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Comparison of meteorological drought over two normal periods

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The frequency of extreme meteorological events, including drought, has risen in the last years. This is, among, due to climatic changes occurring in the atmosphere. These extremes have been monitored also on the East Slovakian Lowland. Dry periods are defined as periods of water scarcity in their various forms. In order to quantify changes in the climate at a particular location, it is useful to compare the climatic characteristics monitored over two normal periods. The basic assumption of this work is that Earth's climate has been warming and therefore the drought incidence has been increasing. The aim of this work is to quantify differences in the climate at a particular location over two consecutive normal periods. The two normal periods (NP) are the years 1961–1990 (NP1) and 1991–2020 (NP2). Compared atmospheric elements were monitored at the meteorological station of SHMÚ (Slovak Hydrometeorological Institute) in Milhostov, which is in the central part of the East Slovakian Lowland. Normal periods were analysed in terms of precipitation, temperature, potential evapotranspiration, and selected drought indices. The analysis has shown that the normal period of 1991–2020 (NP2) is both annually and monthly drier than the period of 1961–1990 (NP1), with a significant increase in temperatures and potential evapotranspiration.

KEY WORDS: drought index, normal period, meteorological elements

Introduction

Changes in the atmosphere have caused an increase in the frequency of extreme hydrological events (Raikes et al., 2019; Trnka et al., 2016; Climate atlas of Slovakia, 2015; Rodný and Šurda, 2010). In Slovakia, this is manifested in prolonged rainless periods and a higher frequency of extreme precipitation in terms of intensity and abundance. It is useful to compare the changes in atmospheric elements in two different normal periods for the quantification of climate change in the investigated locality. These normal periods allow the comparison of both atmospheric and hydrometeorological elements in different regions and periods. Representative hydrological and atmospheric elements are, in general, calculated from the normal period. The length of the normal period is at least 30 years. It is a common problem to obtain an uninterrupted series of measurements over 30 years (Bonacci et al., 2023; Pinheiro and Blanco, 2021). World Meteorological Organization (WMO, 1935) has specified that for the worldwide comparison of data, three reference normal periods will be used: periods between 1901–1930, 1931–1960 and 1961–1990. WMO recommended that standard 30-years long reference periods should be updated every decade so that they reflect climate change. WMO congress (WMO, 2021) suggested that new 30-years long standard reference period from 1991to 2020 is set.

The studies of drought need consistent analysis method. The first step in drought analysis is to define the term drought. This is not an easy task, as the impact and form of drought are different in different climatic regions. What is considered drought in the tropical forest, is not considered drought in deserts. Originally, there was only one, very general definition of drought, saying: "Basic characteristic of drought is the decrease in water availability over specified period on a specific area". Beran and Rodier (1985) and Yevjevich (1967) believe that this absence of an accurate and objective definition of the term drought was the fundamental obstacle to scientific investigation of the phenomenon in the past. At present, drought is considered a state when water availability from water sources is lower than the statistical needs of water in the concerned area. In this sense, it is perceived as the discrepancy between natural water sources and social needs for water supply. Currently, the widespread definition of drought (especially in the US) is that a drought is a period of unusually dry weather that is long enough for a lack of water to cause a hydrological imbalance in the affected area American Meteorological Society (2019).

Drought can have a severe impact on the environment, economy, and human society. By reducing the agricultural yield, it can threaten food security (Haigh et al., 2022a; 2022b; Pecho, 2016) of people. Dry or damaged vegetation affects the quality of soils, increases fire risks (Hološ et al., 2022; Li et al., 2022) and provokes the death of animals and changes in biodiversity and ecosystems. A decrease in water availability and water quality may provoke social tension and bring about a struggle between different social groups for access to water sources (Brázdil et al., 2016). Based on this, drought can be of several types: meteorological (Gomboš and Pavelková, 2009), hydrological (Almikaeel et al., 2023), soil and socio-economic. At this point, it is needed to say that the timing of phases of drought are different, depending on the drought type (Wilhite and Glantz, 1985).

The work assumes that Earth's climate has been warming and therefore the drought incidence has been increasing (Wilhite, 2016). The aim of this work is to quantify differences in the local climate over two consecutive normal periods – the period between the years 1961–1990 and 1991–2020. Compared atmospheric elements were monitored at the meteorological station of SHMÚ (Slovak Hydrometeorological Institute) in Milhostov, which is in the central part of the East Slovakian Lowland. Normal periods were analysed in terms of precipitation, temperature, potential evapotranspiration, and selected drought indices. Quantification of the climate change is necessary for forecasting future development and the proposal of measures to eliminate drought impact on the environment.

Methodology

Data for the study were obtained from the meteorological station in Milhostov which is located in the central part of the East Slovakian Lowland (48° 40′ 11″; 21° 44′ 18″). This station has monitored meteorological data from the area since 1960. It is situated in the locality which, from the climatic point of view, lies in the transitional area between oceanic and continental climate. The local climate is mainly warm and semi-humid with cold winters. Great temporal variability of the weather and all the meteorological elements is typical of the climate in the area. Air masses swiftly change throughout the year, regardless of season, and cyclonic activity is highly developed (Kveták, 1983a; 1983b; Markovič et al., 2021).

This work compares the data from two consecutive normal periods 1961–1990 and 1991–2020 (Mikulová et al., 2008). Database for the analysis contains annual precipitation totals, long-term average monthly precipitation totals, average annual air temperatures and average annual and monthly potential evapotranspiration totals. Precipitation, temperature and evaporation are key balance characteristics of hydrological processes in the system of atmosphere – plant cover – unsaturated zone – groundwater (Faško et al., 2000; Hlavatá and Tomková, 2015). Evaporation in this work is represented by potential evapotranspiration (Novák, 1995). It contains the energy balance of the environment and the conditions for water vapour transport to the atmosphere.

