ACTA SCIENTIARUM POLONORUM

Acta Sci. Pol.
Formatio Circumiectus 22 (4) 2023, 5–21
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2023.22.4.15

ORIGINAL PAPER Accepted: 26.10.2023

VARIABILITY OF THERMAL AND PRECIPITATION CONDITIONS IN THE AREA NORTH-EASTERN LUBLIN REGION IN THE ASPECT OF ATMOSPHERIC DROUGHT RISK IN THE PERIOD FROM 1971 TO 2020

Barbara Skowera[1] 0000-0003-3082-496X, Alicja Baranowska[2]✉ 0000-0003-0998-1944, Jozefína Pokrývková[3] 0000-0002-1545-2515

[1] Department of Ecology, Climatology and Air Protection, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Krakow, 24/28 Mickiewicza Ave, 30-059 Krakow, Poland
[2] Department of Agriculture, John Paul II University in Biała Podlaska, 95/97 Sidorska St. 21-500 Biała Podlaska, Poland
[3] AgroBioTech Research Centre, Tr. Slovak University of Agriculture in Nitra, A. Hlinku 2, 949 76 Nitra, Slovak Republic

ABSTRACT

Aim of the study
The purpose of this research was to assess the variability of thermal and precipitation conditions, as well as the risk of atmospheric drought in the north-eastern Lublin region in the period from 1971 to 2020.

Material and methods
The study used data of air temperature and monthly precipitation totals from three stations. Basic statistical characteristics of thermal-precipitation conditions were calculated, including: mean values of monthly air temperature and precipitation totals, standard deviations of air temperature (σt), and coefficients of variation of precipitation (cv) in the period 1971–2020. Atmospheric drought risk was assessed on the basis of the calculated values of thermal-precipitation index A.

Results and conclusions
A statistically significant increase in the average air temperature was determined, following from the calculated basic characteristics of air temperature and precipitation, which on average amounted from 0.4 to 0.6°C over the period of 10 years during summer months, autumn months, and in April. Statistically significant increase in precipitation totals was observed in the cold half-year: a stronger trend in January, and a weaker growing trend in February and March. An increase in the risk of atmospheric drought in the north-eastern Lublin region was found based on the calculated thermal-precipitation aridity index A, while intensification of this phenomenon occurred in the last two decades, particularly during summer and slightly less so in autumn. It was indicated that the primary cause of drought risk in the studied area consisted of a significant increase in air temperature combined with the lack of tendency in the scope of change in atmospheric precipitation.

Keywords: air temperature, atmospheric precipitation, thermal-precipitation aridity index A, meteorological drought, Lublin region

✉e-mail: a.baranowska@dyd.akademiabialska.pl

INTRODUCTION

Climate change has been progressing since the 1980s, and this is a scientifically proven fact. The whole world can feel the socio-economic consequences of this phenomenon, as well as the resulting effects on people and on natural systems, including increase in air temperature, changes in the precipitation structure, changes in the frequency and distribution of weather events (droughts, storms, floods and heat waves), increase in the sea and ocean levels (IPCC, 2013; Hoy et al., 2016; Riedy, 2016; Graczyk et al., 2017).

Along with warming, also an increase in the variability of precipitation is predicted. The current climate models show that growing temperature intensifies the Earth's water cycle, while also increasing potential evaporation. Increased evaporation results in more frequent and more intense storms, as well as extreme weather events. Furthermore, it also contributes to the occurrence of droughts (Zhang et al., 2021; Martinez-Villalobos and Neelin, 2023).

The changes that are observed in climate system on a global scale do not adequately reflect the spatial differentiation of the rate of above-mentioned changes, thus there is a need to carry out deeper analysis of the variability of climatic conditions on a regional scale and on a local scale. In addition to macro-regional climatic processes, a significant role in the shaping of local climate is played by local environmental factors, and to an increasing extent, byanthropogenic factors (Uscka-Kowalkowska and Kejna, 2009).

As a result, research on the variability of thermal and precipitation conditions should be conducted in the areas characterised by a low degree of industrialisation and low level of urbanisation. The above-mentioned criteria are met by the north-eastern Lublin region, particularly by the area of South Podlasie Lowland and West Polesie. Furthermore, the area of West Polesie is an exceptional area on the scale of Poland as well as Europe. It is characterised by a wealth of rare species of fauna and flora, as well as unique landscape values: many karst and thermokarst lakes, extensive wetlands, monadnock hills (Dobrowolski and Mroczek, 2014).

In the context of climate warming and the risk of drought in this area, studies conducted in this region are particularly important for the protection of natural wealth. Moreover, this area is also characterised by favourable conditions in terms of plant production, especially ecological farming.

The purpose of the present research was to assess the variability of thermal and precipitation conditions, as well as the risk of atmospheric drought in the north-eastern Lublin region in the period from 1971 to 2020, based on average monthly air temperature values and monthly atmospheric precipitation totals.

MATERIAL AND METHODS

Materials and research area

This research was conducted in the north-eastern part of the Lublin Province (Lublin region). The Lublin region is an area located in central-eastern Poland. This study uses data for 50-year period (1971–2020) concerning the average monthly air temperature and monthly atmospheric precipitation totals from 3 meteorological stations: Cicibór near Biała Podlaska (52° 02′ 0″ N, 23° 7′ 0″ E), Terespol (52° 04′ 27″ N, 23° 36′ 40″ E), and Włodawa (51° 32′ 41″ N, 23° 32′ 52″ E), all belonging to the Institute of Meteorology and Water Management of the National Research Institute in Warsaw.

In terms of physico-geographical division of Poland, Cicibór near Biała Podlaska is situated on the border of South Podlasie Lowland and West Polesie, while Terespol and Włodawa are located in West Polesie.

Figure 1 presents the division of the Lublin Province into geographical regions, which are characterised by high landscape and geological variability. The north-eastern part of this province is occupied by West Polesie (Lublin Polesie), while the north-western part constitutes South Podlasie Lowland (Kondracki, 2002).

The Lublin Province and the research area are characterised by a low degree of industrialisation. As a result of its peripheral location, the eastern part of this province is characterised by low population density. In the case of border counties (e.g. Biała County, Włodawa County), it does not exceed 50 persons/km^2, which translates into low pressure exerted by humans on the environment (Wesołowska, 2019).

