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ATMOSPHERIC DROUGHT IN THE POLISH TATRAS AND THEIR FORELAND IN THE YEARS 1951–2017

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ABSTRACT

Aim of the study
The aim of this study is to assess the variability of the lowest monthly totals of precipitation, and to evaluate the impact of atmospheric circulation on the occurrence of months with a deficit of precipitation.

Material and methods
Material: The monthly totals of atmospheric precipitation for the years 1951–2017 from 19 meteorological stations located in the Polish Tatra Mountains and in their foreland. and the calendar of atmospheric circulation types for southern Poland, which was developed by Niedźwiedź (1981; 2018).
Methods: Standardized Precipitation Index (SPI), the Mann-Kendall test

Results and conclusions
No statistically significant trend at a significance level of 0.05 was noted in the course of the lowest monthly precipitation totals at any of the meteorological stations. In the 67-year period, all the measuring stations saw a total of 499 (3.3%) dry months with varying drought severity. The largest number of extremely dry months occurred in August and April, respectively. In the case of months when the lowest totals of precipitation occurred in the same month at all or almost all of the meteorological stations, three types of anticyclonic circulation dominated, i.e. eastern, south-eastern, southern, and the anticyclonic wedge.

Keywords: meteorological drought, lowest monthly precipitation totals, Standardized Precipitation Index (SPI), atmospheric circulation, the Polish Tatra Mountains

INTRODUCTION

Drought as a randomly recurring extreme phenomenon is one of the main natural threats to the environment. It is caused by the scarcity of precipitation. Long-term lack of precipitation may result in the development of subsequent phases of soil drought, and even hydrological drought (Byczkowski and Meyer, 2001) characterized by a significant water deficit in surface rivers (Mishra and Singh, 2010). The occurrence of an atmospheric drought is associated with losses in the socio-economic sector (Hanewinkel et al., 2013; Spinoni et al., 2013; Hanel, 2018). In the era of climate change, rainwater deficits are increasingly affecting various parts of the world, e.g. the north-eastern areas of Brazil in 2010–2013 (Gutiérrez et al., 2014), significant areas of China in 2010––2011 (Xu et al., 2015) with further extreme drought events in the years 2001 and 2010 (Li et al., 2020), and the area of the United States in the years 1986––1992, 1994, 1996, and 1998 (Wilhite, 2000). A severe drought on a national scale combined with high air temperature also occurred in 2012 (Heim, 2017). In Europe, in many years of the 21st century, droughts

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were the result of a shortage of rainwater and were also associated with the occurrence of high temperatures (Hanel, 2018). For instance, the European drought in 2003, and then the one in Russia in 2010 caused significant social and economic losses (Fink et al., 2004; Trenberth and Fasullo, 2012). As shown by Hanel's (2018) research, the years 2003 (Schär et al., 2004; Spinoni et al., 2013; Vido et al., 2015) and 2015 (Brázdil et al., 2016; Ionita et al., 2017) can be considered extremely hot and dry, against the background of the last 250 years. In the summer of 2015, Western, Central, and Eastern Europe experienced exceptionally high air temperatures, with the maximum daily temperatures higher by 2–3˚C than the seasonal average for the years 1971–2000 (Ionita et al., 2017). The period from the spring to the summer of 2018 was also hot and dry in Europe (Imbery et al., 2018; Hänsel et al., 2019). According to Nicholls (2004), the study of the relationship between precipitation and temperature may be more important than studying changes in precipitation or air temperature separately.

In the area of the Polish and Ukrainian Carpathians, there are not only periods with an excess of rainwater (Młyński et al., 2018; Kholiavchuk and Cebulska, 2019; Twardosz and Cebulska, 2020), but also periods with a deficit of rainwater (Cebulska, 2016; Cebulska, 2018). Atmospheric droughts of varying severity can occur in this area at different times of the year. The longest period without precipitation in the 21st century occurred in October and November 2011 and lasted from 26 to 40 days, covering the western and southern part of the Polish Carpathians (Cebulska, 2018).

In the light of the research by Wypych et al. (2018), precipitation in the Polish Carpathians does not demonstrate any substantial trend and is characterized by high variability from year to year. Also the warming, particularly pronounced in this area over the last few decades, will continue in the years to follow (Wypych et al., 2018).

The aim of this study is to assess the variability of the lowest monthly totals of precipitation and to assess the impact of atmospheric circulation on the occurrence of months with a deficit of precipitation. These periods were determined using the Standardized Precipitation Index (SPI).

STUDY AREA, DATA, AND METHODS

The study area is the Polish Tatra Mountains and their foreland, which is part of the Western Carpathians. 88% of the area of the Polish Carpathians belongs to the Western Carpathians, with the highest peak of Mt. Rysy (2499 m asl), and 12% of the area belongs to the Eastern Carpathians, with the highest peak of Mt. Tarnica (1346 m asl) (Warszyńska, ed., 1995). The highest peaks of the Polish Tatra Mountains are included in the cold zone and characterized by an average annual air temperature from –2ºC to –4ºC, while the lower parts of the Tatra Mountains belong to the cool zone with an annual average temperature from 2ºC to 4ºC. In the lowest location of the study, the temperature ranges from 6°C to 4°C (Hess 1965). In the Polish Tatra Mountains, only in June and July, the average precipitation in these months, determined from the years 1951–2017, is over 200 mm, while in other meteorological stations in these months the average precipitation range is 100–187 mm. However, over the entire research area, in the months from November to March, the average precipitation is below 100 mm.

The study of the variability of months with a deficit of precipitation was made taking into account the monthly totals of precipitation in the years 1951–2017 from 19 measuring stations (see: Fig. 1) located in the Polish Tatra Mountains and in their foreland. These data were obtained from the Institute of Meteorology and Water Management - National Research Institute. The work includes only those measuring stations for which it was possible to develop a database of monthly precipitation totals for the longest common period. On the basis of the developed database, the lowest monthly precipitation total was selected from each station in each year of the multiyear period 1951–2017. The lowest monthly totals of precipitation at individual measuring stations in the 67-year period were examined to see whether a trend occurs. To this end, the Mann-Kendall test was applied (Kendall, 1975; von Storch and Zwiers, 2002; Młyński et al., 2018; Kholiavchuk and Cebulska, 2019precipitation, sunshine hours, nebulosity, relative humidity and wind speed were investigated. The Mann-Kendall nonparametric trend test was used in order to find statistically-significant trends, whilst the magnitude of trends was estimated using the Kendall-Theil method. The results point to significant climatic changes at annual scale in Romania. The most drastic change regards the air temperature, which is increasing at all stations. The number of sunshine hours follows a similar pattern, increasing at most stations – except in the mountainous regions of Meridional and Curvature Carpathians. The wind speed presents a significant decreasing signal at the majority of the locations, in agreement with the overall tendency of terrestrial stilling. The annual precipitation amount is rather stable, with increasing trends North-Western Romania and decreasing trends in the Danube Delta (South-East).

