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# Changes in the structure of days with precipitation in Southern Poland in 1971-2010

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**Abstract—** In Poland, no clear tendencies have been detected in multi-year trends in precipitation sums. However, the number of days with precipitation has increased significantly. Therefore, we analyzed changes in the structure of days with precipitation, i.e., trends in the percentage of days with different ranges of daily precipitation sums. The precipitation data were from 1971–2010, from four stations in Southern Poland representing agricultural areas (Stare Olesno, Glubczyce, Lapanow, and Tuchow). Statistically significant upward trends (1–9 days per 10 years) and low variability were found for the number of days with daily precipitation sums up to 5 mm, mainly in the cold half of the year, and downward trends were found for days with 20–30 mm of precipitation (1 day per 10 years), with high variability. Comparison with the results of previous studies shows that the increase in the number of days with precipitation is not linked to a significant increase in precipitation sums.

*Key-words*: precipitation, Poland, trends, water resources, agriculture

## *1. Introduction*

Changes in precipitation observed worldwide in recent decades are much more diversified regionally than changes in air temperature. The results presented in the Fifth Assessment Report of the IPCC *(Hartmann et al.,* 2013*)* show an overall increase in precipitation in the mid-latitudes of the Northern Hemisphere (30°N to 60°N) from 1901 to 2008, with statistically significant trends for each dataset used. For all other zones, due to data sparsity, poor data quality, and/or a lack of quantitative agreement among available estimates, characterization of such long-term trends in zonally averaged precipitation may be unreliable. Analyses of annual precipitation sums in Europe in the period 1960–2014, provided by the European Environmental Agency (*European Environmental Agency,* 2014*),* show a decrease in Southern Europe (–37.07 mm per decade) and an increase in Northern Europe (20.64 mm per decade), both statistically significant. These tendencies were also found in earlier studies *(Schönwiese et al.,* 1997*; Brunetti et al.,* 2000*;, Førland* and *Hanssen-Bauer,* 1995*; Degirmendžić et al.,* 2004*; Klein Tank* and *Können,* 2003*; Bartholy et al.,* 2015*).* Central Europe is located in a transitional zone. A study by *Niedźwiedź et al.* (2009) showed that precipitation in Central Europe fluctuates greatly in both time and space. No changing trend was found in any of the precipitation series studied, but a certain spatial regularity could be discerned. The test statistics change from a strongly negative value in Budapest to positive values that increase north-eastwards. These results are consistent with other studies covering smaller areas in Central Europe *(Domonkos* and *Tar,* 2003*, Kürbis et al,* 2009*; Tošić et al.,* 2016).

Previous studies of precipitation sums in Poland have not shown statistically significant changes *(Czarnecka and Nidzgorska-Lencewicz,* 2012*; Degirmendžić et al.,* 2004*)*. The authors of studies devoted to characteristics of the precipitation regime in Poland emphasize long-term fluctuations in the number of days with precipitation $\geq$ 0.1mm (*Degirmendžić et al.,* 2004*; Podstawczyńska,* 2007*; Wibig* and *Fortuniak,* 1998*; Bochenek,* 2012*; Skowera et al.,* 2014*)* and statistically significant upward trends in the number of days with precipitation *(Bochenek,* 2012*; Skowera et al.,* 2014*; Twardosz,* 2000). Therefore, the objective of this study was to analyze the multi-year variability in the structure of the number of days with precipitation, trends in the number of days with precipitation, and the role of days in particular classes of precipitation in determining the precipitation sum in the years 1971–2010, at stations representing agricultural areas in four regions of southern Poland. Regional aspects of both the structure of and trends in the number of days with precipitation are important in terms of formation of underground water resources and securing the precipitation needs of crop plants. Therefore, in this study we have considered all classes of precipitation sums. Agricultural regions of southern Poland, unlike in central and northern Poland, are located on diverse terrain, which in the case of atmospheric precipitation is an additional significant factor determining the spatial variability of this element.

Hence, in this study long-term changes in characteristics of the number of days with precipitation were considered with respect to the role of terrain relief.

## *2. Study areas*

The data analyzed come from four meteorological stations, representing agricultural areas located in four mesoregions (following the division by *Kondracki* (2011)) belonging to two voivodeships (administrative regions) of southern Poland (*Fig. 1*). *Table 1* presents basic data on each station.