Moreover, this province includes many valuable natural areas that are unique on the scale of Poland and the whole of Europe, which are covered by legal pro-

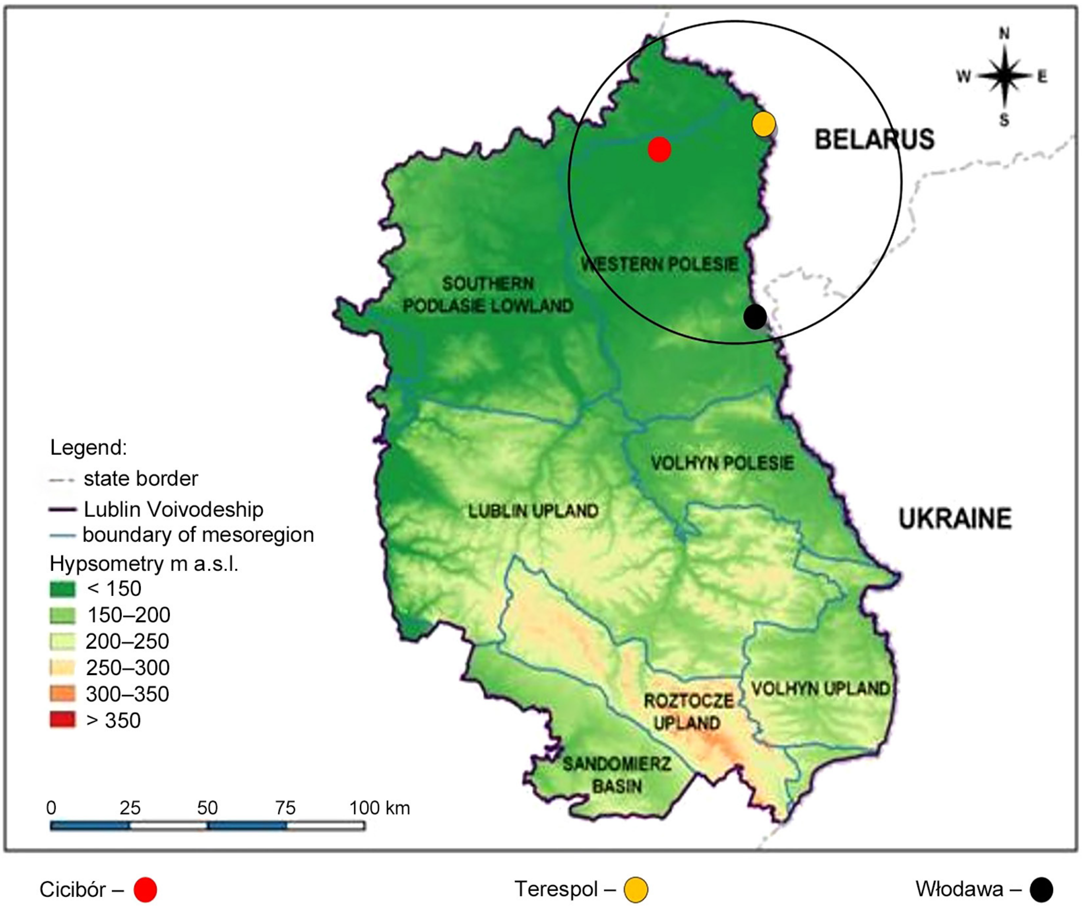

Fig. 1. The Lublin Province with division into geographical regions according to Kondracki (2002) (source: according to Bartoszek et al., 2021)

tection, both in the framework of the national system of protected areas, as well as in the European system of Natura 2000 sites. Among others, these include the area of Polesie (Poleski National Park), Roztocze (Roztocze National Park), and the Łęczna-Włodawa Lake District, as well as river valleys (Harasimiuk et al., 2011).

In the case of north-eastern part of the province, the main rivers include the Vistula and the Bug. It is also necessary to emphasise high biodiversity of the river valleys of this region (Kałamucka, 2009).

The Lublin Province is situated in the temperate climate zone, transitional between the oceanic climate (western Europe) and the continental climate (eastern Europe). Kaszewski et al. (1995) indicate that in the multiannual period 1951–1990, the average temperature of the warmest month of July amounted to 17.2°C–18.5°C, while in the case of the coldest month of January it ranged from –4.3°C to –2.6°C, and the wettest month was July, which was characterised by an average precipitation total of 77.0 mm (Kaszewski et al., 1995).

Research methods and statistical calculations

For the purpose of assessment of the changes in thermal and precipitation conditions in the north-eastern Lublin region, during the first stage of the present research, the basic statistical characteristics of thermal and precipitation conditions were calculated, which were the average values of monthly air temperature and precipitation totals, as well as standard deviations of air temperature (σt) and coefficient of precipitation variability (cv) in the period from 1971 to 2020. The above-mentioned indicators were also calculated for the average air temperature and atmospheric precipitation totals for the whole area (i.e. arithmetic average of the values of these meteorological elements from 3 stations: Cicibór, Terespol and Włodawa) in terms of year and seasons (specifically, thermal seasons: spring, summer, autumn, and winter).

Assessment of the risk of atmospheric drought was carried out based on the calculated values of thermal-precipitation aridity index **A**, which was proposed by Ped (1977).

The above-mentioned index is a synthetic indicator that facilitates temporal and spatial assessment of the risk of atmospheric drought in a given area over a long time period. It was applied to perform assessment of the risk of atmospheric drought in the area of Central and Eastern Europe (Koleva and Aleksanrov, 2008; Podstawczyńska, 2010).

The thermal-precipitation aridity index **A** is calculated as the difference between two partial indexes, i.e. standardised deviations of average monthly air temperature and standardised deviations of monthly atmospheric precipitation totals. The index assumes positive values for dry months and negative values for wet months, and it is calculated in accordance with the following formula:

$$\boldsymbol{A} = \frac{t_i - t_m}{\sigma_t} - \frac{P_i - P_m}{\sigma_P} \; [-] \qquad (1)$$

Where:

- $\boldsymbol{A}$ – thermal-precipitation aridity index
- t_i – average monthly air temperature in a given month [°C],
- t_m – average monthly air temperature in multiannual period [°C],
- σ_t – standard deviation of average monthly air temperature [°C],
- P_i – monthly atmospheric precipitation total in a given month [mm],
- P_m – average monthly precipitation total in multiannual period [mm],
- σ_p – standard deviation of monthly precipitation total [mm].

In the case of our study, the values of thermal-precipitation index **A** were classified in accordance with the criteria adopted by Koleva and Alexandrov (2008) as well as Podstawczyńska (2010). According to the above-mentioned criteria, the values **A** > 1 indicate various intensities of meteorological drought: 1 ≤ **A** < 2 (months with the signs of light drought), 2 ≤ **A** < 3 (months with moderate drought), **A** ≥ 3; 3 ≤ **A** < 4 and 4 ≤ **A** < 5 (months with extreme drought).

In the case of this study, the values of thermal-precipitation index **A** from the range of –1 ≤ **A** < 1 were adopted as optimal (normal) in terms of humidity. Moreover, the range of normal thermal and precipitation conditions refers to the monthly variability of precipitation in the territory of Poland, as well as the range of average monthly precipitation spanning from 76 to 125% of normal precipitation (Kaczorowska, 1962). Classification of wet conditions was adopted in accordance with Podstawczyńska (2010): values –2 ≤ **A** < –1 meant wet months, while values **A** < –2 meant very wet months.

Furthermore, an analysis of the course of average annual and seasonal values of the thermal-precipitation aridity index **A** was conducted (values of the index **A** from 3 measurement stations were averaged). The courses of average values of the index **A** are presented in the graphs. Subsequently, the following trends were examined: monthly air temperature, atmospheric precipitation, totals and thermal-precipitation aridity index A, with the use of non-parametric Mann-Kendall test (Z), which is designed to identify downward or upward trends in the data series (Hirsch et al., 1982). In the case of data for which a statistically significant upward or downward trend occurred, the value of changes was estimated via calculation of the Sen's slope estimator (Hensel and Hirsch, 1992).

The statistical calculations were carried out using MAKESENS application (Salmi et al., 2002) as well as the Statistica 13 StatSoft – Poland Package.