Apart from the abovementioned hydrometeorological elements, selected drought indices have been used for comparing the two normal periods. Drought indices are used as a substitute for complex climatic functions (Mukherjee et al., 2018) in the monitoring and quantification of drought. They enable the quantification of climatic anomalies in terms of their severity, duration and incidence (Choudhary et al., 2023). They can convey, in an understandable way, important information on the severity of drought event (Tsakiris et al., 2007; Soľáková et al., 2022). Drought indices are used in the investigation, in the decision-making processes as well as in the proposal of adaptive measures. The indices are not universal and thus it is usually necessary to use more than one index at a time (Morid et al. 2006; Čimo et al., 2008; Jarošová and Igaz, 2018).

For the analysis of the normal periods, simple indices commonly used in the past were applied: Vysocky index, Climatic indicator of irrigation, Hydrothermal coefficient of Selyaninov, Lang`s rain factor, Drought index and Palmer drought severity index (PDSI). All but PDSI are simple indices. Their calculation is based on precipitation, temperatures and potential evapotranspiration. The formulas for the calculation of the indices and the classification tables for evaluating the calculated values are described below.

Vysocky index (V_i)

$$V_i = \frac{P_r}{ET_{pot}} \qquad (1)$$

where

P_r – precipitation total for the evaluated period,

ET_{pot} – potential evapotranspiration total for the evaluated period.

Table 1. Evaluating scale for Vysocky index

0–1	Evapotranspiration predominates
1	Precipitation equal to evapotranspiration
>1	Precipitation predominate

Climatic indicator of irrigation (K_z)

$$K_z = ET_{pot} - P_r \qquad (2)$$

where

ET_{pot} – potential evapotranspiration total for the evaluated period,

P_r – precipitation total for the evaluated period.

Table 2. Evaluating scale for Climatic indicator of irrigation

>0	Evapotransporation predominates
0	Precipitation equal to evapotranspiration
<0	Precipitation predominates

Hydrothermal coefficient of Selyaninov (K_{HT}) (Jůva, 1959)

$$K_{HT} = \frac{\sum H_Z}{0.1 \sum t_{10}} \tag{3}$$

where

$\sum H_Z$ – precipitation total for the evaluated period [mm],

$\sum t_{10}$ – sum of average daily temperatures (t >10°C) for the evaluated period [°C].

Table 3. Evaluating scale for Hydrothermal coefficient of Selyaninov

<0.30	Catastrophic drought
0.31–0.50	Drought
0.51–0.99	Water shortage
1.00	Precipitation equal to evapotranspiration
1.01–2.00	Sufficient water
>2.00	Water excess

Lang´s rain factor (f)

$$f = \frac{P_r}{T_p} \tag{4}$$

where

P_r – precipitation annual total [mm],

T_p – average annual air temperature [°C].

Table 4. Evaluating scale for Lang´s rain factor

20–40	Arid climate area
40–60	Intermediate climate area
>60	Humid climate area

Drought index (S_i) (Klementová, 1990)

$$S_i = \frac{\Delta t_i}{\sigma_t} - \frac{\Delta z_i}{\sigma_z} \tag{5}$$

where

$$\Delta t_i = t_i - \bar{t} \qquad \Delta z_i = z_i - \bar{z}$$

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i \qquad \bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i$$

$$\sigma_t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t}\,)^2}$$

$$\sigma_z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z - \bar{z}\,)^2}$$

Δt – deviation of the average monthly temperature from the long-term monthly average [°C],

Δz – deviation of the average monthly precipitation total from the long-term monthly average [mm],

n – range of the statistical file (number of evaluated years (1961–2020)),

σ_t, σ_z – standard deviations (of average monthly temperature and monthly precipitation totals),

t_i – average monthly air temperature [°C] in the *i*-th year,

z_i – monthly precipitation total [mm] in the *i*-th year,

$\bar{t}$ – long-term average air temperature of the relevant month [°C],

$\bar{z}$ – average monthly precipitation [mm].

Table 5. Scale for evaluating the values of Drought index

>2	Very arid area
1–2	Arid area
0–1	Moderately arid area
0–(-1)	Moderately humid area
(-1)–(-2)	Humid area
<-2	Very humid area

Palmer drought severity index (PDSI)

The last evaluated drought index is Palmer Drought Severity Index (PDSI). This index is used for drought quantification of a large area with variable pedological and climatic conditions (Palmer, 1965; Litschmann et al., 2002). It is used mainly in the US. Its relatively high complexity in terms of calculation is compensated by its versatility. Input variables for calculating PDSI are precipitation, potential evapotranspiration (monthly totals) and the value of available water capacity. For calculating ET_{pot} the formula (6) is used. It is necessary that various meteorological parameters are known: air temperature, duration of sunshine, water vapour pressure and wind speed. Algorithm for PDSI calculation for

Table 6. Evaluation scale for Palmer drought severity index

>4.00	Extreme wet spell
3.00–3.99	Severe wet spell
2.00–2.99	Moderate wet spell
1.00–1.99	Mild wet spell
0.50–0.99	Developing wet spell
-0.49–0.49	Normal
-0.50– -0.99	Developing drought
-1.00– -1.99	Mild drought
-1.99– -2.99	Moderate drought
-2.99– -3.99	Severe drought
<-4.00	Extreme drought

the purposes of this study was created at SHMI in Michalovce on the basis of the original Palmer methodology using the programming language Visual Basic for Application (VBA).