Periods with a deficit of precipitation were identified on the basis of the Standardized Precipitation Index so in order to make that determination, it was necessary to transform probability distribution of monthly precipitation into standarized normal distribution. SPI values were calculated based on a historical record of monthly precipitation totals at each meteorological station, from the following formula (McKee et al., 1993, 1995; Łabędzki, 2006, 2017):

$$SPI = \frac{f(P) - \overline{f(P)}}{d_u} \tag{1}$$

where:

$f(P) = \sqrt[3]{P}$ – transformed normalized sum of precipitation, mm;

$\overline{f(P)}$ – mean value of the normalized precipitation sequence, mm;

d_u – standard deviation of the normalized precipitation sequence, mm.

Transformation function f(P) is used in reference to precipitation sequence, which does not follow normal distribution. Most often, periodical sums of precipitation (monthly, annual) conform to the gamma distribution. (Łabędzki, 2006, 2017). According to the developed criterion, negative SPI values represent dry conditions, i.e. the lower the SPI, the drier the given period of time (Hayes 2006). An extremely dry period was one with an SPI value of ≤–2.0, a very dry period with an SPI value of Є (–2.0 ÷ –1.50⟩, and a moderately dry period with an SPI value of Є (–1.50 ÷–1.00⟩ (McKee et al., 1993, 1995).

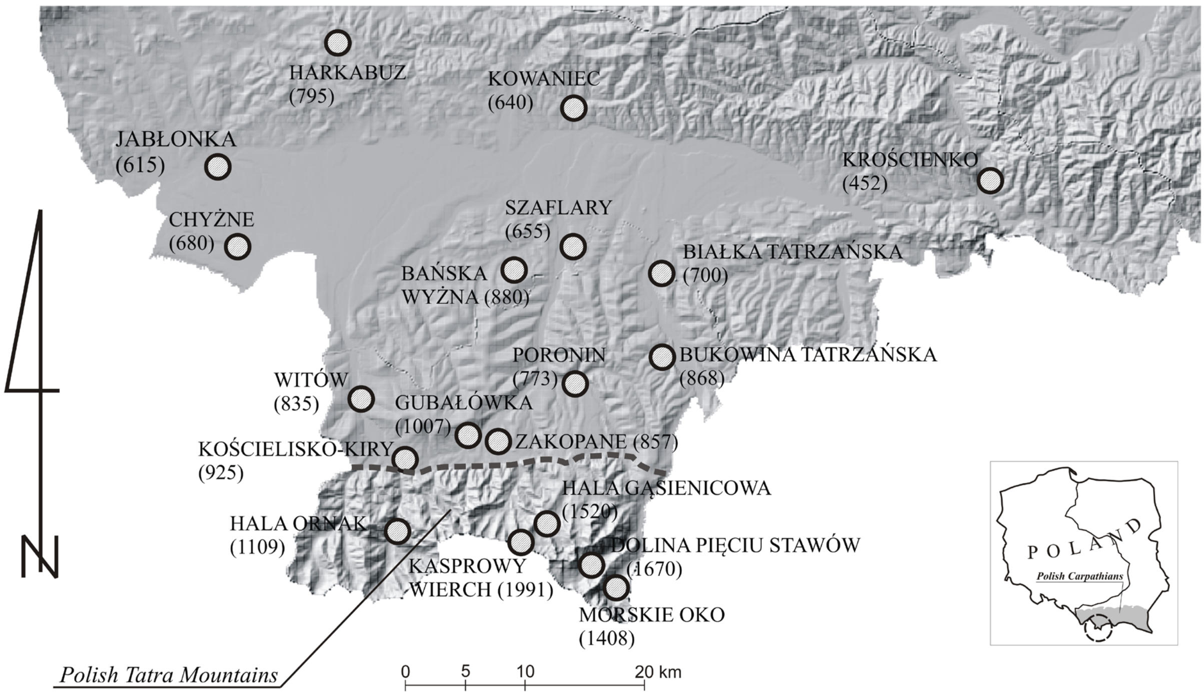

Fig. 1. Location of the meteorological stations in the study area (station altitude above sea level)

In the study area, the highest average annual precipitation of 1759 mm occurs at Kasprowy Wierch. Even though this part of the Polish Carpathians has the highest precipitation, in the era of climate change, dry periods with varying drought severity were also recorded in this area. They were identified and assessed for their incidence. The reasons for the occurrence of atmospheric drought in the area of the Polish Tatra Mountains and their foreland were sought in the types of atmospheric circulation..

To this end, the calendar of atmospheric circulation types for southern Poland, which had been developed by Niedźwiedź (1981; 2018), was consulted. It comprises a list of 21 types of atmospheric circulation (N, E, NE, SE, S, SW, W, NW), which are marked with the letter symbols of advection direction, with "a" standing for anticyclonic systems and "c" for cyclonic systems. The next 4 types, namely: Ca, Ka, Cc, and Bc, constitute a non-supplementary situation with different directions of advection. The 21st type of this classification includes situations that cannot be classified into the other distinguished types of circulation and baric saddles. It was marked with the symbol "X" (Niedźwiedź, 1981).

RESULTS AND DISCUSSION

Verification of the significance of the trend in the lowest monthly precipitation totals

