary in Maps. Geographical Research Institute, Hungarian Academy of Sciences, Budapest.
- Lakatos, M., Szentimrey, T., Bihari, Z., and Szalai, S., 2013: Creation of a homogenized climate database for the Carpathian region by applying the MASH procedure and the preliminary analysis of the data. *Időjárás*, 117(3), 143–158.
- Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M.A., Tanarhte, M., Tyrllis, E., and Xoplaki, E., 2012: Climate change and impacts in the Eastern Mediterranean and the Middle East. *Climatic Change*, 114(3–4), 667–687. <https://doi.org/10.1007/s10584-012-0418-4>
- McLeod, A. 2022: Kendall Rank Correlation and Mann-Kendall Trend Test, R package version 2.2.1. <https://doi.org/10.32614/CRAN.package.Kendall>
- Péczeley, G., 1979: *Eghajlattan*. Nemzeti Tankönyvkiadó, Budapest. (in Hungarian)
- Pohlert, T. 2023: Non-Parametric Trend Tests and Change-Point Detection, R package version 1.1.6. <https://doi.org/10.32614/CRAN.package.trend>
- Pongrácz, R., Bartholy, J., and Miklós, E., 2011: Analysis of projected climate change for Hungary using ENSEMBLES simulations. *Applied Ecology and Environmental Research*, 9(4), 387–398. [https://doi.org/10.15666/aeer/0904\\_387398](https://doi.org/10.15666/aeer/0904_387398)
- Seneviratne S.I., Nicholls N., Easterling D., Goodes M.C., Kanae, S., Kossin, J., Lou, Y., Marengo, J., McInnes, K., and Rahimu, M., 2012: Changes in Climate Extremes and their Impacts on the Natural Physical Environment. In Field C.B, Barros V., Stocker T.F., Dahe Q., (eds.) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 109-230. <https://doi.org/10.1017/CBO9781139177245.006>
- Spinoni, J., Naumann, G., Vogt, J., and Barbosa, P., 2015: The biggest drought events in Europe from 1950 to 2012. *Journal of Hydrology: Regional Studies*, 3, 509–524. <https://doi.org/10.1016/j.ejrh.2015.01.001>
- Szabó, S., Szopos, N.M., Bertalan-Balázs, B., László, E., Milošević, D.D., Conoscenti, C., and Lázár, I., 2019: Geospatial analysis of drought tendencies in the Carpathians as reflected in a 50-year time series. *Hungarian Geographical Bulletin*, 68(3), 283–301. <https://doi.org/10.15201/hungeobull.68.3.5>
- Szalai, S. and Szinell, Cs., 2000: Comparison of two drought indices for drought monitoring in Hungary—A case study. In J. V. Vogt & F. Somma (Eds.), *Drought and Drought Mitigation in Europe* (pp. 161–166). Springer. [https://doi.org/10.1007/978-94-015-9472-1\\_12](https://doi.org/10.1007/978-94-015-9472-1_12)
- Thorntwaite, C.W., Mather, Jr. 1955: The Water Balance. Laboratory of Climatology, Centerton, NJ, USA.
- Tölgyesi, C., Török P., Hábczyus A.A., Bátori, T., Valkó, O., Deák, B. Tóthmérész, B., Erdős, L., and Kelemen, A., 2020: Underground deserts below fertility islands? Woody species desiccate lower soil layers in sandy drylands. *Ecography*, 43(6), 1–12. <http://dx.doi.org/10.1111/ecog.04906>
- Vadas, A. and Rácz, L. 2013: Climatic Changes in the Carpathian Basin during the Middle Ages. The State of Research. *Global Environment*, 6, 198-227. <https://doi.org/10.3197/ge.2013.061209>