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Application of the standardised precipitation evapotranspiration index to identify drought and wet periods in Western Polesie

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Abstract: The paper used monthly precipitation and temperature values to analyse climatic water conditions in Western Polesie, Poland. Annual precipitation was 540 mm, ranging from 347 to 746 mm in 2003 and 2009, respectively. Evapotranspiration averaged 458 mm over the multiannual period, ranging from 427 to 491 mm in wet and dry years, respectively. Standardised precipitation evapotranspiration index (*SPEI*) was calculated based on weighted averages for 1981–2020 at different periods. Based on time steps including 6-, 12-, and 24-month periods, periods with varying levels of wetness were distinguished. The average frequency of dry and wet periods was 30.2% and 29.4%, respectively. Four intense drought periods were identified: 1982–1985, 1990–1993, 2002–2005, and 2018–2020. Drought was often associated with low monthly and annual precipitation, below 20 and 450 mm, respectively. Another factor contributing to drought was low winter precipitation and the high summer temperatures. Intense wet periods occurred in 1981–1982, 1998–2002, 2008–2012, and 2013–2015. Wet periods were often associated with heavy monthly and annual precipitation totals, above 150 mm and 650 mm, respectively. In the 21st century, the frequency, duration and magnitude of dry and wet periods increased significantly. This increase indicates greater climatic variability. Water resources need to be increased and adaptation measures introduced in response to predicted climate change in the region.

Keywords: dry and wet periods, precipitation, standardised precipitation evapotranspiration index, temperature

INTRODUCTION

The average annual amount of water per capita in Poland is 1,600 m^3, which is 2.5 times lower than the European average and 4.5 times lower than the world average. Poland ranks 24th in the European Union regarding renewable freshwater resources per capita. Moreover, water resources in Poland are relatively small and are characterised by seasonal variability and spatial diversity. According to the global indicator of water demand, Poland's water stress is 30%. Industry has the highest water consumption, accounting for 70% of the water used; municipal services use 20% (Rączka, Skąpski and Tyc, 2021).

Moisture conditions are identified and monitored using various meteorological, soil, and hydrological indicators. Zargar *et al.* (2011) presented an overview of drought indicators, whereas Łabędzki (2017) reviewed methods used in drought studies in Poland. Some indices are used in specific conditions and reflect different types of drought. Individual drought indices have their advantages and disadvantages (Mishra and Singh, 2010). The standardised precipitation index is most commonly used to monitor meteorological drought. The crop moisture index is used to characterise soil drought. The last group of hydrological droughts includes the Palmer hydrological drought index (*PDSI*) (Zhou *et al.*, 2022). In studies conducted in the United States, the possibility of utilising the most commonly used drought indices (*PDSI*, Palmer *Z*-index, standardised precipitation-evapotranspiration index – *SPEI*, standardised precipitation index – *SPI*, normal percentage of precipitation, and precipitation percentiles)

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was analysed for the assessment of agricultural drought (Tian, Yuan and Quiring, 2018). Similar studies were conducted in Sweden to analyse the frequency of fire occurrence (Drobyshev *et al.*, 2012).

Palmer drought severity index (*PDSI*) is a soil-moisture algorithm calibrated for homogeneous regions that accounts for precipitation, temperature, and available soil water content. Drought identification based on *PDSI* was performed in Huaibei Plain during 1953–2020 (Zhou *et al.*, 2022) and in Croatia (Pandzić *et al.*, 2022). The *SPI* is based on the probability of monthly precipitation but does not take into account other meteorological factors. The standardisation of the index allows for comparison of droughts in different regions and preliminary identification of drought types. Spatiotemporal drought analysis was performed in Sichuan Province during the period 1961–2019 (Liu *et al.*, 2021) and Turkey between 1970 and 2021 (Şimşek and Turhan, 2025). Precipitation percentiles are observation values below which a specified percentage of precipitation occurs. Long-term observed precipitation values are sorted into a monthly ranking. The percentile method was used to evaluate extreme precipitation in Beijing (Song *et al.*, 2019). Normal percent precipitation (PN) is calculated by comparing the actual precipitation with the multi-year average value for a period of 30 years. In Pakistan, the percent normal index was used for the temporal evolution of extreme precipitation episodes (Ullah *et al.*, 2021). The *SPEI* standardises the difference between precipitation and potential evapotranspiration using a gamma distribution. The spatio-temporal variability of *SPEI* was analysed in Spain during the period 1961–2014 (Domínguez-Castro *et al.*, 2019), in China during the period 1961–2016 (Wu *et al.*, 2020), and in Iran during the period 1966–2018 (Majd, Montaseri and Amirataee, 2025).