the lowest monthly totals of atmospheric precipitation identified at individual measuring stations were examined for possible trends. Based on the Mann-Kendall statistical test (Kendall, 1975; von Storch and Zwiers, 2002; Młyński et al., 2018; Kholiavchuk and Cebulska, 2019; Fathian et al*.,* 2020precipitation, sunshine hours, nebulosity, relative humidity and wind speed were investigated. The Mann-Kendall nonparametric trend test was used in order to find statistically-significant trends, whilst the magnitude of trends was estimated using the Kendall-Theil method. The results point to significant climatic changes at annual scale in Romania. The most drastic change regards the air temperature, which is increasing at all stations. The number of sunshine hours follows a similar pattern, increasing at most stations - except in the mountainous regions of Meridional and Curvature Carpathians. The wind speed presents a significant decreasing signal at the majority of the locations, in agreement with the overall tendency of terrestrial stilling. The annual precipitation amount is rather stable, with increasing trends North-Western Romania and decreasing trends in the Danube Delta (South-East), their statistical significance was examined at significance levels of 0.05 and 0.1. At none of the meteorological stations was there a statistically significant trend at a significance level of 0.05 recorded in the course of the lowest monthly precipitation totals. A growing tendency proving the variability of the precipitation, statistically significant at a significance level of 0.1, was shown by the lowest monthly totals of precipitation in the analysed period only in Poronin (0,85mm/10 years). The lowest monthly precipitation totals (Cebulska and Twardosz, 2010; Twardosz and Cebulska, 2020), as well as the highest daily precipitation totals (Młyński et al., 2018), and the highest monthly totals (Kholiavchuk and Cebulska, 2019; Twardosz and Cebulska, 2020) show extensive variation in the values over a long-term course. A statistically significant trend of the highest daily precipitation totals in the upper Vistula basin, significant at a level of 0.01 was observed in almost 4% of all precipitation stations; and in 12% of the stations at a significance level of 0.05 (Młyński et al., 2018), while in the course of the highest monthly precipitation totals, trends significant at levels of 0.05 and 0.1 were also noted in the Polish and Ukrainian Carpathians. The only significant trend at a level of 0.05 was observed at 3 measuring stations, i.e. in Stróża, Grybów, and Górki Wielkie (Kholiavchuk and Cebulska, 2019). Also in Slovakia, Zelenáková et al. (2017) noted upward trends in precipitation time series at numerous measuring stations. Downward trends were detected in the northern part of Slovakia in December, while upward trends were recorded in the central and southern parts. Increasing precipitation trends were observed in the summer season, especially in July at most stations (Zelenáková et al., 2017).

Variation of the lowest monthly precipitation totals

the region of the Polish Tatra Mountains is an area with high amounts of monthly and annual precipitation on a country-wide scale. However, research has shown that this area may have months with no precipitation. Such a situation may occur especially in the months from October to March. In the years 1951–2017, in the high mountain part of the Polish Tatra Mountains, no month in which no precipitation occurred was recorded. However, at all of the measuring stations in this area in March 1974, October 1951, and November 2011, precipitation did not exceed 11 mm. It accounted for less than 10% of the average precipitation in the studied period. During the 67-year period of observations, only in Jabłonka in November 2011 and Szaflary in October 1951 was there no precipitation.

The lowest monthly totals in June constitute most, i.e. over 30%, of the long-term average. On the other hand, the lowest percentage share of this precipitation in the long-term average (below 2%) is visible in November. In the foreland of the Polish Tatra Mountains, the highest of the lowest monthly precipitations occurs most frequently in July, but at many stations in this area, it occurs in June. The lowest precipitation in this region constitutes just over 40% of the average precipitation for the studied multi-year period.

In the yearly course, the lowest monthly totals of precipitation may occur in each month, but they are most frequent from October to April. In January, February, and October, they account for over 15%. Occasionally, the lowest precipitation occurred from May to September, and its percentage share in the analysed period did not exceed 5%. At all of the measuring stations, the lowest total monthly precipitation occurred in the same month for two consecutive years, while at some of the stations there were cases where it occurred in the same month for three or four consecutive years. This happened in Bańska Wyżna for four consecutive years in January from 1990 to 1993, at Hala Ornak – in February from 1978 to 1981 (see: Fig. 2), and also in Krościenko – in January from 1955 to 1958.

The Polish Tatra Mountains are represented by five measuring stations located above 1,100 m asl, in which the course of the lowest monthly precipitation totals varies. Such precipitation does not occur at all of the stations in June, while it does in May only at Morskie Oko, Hala Gąsienicowa, and Dolina Pięciu Stawów (see: Fig. 2). Most often, the lowest monthly totals of precipitation in this area occur in January and February. At all of the measuring stations, except for Kasprowy Wierch, their percentage share in the studied period exceeded 15%. According to research in some regions of Poland or Europe, the lowest monthly totals are subject to long-term changes (Schönwiese et al., 2003; Trömel and Schönwiese, 2007).

In the entire study area, the lowest totals of monthly precipitation occur most often at individual stations, however, during the entire studied period, years in which this precipitation covered the entire study area were recorded. They occurred only in the month of October in 6 different years (see: Table 1), i.e. in 1951, 1962, 1965, 1977, 1995, and in 2001. However, the lowest monthly totals appeared at all of the stations in the studied area in 2 years in January, February, and in December. In January, the lowest monthly totals occurred in 1971 and 1997, in February in 1954 and 1994, and in December in 1972 and 2004.

The course of periods of atmospheric drought

In the 67-year yearly course, there was a deficit of precipitation in each month and at each meteorological station. At each station, on average, there was a dry month with a varying severity of drought every 3 years. However, the highest frequency of dry periods fell in June and January – almost 17%. On the other hand, in the other months of the studied area, the incidence of dry periods with a varying severity of drought ranged from 13% in March to 16% in February. The greatest number of moderately dry periods for which the determined SPI index ranged from –1.0 to –1.50 occurred at all of the weather stations. The highest number of such months occurred in January – 152 (12%), and the lowest in August – 82 (6.4%) (see: Fig. 3).

In the years 1951-2017, in the area of the Polish Tatra Mountains and their foreland, most of the very dry months, i.e. with an SPI index in the range of (–2.0 ÷ –1.50⟩, were observed in April, June, September, and October – more than 60 months (ca. 5%). The fewest of such months were observed in November – 37 (2.9%). Extremely dry periods, for which SPI ≤ –2.0 were selected in each month in the annual course of the considered research period. However, most of them occurred in August and April – 47 (3.7%) and 42 (3.3%) months, respectively.

In the Polish Tatras and in their foreland, the most severe drought occurred in November 2011, with the SPI value ranging from –3.07 in Bukowina Tatrzańska to –5.22 in Jabłonka. However, the lowest SPI values at the measuring stations, which indicate the intensity of drought, were noted not only in November 2011,