RESULTS AND DISCUSION

Thermal conditions in the area of north-eastern Lublin region in the period from 1971 to 2020

In the case of north-eastern Lublin region, the average annual air temperature in the period 1971–2020 amounted to 7.9°C (Figure 2), while the standard deviation of average annual air temperature (σ_t) amounted to 1.0°C. However, considerable variability of tem-

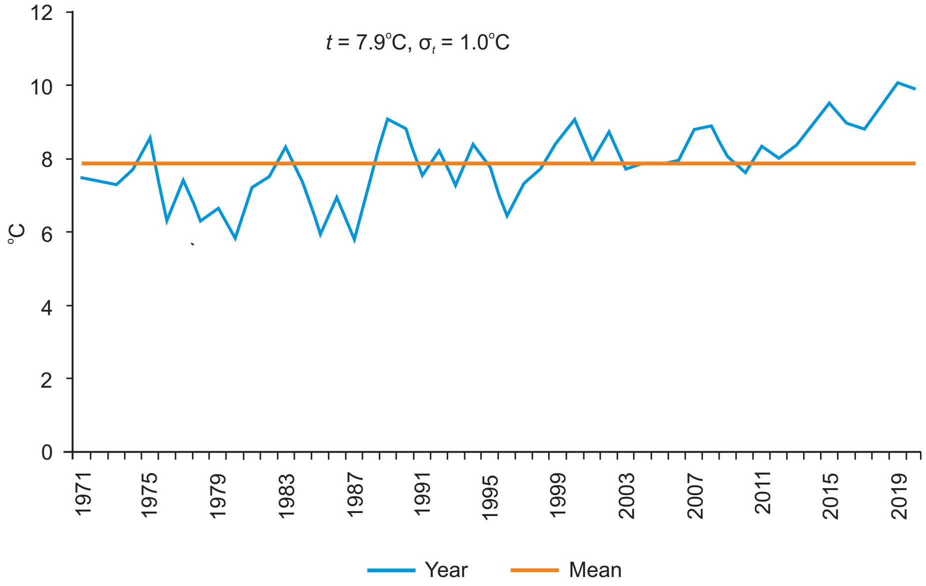

Fig. 2. The course of average annual air temperature in the period from 1971 to 2020 in the north-eastern Lublin region (source: own study)

perature from year to year was observed in the studied period: from 5.8°C in 1980 to 10.1°C in 2019.

In the case of the multiannual course of average air temperature, the cooler periods with predominance of values below the multiannual average were distinguished, and these were the years from 1971 to 1998. However, from 1998 to 2020, the years characterised by temperature higher than the multiannual average were prevailing, whereas the last two decades of the studied multiannual period were the warmest (Figure 2).

It is also the opinion of Michalska (2011) that in most of Poland, the multiannual (1951–2005) trends of average annual air temperature indicated its decrease until the end of the 1970s, and subsequently a gradual increase from the 1980s. According to the above-mentioned author, the average annual temperature increased by approx. 0.2°C per 10 years in most of our country. This may be associated not only with human activity and local or regional conditions (Koźmiński et al., 2007), but also with an increasing impact of the Atlantic Ocean on the decrease in annual air temperature amplitudes in Poland (Michalska, 2011).

Based on the trends calculated with the use of the Mann-Kendall test (Z) and Sen's estimator (S), our research proved a statistically significant increase in the average annual air temperature, amounting to 0.5°C per 10 years in all stations of the studied area (Cicibór near Biała Podlaska, Terespol, Włodawa) (Table 1).

The above-mentioned increase in the average annual air temperature remains in line with the trends observed all over the world in recent decades. As indicated in the Report of the Intergovernmental Panel on Climate Change (IPCC), the period from 2011 to 2020 was recognised as the warmest decade in recorded history, while in the last decade of the twenty-first century, the average global surface temperature of the Earth was by 1.09°C higher than in the second half of the nineteenth century (IPCC, 2021).

In the case of Poland, an increase in average annual air temperatures, both in the entire country and in individual physico-geographical regions, has been demonstrated in research conducted by many other authors: Wójcik and Miętus (2014); Wypych et al. (2017); Bartoszek et al. (2021); Ustrnul et al. (2021). Furthermore, Marosz et al. (2023) proved that in Poland the highest values of positive air temperature anomalies occurred within the last twenty years (2001–2021). A consequence of climate warming is an increase in the quantity of hot days and a decrease in the quantity of frosty days.

After analysing the average air temperature in calendar seasons: spring (March, April, May), summer (June, July, August), autumn (September, October,

Table 1. Statistical characteristics of air temperature in the north-eastern part of the Lublin region (1971–2020) (source: own study)

Station	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Cicibór	*t* (ºC)	–3.1	–2.1	1.9	7.8	13.7	16.8	18.6	17.9	12.9	7.7	2.8	–1.0	7.8
	σ_t (°C)	3.6	3.7	2.5	1.7	1.6	1.5	1.7	1.4	1.5	1.6	2.1	2.7	1.1
	Z test (–)	1.12	1.41	1.84	3.92	1.31	4.24	3.74	4.89	3.35	2.31	2.88	1.72	5.05
	Signific.	n.s.	n.s.	+	***	n.s.	***	***	***	***	*	**	+	***
	Sen's slope: Δt/year (°C)	–	–	0.05	0.06	–	0.06	0.06	0.06	0.05	0.04	0.05	0.04	0,05
Terespol	*t* (ºC)	–2.9	–1.9	2.2	8.3	13.9	16.8	18.6	17.9	13.0	7.9	2.9	–0.9	7.8
	σ_t (°C)	3.6	3.6	2.4	1.6	1.6	1.5	1.7	1.4	1.4	1.5	2.1	2.6	1.0
	Z test (–)	0.87	1.33	1.74	3.49	0.73	3.78	3.72	4.36	2.91	1.97	2.62	1.66	5.06
	Signific.	n.s.	n.s.	+	***	n.s.	***	***	***	**	*	**	+	***
	Sen's slope: Δt/year (°C)	–	–	0.04	0.05	–	0.05	0.06	0.05	0.04	0.03	0.05	0.04	0.04
Włodawa	*t* (ºC)	–3.1	–2.0	2.1	8.1	13.7	16.8	18.6	18.0	13.1	7.9	2.8	–1.0	7.8
	σ_t (°C)	3.5	3.5	2.5	1.7	1.6	1.5	1.7	1.4	1.5	1.5	2.2	2.5	1.0
	Z test (–)	0.95	1.22	1.72	3.68	0.90	3.94	3.75	4.62	2.73	2.38	2.71	1.67	5.05
	Signific.	n.s.	n.s.	+	***	n.s.	***	***	***	**	*	**	+	***
	Sen's slope: Δt/year (°C)	–	–	0.04	0.06	–	0.06	0.06	0.06	0.04	0.04	0.05	0.04	0.04

Explanations: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ – significance level; *t* – average monthly air temperature; σ_t – standard deviation of average monthly air temperature; Mann-Kendall test (Z test) – coefficient value of average monthly air temperature trend; Sen's slope – increase/decrease of average monthly air temperature in terms of 1 year

November), and winter (December, January, February) in the period from 1971 to 2020, it was concluded that the average air temperature in spring amounted to 8.0°C, in autumn 7.9°C, in summer 17.8°C, while in winter −2.0°C (Figure 3).