For calculating these indicators, daily meteorological parameters such as air temperature, precipitation, duration of sunshine, water vapour pressure and wind speed were used. Meteorological parameters were obtained from Slovak Hydrometeorological Institute in Košice from the meteorological station in Milhostov for period of 1961–2020.

Potential evapotranspiration (ET_{pot}) is calculated by the formula (Allen et al., 1998):

$$ET_{pot} = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad (6)$$

where

ET_{pot} – reference evapotranspiration [mm day^{-1}],
R_n – radiation balance of the crop surface [MJ m^{-2} day^{-1}],
G – heat flow in the soil [MJ.m^{-2} day^{-1}],
T – average daily air temperature at a height of 2 m [°C],
u_2 – average daily wind speed at a height of 2 m [m s^{-1}],
e_s – saturated water vapor pressure [kPa],
e_a – current water vapor pressure [kPa],
Δ – derivative of saturated water vapor pressure [kPa C^{-1}],
γ – psychrometric constant [kPa °C^{-1}].

Results and discussion

Table 7 describes the characteristics of descriptive statistics for the average annual air temperatures, annual precipitation totals and annual ET_{pot} totals for the normal periods of 1961–1990 and 1991–2020. It is obvious that, in comparison to the previous normal period of 1961–1990 (NP1), the normal period of 1991–2020 (NP2) is warmer by 1°C on average. Its average annual precipitation total is higher by 5.8% and average annual potential evapotranspiration is higher by 11.9%. The difference between average annual ET_{pot} and average annual precipitation total raised from 24% in NP1 to 31% in NP2. Variability of the evaluated parameters in NP2 is slightly higher compared to NP1, however, when related to the average, it is the same. Statistical distribution of the evaluated parameters is skewed to the left, in NP2 it is skewed to the right.

Fig. 1 illustrates the development of average annual temperatures in both normal periods. There was a significant increase in temperatures in NP2. Warming is visible also in long-term average monthly temperatures in Fig. 2. In summer, this is most striking in July and August and in winter in January.

Annual precipitation totals and their linear trends are shown in Fig. 3. From Fig. 3 and Table 7 it is obvious that NP2 has more abundant precipitation with slightly increasing linear trend in comparison to NP1. Regarding long-term average monthly precipitation totals shown in Fig. 4, their increase in NP2 is most evident in May, Jun, July and September. In other half of the year, the increase is most significant in October and a bit less in February. In other months, long-term average monthly precipitation totals in NP1 exceed precipitation in NP2.

The course of annual potential evapotranspiration totals and their trends is shown in Fig. 5. The course of the trends in the normal periods are analogous to the course of temperature trends. In NP2, there is a rising trend in the potential evapotranspiration totals in comparison to NP1. In terms of average monthly ET_{pot} total (Fig. 6), there is a significant increase between April and September. In winter and autumn, the changes were negligible.

Table 7. Descriptive statistics for the average annual air temperatures, annual precipitation totals and annual ET_{pot} totals at Milhostov meteorological station in the normal periods 1961–1990 and 1991–2020

	average annual air temperature		annual precipitation total		annual Et_{pot} total	
	1961–1990	1991–2020	1961–1990	1991–2020	1961–1990	1991–2020
Mean	9.0	10.0	546.9	578.4	678.0	758.6
Standard Error	0.1	0.1	16.7	17.6	8.4	9.2
Median	9.0	10.0	546.3	562.5	675.2	750.9
Standard Deviation	0.6	0.7	91.6	96.4	45.8	50.6
Sample Variance	0.4	0.6	8389.8	9284.4	2096.5	2560.4
Kurtosis	-0.5	-0.8	-0.3	2.6	-0.8	-0.7
Skewness	-0.2	0.2	-0.1	1.2	0.1	0.2
Range	2.2	2.6	364.7	453.7	166.5	192.4
Minimum	7.8	8.7	351.9	438.1	596.2	667.0
Maximum	10.0	11.4	716.6	891.8	762.7	859.4
Sum	268.9	300.7	16405.9	17351.0	20339.6	22759.5
Count	30	30	30	30	30	30
Confidence Level (95.0%)	0.2	0.3	34.2	36.0	17.1	18.9