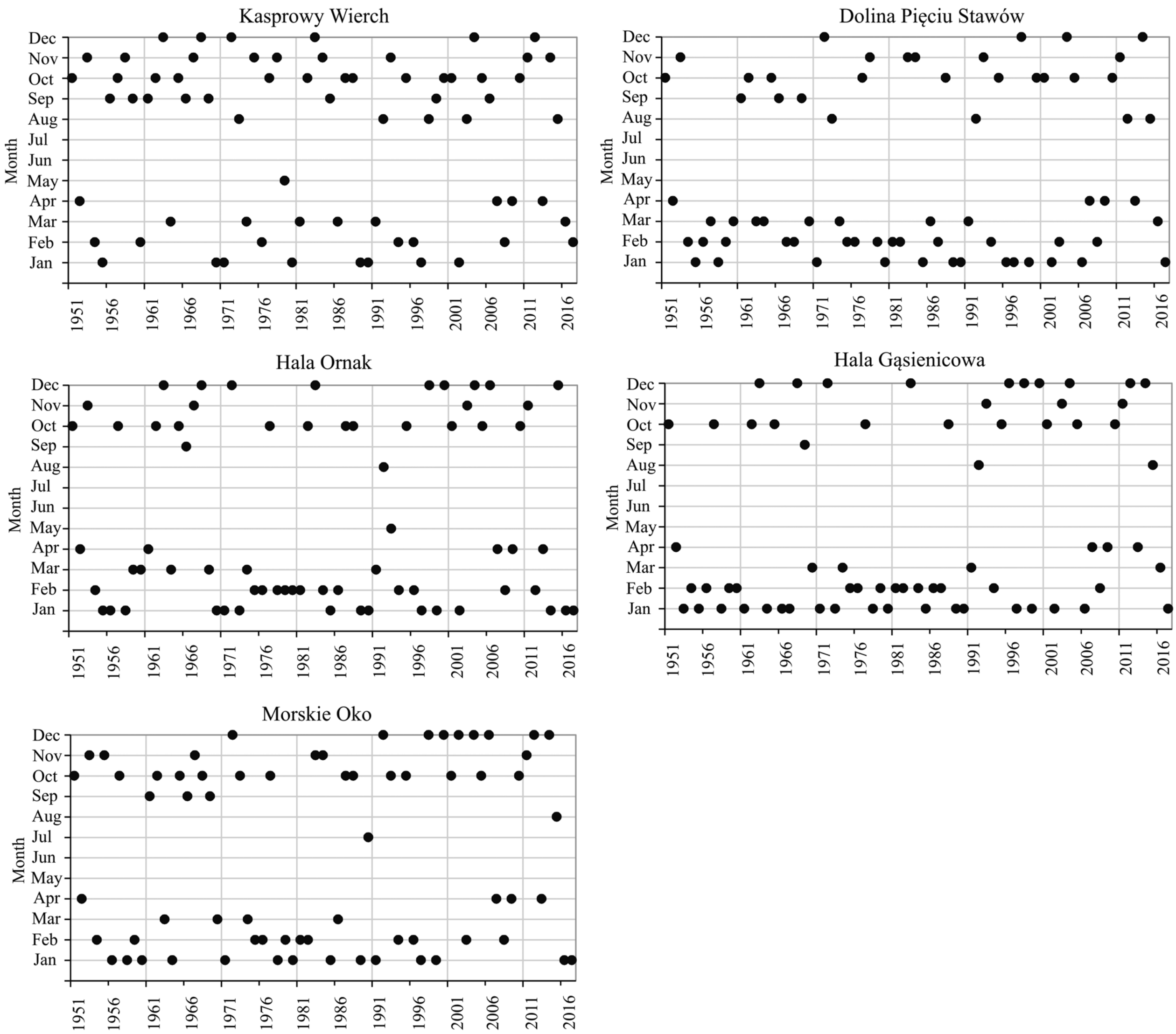

Fig. 2. Occurrence of the lowest monthly totals of precipitation at the meteorological stations within the Polish Tatra Mountains (1951–2017)

but also in March 1974, especially in the central part of the study area. At all weather stations, atmospheric drought of varying severity covered 3 consecutive months of the year at the most. In the 67-year period, such cases were identified from 2 in Chyżne, Bańska Wyżna, Białka Tatrzańska, and Hala Ornak, to 5 cases in Harkabuza and Kowaniec. In the studied area, except for Kasprowy Wierch (1991 m a.s.l.) and Hala Gąsienicowa (1520 m a.s.l.), there was an atmospheric drought of varying intensity in February, March and April 1986. On the other hand, the area of Kasprowy Wierch, which is located highest in the studied area, is also characterized by a deficit of precipitation. The dry period, which covered 3 consecutive months, occurred in this area only 3 times and covered the following months: August, September, and October in 1982, September, October, and November in 1986, as well as January, February, and March in 2017 (see: Fig. 4).

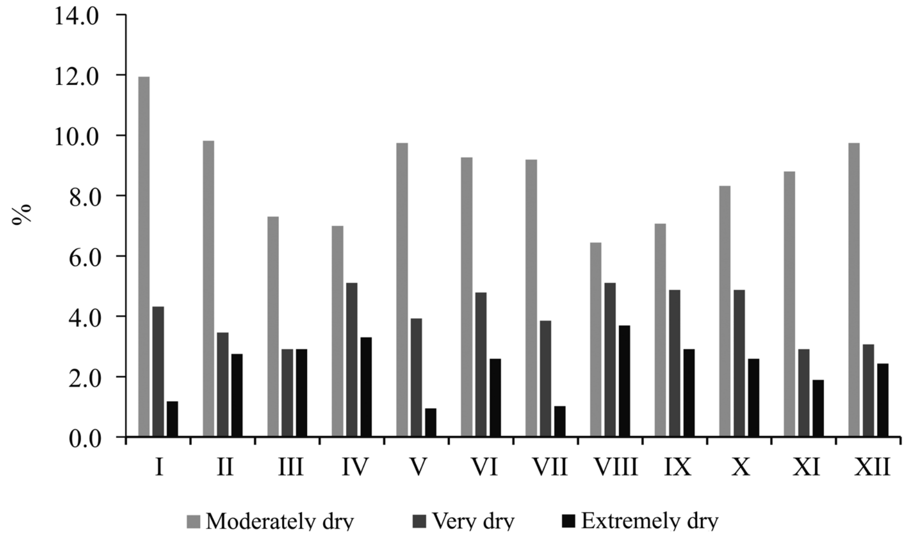

Fig. 3. The incidence (%) of dry months with varying severity of drought in the Polish Tatra Mountains and in their foreland (1951–2017)