In the scope of the studied 50-year period, a large variability of average air temperature was observed in individual seasons. The greatest level of variability of thermal conditions was found in the winter season (Figure 3). In comparison to other seasons, the standard deviation values were the highest during winter (σ_t = 2.1°C) and the lowest during autumn (σ_t = 1.0°C). As indicated by Wójcik and Miętus (2014), one of the distinguishing characteristics of climatological winter in Poland consists of the large fluctuations of average air temperature. According to the above-mentioned authors, the range of temperature changes in the period from 1951 to 2010 amounted to approx. 10.2°C, while among the months recognised as climatological winter, the lowest temperature variability was observed in December.

Warming was observed in the time series of average air temperature. In the case of all seasons, an upward air temperature trend of varying intensity was observed. In the scope of the analysed stations within the studied area, the strongest increase in the average air temperature was observed during summer: the trend coefficient, which was calculated based on

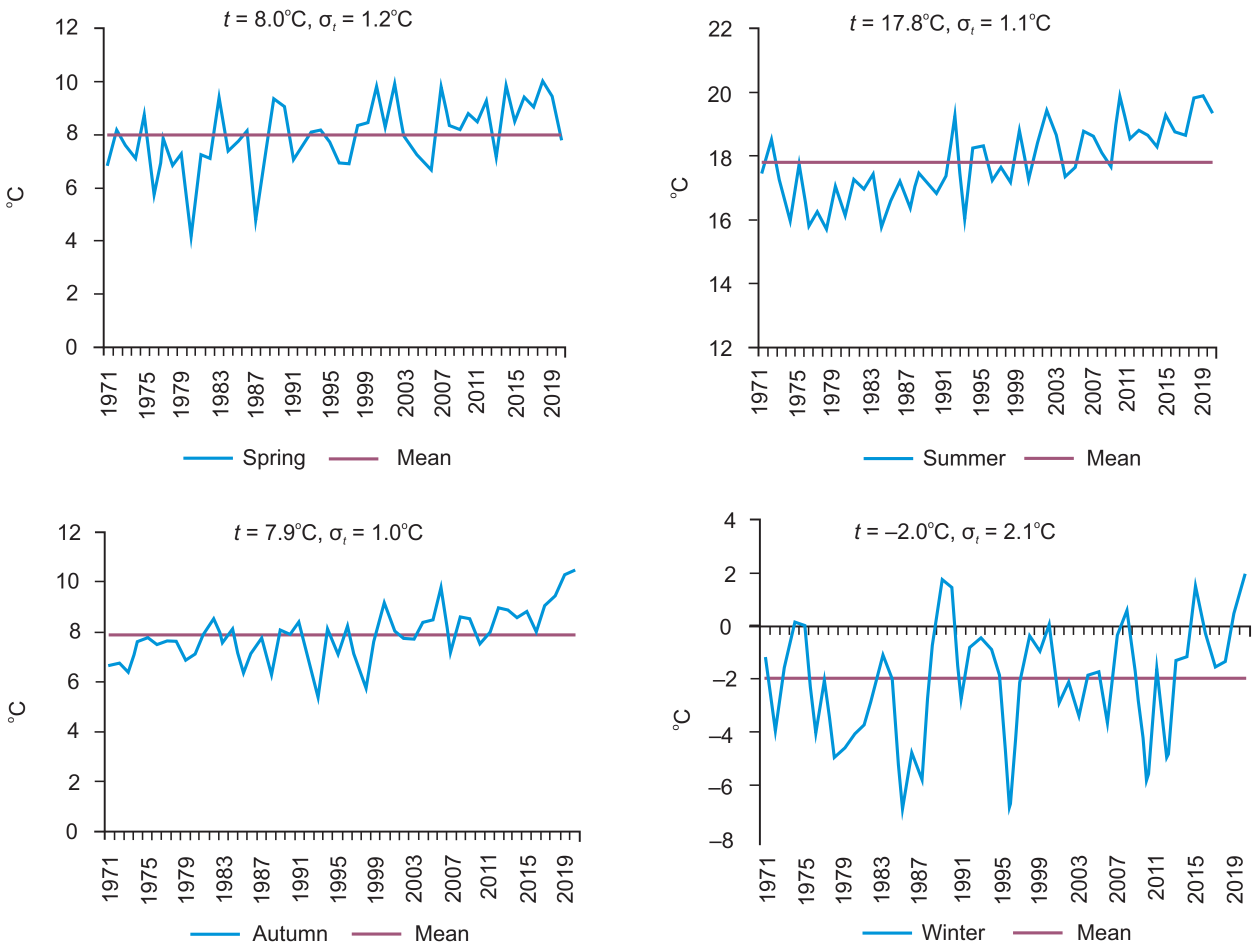

Fig. 3. The course of average seasonal air temperatures in the period from 1971 to 2020 in the north-eastern Lublin region (Source: own study)

the Mann-Kendall test (Z test), amounted to 5.4–5.9 ($p < 0.001$). Based on the calculated values of Sen's estimator (S), the increase in average air temperature during this season amounted to 0.6°C per 10 years. In the case of autumn, the trend (Z) coefficient ranged from 4.6 to 5.0 ($p < 0.001$), while an increase in temperature on average amounted to 0.4°C per 10 years. Lower values of the trend (Z) were observed during spring season: from 3.3 to 3.8 ($p < 0.001$). Furthermore, during spring the situation was similar to autumn and the increase in average air temperature amounted to 0.4°C per 10 years. In the case of winter, the smallest values (compared to other seasons) of the trend $Z = 1.9$ ($p < 0.1$) were observed. The increase in average air temperature amounted to 0.4°C per 10 years (Terespol station, Włodawa station) and 0.5°C per 10 years (Cicibór station near Biała Podlaska).

The observed increase in air temperature during winter period results in a decreasing tendency of annual amplitude, which makes the Polish climate more and more marine. Moreover, the thermal seasons of spring and summer tend to start earlier, while autumn, early winter, and winter seasons tend to start later (Wibig and Głowicki, 2002; Czernecki and Miętus, 2017). According to Michalska (2009, 2011), the air temperature upward trends in Europe are mainly manifested by the occurrence of increasingly warmer winters, and the warming is visible not only during the winter season, but also during the summer. At the beginning of the twenty-first century, a clear summer warming (June–August) occurred in Europe, which was accompanied by an increase in strong heat waves (Christidis et al., 2015; Russo et al., 2015).

While analysing the course of average monthly air temperature in the period from 1971 to 2020 (Table 1), a high temperature variability from year to year was observed in individual months, particularly during winter months, which is evidenced by the highest values of standard deviation (σ_t). By contrast, the lowest variability of average air temperature from year to year was observed during summer months (Figure 3, Table 1).

In the scope of analysed stations, the strongest statistically significant ($p < 0.001$) positive trend of air temperature occurred in the following months: April, June, July, and August, while a weaker statistically significant positive trend of air temperature was found in March, and from September to December. On the basis of the calculated values of Sen's estimator (S), the temperature increase on average ranged from 0.4°C to 0.6°C per 10 years (Table 1). Moreover, changes characterised by various intensity of monthly and annual air temperature within the territory of Poland have been proven in the studies conducted by other authors: Haensel et al. (2019); Bartoszek et al. (2021); Szyga-Pluta (2021); Ustrnul et al. (2021). According to Wójcik and Miętus (2014), in Poland, July is the warmest month in the annual cycle (in 60% of years in the period from 1951 to 2010), while January is the coldest (in 45% of years in the period from 1951 to 2010).