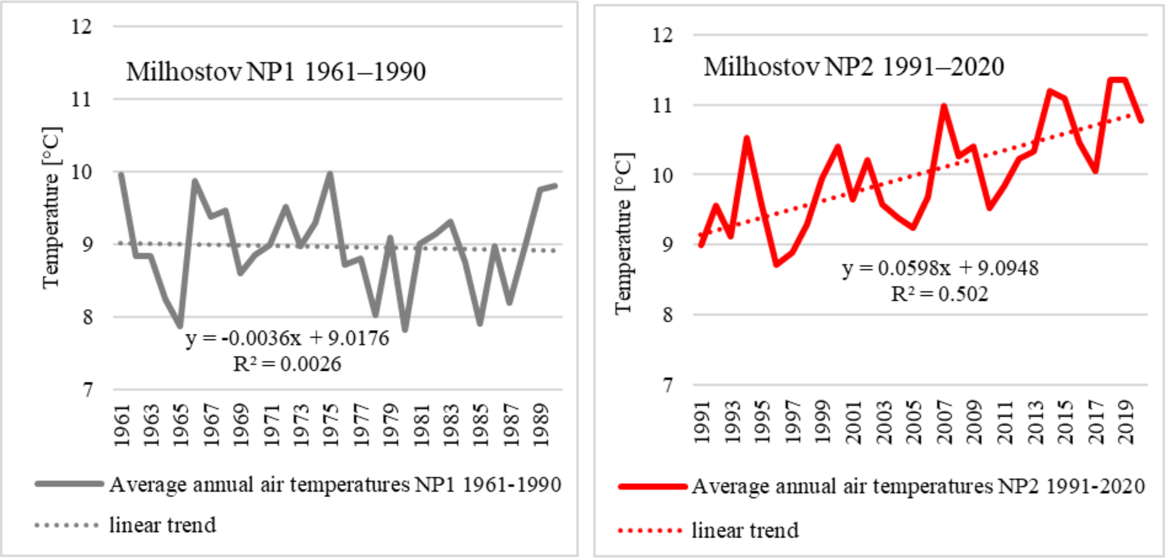

Fig. 1. Average annual air temperatures and their trends at Milhostov meteorological station in the normal periods of NP1 1961–1990 and NP2 1991–2020.

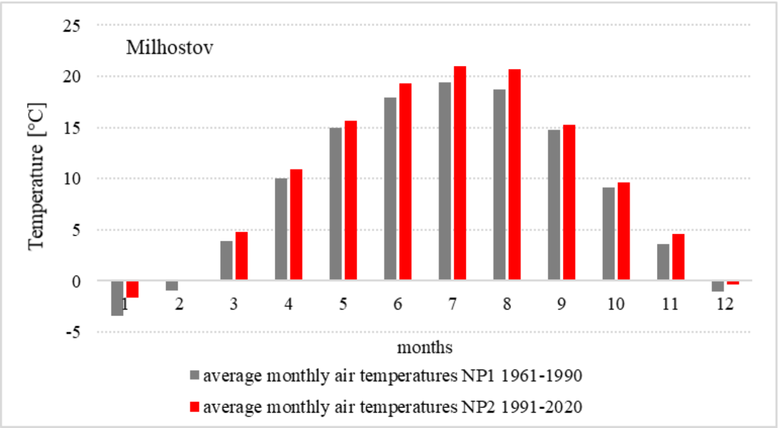

Fig. 2. Comparison of long-term average monthly air temperatures at Milhostov meteorological station between the two normal periods NP1 1961–1990 and NP2 1991–2020.

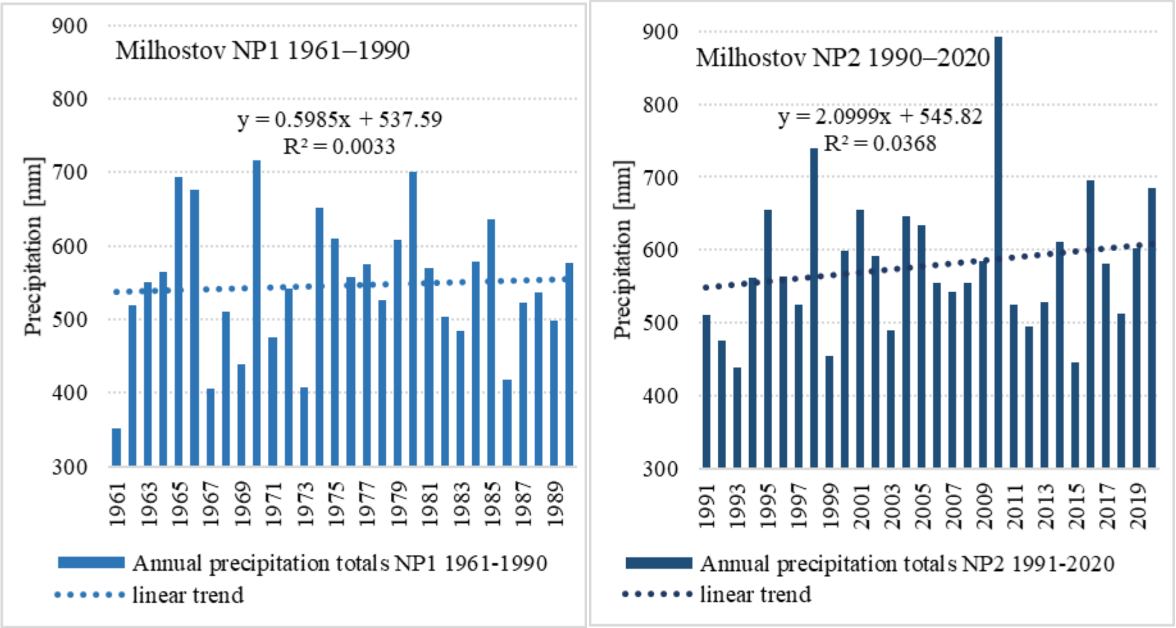

Fig. 3. Annual precipitation totals and their trends at Milhostov meteorological station in the normal period of NP1 1961–1990 and NP2 1991–2020.