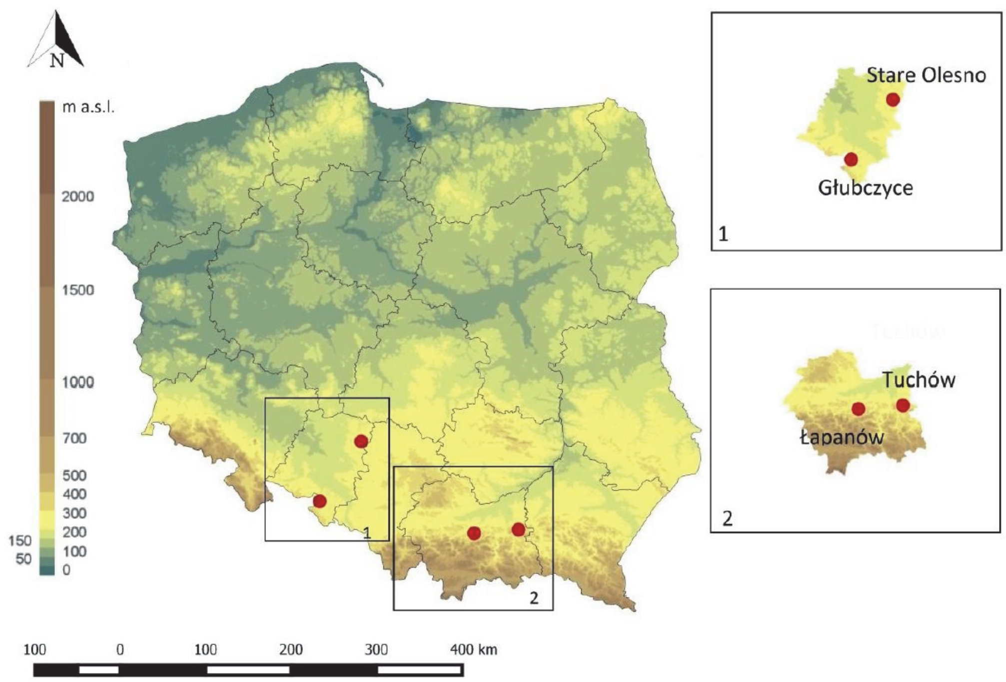


Fig. 1. Location of the Stare Olesno and Glubczyce in Opole Voivodeship (1) and Lapanow and Tuchow in Lesser Poland Voivodeship (1).

*Table 1.* Meteorological stations used in the study

| Station | Voivodeship | Region | Coordinates | Altitude (m a.s.l.) |
|---|---|---|---|---|
| Stare Olesno | Opole | Woznicki cuesta | 50°54′N 18°21E′ | 230 |
| Glubczyce | | Glubczyce Plateau | 50°12′N 17°49′E | 290 |
| Lapanow | Lesser Poland | Wisnicz Foothills | 49°52′N 20°19′E | 236 |
| Tuchow | | Ciezkowice Foothills | 49°54′N 21°03′E | 235 |

As the spatial distribution of precipitation is highly dependent on the impact of land forms, both on a regional and a local scale, a short description of each mesoregion is provided. Woznicki cuesta, where the Stare Olesno station is located, is a low ridge running NW to SE. The mesoregion is located on the western border of the Woznicki-Wielun Upland. The neighboring region to the west and south is the Opole Lowland, and the difference in altitude between the regions is about 60 m. Glubczyce Plateau, where the Glubczyce station is located, is surrounded to the west by the Sudety Mountains. (altitude difference between the regions is about 1,000 m), and the neighboring region to the east is the Raciborz Basin (altitude difference is about 90 m). Lapanow and Tuchow are located in two foothill mesoregions belonging to the Carpathian Foothills, but Lapanow represents its western part and Tuchow its central part. Both stations are situated in river valleys (of the Stradomka River and the Biala River, respectively) which run south to north and are surrounded by hills (altitude about 400 m and 500 m a.s.l., respectively). Both mesoregions are surrounded by the Beskidy Mountains. to the south (altitude difference between the regions is about 1,000 m) and by the Sandomierz Basin to the north (altitude difference about 200 and 300 m, respectively). All four stations are located so as to represent the climatic conditions of the agricultural areas on a mesoregional scale. A factor contributing to the origin of precipitation in all study areas is the domination of western winds in Poland. As humid air masses bringing precipitation come from the west, the local land forms can enhance precipitation sums, acting as orographic barriers, or, conversely, can reduce precipitation sums in comparison to neighboring regions, i.e., create a rain shadow effect.