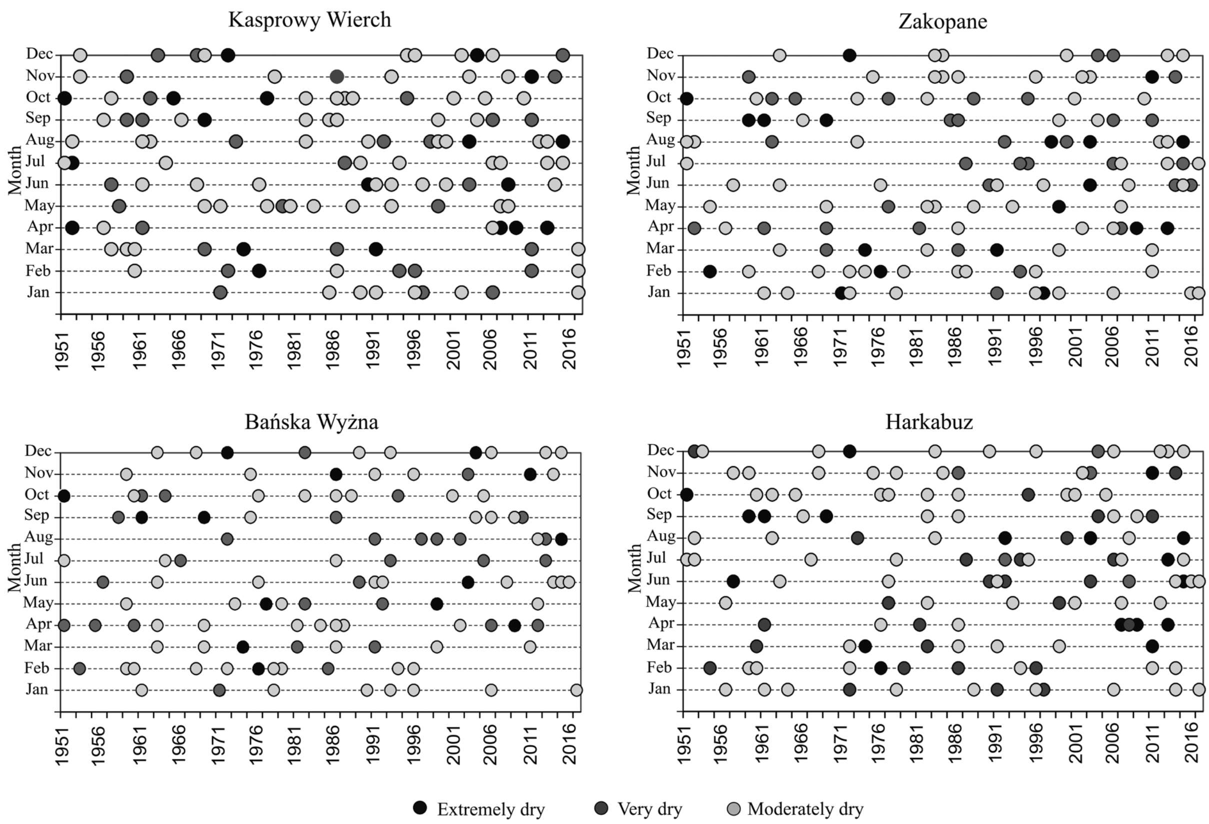

Fig. 4. Occurrence of dry periods of varying drought severity at selected stations

Over the long-term course of precipitation, its deficit most often occurred in June, in subsequent years. The longest such dry period covered four consecutive years. June in 2014, 2015, 2016, and at some stations also in 2017 turned out to be dry in most of the studied area. In the 67-year period, all the weather stations saw a total of 499 (3.3%) dry months with varying drought severity. The greatest number of dry months occurred at individual stations (146 in total), while the least number concerned all or at nearly all weather stations. In the entire area of the Polish Tatra Mountains and their foreland, only in March, April, and also in October, November, and December, was there an extreme atmospheric drought observed, which covered the entire area (19 stations) or nearly the entire area (18 stations). On the other hand, no month was singled out in which the entire area or nearly the entire area could be considered moderately dry or very dry according to the adopted criterion (see: Fig. 5). The whole of the studied area, distinguished by a diversified topography in the entire 67-year period, was struck by extreme atmospheric drought only 3 times (see: Fig. 5). This took place in October 1951, November 2011, and in December 1972. In these months, the highest amount of precipitation was 13 mm (December 1972) in the Dolina Pięciu Stawów Polskich (Five Polish Ponds Valley), 10.5 mm (October 1951) on Kasprowy Wierch, and only 2.6 mm (November 2011) in Bańska Wyżna. The standardized precipitation index values in these months at all weather stations were below –2.0. These months would have been considered dry (SPI≤-1) with the monthly precipitation below 70 mm (see: Fig. 6) – this value was determined from equation (1) through its transformation.

In nearly the entire study area, an extreme drought occurred in March 1974 and April 2009, and covered 18 meteorological stations (excluding the station in Krościenko, which is located the lowest). On the other hand, in February 1976 an extreme drought affected 17 weather stations (excluding the stations in Krościenko and Kowaniec). In the studied area, in the years 1951–2017, the greatest number of moderately dry months occurred, i.e. up to 77 at Kasprowy Wierch and on Hala Gąsienicowa. Far fewer very dry months occurred in this area, i.e. up to 42 in Kościelisko-Kiry. In the case of extremely dry periods, more than 15 such months occurred at each meteorological station, but most of them, i.e. 24 months, were recorded in Białka Tatrzańska. In the yearly course, in

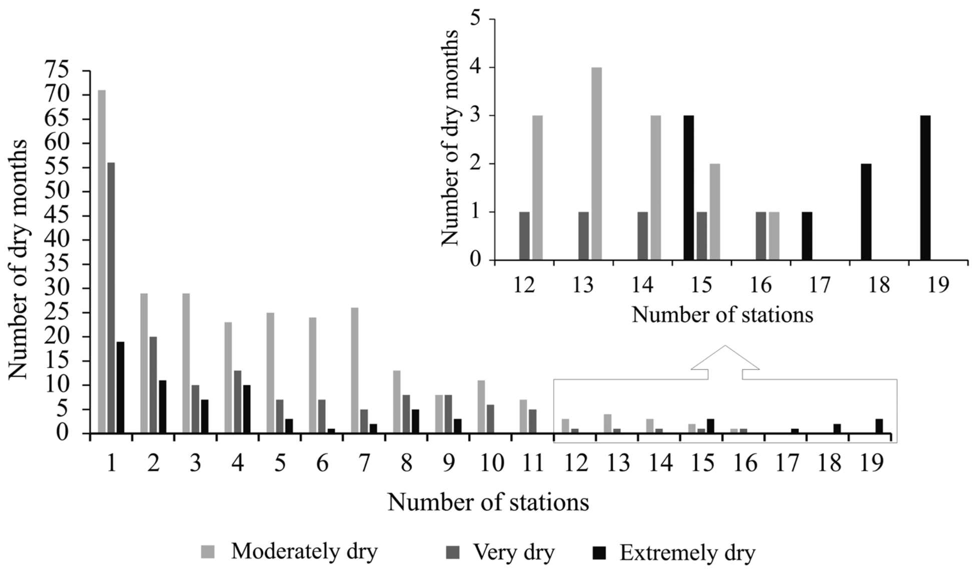

Fig. 5. Number of dry months with varying drought severity occurring simultaneously at a given number of meteorological stations