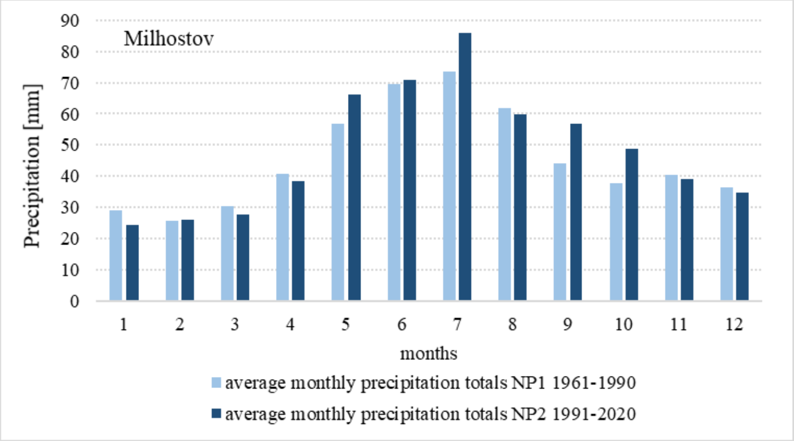

Fig. 4. Long-term average monthly precipitation totals and long-term average precipitation totals at Milhostov meteorological station in the normal periods of NP1 1961–1990 and NP2 1991–2020.

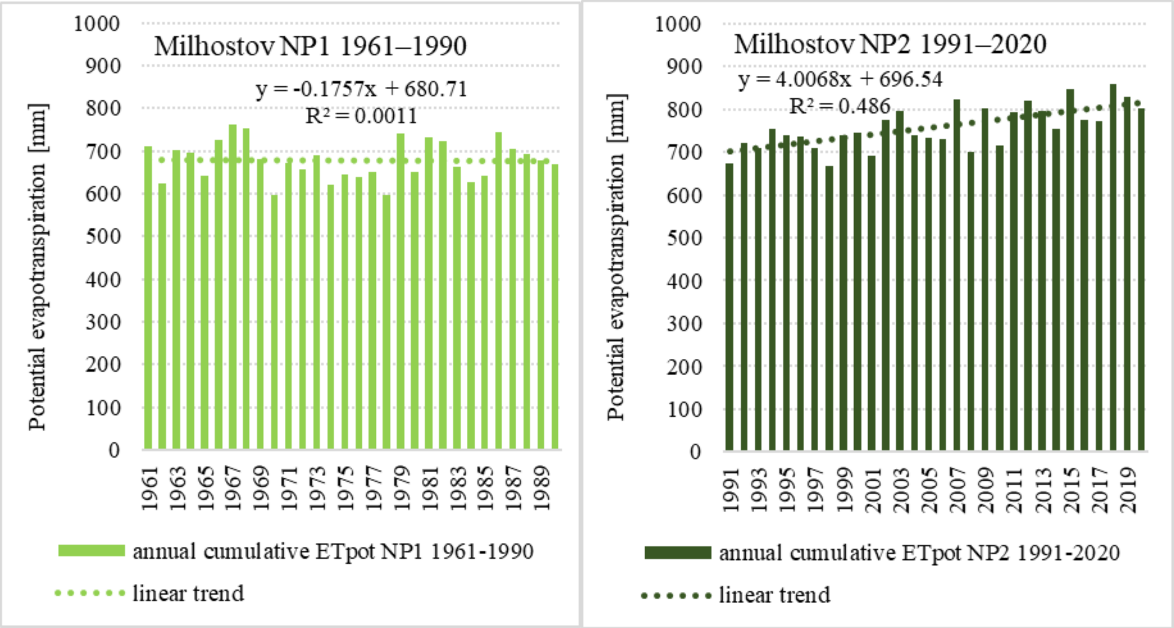

Fig. 5. Trend analysis of the annual cumulated values of potential evapotranspiration (ET_{pot}) at Milhostov meteorological station in the normal periods of NP1 1961–1990 and NP2 1991–2020.

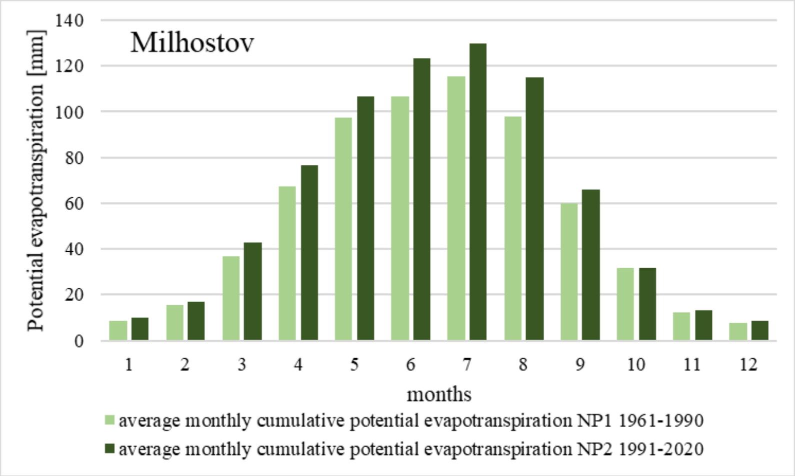

Fig. 6. Long-term average monthly cumulated potential evapotranspiration (ET_{pot}) at Milhostov meteorological station in the normal periods of NP1 1961–1990 and NP2 1991–2020.

Fig. 7 shows courses and trends of Vysocky index in the evaluated normal periods. It is clear, that in both periods potential evaporation exceeds precipitation while there is no significant trend shift. In NP1, 4 years were identified (1965, 1970, 1974 and 1980) in which precipitation exceeded ET_{pot}. In NP2 such situation occurred in two years (1998 and 2010).

The same is manifested in Fig. 8 which represents Climatic indicator of irrigation. In both normal periods, the same years were identified in which precipitation exceeded ET_{pot}.

The course of the hydrothermal coefficient, shown in Fig. 9, mostly moves within the interval 1.01–2.00. This is defined as water sufficiency. Although the values of hydrothermal coefficient in NP2 approach the lower boundary of the interval, they do not drop further. The years in which water sufficiency is most marked and the years in which precipitation exceeded potential evapotranspiration, are identical.