Moisture conditions can be characterised by standardising rainfall, evapotranspiration, and water-balance indicators, which enables comparable assessment of the phenomenon under different climatic conditions and periods (Łabędzki and Bąk, 2017). Another important issue is identifying quantitative relationships between atmospheric and agricultural drought and assessing the usefulness of atmospheric drought indicators for determining agricultural drought intensity (Kubiak-Wójcicka and Juśkiewicz, 2020; Kuśmierek-Tomaszewska and Żarski, 2021). Due to the large number of studies carried out using various methods, researchers identify drought using several methods simultaneously and critically evaluate these methods (Ziernicka-Wojtaszek and Kopcińska, 2020).

This indicator has been used to identify deficit or excess of rainfall under various climatic conditions. The variability of meteorological drought has been studied on a regional scale in Central Europe (Jaagus *et al.*, 2022). In Poland, drought occurrence was analysed in the context of future climate changes (Osuch *et al.*, 2016); the research concerned mountainous (Młyński, Wałęga and Kuriqi, 2021) and central regions (Bąk and Kubiak-Wójcicka, 2017). No analysis of meteorological drought patterns in Eastern Poland has yet been conducted. The World Meteorological Organisation recommends *SPI* as the basic drought monitoring indicator (WMO, 2012). However, *SPI* has the disadvantage that it is based only on monthly precipitation. Meanwhile, other variables such as transpiration and evaporation can significantly impact drought occurrence. Many researchers have argued that temperature changes also affect drought occurrence. To improve drought assessment, an index based on the *SPEI* was developed (Vicente-Serrano, Beguería and López-Moreno, 2010). These studies found statistically insignificant decreasing trends in precipitation. The aims of the paper were: 1) to analyse the temporal variability of monthly precipitation in a multi-year period of 1981–2020, 2) to examine air temperature variability and identify trends in annual temperatures, 3) to analyse the occurrence of drought and wet periods, and 4) to determine the effect of climate change on the intensity of dry and wet periods.

MATERIAL AND METHODS

Western Polesie has a temperate climate and lies in a transition zone between oceanic and continental climates. In 1951–2020, the average temperature in the warmest month of July was 18°C, while for the coldest month of January it was −3°C. The wettest month was July, with an average precipitation of 77 mm, and the driest month was January, with an average precipitation of 24 mm (Kaszewski, 2002). Western Polesie is a physical and geographical macroregion, the north-western part of Polesie, which is part of the East European Plain megaregion. Cretaceous marls on the surface or at shallow depths contributed to the development of karst phenomena in Western Polesie. This area contains the only concentration of lakes of karst or thermokarst origin in Poland. Because of its extensive swamps and infertile soils, Western Polesie has been only slightly transformed by human activity. In land use terms, arable land covers smaller areas than in other regions of the Central Poland lowlands, while the share of meadows and pastures is greater. Groundwater lying just below the surface creates shallow lakes and vast swamps. In Polesie, there are numerous rivers, and among the marshes, there are slightly higher moraine and glacial-water plains and fixed dunes. About 40% of the area is covered by wetlands and related peat bog complexes (Chmielewski *et al.*, 2016). Based on the hierarchy of small retention needs, Western Polesie was classified as an area requiring increased water resources. According to the division of Poland's climate, Western Polesie lies in the Great Valleys climate region in the Podlasie region. This region is characterised by an average temperature of 7.7°C and an average rainfall of 560 mm (Skowera and Kopeć, 2008).

The data covered the period from 1981 to 2020 and were collected from six meteorological stations in Western Polesie, Poland (Fig. 1). The terrain is lowland, with minimal elevation differences. Elevation ranges from 135 to 180 m a.s.l., and the terrain rises gradually from Terespol to Bezek. The 40-year sequence of meteorological data covering monthly precipitation and average monthly temperature amounts was used to analyse drought and wet periods. The data met homogeneity criteria: measurements were made using the same method and without any gaps. The summer and growing seasons are long (105 and 215 days, respectively). The duration of snow cover is 80 days (Kaszewski, 2002).

In this study, *SPEI* was used to analyse drought and wet periods. *SPEI* is based on the difference between precipitation and potential evapotranspiration. Potential evapotranspiration can be calculated using various methods, such as the Thornthwaite equation (Thornthwaite, 1948), which is used in the global drought monitor (Begueria *et al.*, 2010). The Penman–Monteith method, recommended by the Food and Agriculture Organiza-