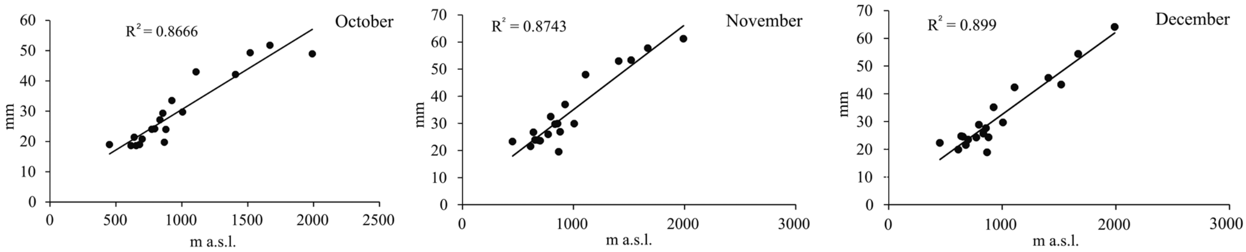

Fig. 6. Precipitation limits (mm) below which a selected month can be considered dry

the entire 67-year period, there were no months that could be considered extremely dry, i.e. in January in Bukowina Tatrzańska, Chyżne, Jabłonka, in the Dolina Pięciu Stawów Polskich, Kowaniec, Harkabuza, on Kasprowy Wierch, in Krościenko and in Bańska Wyżna; in February only in Krościenko; whereas in May in Bukowina Tatrzańska, Chyżne, Jabłonka, on Gubałówka, Hala Gąsienicowa, in Kościelisko-Kiry, Harkabuza, Poronin, and on Kasprowy Wierch. During the entire studied period, also June in Bukowina Tatrzańska, July in Bańska Wyżna, Białka Tatrzańska, Hala Ornak, Kościelisko-Kiry, Poronin, Zakopane, Krościenko, and September in Kowaniec were not considered extremely dry. The weather stations located in the Polish Tatra Mountains had a total from 17 months of extremely dry weather in the Dolina Pięciu Stawów Polskich, to 23 months on Hala Ornak.

Relationship of dry periods with atmospheric circulation

Atmospheric circulation is a factor conducive to the achieving of the lowest and the highest values by meteorological factors. This is reflected in numerous publications (e.g. Niedźwiedź et al., 2015; Valeriánová et al., 2017; Młyński et al., 2018; Twardosz and Cebulska, 2020), in which the authors examine the relationship between the types of atmospheric circulation and extreme values of meteorological elements. In the Polish Tatra Mountains and in their foreland, in the case of months when the lowest totals of precipitation occurred in the same month at all or nearly all meteorological stations, three types of anticyclonic circulation dominated, i.e. eastern (Ea), south-eastern (SEa), southern (Sa), and the anticyclonic wedge (Ka). In total, nearly 60% of days occurred with these types of atmospheric circulation in these months. A much lower incidence of days in the circulation types was observed for Na – 0.5% and NWa – 1.1%. On the other hand, the incidence of days in the types of cyclonic circulation did not exceed 6%. In November 2011, atmospheric drought covered the entire study area, with only the anticyclonic type of situation dominating at that time. For 30% of days, there was a non-advective situation (Ka), while nearly 50% of the days in that month were influenced by the anticyclonic circulation from the west (Wa) and from the south (Sa). In October 1951, however, more than 80% of the days occurred in three types of anticyclonic circulation, i.e. eastern (Ea), south-eastern (SEa), and southern (Sa). In December 1972, for over 32% of the days, the non-advective situation (Ca) dominated, and slightly over 32% of the days in that month were influenced by the anticyclonic circulation from the south-east (SEa) and south-west (SWa). In the years 1951-2017, in the studied area, the greatest number of dry periods occurred in the yearly course in January and June. In January, in the long-term period, almost 55% of days occurred in the anticyclonic situation, including 13.3% in the western anticyclonic situation (see: Fig. 7). Conversely, in June, 47% of the days were under the influence of the anticyclonic situation, of which for 13.6% of the days the non-advective situation (Ka) dominated.

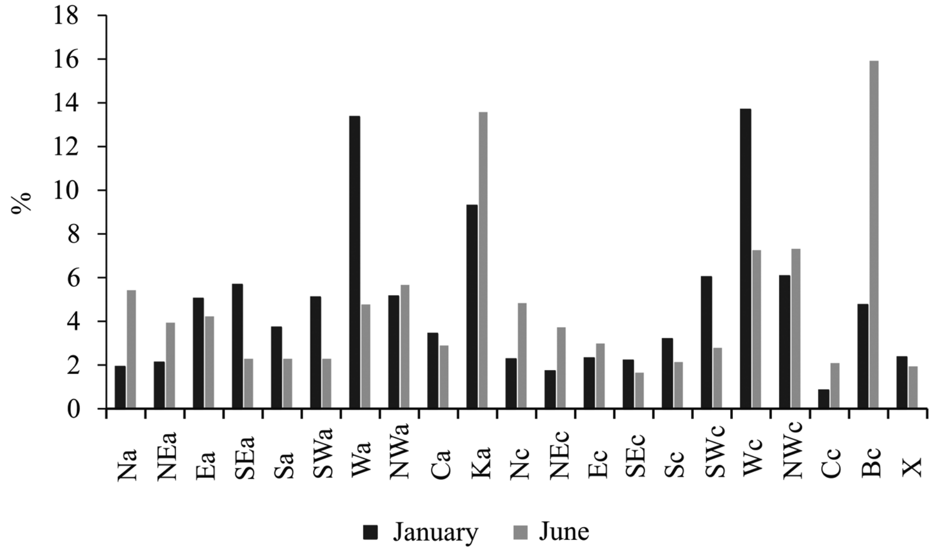

Fig. 7. Synoptic situation in the months with the highest incidence of dry periods, 1951–2017

CONCLUSIONS

In the area of the Polish Tatra Mountains and in its foreland, the lowest monthly precipitation totals in the yearly course occur with the highest incidence from October to April. During the entire studied period, months when this precipitation covered the entire studied area were noted. Only in the month of October, lowest precipitation occurred in 6 years, i.e. in 1951, 1962, 1965, 1977, 1995, and in 2001. At all meteorological stations, in the course of the lowest monthly precipitation totals, no statistically significant trend at a significance level of 0.05 was observed, which would indicate the variability of this precipitation.

In the yearly course in the 67-year period, there occurred a deficit of precipitation in each month and at each meteorological station. The highest incidence of dry periods was recorded in June and January, i.e. almost 17%. Then again, in the other months of the studied area, the incidence of dry periods with varying drought severity ranged from 13% in March to 16% in February. During the study period, all of the weather stations saw a total of 499 (3.3%) of dry months with varying drought severity. The greatest number of dry months occurred at individual measuring stations (146 in total), while the lowest number occurred at all of the stations or nearly all of the meteorological stations. In the entire area of the Polish Tatra Mountains and their foreland, only in March, April, and also in October, November, and December, was there an extreme atmospheric drought recorded, which covered the entire area (19 stations) or almost the entire area (18 stations). However, there was no month in which all or nearly all of the area could be considered dry or very dry. In the case of months with a deficit of precipitation, which covered all or almost all of the meteorological stations, three types of anticyclonic circulation dominated, i.e. eastern (Ea), south-eastern (SEa), southern (Sa), and the anticyclonic wedge (Ka). In total, nearly 60% of the days with these types of atmospheric circulation occurred in these months.