## *3. Materials and methods*

In the study, we used the daily precipitation sums from 1971–2010 from the four meteorological stations described in Section 2. A day with precipitation was defined as a day with a daily precipitation sum $\geq$ 0.1mm. The structure of days with precipitation was presented according to the criterion proposed by *Olechnowicz–Bobrowska* (1970). This method classifies days with precipitation according to daily precipitation sums in 6 classes:

0.1–1.0 mm: day with very light precipitation,

1.1–5.0 mm: day with light precipitation,

5.1–10.0 mm: day with moderate precipitation,

10.1–20.0 mm: day with moderately heavy precipitation,

20.1–30.0 mm: day with heavy precipitation,

> 30.0 mm: day with very heavy precipitation.

The number of days with precipitation was calculated in each class in successive months and half-years, i.e., the cold half of the year (October-March) and the warm half (April-September), and mean values were calculated for the period 1971–2010. The structure of days with precipitation was based on successive decades of the period 1971–2010 and presented as the percentage share of the number of days with precipitation of a given class during the year and for the warm and cold halves of the year. The warm half of the year is the growing season for plants and the time of work in the fields, and the cold half is the period of dormancy for crop plants. Coefficient of variation $V$ (%) was calculated for days with a daily precipitation sum $\geq 0.1$ mm and separately for each class of days with precipitation.

Trends in the number of days with precipitation were analyzed for each month and half-year. The Mann-Kendall test *(Kendall,* 1975*)* was used to verify whether we could reject the null hypothesis, that there is no trend in the sequence of data in favor of the alternative hypothesis of an upward or downward trend in the data $y_i$. The test determines whether the difference between a given element of the data sequence and a previous element is a positive or a negative value ($y_j - y_i$, where $j > i$) and assigns a value of 1 if the difference is positive, –1 if it is negative and 0 if it is 0. The statistic $S$ was calculated as the sum of the integers according to the following formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(y_j - y_i), \tag{1}$$

where $n$ is the total number of data.

The null hypothesis, that there is no trend in the data sequence, is rejected when the value of statistic $S$ is significantly different from zero. We verify the null hypothesis on the basis of a normal Gaussian distribution, standardizing the statistic $S$ according to the following formula:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & S > 0 \\ 0 & S = 0, \\ \dfrac{S+1}{\sqrt{VAR(S)}} & S < 0 \end{cases} \qquad VAR(S) = \sqrt{\frac{n(n-1)(2n+5)}{18}}. \tag{2}$$

We reject the null hypothesis when the absolute value of statistic $Z$ is greater than the theoretical value of the normal distribution $Z_{1-\frac{\alpha}{2}}$, where α is the level of significance. We adopted the values $\alpha = 0.05$ and $\alpha = 0.1$. The $Z$ values are

$Z_{1-\frac{\alpha}{2}} = 1.95$ for $\alpha = 0.05$ and $Z_{1-\frac{\alpha}{2}} = 1.28$ for $\alpha = 0.1$. For data for which an upward or downward trend was found, the magnitude of the changes was estimated by calculating the Sen's slope estimator *(Hirsch et al.,* 1982) according to the following formula:

$$\beta = median\left(\frac{y_j - y_I}{j - i}\right), \qquad \text{for } i < j\text{ ; } i = 1, 2, \ldots, n\text{-}1, \qquad j = 2, 3, \ldots, n. \qquad (3)$$

Monthly, annual and semi-annual precipitation sums were also calculated, and then Spearman's rank coefficients were calculated between these sums and the number of days with precipitation in particular classes.

## *4. Results*

Analysis of the structure of the number of days with precipitation in four regions of southern Poland in 1971–2010 revealed temporal and spatial variation in this characteristic of the precipitation regime. The highest mean annual number of days with precipitation was noted at the Stare Olesno station, with 171.3 days, and the lowest at the Glubczyce station, with 155.7 days (*Table 2*).