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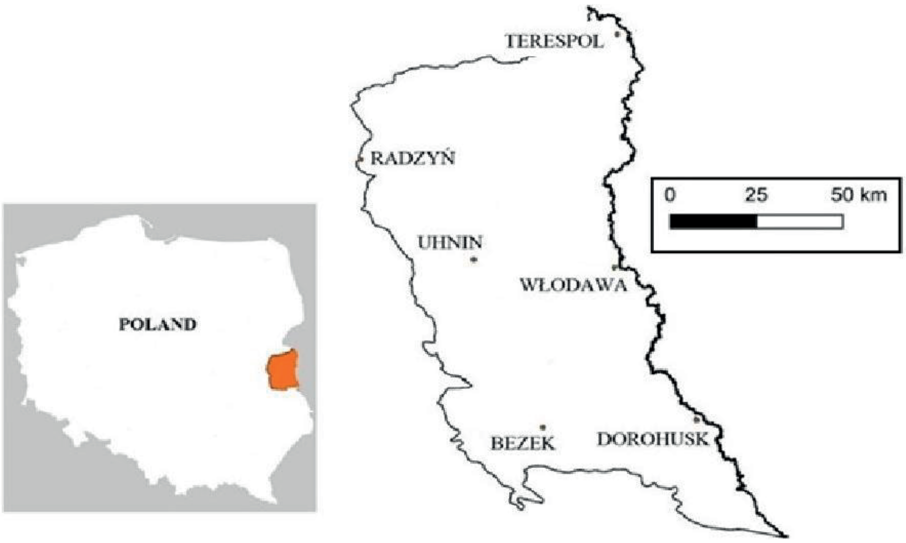

Fig. 1. Location of meteorological stations; source: own elaboration

tion of the United Nations, is more reliable and effective (Moratiel *et al.*, 2020). Unfortunately, this method requires several climate data points, which are not always recorded at all meteorological and precipitation stations. In Poland, *SPEI* changes were analysed using the Thornthwaite equation. The *SPEI* is based on the climatic water balance, which determines the difference between precipitation and potential transpiration vapour (Begueria *et al.*, 2010):

$$SPEI = P - PET \tag{1}$$

where: P = monthly precipitation (mm), PET = potential evapotranspiration, calculated acc. to Thornthwaite's method:

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \tag{2}$$

where: T = monthly mean temperature (°C), I = heat index, which is calculated as the sum of 12 monthly index values i, the latter being derived from mean monthly temperature (Eq. (3)), m = a coefficient depending on I, calculated using Equation (4), K = a correction coefficient computed as a function of the latitude and month (Eq. (5)).

$$i = \left(\frac{T}{S}\right)^{1.514} \tag{3}$$

$$m = 6.75 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.492 \tag{4}$$

$$K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right) \tag{5}$$

where: NDM = the number of days of the month, N = the maximum number of sun hours, which is calculated using Equation (6):

$$N = \frac{24}{\pi}\omega \tag{6}$$

where: ω = the hourly angle of sun rising, which is calculated using Equation (7):

$$\omega = \arccos(-\tan\varphi \tan\delta) \tag{7}$$

where: φ = the latitude in radians, δ = the solar declination in radians, calculated using Equation (8):

$$\delta = 0.4093 \sin\left(\frac{2\pi J}{365} - 1.405\right) \tag{8}$$

where: J = the average Julian day of the month.

The full calculation procedure for *SPEI* can be found in the article by Vicente-Serrano, Beguería and López-Moreno (2010). This study uses the latest data and considers longer time scales of water deficits or excess: 6, 12, and 24 months. The 40-year sequence of meteorological data covering monthly precipitation and average monthly temperature amounts was used to analyse drought and wet periods. Monthly precipitation and temperature data were used to determine the intensity of drought and wet periods using the *SPEI* method (Tab. 1).

Statistical analyses were carried out to assess variability in precipitation and temperature. First, descriptive statistics and dispersion measures (maximum, minimum, standard deviation – *SD*, and coefficient of variation – *CV*) were used for pluviometric

Table 1. Classification of standardised precipitation evapotranspiration index (*SPEI*)

Class	*SPEI*
Very extreme wet	>1.65
Extreme wet	<1.28; 1.65)
Severe wet	<0.84; 1.28)
Moderate wet	<0.49; 0.84)
Normal	<0.49; 0.49)
Moderate dry	<−0.84; −0.49)
Severe dry	<−1.28; −0.84)
Extreme dry	<−1.65; −1.28)
Very extreme dry	<−1.65

Source: own elaboration.

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data from six stations. The coefficient is expressed as a percentage, and the interpretation depends on the calculated value. The following ranges were adopted: below 25% – very low variability, 25-45% – average variability, 45–100% – strong variability, and above 100% – very intense variability. To obtain a more accurate assessment of variability, average precipitation and temperature were compared for years and months (ANOVA). Trend detection in the *SPEI* data series was performed with the nonparametric Mann–Kendall test, at a statistical significance level of $\alpha = 0.05$ using the Statistica program. Trend coefficients were determined using the least squares method. The Wilcoxon rank sum test was used to analyse the occurrence of frequencies in two groups of data collected according to the independent variables model (period 1981–2000 compared to period 2001–2020). An attempt was also made to relate dry and wet periods to meteorological conditions (temperature, precipitation) using sensitivity analysis.