Atmospheric precipitation in the north-eastern Lublin region in the period from 1971 to 2020

Polish climate is described as transitional, changeable and contrasting. Among others, it is characterised by the variability of precipitation, both in terms of time and space (Kaczorowska, 1962; Wibig, 2020). Nevertheless, precipitation does not change as much as air temperature does, although significant differences in the precipitation amount may occur in relatively small areas (Wójcik et al., 2016).

After analysing the sums of average annual area precipitation in the north-eastern Lublin region, it was concluded that the average annual precipitation total in the studied multiannual period amounted to 543 mm, and was characterised by spatial and temporal variability (cv = 16%) – Figure 4.

Just like in the case of annual precipitation, the temporal and spatial differences in atmospheric precipitation totals in individual seasons (spring, summer,

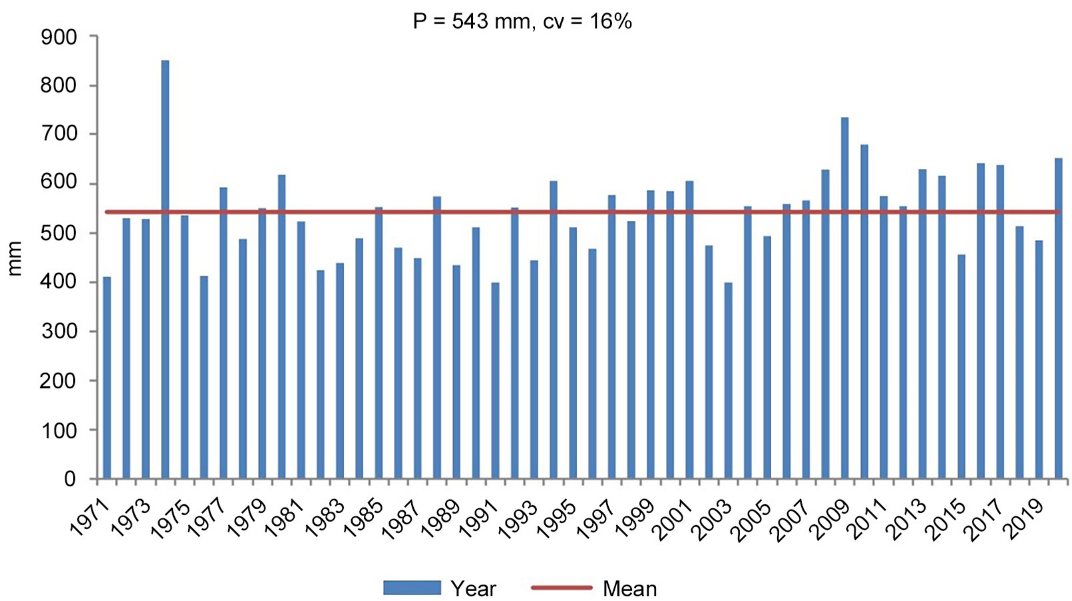

Fig. 4. The course of annual atmospheric precipitation totals (P) in the period from 1971 to 2020 in the north-eastern Lublin region (source: own study)

autumn, winter) were also found (Figure 5, Table 2). Moreover, it was observed that the summer season precipitation had the biggest share in annual precipitation total and it amounted to 211 mm, while the lowest precipitation totals occurred during winter season and amounted to 87 mm.

In comparison to other seasons, the summer precipitation totals were distinguished by the highest variability, cv = 39%, whereas the lowest variability of precipitation totals was observed during the winter season, cv = 16% (Figure 5).

Similarly to the annual and seasonal precipitation, the monthly precipitation totals in individual stations of the studied area were characterised by significant temporal differences (Table 2). The highest average precipitation totals occurred during the summer months: July – from 65 mm to 84 mm, June – from 65 to 74 mm, while the lowest totals were observed during the winter months, particularly in February – from 22 to 25 mm (Table 2).

The highest variability of monthly precipitation totals was found in October – the values of precipitation variability coefficient (cv) in individual stations ranged from 88% to 94%. The lowest variability of precipitation totals occurred in May and November (Table 2). The studies conducted by Olechnowicz-Bobrowska et al. (2005) and Ziernicka-Wojtaszek (2006) generated similar coefficients of precipitation variability.

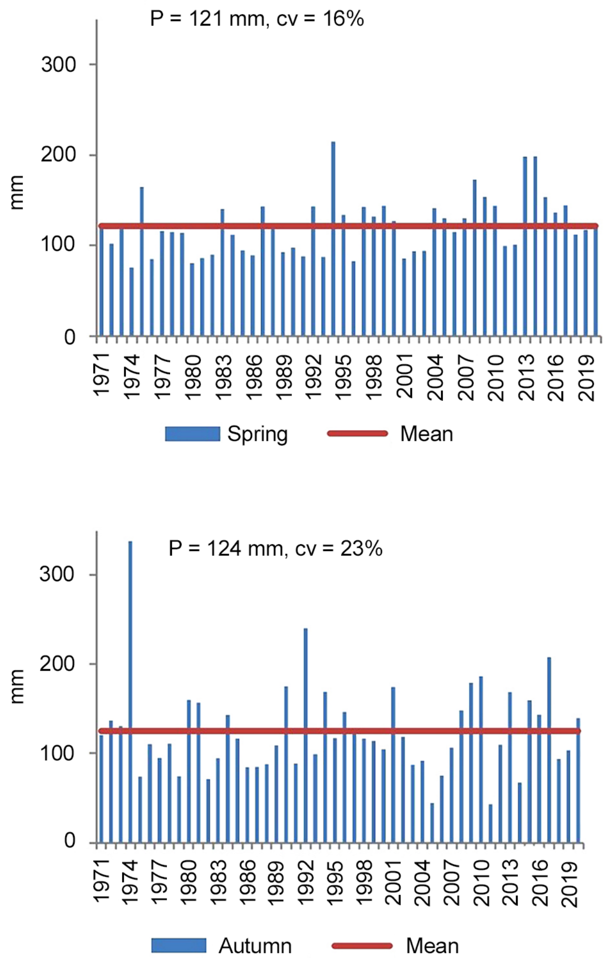

Fig. 5. The course of seasonal atmospheric precipitation totals (P) in the period from 1971 to 2020 in the north-eastern Lublin region (source: own study)

Based on the values of the Mann-Kendall trends (Z) and the Sen's estimator, our research found a significant positive trend of precipitation totals in the following months: January, February, March, and May – observed only at the station in Włodawa (Table 2). The significant positive trends of precipitation totals in the period of January-March in central-eastern Poland in 1971–2015 are confirmed by the studies conducted by Bartoszek et al. (2021). Furthermore, Marosz et al. (2011) proved that during the winter the area distinguished by a decrease in precipitation totals was mainly limited to the south-eastern part of the country. They also observed statistically significant decreases in precipitation totals in the period from 1960 to 2008 in Włodawa, and on average they amounted to 30–40 mm. In turn, Romanowicz et al. (2016) predict an increase in precipitation totals and intensification of extreme precipitation in Poland by 2100.

In his research conducted in the Lublin region, Kaszewski (2008) emphasised large spatial differentiation of the distribution of average values of the atmospheric precipitation totals in individual months, seasons, and years.