*Table 2.* Average number of days with precipitation per year and half-year in each precipitation class in 1971–2010.

| Sum (mm) | Stare Olesno | | | Glubczyce | | | Lapanow | | | Tuchow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep |
| > 0.1 | 171.3 | 79.4 | 91.8 | 155.7 | 79.2 | 76.2 | 160.9 | 80.9 | 79.9 | 166.2 | 78.8 | 87.4 |
| 0.1 – 1.0 | 64.2 | 24.1 | 40.1 | 66.0 | 26.5 | 39.6 | 51.2 | 20.3 | 30.7 | 58.3 | 22.2 | 36.1 |
| 1.1 – 5.0 | 66.8 | 30.1 | 36.7 | 55.0 | 27.9 | 27.0 | 64.6 | 29.8 | 34.7 | 64.7 | 28.7 | 36.0 |
| 5.1 – 10.0 | 24.1 | 13.1 | 11.0 | 19.4 | 13.2 | 6.1 | 23.8 | 14.4 | 9.4 | 24.0 | 14.3 | 9.7 |
| 10.1 – 20.0 | 12.0 | 8.4 | 3.6 | 10.6 | 7.6 | 3.0 | 14.9 | 10.8 | 4.1 | 13.7 | 10.1 | 3.5 |
| 20.1 - 30.0 | 2.6 | 2.3 | 0.3 | 3.3 | 2.8 | 0.5 | 3.7 | 3.0 | 0.7 | 3.3 | 2.9 | 0.5 |
| > 30.0 | 1.5 | 1.4 | 0.05 | 1.4 | 1.4 | 0.02 | 2.7 | 2.6 | 0.1 | 2.2 | 0.6 | 1.7 |

These differences can be attributed to the location of Glubczyce leeward of the Sudety Mountains., at their eastern foot. These mountains form an orographic barrier for moist polar air masses from the west. Precipitation is much lower to the east of the mountain range than to the west *(Kondracki,* 2011*).* Stare Olesno is situated on a convex landform, where the precipitation is determined mainly by atmospheric circulation processes. The average annual number of days with precipitation at all stations during the study period was about 10-20 days higher than those reported by *Olechnowicz-Bobrowska* (1970) for the period 1951–1960. According to the *Atlas of the climate in Poland* (2005), in 1971–2000 the average annual number of days with precipitation >0.1 mm in the regions discussed was about 170, which was similar to the results obtained in our study. The number of days with precipitation >10 mm was also comparable. On an annual scale, light precipitation (class 1.1–5.0 mm) had the largest share in the structure of days with precipitation, with the exception of Glubczyce, where days with very light precipitation (0.1–1.0 mm) were dominant. In the warm half of the year, days with precipitation in the 0.1-1.0 mm class were dominant (except for Lapanow, with the greatest number of days in the 1.1–5.0 mm class), while in the colder half of the year, days with 1.1–5.0 mm dominated.

The structure of days with precipitation in successive decades of the study period is presented in *Figs. 2.1* and *2.2* for classes 0.1–1.0, 1.1–5.0, 5.1–10, and > 10.0 mm (the class of days with precipitation > 10.0 mm was introduced because the number of days in higher classes was small). Notable in this structure are the upward trends primarily in classes of days with very light and light precipitation in the cold half of the year and the variation in the number of days with precipitation between different meteorological stations in each decade.

The parametric Mann-Kendall test was used to verify whether the tendencies observed in changes in the structure of days with precipitation were statistically significant (significant trends $\alpha \leq 0.05$ and weak trends $0.05 < \alpha \leq 0.1$) (*Table 3.a*). Significant changes in very light precipitation (0.1–1.0 mm) were noted in Lapanow and Tuchow in both half-years and for the year, and in Glubczyce for the year and for the cold half of the year, while in Stare Olesno no trend coefficients were statistically insignificant. In Glubczyce, Lapanow, and Tuchow statistically significant trends were also noted in certain months, mainly in the cold half of the year. All statistically significant trends were upward; according to the Sen estimator, the number of days with precipitation in class 0.1–1.0 mm increased by about 1–9 per decade. In the case of higher classes, no significant trends were found in individual months and, therefore, for these classes the trends for the year and for each half-year are presented (*Table 3.b*). Statistically significant trends were noted only for classes 1.1–5.0 mm and 20.1–30 mm. In the case of class 1.1–5.0 mm these were upward trends, affecting only the number of days with such precipitation sums in Stare Olesno and Tuchow; for the year and the cold half-year they were about 2–3 days per decade. In the case of class 20.1–30.0 mm in Stare Olesno and Tuchow in the warm half of the year, a decrease was noted of about 1 day per 10 years. In successive months of the warm half-year, no significant trends were found in the total number of days with precipitation (daily sum ≥0.1 mm) (*Table 4*).