RESULTS AND DISCUSSION

Annual precipitation ranged from 377 mm in 2003 to 746 mm in 2009 (Fig. 2). Annual precipitation showed a statistically insignificant increasing trend. The average annual precipitation in the study area was 540 mm and was 100 mm lower than the average annual precipitation in Poland, which amounted to 640 mm. Temporal and spatial differences were found both in the case of annual and seasonal precipitation (Tomczyk and Szyga-Pluta, 2019; Grzywna *et al.*, 2020). The largest share of annual precipitation was recorded in the summer season, totalling 210 mm, while the lowest total occurred in winter, at 86 mm. Annual precipitation totals over the 40-year period did not show a clear trend. However, the results confirm that changes in precipitation are not uniform. We can distinguish periods when a decrease in air temperature is accompanied by an increase in precipitation, which is especially visible in the summer season. No statistically significant differences were found between seasons. Strong fluctuations and, in the case of precipitation, successive dry and wet periods dominate the long-term course of some meteorological elements. Significant trends appear only in a few regions of Poland, in selected periods of the year, and for specific precipitation characteristics (Łupikasza and Małarzewski, 2021). In the average annual course of atmospheric precipitation throughout Poland, the summer maximum is visible; however, according to the Köppen-Geiger climate classification (Beck *et al.*, 2006), most of Poland belongs to the zone of warm, temperate, moist climate.

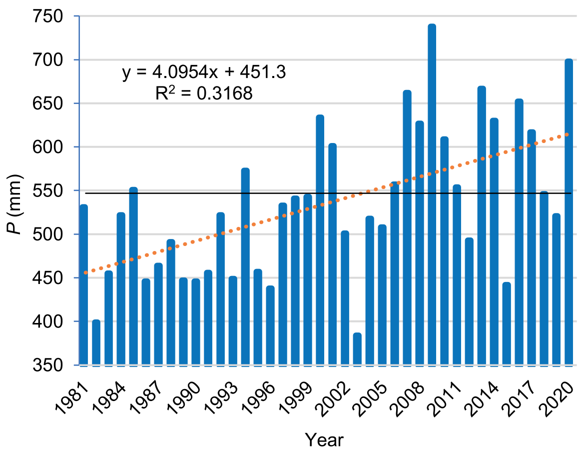

Fig. 2. The annual precipitation in the period 1981–2020, source: own study

Significant differences over time characterised monthly precipitation totals at individual stations in the study area. The highest average monthly precipitation occurred in July and amounted to 77.4 mm, while the lowest was in January and amounted to 23.8 mm. The lowest monthly precipitation was recorded in January 2002 and amounted to 1.1 mm, whereas the highest was recorded in August 2007 and amounted to 262 mm. The greatest variation in precipitation determined using the standard deviation was found in July – 54.1 mm, and the coefficient of variation in August – 76.2%. The smallest standard deviation was recorded in March – 14.3 mm, and the smallest variability in November – 49.3% (Tab. 2). Similar values of precipitation coefficients of variation were reported in other studies in Poland for the 1971–2000 multiyear period (Ziernicka-Wojtaszek and Zawora, 2008). Research conducted in the Lublin region highlighted large spatial differences in the distribution of average precipitation amounts in individual months, seasons, and years. Based on the analysis of data for the period 1971–2015 for eastern Poland, clear trends in the increase in precipitation totals in the period January–March were found (Bartoszek *et al.*, 2021). Moreover, an increase in precipitation totals and an intensification of extreme rainfall events were expected for the 21st century (Wypych and Ustrnul, 2024). Other researchers have observed the occurrence of long sequences of days without precipitation and an increase in the frequency of intense precipitation, which is

Table 2. Descriptive statistics of monthly precipitation in 1981–2020

Statistics	Value in month (mm)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	23.8	25.6	28.4	40.5	62.9	65.7	77.4	60.6	52.3	38.2	33.8	30.5
Min.	1.1	2.6	7.4	5.9	19.6	7.1	7.5	3.8	6.8	6.7	1.9	3.5
Max.	62.7	67.1	74.9	84.1	174	172	242	262	141	122	72.5	82.2
SD	16.1	15.7	14.3	19.7	33.4	39.6	54.1	46.2	31.3	27.7	16.6	17.4
CV	67.7	61.5	50.4	55.4	53.0	65.2	69.9	76.2	59.9	72.4	49.3	57.3

Explanations: *SD* = standard deviation, *CV* = coefficient of variation.
Source: own study.