Due to the fact that the Lublin region is a typically agricultural region, an increase in average precipitation totals – which was observed in our research from January to March – is beneficial from the viewpoint of meeting the precipitation needs of plants. It is un-

Table 2. Statistical characteristics of monthly precipitation totals in the north-eastern part of the Lublin region (1971–2020) (source: own study)

Station	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Cicibór	P (mm)	26	29	36	57	70	74	65	51	39	34	35	525	557
	cv (%)	62	60	56	46	44	63	57	63	56	88	44	57	18
	Z test (–)	2.80	2.20	1.90	0.02	1.52	0.23	0.23	–0.86	–0.60	0.24	–0.12	1.61	1.94
	Signific.	**	*	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+
	Sen's slope: ΔP/year (mm)	0.46	0.38	0.24	–	–	–	–	–	–	–	–	–	1.96
Terespol	P (mm)	28	24	27	35	57	65	74	61	51	38	33	33	525
	cv (%)	61	61	56	51	45	57	54	71	59	93	48	50	17
	Z test (–)	2.59	1.71	2.13	–0.59	1.34	–0.40	0.64	–0.42	–0.37	0.39	–0.33	0.28	1.71
	Signific.	**	+	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+
	Sen's slope: ΔP/year (mm)	0.36	0.28	0.24	–	–	–	–	–	–	–	–	–	1.46
Włodawa	P (mm)	26	22	28	36	59	70	81	63	52	40	32	32	544
	cv (%)	60	58	57	47	52	62	56	67	53	94	46	58	18
	Z test (–)	1.71	1.66	2.99	0.00	1.97	–0.54	–0.14	0.74	–0.79	1.06	0.48	0.28	2.78
	Signific.	+	+	**	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**
	Sen's slope: ΔP/year (mm)	0.24	0.23	0.31	–	0.51	–	–	–	–	–	–	–	2.77

Explanations: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ – significance level; P(mm) – average monthly precipitation total; cv(%) – coefficient of precipitation variability; Mann-Kendall (Z test) test – coefficient value of average monthly precipitation total trend; Sen's slope – increase/decrease of average monthly precipitation total in terms of 1 year favourable from the point of view of plant production that precipitation is not evenly distributed during the growing season – long periods of days without precipitation or an increase in the frequency of intensive precipitation can be observed (Pińskwar et al., 2019; Kalbarczyk and Kalbarczyk, 2022).

Thermal-precipitation aridity index A in the north-eastern Lublin region in the period from 1971 to 2020

The last stage of our research involved the performance of assessment of the thermal and precipitation conditions, based on the calculated thermal-precipitation aridity index **A**. The index **A** – also referred to as the Ped's index (derived from the name of its author) – is calculated based on 2 meteorological elements, i.e. air temperature and atmospheric precipitation totals (components of the heat and water balance), and it can be used for potential drought risk monitoring. Due to the use of multiannual thermal and precipitation data, it is possible to identify the periods and areas at risk of drought (Potop et al., 2010; Kopcińska et al., 2018). Figure 6 presents the distribution of average value of the aridity index **A** from 3 meteorological stations analysed in this study. In the scope of multiannual course of the value of the index **A**, high fluctuations were ob-

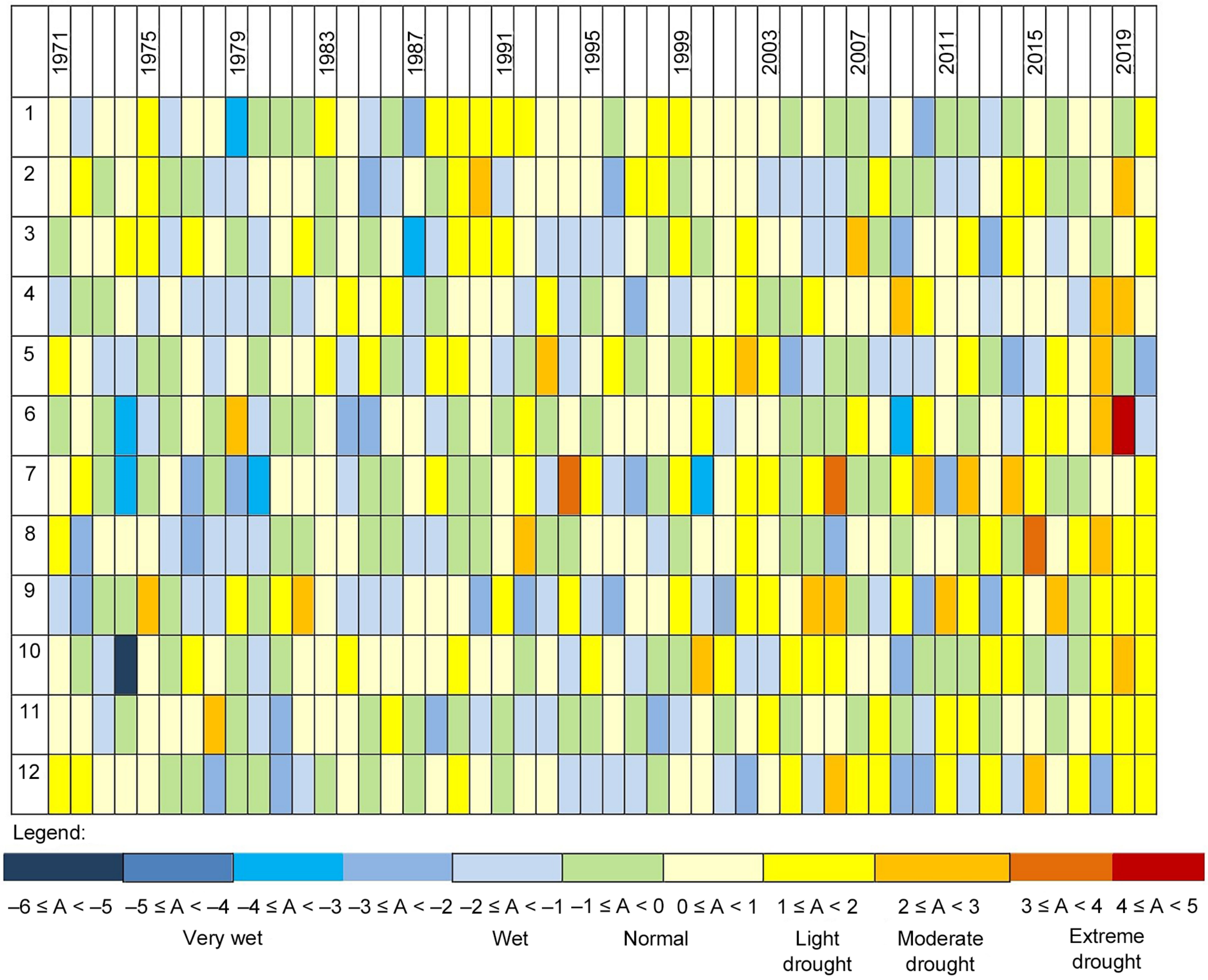

Fig. 6. The course of thermal-precipitation aridity index A in the north-eastern Lublin region in the period from 1971 to 2020 (source: own study)

served from year to year, and from month to month. The index values **A** > 1 indicate months characterised by various drought intensity, i.e. months with the signs of drought, months with moderate drought, and months with extreme drought. Depending on the value of index **A**, the above-mentioned months are distinguished with the use of colours. Figure 6 demonstrates an increase in the index value (**A** > 1) since the 1990s (24% of dry months), particularly in the last 2 decades of the twenty-first century (33% of dry months).