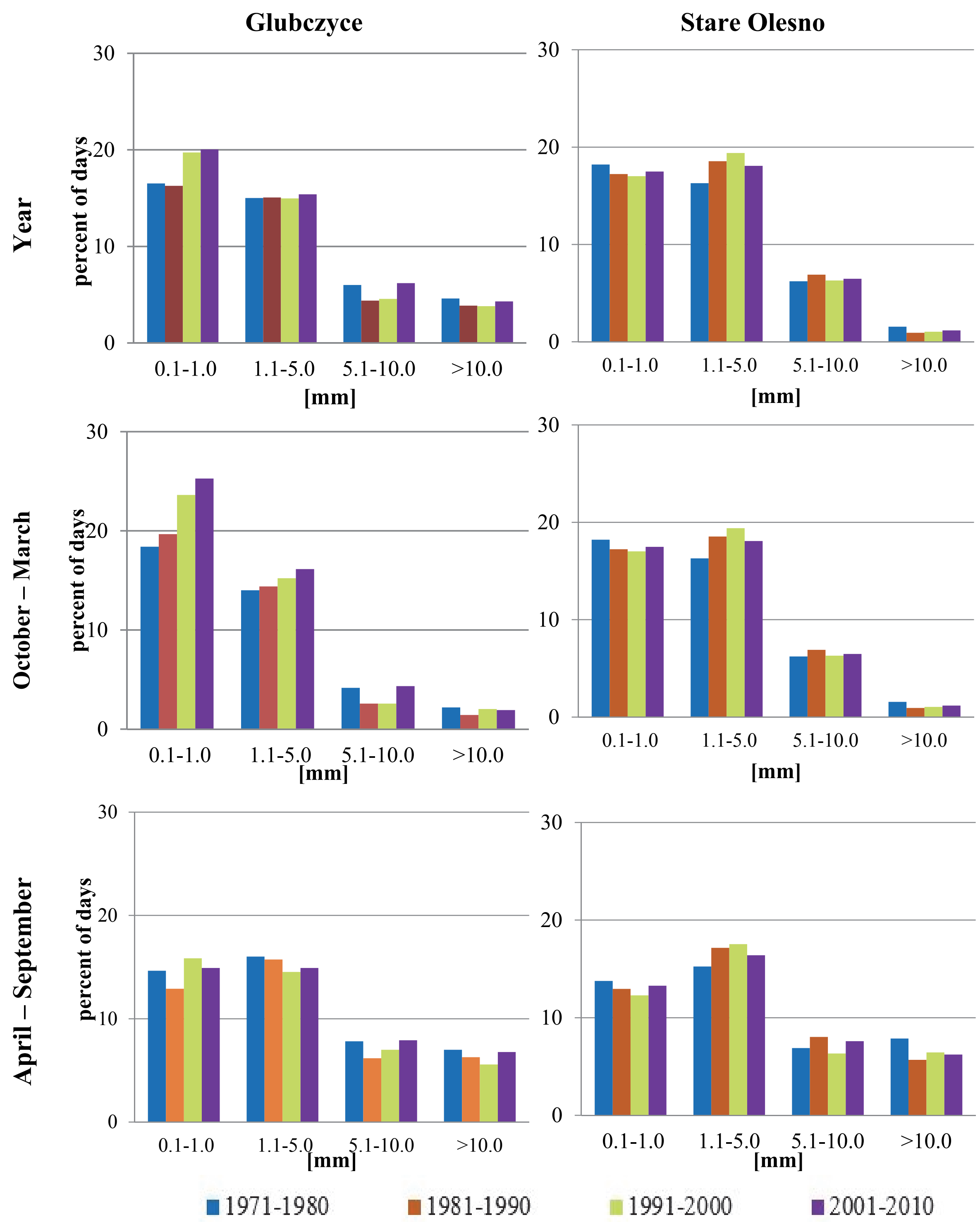


*Fig. 2.1.* Structure of days with precipitation (in successive decades) at selected stations in Opole Voivodeship in southern Poland (1971–2010).