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unfavourable for meeting plants' water needs (Kalbarczyk and Kalbarczyk, 2022).

In Poland, the lowest precipitation occurs in the Greater Poland Lake District, where it amounts to 490 mm per year and increases towards the north and south (Ziernicka-Wojtaszek and Kopcińska, 2020). Based on the hierarchy of small retention needs, Western Polesie was classified as an area requiring an increase in water resources. Annual rainfall totals reflect multi-annual variability but do not capture within-year variability. In the analysed period, precipitation shows a statistically insignificant increasing tendency (Fig. 2). In the analysed area, this is particularly visible in August, when the lowest precipitation was 3.8 mm and the highest was 262 mm (Tab. 2).

The multi-year average air temperature in the study area was 7.8°C (Fig. 3). The average monthly temperature in Western Polesie ranged from −3.2 to 18.8°C, in January and July, respectively (Tab. 3). The lowest average monthly temperature was recorded in January 1987, at −10°C. The highest monthly temperature was recorded in June 2019, when it was 21°C. The greatest variation in temperature determined using the standard deviation was found in February, which amounted to 3.1°C. The smallest standard deviation was recorded in July, which amounted to 1.1°C. Data analysis showed that the average temperature increased by 2.26°C in 1981–2020. In the cold season, the temperature increased by 2.7°C, and in the warm season by 1.8°C. The largest increase in temperature occurred in December by 5.1°C. These differences were statistically significant. The lowest mean annual temperature was observed in 1987 when it was 5.8°C, while the highest temperature was recorded in 2019 when it was 10°C (Fig. 3). The mean air temperature values in the individual decades of the period range between 7.4°C in the decade 1981–1990 and 9.1°C in the decade 2011–2020. A similar pattern was observed for 30-year averages (normal climatological periods). In this case, there was an increase from 7.7°C for the period 1981–2010 to 8.4°C for the period 1991–2020. This means that the 30-year norm increased by 0.7°C.

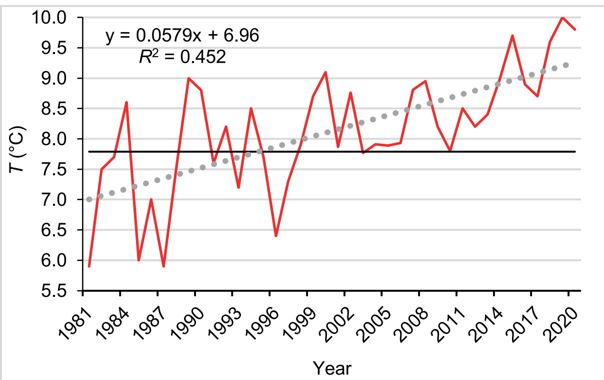

Fig. 3. The annual temperature in the period 1981–2020; source: own study

The observed changes correspond to the changes predicted in regional climate models (RCA3, HadRM3, HIRHAM5). The long-term increase in air temperature in Poland is expressed by an increase in the average annual temperature and the maximum temperature in the summer season (Falarz, 2021). Forecasts of changes in thermal conditions for the years 2021–2050 indicate that the greatest warming will occur in winter. A predicted temperature increase of about 1–3°C will shorten the duration of snow cover and reduce its thickness. The two most frequently considered forecasts (RCP4.5, RCP8.5) indicate the risk of more dramatic changes that may cause an intensification of the hydrological cycle (Szyga-Pluta *et al.*, 2022; Szwed and Holka, 2024). Studies by many authors (Ziernicka-Wojtaszek and Zawora, 2008) confirm the clear increase in air temperature observed since the mid-20th century. Since the 1950s, there has been a very marked increase in global temperature, with each 30-year period getting warmer (Jarraud, 2013). The greatest warming occurred in the last 40 years, and the analysed period was one of the warmest in world history (Pörtner *et al.*, 2022).

Evapotranspiration, calculated using the Thornthwaite method, averaged 458 mm over the multiannual period, ranging from 427 to 491 mm in wet and dry years, respectively. The lowest evapotranspiration occurred in 1987, while the highest in 2019 was 399 mm and 520 mm, respectively. Evapotranspiration occurs mainly during the growing season, while in winter it is very low and close to zero.