The analysis of Lang`s rain factor (Fig. 10) shows that in NP1 the prevailing values belong in the interval for humid climate area and the prevailing values in NP2 belong in the interval for intermediate climate area. The results obtained from data at Milhostov station were compared to the results from obtained from data at eight meteorological stations in the western part of Slovakia (Jarošová and Igaz, 2018). The station in Piešťany gave very similar results to those from Milhostov.

Fig. 11 shows the drought indices and their linear trends. NP1 gave a flat, slightly decreasing trend. Most values

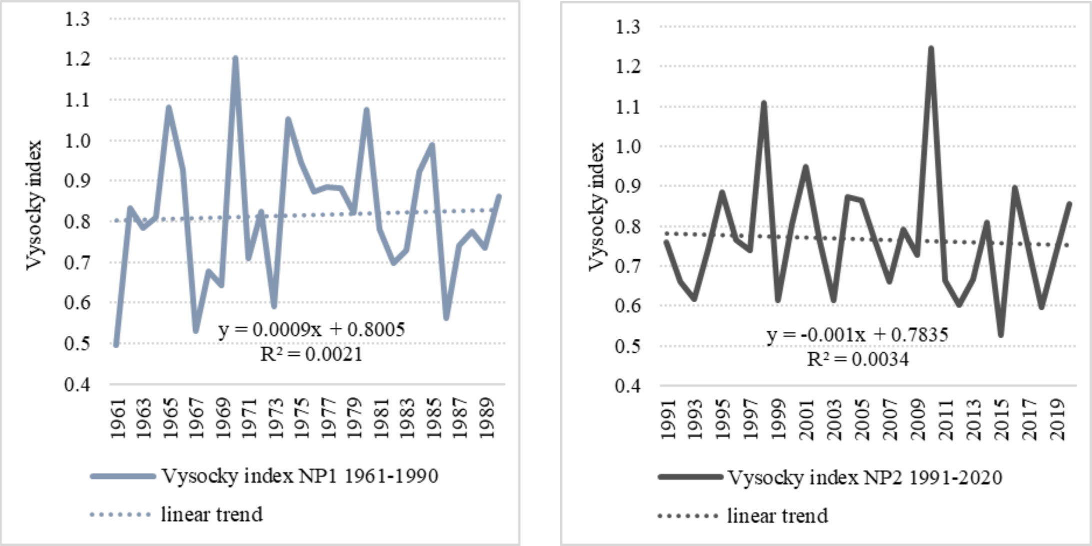

Fig. 7. Course of Vysocky index at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

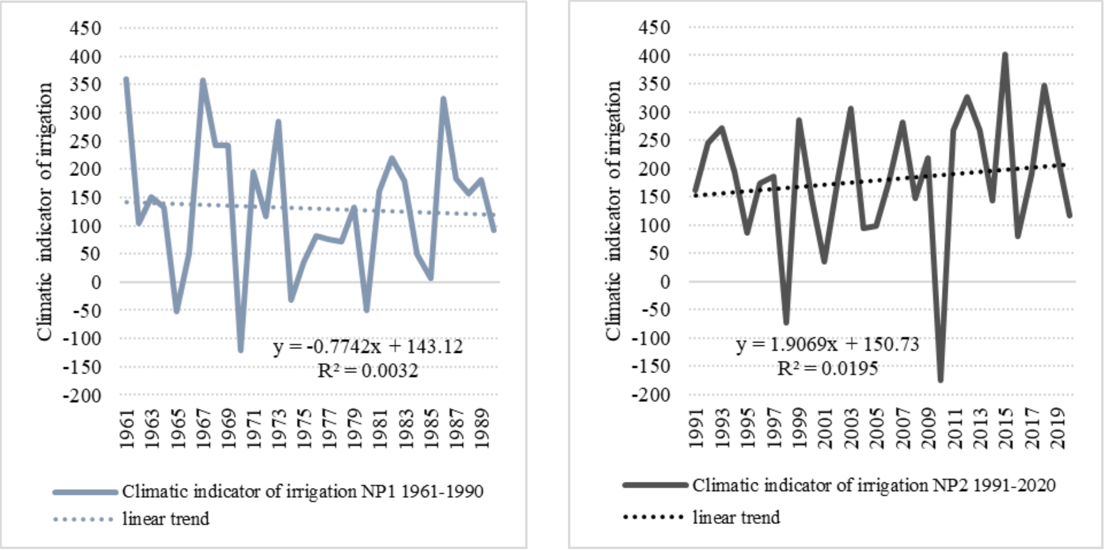

Fig. 8. Course of Climatic indicator of irrigation at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