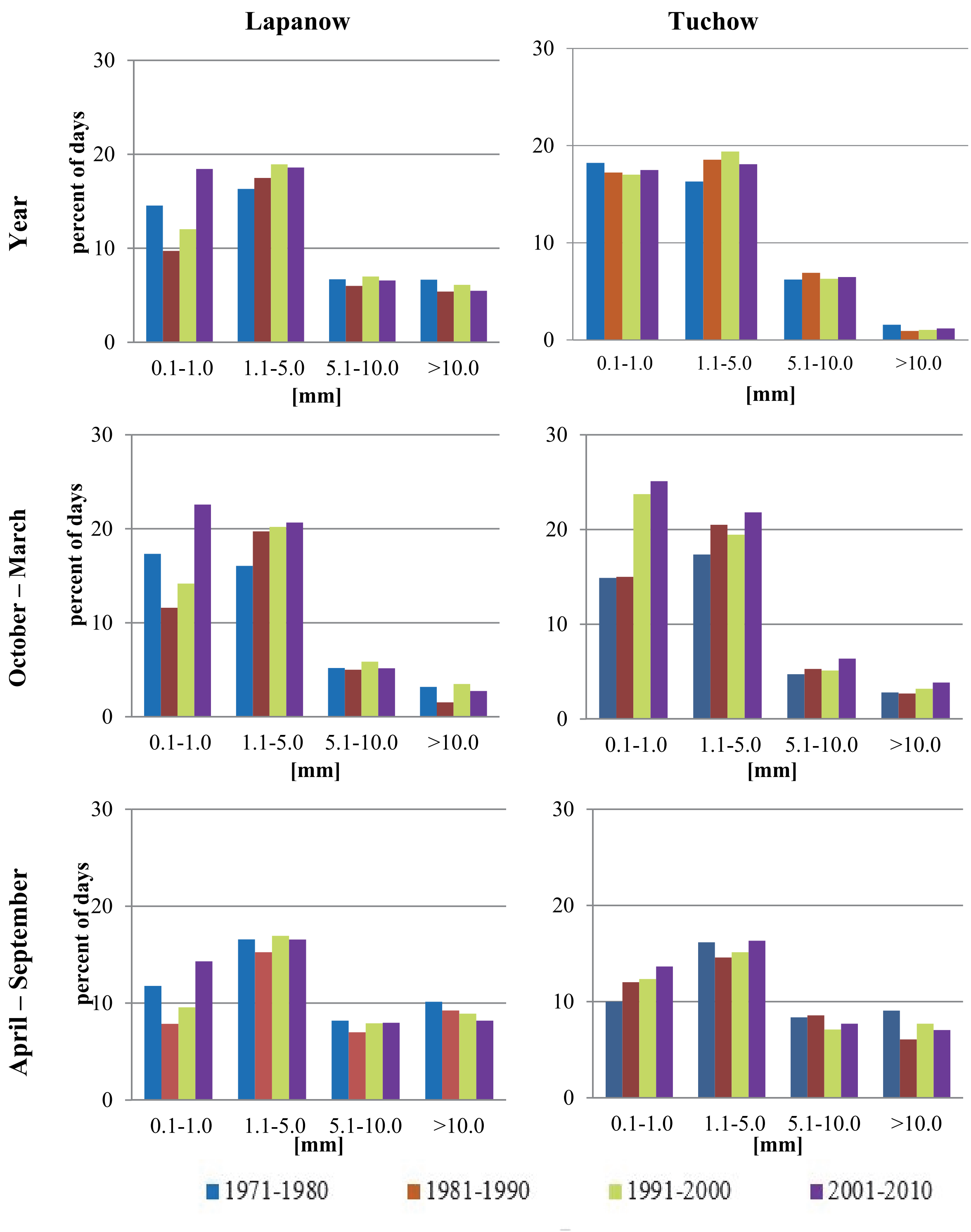


*Fig. 2.b.* Structure of days with precipitation (in successive decades) at selected stations in Lesser Poland Voivodeship in southern Poland (1971–2010).