The longest drought periods lasted from 3 months for *SPEI*-6 to 34 months for *SPEI*-24. The results allowed to identify four main periods of intense drought in 1981–2020. They occurred in the periods 1982–1985, 1990–1993, 2002–2005, and 2018–2020. Dry periods lasted from one to three years and were followed by wet periods. In agriculture, it important to assess the effects of drought that follow precipitation deficiency. Soil drought is most often a consequence of a drought period. For this reason, longer periods are used for long-term precipitation anomalies. Soil drought is preceded by precipitation deficiency and the negative effects of precipitation deficiency (soil moisture, groundwater

Table 3. Descriptive statistics of monthly air temperature in 1981–2020

Statistics	Value in month (°C)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	−3.2	−2.0	2.3	7.8	12.7	16.7	18.8	17.8	12.6	7.8	3.7	−1.6
Min.	−10.0	−8.6	−2.4	5.7	10.2	13.8	17.3	16.0	10.5	4.2	0.0	−8.2
Max.	2.1	3.2	5.5	13.0	16.1	21.0	20.7	20.5	14.6	10.1	5.9	2.6
SD	2.9	3.1	2.5	1.6	1.4	1.6	1.1	1.2	1.3	1.7	1.6	2.8
CV	12.1	11.8	7.9	7.3	5.9	7.2	2.4	4.5	4.1	5.9	5.9	10.8

Explanations: as in Tab. 2.
Source: own study.

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depth) (Radzka, 2015; Grzywna, 2017; Łabędzki and Bąk, 2017; Oleszczuk *et al.*, 2022). Catastrophic soil droughts occurred in Poland in 1992, 2003, and 2019 (Łabędzki and Bąk, 2014; Ziernicka-Wojtaszek, 2021). For *SPEI*-12 and *SPEI*-24, the first period of drought began in July 1982 and ended in August 1985 (Fig. 4). The main cause of this drought was low annual precipitation, which in 1982 and 1983 amounted to 399 and 455 mm, respectively (Fig. 2). A second cause was the high temperature recorded in 1984, which reached 8.6°C (Fig. 3). In the winter of 1982/1983, drought of varying intensity covered over 90% of the area of Poland. The second drought period lasted from December 1989 to September 1993. The main cause of this drought was low annual precipitation, which in 1989, 1990, 1991 and 1993 amounted to 450 mm (Fig. 2). The second cause was high air temperatures, which in 1989 and 1990 amounted to 9.0 and 8.8°C, respectively (Fig. 3). For *SPEI*-6, three droughts lasting about five months were recorded in spring 1989, spring 1990, and winter 1991/1992 (Fig. 4). Droughts in 1989–1994 were also recorded in the river basins of northern Poland (Bąk and Kubiak-Wójcicka, 2017). In 1990–1992, catastrophic droughts covered over 60% of Poland. The third drought period lasted from July 2002 to March 2005 (Fig. 3). One of the reasons was the high air temperatures recorded in Poland in 2000, when they reached 9.0°C. In the analysed period, an increase in the number of hot days was recorded during the growing season, which was particularly visible in 2003 (Graczyk *et al.*, 2017). The second cause of the long-term drought was low annual precipitation, which in 2002–2005 ranged from 384 to 518 mm. Droughts in 1990–1993 and