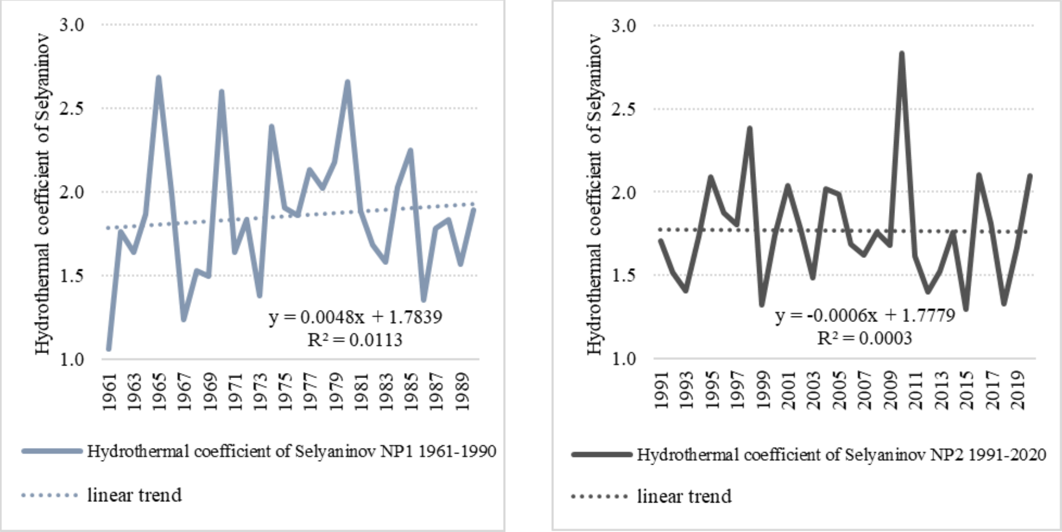

Fig. 9. Course of Hydrothermal coefficient of Selyaninov at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

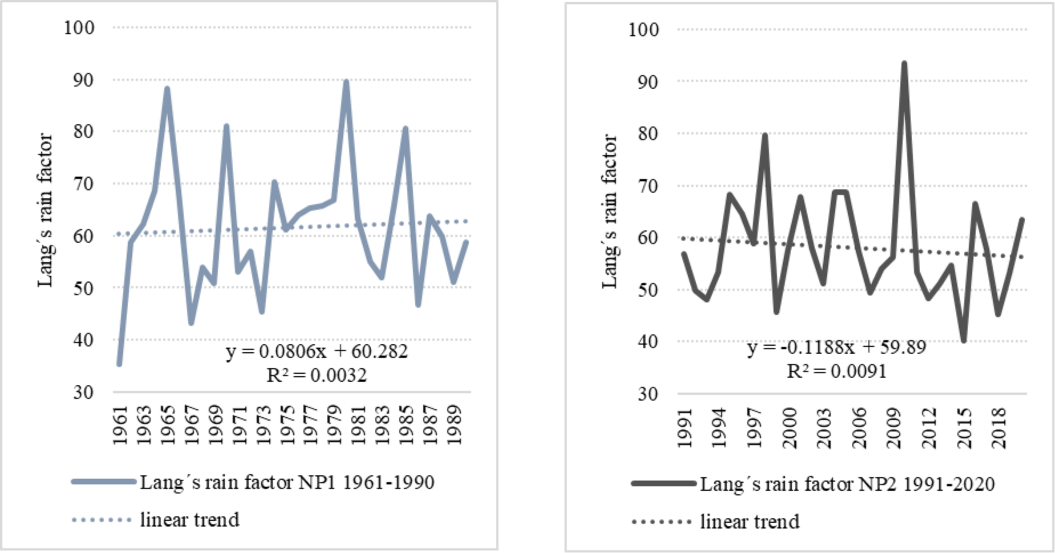

Fig. 10. Course of Lang´s rain factor at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

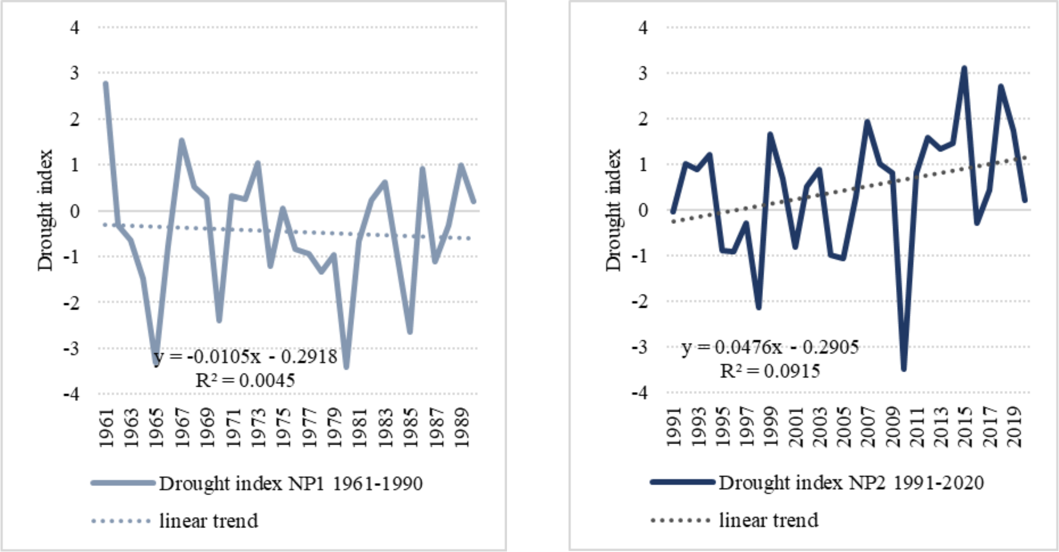

Fig. 11. Course of the Drought index at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

belong to the interval for moderately humid area and moderately arid area. In NP2, the values are similar, however, the trend is rising towards the values for arid areas. Extremely wet years are identical to those identified by previous analyses.

Fig. 12 shows the courses of PDSI. It is obvious that in NP2, there is a moderate trend towards drought. Dry years occurred mainly in the last years of NP2. Extremely dry years were identified in 1968, 2015 and 2019. Extremely wet years are identical to those identified by previous analyses, i.e., 1965, 1970, 1974, 1980, 1998 and 2010.