*Table 3.a.* Trend coefficients for the number of days with precipitation |z| in 1971-2010: class 0.1–1.0 mm (individual months, half-years, and year)

| Meteorological station | January | February | March | April | May | June | July | August | September | October | November | December | Year | Oct-Mar | Apr-Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stare Olesno | 0.53 | 0.20 | -0.03 | -1.47* | 1.06 | 0.85 | 0.00 | 1.20 | -1.05 | 0.47 | -1.15 | -0.24 | 0.52 | -0.35 | -0.05 |
| Increase in days/10 years | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Glubczyce | 1.72* | 3.40** | 1.28 | -0.30 | -0.35 | 0.01 | 1.31* | 0.34 | -0.48 | 1.47* | 2.88** | 1.31* | 2.81** | 2.96** | 1.41* |
| Increase in days/10 years | - | 1.3 | - | - | - | - | - | - | - | - | 1.2 | - | 5.2 | 4.5 | - |
| Lapanow | 0.12 | 3.92** | 0.66 | 2.07** | 0.16 | 2.32** | 0.79 | 1.02 | 0.76 | 0.76 | 2.11** | 2.43** | 2.74** | 2.79** | 2.16** |
| Increase in days/10 years | - | 1.3 | - | 0.6 | - | 0.5 | - | - | - | - | 0.8 | 1.1 | 7.3 | 4.7 | 2.5 |
| Tuchow | 2.63** | 2.92** | 2.57** | 0.17 | 1.59* | 1.25 | 0.13 | 3.24** | 1.28 | 3.01** | 3.54** | 2.63** | 4.80** | 4.57** | 2.75** |
| Increase in days/10 years | 2.69 | 1.0 | 0.8 | - | - | - | - | 1.4 | - | 1.4 | 1.3 | 0.8 | 8.2 | 6.3 | 2.0 |

*Table 3.b.* Trend coefficients for the number of days with precipitation |z| in 1971–2010: remaining classes of precipitation sums (half-years and year).

| | 1.1-5.0 | | | 5.1-10.0 | | | 10.1-20.0 | | | 20.1-30.0 | | | >30.0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meteorological station | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep | Year | Oct-Mar | Apr-Sep |
| Stare Olesno | 2.54** | 2.38** | 0.42 | 0.23 | 0.54 | -0.70 | 0.34 | 0.26 | -0.13 | -2.82** | 0.08 | -3.48** | 1.09 | 0.00 | 0.00 |
| Increase in days/10 years | 3.3 | 2.5 | - | - | - | - | - | - | - | -0.6 | - | -0.6 | - | - | - |
| Glubczyce | 0.36 | 1.05 | -0.60 | 0.04 | -0.44 | 0.15 | 0.31 | -0.21 | 0.49 | -0.77 | -0.27 | -0.63 | 0.54 | 0.00 | 0.00 |
| Increase in days/10 years | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Lapanow | 1.60* | 1.66* | 0.18 | -0.38 | -1.12 | 0.35 | -0.61 | 0.17 | -1.29* | -1.65* | -0.02 | -2.30** | -0.05 | 0.00 | 0.00 |
| Increase in days/10 years | - | - | - | - | - | - | - | - | - | - | - | -0.7 | - | - | - |
| Tuchow | 2.61** | 2.30** | 0.43 | -0.36 | 1.28 | -1.44* | -0.68 | 0.48 | -0.67 | -0.76 | 0.31 | -0.48 | *1.80** | *3.70*** | *-2.27*** |
| Increase in days/10 years | 2.9 | 2.3 | - | - | - | - | - | - | - | - | - | - | - | *0.5* | *0* |

Statistical significance: ** - for $\alpha = 0.05$ with |z|> 1.95; * - for $\alpha = 0.1$ with |z|> 1.28

Italics indicate values, which due to the small number of cases of days with precipitation >30mm (despite significant values for statistic |z|) can not be treated as reliable