Figure 7 presents the course of average annual values of the aridity index A in the studied multiannual period. Temporal variability of the value of this index was detected. In the period from 2000 to 2020, the positive values of the aridity index A were prevailing. The increase in the value of above-mentioned index results from the positive trend of average annual air temperature (Figure 2, Table 1).

In the case of average seasonal values of the aridity index A (spring, summer, autumn, winter), a high variability of this index was observed from year to year (Figure 8), while particular intensification and a clear upward trend of the index A – which indicates the risk of atmospheric drought – were observed in the autumn season (Table 3 and 4).

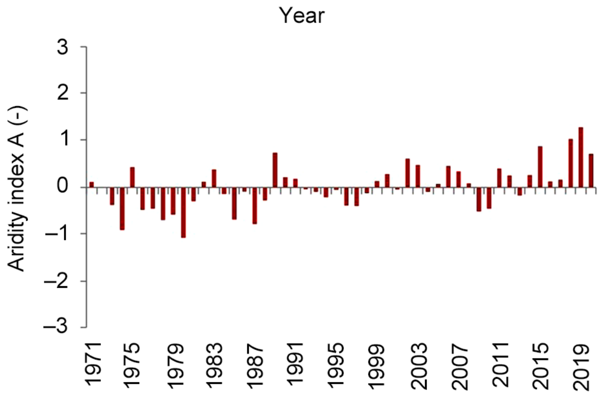

Fig. 7. Average annual values for the aridity index A from 1971 to 2020 (source: own study)

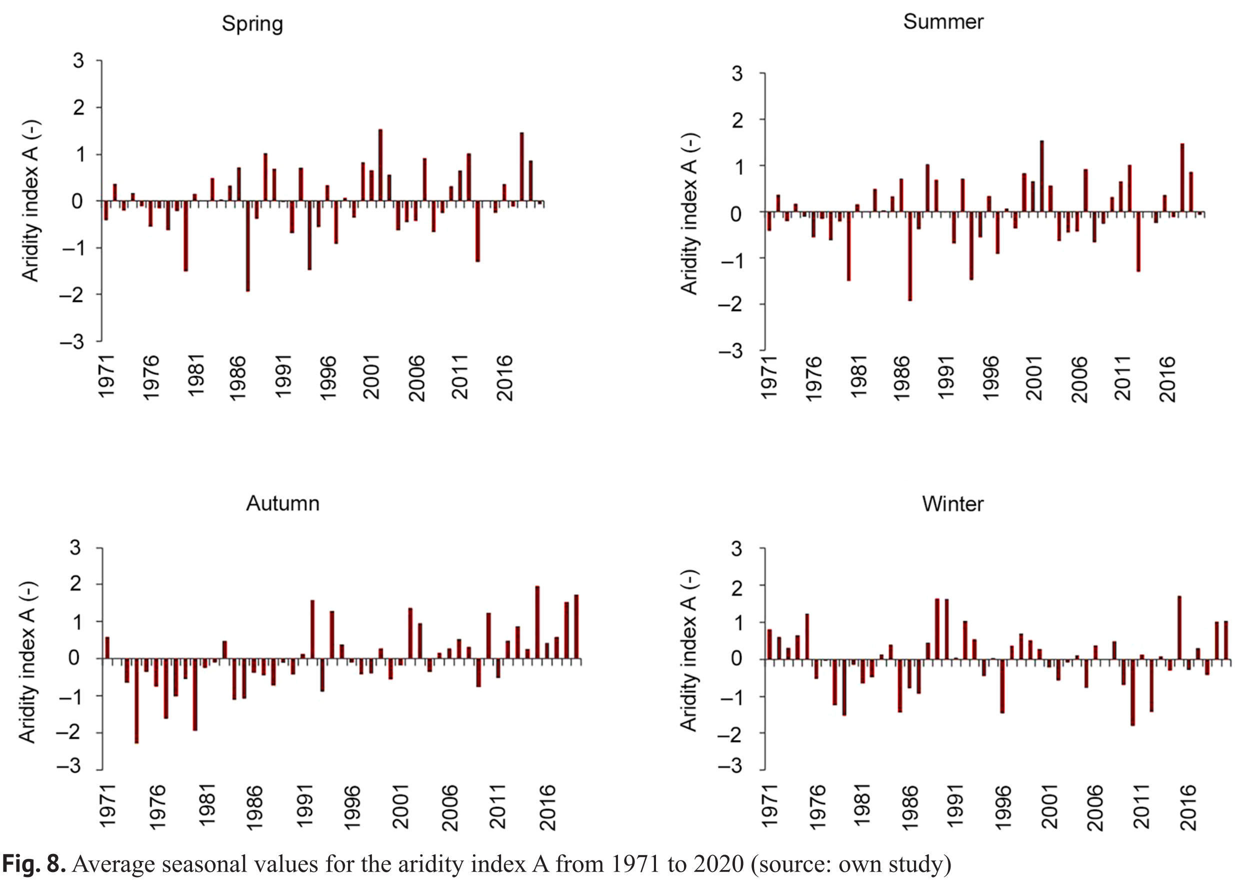

Fig. 8. Average seasonal values for the aridity index A from 1971 to 2020 (source: own study)

Table 3. The Mann-Kendall trend (Z) coefficients of aridity index **A** and the Sen's estimator that indicates changes in the index per unit in the period from 1971 to 2020 (source: own study)

Station	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Cicibór	Z test (–)	–1.74	–1.25	0.00	2.93	–0.30	3.15	2.71	3.80	2.44	1.97	1.62	–0.23	3.46
	Signific.	+	n.s.	n.s.	**	n.s.	**	**	***	*	*	n.s.	n.s.	***
	Sen's slope: ΔA/year (–)	–0.02	–	–	0.04	–	0.05	0.05	0.07	0.04	0.03	–	–	0.02
Terespol	Z test	–1.56	–0.33	–0.18	2.96	–0.42	2.52	1.89	3.15	1.84	1.81	1.76	0.75	3.58
	Signific.	n.s.	n.s.	n.s.	**	n.s.	*	+	**	+	+	+	n.s.	***
	Sen's slope: ΔA/year (–)	–	–	–	0.04	–	0.04	0.03	0.05	0.03	0.03	0.02	–	0.02
Włodawa	Z test (–)	–0.87	–0.65	–0.33	2.68	–0.70	2.48	1.86	2.01	2.01	1.81	1.59	0.59	3.98
	Signific.	n.s.	n.s.	n.s.	**		*	+	*	*	+	n.s.	n.s.	***
	Sen's slope: ΔA/year (–)	–	–	–	0.04	–0.01	0.04	0.03	0.04	0.04	0.03	–	–	0.02

Explanations: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ – significance level, Z – Mann-Kendall trend coefficients, S – Sen's estimator (its value indicates an increase/a decrease of an aridity index A per year)

The analysis of multiannual trends of the aridity index **A**, which were assessed based on the Mann-Kendall trend (Z) coefficients, demonstrated that the month of April and the months from June to November were characterised by a positive upward trend of the above-mentioned index, while negative trend was observed in January, February, March and May (Table 3, Figure 8).

The research by Bartoszek et al. (2021), which was conducted in the Lublin region in the period from 1971 to 2015, confirms an increase in the risk of drought during summer and autumn seasons in agricultural areas in Poland. In the scope of shorter 30-year period in the Opole region, Skowera et al. (2016) found a significant increase in the aridity index **A** in July, as well as local upward trends of monthly precipitation totals. Based on the 103-year series of meteorological measurements, Podstawczyńska (2010) proved that all months, except for December, were characterised by an increasing trend of the aridity index **A** – the highest increase was noted in August.