Table 8 represents a complex evaluation of both normal periods by drought indices and their trends. Overall results in all indices show that NP2 is drier than NP1.

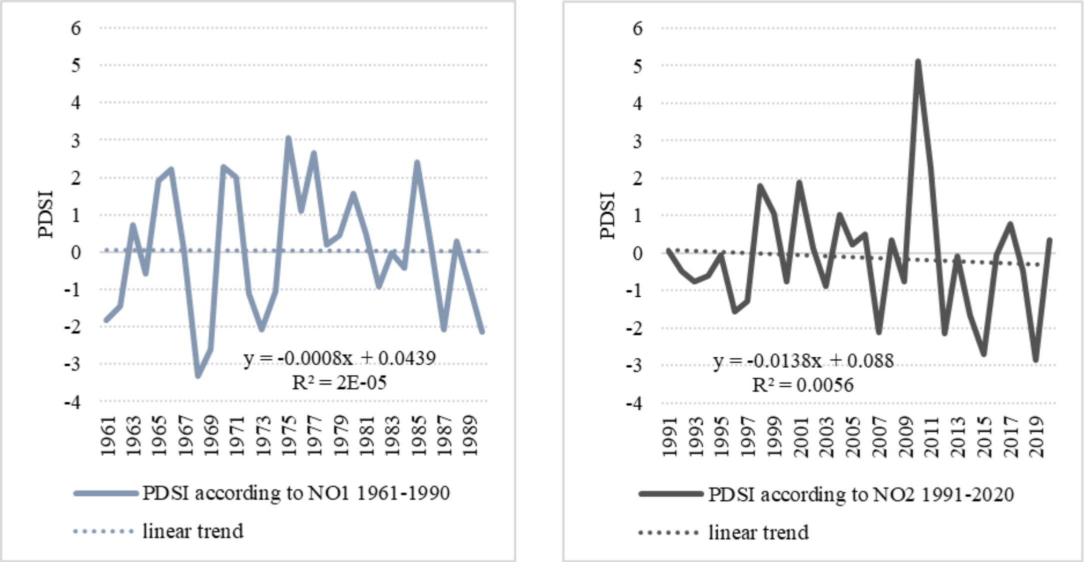

Fig. 12. Course of Palmer drought severity index at Milhostov meteorological station in the evaluated normal periods NP1 1961–1990 and NP2 1991–2020.

Table 8. Analysis of normal periods NP1 1961–1990 and NP2 1991–2020 as to drought indices and their trends at Milhostov meteorological station

Drought indicator	**trend**	**NP1 1961–1990**				**trend**	**NP2 1991–2020**				**NP2 versus NP1**
		description	**avg**	**st. dev.**	**C_v**		**description**	**avg**	**st. dev.**	**C_v**	
Vysocky index	slightly increasing	in most years evaporation predominates	**0.81**	0.17	0.21	slightly decreasing	in most years evaporation predominates	**0.77**	0.15	0.20	**drier**
Climatic indicator of irrigation	slightly increasing	in most years evaporation predominates	**131.12**	119.75	0.91	increasing	in most years evaporation predominates	**180.28**	120.27	0.67	**drier**
Hydrothermal coefficient of Selyaninov	increasing	sufficient water	**1.86**	0.40	0.21	decreasing	tends to normal /sufficient water	**1.77**	0.33	0.19	**drier**
Lang´s rain factor	increasing	intermediate / wet	**61.53**	12.50	0.20	slightly increasing	tends to drying	**58.05**	10.95	0.19	**drier**
Drought index	decreasing	dry / wet	**-0.45**	1.38	-3.03	increasing	tends to drying	**0.45**	1.39	3.10	**drier**
PDSI	slightly decreasing	tends to drying	**0.26**	2.27	8.73	slightly decreasing	tends to drying	**0.15**	2.19	14.60	**drier**

C_v – coefficient of variation

Conclusion

In the past years, the incidence of dry periods on the East Slovakian Lowland has increased. Dry periods are periods in which water availability from other water sources is below the statistical need for water in drought-stricken areas. From the social point of view, drought is understood as a period with stable, uncommonly dry weather, which is long enough for the lack of water to damage plant cover and cause serious problems in water supply. The magnitude of drought regarding its impact on the countryside depends on its duration, degree of moisture deficit and the size of affected area. In this sense, one of possible causes of drought are climatic changes. The work is based on the assumption that Earth's climate has been warming and therefore the drought incidence has been increasing. The aim of this work is to quantify differences in the climate at a particular location over two consecutive normal periods. For the purpose of the work, the normal periods defined are NP1 between the years 1961 and 1990 and NP2 between the years 1991 and 2020. Analysed meteorological parameters were measured at Milhostov meteorological station, which is in the central part of East Slovakian Lowland. The normal periods were analysed in terms of precipitation, temperature, potential evapotranspiration and selected drought indices. For the analysis of the normal periods, simple indices commonly used in the past were applied: Vysocky index, Climatic indicator of irrigation, Hydrothermal coefficient of Selyaninov, Lang`s rain factor, Drought index and Palmer drought severity index. All but PDSI are simple indices. Their calculation is based on precipitation, temperatures and potential evapotranspiration. The analysis of normal periods identified significant changes in temperatures and potential evapotranspiration. In NP2, the values of these parameters were annually and monthly higher. The linear trends of these parameters have the rising tendency. Contrary to this, the linear trends of annual precipitation totals were flat. The analysis of the normal periods in terms of the values and linear trends of drought indices shows that NP2 is drier than NP1. The trends in NP2 are approaching the drought limits.

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