REFERENCES

Brázdil, R., Raška, P., Trnka, M., Zahradníček, P., Valášek, H., Dobrovolný, P., Řezníčková, L., Treml, P., Stachoň, Z. (2016). The Central European drought of 1947: causes and consequences, with particular reference to the Czech Lands. Climate Research, 70, 161–178. https://doi.org/ 10.3354/cr01387

Byczkowski, A., Meyer, W. (2001). Hydrological drought: objective criteria of its evaluation. Proc. 19th Regional Conference of ICID, Brno-Prague, 4–8 June.

Cebulska, M. (2016). Deficiencies of precipitation in the growing season in the Mała Wisła catchment (1984–2013). Acta Scientiarum Polonorum Formatio Circumiectus, 15(2), 13–26. https://doi.org/ 10.15576/ASP.FC/2016.15.2.13

Cebulska, M. (2018). Periods without precipitation and with low precipitation in the Polish Carpathians in the period from 1984 to 2015. Polish Journal of Agronomy, 34, 52–61.
https://doi.org/10.26114/pja.iung.355.2018.34.06

Cebulska, M., Twardosz, R. (2010). Temporal variability of the lowest monthly precipitation in the Upper Vistula River (1901-2000). Przegląd Geofizyczny 3–4, 175–188.

Fathian, F., Ghadami, M., Haghighi, P., Amini, M., Naderi, S., Ghaedi, Z. (2020). Assessment of changes in climate extremes of temperature and precipitation over Iran. Theoretical and Applied Climatology, 141, 1119–1133. https://doi.org/10.1007/s00704-020-03269-2

Fink, AH., Brücher T., Krüger, A., Leckebusch, GC., Pinto, JG., Ulbrich, U. (2004). The 2003 European summer heatwaves and drought – synoptic diagnosis and impacts. Weather. John Wiley & Sons, Ltd, 59(8), 209–216. https://doi.org/10.1256/wea.73.04

Gutiérrez, APA., Engle, NL., De Nys, E., Molejón, C., Martins, ES. (2014). Drought preparedness in Brazil. Weather and Climate Extremes, 3, 95–106. http://doi.org/10.1016/j.wace.2013.12.001

Hanel, M., Rakovec, O., Markonis, Y., Máca, P., Samaniego, L., Kyselý, M., Kumar, R. (2018). Revisiting the recent European droughts from a long-term perspective. Scientific Reports. Nature Publishing Group. https://doi.org/10.1038/s41598-018-27464-4

Hanewinkel, M., Cullmann, DA., Schelhaas, MJ., Nabuurs, GJ., Zimmermann, NE. (2013). Climate change may cause severe loss in the economic value of European forest land. Nature Climate Change, 3, 203–207. https://doi.org/10.1038/nclimate1687

Hayes, MJ. (2006). Drought indices. What Is Drought? Lincoln, Nebraska: National Drought Mitigation Center. Available at: http://drought.unl.edu/whatis/indices.htm

Hänsel, S., Ustrnul, Z., Łupikasza, E., Skalak, P. (2019). Assessing seasonal drought variations and trends over Central Europe. Advances in Water Resources, 127, 53–75. https://doi.org/10.1016/j.advwatres.2019.03.005

Heim, RR. (2017). A comparison of the early twenty-first century drought in the United States to the 1930s and 1950s drought episodes. American Meteorological Society, 98(12), 2579–2592. https://doi.org/10.1175/BAMS-D-16-0080.1

Hess, M. (1965). Vertical climatic zones in the Polish Western Carpathians. Zeszyty Naukowe UJ, Prace Geograficzne, 11, 1–267.

Imbery, F., Friedrich, K., Haeseler, S., Koppe, C., Janssen, W., Bissolli, P. (2018). Vorläufiger Rückblick auf Den Sommer 2018 – Eine Bilanz Extremer Wetterereignisse. Deutscher Wetterdienst, Offenbach am Main.

Ionita, M., Tallaksen, LM., Kingston, DG., Stagge, JH., Laaha, G., Van Lanen, HAJ., Scholz, P., Chelcea, SM., Haslinger, K. (2017). The European 2015 drought from a climatological perspective. Hydrology and Earth System Sciences, 21, 1397–1419. https://doi.org/ 10.5194/hess-21-1397-2017

Kendall, MG. (1975). Rank correlation methods, 4th edn. Charles Griffin: London

Kholiavchuk, D., Cebulska, M. (2019). The highest monthly precipitation in the area of the Ukrainian and the Polish Carpathian Mountains in the period from 1984 to 2013. Theoretical and Applied Climatology, 138(3–4), 1615––1628. https://doi.org /10.1007/s00704-019-02910-z

Li, W., Duan, L., Wang, W., Wu, Y., Liu, T., Quan, Q., Chen, XJ., Yin, P., Zhou, Q. (2020). Spatiotemporal characteristics of drought in a semi-arid grassland over the past 56 years based on the Standardized Precipitation Index. Meteorology and Atmospheric Physics, 133, 41––54. https://doi.org/10.1007/s00703-020-00727-4

Łabędzki, L. (2006), Agricultural droughts an outline of problems and methods of monitoring and classification. Institute for Land Reclamation and Grassland Farming. Falenty, 107.

Łabedzki, L. (2017). Categorical forecast of precipitation anomaly using the Standardized Precipitation Index SPI. Water 2017, 9, 8; doi:10.3390/w9010008

McKee, TB., Doesken, NJ., Kleist, J. (1993). The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology, California, 17–22 January.