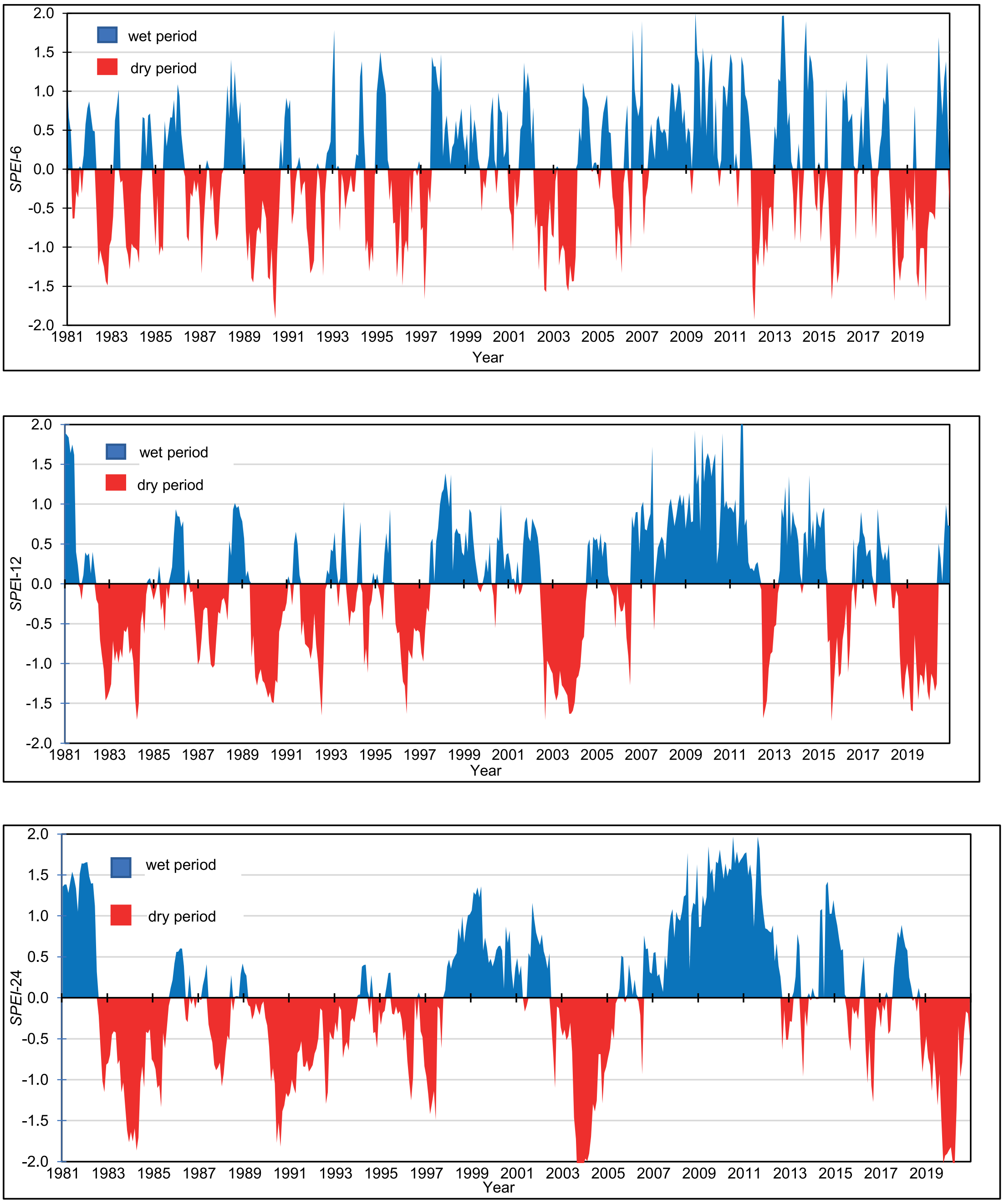

Fig. 4. Dry and wet periods in the Western Polesie in 1981–2020 according to *SPEI*-6, *SPEI*-12, and *SPEI*-24; source: own study

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2002–2005 also occurred in other European countries (Spinoni *et al.*, 2015; Trnka *et al.*, 2016; Hanel *et al.*, 2018; Hänsel *et al.*, 2019). The same periods were confirmed in other studies using the *SPEI*. In the case of *SPEI*-12 and *SPEI*-24, the last drought lasted from October 2018 to August 2020. One of the main reasons for this drought was the very low precipitation totals in the spring and summer of 2020. In February and July 2019, monthly precipitation totals did not exceed 20 mm. Total annual precipitation in 2019 was also low and amounted to 527 mm. June 2019 was the warmest month in the entire multi-year period with a temperature deviation of 4.8°C (Ziernicka-Wojtaszek and Kopcińska, 2020).

Very extreme dry periods, according to the criteria presented in Tab. 1, were found only for *SPEI*-24. These periods occurred from December 1983 to May 1984, from June to August 1990, from August 2003 to April 2004, and from September 2019 to April 2020. This means that the longest extreme drought lasted nine months (2003/2004). The second drought period lasted eight months (2019/2020). In addition, in the winter seasons of 2003/2004 and 2019/2020, the *SPEI*-24 was below −2.0. Values of *SPEI* <-2.0 occurred in the 21st century, while in the 20th century, such events did not occur. The literature contains extensive information on drought periods, but much less on wet periods (Oliveira-Júnior de *et al.*, 2021). The information presented in references most often concerns wet years and the growing season. However, these studies most often analyse only the total annual precipitation over multiyear (Caloiero *et al.*, 2018; Gajić-Čapka *et al.*, 2015). In turn, other studies analyse the amount of precipitation during the growing season against the background of evapotranspiration (Tomczyk and Szyga-Pluta, 2019). Various indicators of extreme precipitation are also used to characterise wet periods, such as maximum monthly precipitation and the number of days with precipitation above 10 mm (Pińskwar *et al.*, 2019; Twardosz and Cebulska, 2020).

The longest wet period lasted from 5 months for *SPEI*-6 to 37 months for *SPEI*-24. Four wet periods lasting from two to three years were also distinguished. Intense wet periods occurred in 1981–1982, 1998–2002, 2008–2012, and 2013–2015. Heavy rainfall resulted in catastrophic floods in 1997, 2010, and 2014 (Kundzewicz, Szamalek and Kowalczak, 1999; Dobrovičová, Dobrovič and Dobrovič, 2015; Bryndal *et al.*, 2017). For *SPEI*-12 and *SPEI*-24, the first wet period began in January 1981 and ended in June 1982 (Fig. 4). The primary cause of this wet period was the heavy snowfall in the winter of 1980/1981 and the subsequent melting of the snow cover in spring.