The obtained results in the scope of changes in thermal conditions (statistically significant positive trend of air temperature), as well as an increase in precipitation variability, and consequently the positive trends of the thermal-precipitation aridity index **A**, are compliant with the regional differentiations of the effects of climate change predicted in the climate models (Marosz et al., 2011; IPCC, 2013; Romanowicz et al., 2016).

Table 4. The Mann-Kendall trend (Z) coefficients and the Sen's estimator that demonstrates changes in the index per unit in the period from 1971 to 2020 (spring, summer, autumn, winter) in regard to air temperature, atmospheric precipitation totals, and aridity index A, in selected stations of the north-eastern Lublin region (1971–2020) (source: own study)

Station	Factor	Parameter	Summer	Autumn	Spring	Winter
Cicibór	Temperature	Z test (–)	5.88	5.04	3.83	1.93
		Signific.	***	***	***	+
		Sen's slope: Δt/year (ºC)	0.06	0.04	0.04	0.05
	Precipitation	Z test (–)	–0.07	0.40	2,45	3,71
		Signific.	n.s.	n.s	*	***
		Sen's slope: ΔP/year (mm)	–	–	0.71	1.12
	Aridity index A	Z test (-)	4.83	3.28	1.17	–1.3
		Signific.	***	**	n.s.	n.s.
		Sen's slope: ΔA/year (-)	0.04	0.02	–	–
Terespol	Temperature	Z test (-)	5.40	4.59	3.31	1.87
		Signific.	***	***	***	+
		Sen's slope: Δt/year (ºC)	0.06	0.04	0.04	0.04
	Precipitation	Z test (-)	0.39	0.11	1.76	2.37
		Signific.	n.s.	n.s.	+	*
		Sen's slope: ΔP/year (mm)	–	–	0,58	0,57
	Aridity index A	Z test (-)	3.78	3.09	1.3	-0.49
		Signific.	***	**	n.s.	n.s.
		Sen's slope: ΔA/year (-)	0.04	0.03	–	–
Włodawa	Temperature	Z test (-)	5.56	4.68	3.38	1.91
		Signific.	***	***	***	+
		Sen's slope: Δt/year (ºC)	0.06	0.04	0.04	0.04
	Precipitation	Z test (-)	1.17	0.67	2.74	2.06
		Signific.	n.s.	n.s.	**	*
		Sen's slope: ΔP/year (mm)	–	–	0.9	0.52
	Aridity index A	Z test	3.43	2.43	1.59	1.00
		Signific.	***	*	n.s.	n.s.
		Sen's slope:ΔA/year (-)	0.03	0.02	–	–

Explanations: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ – significance level, Z – Mann-Kendall trend coefficients, S – Sen's estimator (its value indicates an increase/a decrease of a given parameter per year)

CONCLUSIONS

This study presents thermal and precipitation characteristics of the climate in the north-eastern Lublin region, based on a 50-year analysis of the series of meteorological measurements, which are representative for the area of central-eastern Poland, and which confirm opinions regarding the temporal and spatial variability of meteorological elements, even in this relatively small area of the country. The temporal variability of thermal and precipitation conditions is exhibited by the alternating occurrence of years, seasons and months characterised by extreme values of temperature and atmospheric precipitation.

A statistically significant increase in the average annual and monthly air temperature was found, based on the calculated basic characteristics of air temperature in the period from 1971 to 2020, which on average amounted from 0.4 to 0.6ºC per 10 years during summer months, autumn months, and in April. Moreover, the temporal and spatial variability of atmospheric precipitation totals was found. The highest variability of precipitation was found in October: cv = from 88% to 94%, while the lowest variability occurred in May and November. A significant positive trend of monthly precipitation totals ($p < 0.1$) was observed in January, February, March and May, in Włodawa only. Within this period, the upward trend of atmospheric precipitation totals is a favourable phenomenon, because it ensures that the precipitation needs of plants at the beginning of their growing season are met.

An increase in the risk of atmospheric drought in the north-eastern Lublin region was determined based on the calculated values and trend analysis of the aridity index **A**, and it was concluded that the intensification of this phenomenon occurred in the last two decades, particularly during summer and autumn. The risk of drought was associated with an increase in temperature and the lack of increase in atmospheric precipitation totals during the above-mentioned period.

ACKNOWLEDGMENTS

This research was funded by Science Development Fund, project number PB/26/2020, granted to John Paul II University in Biała Podlaska and by the Ministry of Science and Higher Education of the Republic of Poland

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ZMIENNOŚĆ WARUNKÓW TERMICZNO-OPADOWYCH NA OBSZARZE PÓŁNOCNO-WSCHODNIEJ LUBELSZCZYZNY W ASPEKCIE ZAGROŻENIA SUSZĄ ATMOSFERYCZNĄ W LATACH 1971–2020

ABSTRAKT

Cel pracy

Celem pracy była ocena zmienności warunków termiczno-opadowych oraz zagrożenia suszą atmosferyczną obszaru północno-wschodniej Lubelszczyzny w latach 1971–2020.

Materiał i metody

W pracy wykorzystano dane dotyczące średnich miesięcznych wartości temperatury powietrza oraz miesięcznych sum opadów atmosferycznych z trzech stacji (Cicibór, Terespol i Włodawa) z okresu 1971–2020. Obliczono podstawowe charakterystyki statystyczne warunków termiczno-opadowych, którymi były średnie wartości miesięcznej temperatury powietrza i sum opadów atmosferycznych oraz odchylenia standardowe temperatury powietrza (σt) i współczynniki zmienności opadów atmosferycznych (cv) w latach 1971–2020. Zagrożenie suszą atmosferyczną oceniono na podstawie obliczonych wartości termiczno-opadowego wskaźnika suchości A Ped'a (1978).

Wyniki i wnioski

Na podstawie obliczonych podstawowych charakterystyk temperatury powietrza i opadów atmosferycznych stwierdzono istotny statystycznie wzrost średniej temperatury powietrza, wynoszący przeciętnie od 0.4 do 0.6°C/10 lat w miesiącach letnich, jesiennych oraz w kwietniu. Zaobserwowano istotny statystycznie wzrost sum opadów podczas chłodnego półrocza: w styczniu oraz słabszy trend rosnący w lutym i w marcu. Na podstawie obliczonego termiczno-opadowego wskaźnika suchości A stwierdzono wzrost zagrożenia suszą atmosferyczną obszaru północno-wschodniej Lubelszczyzny, a nasilenie tego zjawiska wystąpiło w dwóch ostatnich dekadach, szczególnie latem i nieco mniej intensywnie jesienią. Jako główną przyczynę zagrożenia suszą badanego obszaru wskazano istotny statystycznie wzrost temperatury powietrza oraz brak tendencji zmian opadów atmosferycznych. Wyniki badań naukowych innych autorów na temat zmienności warunków termiczno-opadowych na obszarze Polski nie są jednoznaczne, dlatego też należy prowadzić dalsze badania na ten temat i weryfikować scenariusze zmian klimatu, zwłaszcza w skali regionalnej.

Słowa kluczowe: temperatura powietrza, opady atmosferyczne, termiczno-opadowy wskaźnik suchości A, susza meteorologiczna, Lubelszczyzna