McKee, TB., Doesken, NJ., Kleist, J. (1995). Drought monitoring with multiple time scales. Preprints 9th Conf Applied Climatology, Dallas, 15–20 January. https://doi.org/10.1007/s13398-014-0173-7.2

Mishra, AK., Singh, VP. (2010). A review of drought concepts. Journal of Hydrology, 391(1), 202–216. https://doi.org /10.1016/j.jhydrol.2010.07.012

Młyński, D., Cebulska, M., Wałęga, A. (2018). Trends, Variability, and Seasonality of Maximum Annual Daily Precipitation in the Upper Vistula Basin, Poland. Atmosphere, 9, 313. https://doi.org /10.3390/atmos9080313

Nicholls, N. (2004). The Changing Nature of Australian Droughts. Climatic Change, 63, 323–336. https://doi.org/10.1023/B:CLIM.0000018515.46344.6d

Niedźwiedź, T. (1981). Synoptic situations and its influence on spatial differentiation of selected climatic elements in upper Vistula basin 58. Dissertation of Jagiellonian University in Kraków

Niedźwiedź, T. (2018). Catalogue of synoptic situations and circulation indices in the upper Vistula river basin (1873–2007). Computer file available at Department of Climatology. University of Silesia. http://klimat.wnoz.us.edu.pl/

Niedźwiedź, T., Łupikasza, E., Pińskwar, I., Kundzewicz, ZW., Stoffel, M., Małarzewski, Ł. (2015). Variability of high rainfalls and related synoptic situations causing heavy floods at the northern foothills of the Tatra Mountains. Theoretical and Applied Climatology, 119, 273–284. https://doi.org/10.1007/s00704-014-1108-0

Schär, C., Vidale, PL., Lüthi, D., Frei, C., Häberli, C., Liniger, MA., Appenzeller, C. (2004). The role of increasing temperaturę variability in European summer heatwaves. Nature, 427, 332–336. https://doi.org/10.1038/nature02300

Schönwiese, CD., Grieser, J., Trömel, S. (2003). Secular change of extreme monthly precipitation in Europe. Theoretical and Applied Climatology, 75, 245–250. https://doi.org/10.1007/s00704-003-0728-6

Spinoni, J., Antofie, T., Barbosa, P., Bihari, Z., Lakatos, M., Szalai, S., Szentimrey, T., Vogt, J. (2013). An overview of drought events in the Carpathian Region in 1961––2010. Advances in Science and Research, 10(1), 21––32. https://doi.org /10.5194/asr-10-21-2013

Trenberth, KE., Fasullo, JT. (2012). Climate extremes and climate change: the Russian heat wave and other climate extremes of 2010. Journal of Geophysical Research Atmospheres, 117 (17103). https://doi.org/10.1029/2012JD018020

Trömel, S., Schönwiese, CD. (2007). Probability change of extreme precipitation observed from 1901 to 2000 in Germany. Theoretical and Applied Climatology, 87, 29–39. https://doi.org/10.1007/s00704-005-0230-4

Twardosz, R., Cebulska, M. (2020). Temporal variability of the highest and the lowest monthly precipitation totals in the Polish Carpathian Mountains (1881–2018). Theoretical and Applied Climatology, 140, 327–341. https://doi.org /10.1007/s00704-019-03079-1

Valeriánová, A., Crhová, L., Holtanová, E., Kašpar, M., Müller, M., Pecho, J. (2017). High temperature extremes in the Czech Republic 1961–2010 and their synoptic variants. Theoretical and Applied Climatology, 127, 17––29. https://doi.org/10.1007/s00704-015-1614-8

Vido, J., Tadesse, T., Šustek, Z., Kandrík, R., Hanzelová, M., Škvarenina, J., Škvareninová, J., Hayes, M. (2015). Drought Occurrence in Central European Mountainous Region (Tatra National Park, Slovakia) within the Period 1961–2010. Advances in Meteorology. Edited by M. Hafeez. https://doi.org/10.1155/2015/248728

von Storch, H., Zwiers, FW. (2002). Statistical analysis in climate research. Cambridge: Cambridge University Press.

Warszyńska, J. (ed.) (1995). The Polish Carpathians – nature, man and his activities. Kraków: Uniwersytet Jagielloński.

Wilhite, DA. (2000). Chapter 1 Drought as a Natural Hazard: Concepts and Definitions. Drought Mitigation Center Faculty Publications, 69 (1), 3–18. http://digitalcommons.unl.edu/droughtfacpub/69

Wypych, A., Ustrnul, Z., Schmatz, DR. (2018). Long-term variability of air temperature and precipitation conditions in the Polish Carpathians. Journal of Mountain Science, 15, 237–253. https://doi.org/10.1007/s11629-017-4374-3

Xu, K., Yang, D., Yang, H., Li, Z., Yue Qin, Y., Shen, Y. (2015). Spatio-temporal variation of drought in China during 1961–2012: A climatic perspective. Journal of Hydrology, 526, 253–264. https://doi.org/10.1016/j.jhydrol.2014.09.047

Zelenáková, M., Vido, J., Portela, MM., Purcz, P., Blištán, P., Hlavatá, H., Hluštík, P. (2017). Precipitation Trends over Slovakia in the Period 1981–2013. Water 9(12), 922. https://doi.org/10.3390/w9120922

SUSZA ATMOSFERYCZNA W TATRACH POLSKICH I NA ICH PRZEDPOLU W LATACH 1951– 2017

ABSTRAKT

Cel pracy

Ocena zmienności najniższych miesięcznych sum opadów atmosferycznych, a także ocena wpływu cyrkulacji atmosferycznej na wystąpienie miesięcy z niedoborem opadów atmosferycznych

Materiał i metody
Materiał: miesięczne sumy opadów atmosferycznych z lat 1951–2017 z 19 stacji meteorologicznych położonych w polskich Tatrach i na ich przedpolu,. Uwzględniono również kalendarz typów cyrkulacji atmosferycznej dla Polski południowej, który opracowany został przez Niedźwiedzia (1981, 2018).

Metody: wskaźnik standaryzowanego opadu (SPI), test statystyczny Manna-Kendalla

Wyniki i wnioski
We wszystkich stacjach meteorologicznych w przebiegu najniższych miesięcznych sum opadów nie dostrzeżono trendu istotnego statystycznie na poziomie istotności 0.05. Wykazano, że w 67-leciu we wszystkich stacjach pomiarowych łącznie wystąpiło 499 (3.3%) miesięcy suchych o różnym stopniu nasilenia suszy. Najwięcej miesięcy suchych wystąpiło na pojedynczych stacjach pomiarowych (łącznie 146), natomiast najmniej na wszystkich stacjach lub prawie wszystkich stacjach meteorologicznych. W każdej stacji średnio co 3 lata występuje miesiąc suchy o różnym nasileniu suszy. Najwięcej miesięcy ekstremalnie suchych wystąpiło w sierpniu i w kwietniu - odpowiednio 47 (3.7%) i 42 (3.3%). W przypadku miesięcy, w których najniższe sumy opadów wystąpiły w tym samym miesiącu na wszystkich lub prawie wszystkich stacjach meteorologicznych, dominowały trzy typy cyrkulacji antycyklonalnej – wschodniej (Ea), południowo-wschodniej (SEa), południowej (Sa) oraz w klinie antycyklonalnym (Ka). Łącznie, w tych miesiącach przy tych typach cyrkulacji atmosferycznej wystąpiło blisko 60% dni.

Słowa kluczowe: wskaźnik standaryzowanego opadu (SPI), najniższe miesięczne sumy opadów, cyrkulacja atmosferczna, polskie Tatry