The second wet period lasted from February 1998 to June 2002. One of the main reasons was the very high precipitation totals recorded in July 1997 and May 2000, which reached 202 and 128 mm, respectively. The occurrence of a flood in June 1997 was confirmed in Germany (Becker and Grünewald, 2003).

The third wet period lasted from July 2007 to June 2012. This phenomenon was caused by several short wet periods in 2009–2011; in July 2009 and 2011, and in May 2010, the *SPEI*-6 value exceeded 1.5. One of the reasons was the high precipitation recorded in Poland in 2009-2011. The highest annual precipitation in Western Polesie was recorded in 2009 and amounted to 740 mm, i.e., 200 mm more than the multi-year average (Fig. 2). One of the main reasons for the occurrence of the wet period was the very high precipitation in May 2010, amounting to 174 mm. The main cause of the hydrological flood in May 2010 was very high precipitation. The flood in May 2010 was also recorded in the Czech Republic and France (Alfieri and Thielen, 2015; Gaume *et al.*, 2016).

The last wet period lasted from May 2013 to April 2015. The main cause of the excess water during this period was heavy rainfall in May and June 2013, reaching 110 mm per month. Extreme rainfall was also recorded in August 2014, when it amounted to 108 mm. In addition, annual precipitation in 2013 was very high and amounted to 666 mm. The flood in 2014 also occurred in southern Poland (Twardosz and Cebulska, 2020). For *SPEI*-24, three very extreme wet periods were found (Fig. 4). The longest of these periods lasted from July 2010 to April 2011 (10 months). The second period lasted from August to September 2011 (2 months), and the third occurred in June 2009. In addition, *SPEI*-12 reached its highest value of 2.0 in July and August 2011.

The study compared the frequency of dry and wet periods in the 20th century (1981–2000) and the 21st century (2001–2020). Over the 40-year period, the frequency of dry periods was 30.2%; in the 20th and 21st centuries, it was 22.4 and 38.0%, respectively. The frequency of wet periods was 29.4%; in the 20th and 21st centuries, it was 24.4 and 34.4%, respectively. The data presented show that in the 21st century, there was a statistically significant increase in the frequency of dry and wet periods. Dry and wet periods occurred with greater intensity and lasted longer. In addition, dry and wet periods were characterised by very high temporal variability. Rapid changes in the amount of precipitation are one of the effects of climate change. For example, after an exceptionally dry February 2012 (*SPEI*-6 was −1.95), there was an exceptionally wet May 2013 (*SPEI*-6 was 1.97). For *SPEI*-24 periods, the extreme index values were recorded in September 2003 (drought, −2.3) and in June 2010 (wet period, 1.97).

CONCLUSIONS

The analyses showed high variability in meteorological conditions in Western Polesie, Poland, particularly in temperature and precipitation. Annual precipitation was 540 mm, ranging from 347 mm to 746 mm in 2003 and 2009, respectively. Precipitation is strongly seasonal, with the highest in summer and the lowest in winter. Evapotranspiration averaged 458 mm over the multi-annual period, ranging from 427 to 491 mm in wet and dry years, respectively. The average annual air temperature ranged from 5.8 to 10.0°C in 1987 and 2019, respectively. The average annual temperature increased by 2.26°C in the multi-year period 1981–2020, with a particularly noticeable increase in winter. In the 21st century, there was an increase in precipitation and temperature, as well as an intensification of extreme phenomena, which may affect water management and agriculture. Based on meteorological data, four main periods of intense drought were distinguished: 1982–1985, 1990–1993, 2002–2005, and 2018–2020. The occurrence of very extreme dry periods was found only for *SPEI*-24. These periods occurred from December 1983 to May 1984, from June to August 1990, from August 2003 to April 2004, and from September 2019 to April 2020. Droughts can adversely affect soil moisture and groundwater levels. Periods of prolonged drought alternate with periods of intense wetness. Intense wet periods occurred in 1981–1982, 1998–2002, 2008–2012, and 2013–2015. For *SPEI*-24, three very extreme wet periods were

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found. The first longest period lasted from July 2010 to April 2011 (10 months). The second period lasted from August to September 2011 (2 months), and the third occurred in June 2009. The 21st century has seen an increase in the frequency of dry and wet periods, indicating greater climatic variability. Water resources need to be increased, and adaptation measures need to be introduced because of the predicted climate changes in the region. Factors other than precipitation and temperature also affect the occurrence of dry and wet periods. Therefore, further research into the occurrence of extreme events is necessary.

DATA AVAILABILITY

The datasets analysed during the study are available at: https://danepubliczne.imgw.pl/data/dane_pomiarowo_obserwacyjne/dane_meteorologiczne/miesieczne/.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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