*Table 4.* Trend coefficients for the number of days with precipitation > 0.1mm in 1971–2010

| Meteorological station | January | February | March | April | May | June | July | August | September | October | November | December | Year | Oct-Mar | Apr-Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stare Olesno | 1.38* | 1.61* | 1.29* | –1.61* | 0.98 | -0.21 | 0.13 | 1.72* | –1.37* | 0.29 | –0.16 | –0.39 | 1.06 | 1.14 | –0.31 |
| Glubczyce | 0.81 | 2.93** | 1.53* | –0.64 | 0.75 | –0.50 | 0.96 | –0.16 | –0.62 | 1.24 | 2.32** | 0.23 | 2.68** | 2.67** | –0.07 |
| Lapanow | 1.34* | 2.58** | 2.53** | 0.52 | 0.88 | 0.70 | 0.63 | –0.47 | 0.16 | 0.79 | 0.76 | 0.85 | 2.58** | 2.62** | 0.81 |
| Tuchow | 2.71** | 2.86** | 2.47** | 1.01 | 1.04 | 0.09 | 0.08 | 1.71* | –0.01 | 1.74* | 2.34** | 1.08 | 4.80** | 4.83** | 1.04 |

Statistical significance: ** for $\alpha = 0.05$ for $|z| > 1.95$; * for $\alpha = 0.1$ for $|z| > 1.28$

A characteristic feature of the precipitation sums and the number of days with precipitation in the regions studied is the considerable variability from year to year. As in the case of the trends, the coefficient of variation in each precipitation class was calculated for the year and for both half-years-warm and cold. Following *Sobczyk* (2009): a value > 20% was taken to mean that a given population is significantly varied in terms of the trait analyzed. The coefficient of variation of the annual number of days with precipitation (daily sum ≥ 0.1 mm) ranged from 10% at the stations located in the Opole Voivodeship to 11–12% in the Lesser Poland Voivodeship. In the warm half-year at all stations, the variability of this characteristics ranged from 13% to 15% and was somewhat lower than in the colder half of the year, i.e., from 15% to 19%, which means small variation in annual and semi-annual numbers of days with precipitation. However, the variability in monthly numbers of days with precipitation was much greater. The highest variation in the number of days with precipitation at all stations was noted for October (38–44%), while the lowest variation for this trait (about 26–27%) occurred in different months at different stations. The lowest variation was found for the number of days with light precipitation (1.1–5.0 mm: 11–25%), followed by very light (0.1–1.0 mm: 16–31%) and moderate (5.1–10.0 mm: 21–42%) precipitation. In the higher classes (>10 mm), the variation in the number of days was much greater, at 25–67%, and in the case of these classes, greater variation between seasons can be seen. In the cold half of the year, the coefficient of variation reached a value of 45–67%, and in the warm half, 29–33% (*Table 5*).

*Table 5.* Coefficient of variation for mean annual and seasonal numbers of days with precipitation (%) in the classes distinguished, in the period 1971-2010 at the stations studied

| **Sum (mm)** | **Stare Olesno** | | | **Glubczyce** | | | **Lapanow** | | | **Tuchow** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Year** | **Apr -Sep** | **Oct-Mar** | **Year** | **Apr-Sep** | **Oct-Mar** | **Year** | **Apr-Sep** | **Oct-Mar** | **Year** | **Apr-Sep** | **Oct-Mar** |
| > 0.1 | 10 | 13 | 15 | 10 | 14 | 18 | 12 | 15 | 17 | 11 | 13 | 19 |
| 1.1–1.0 | 16 | 20 | 20 | 17 | 20 | 25 | 27 | 31 | 31 | 24 | 23 | 30 |
| 1.1–5.0 | 14 | 20 | 22 | 13 | 20 | 22 | 14 | 25 | 22 | 11 | 17 | 21 |
| 5.1–10.0 | 21 | 33 | 29 | 29 | 34 | 38 | 27 | 28 | 42 | 22 | 28 | 36 |
| >10.0 | 58 | 31 | 66 | 28 | 33 | 62 | 25 | 29 | 67 | 28 | 32 | 45 |

*Table 6* presents correlations between the number of days with precipitation in individual classes and annual and semi-annual precipitation sums. At all stations, the precipitation sum in both seasons was significantly influenced by the number of days with precipitation in classes > 10 mm, and in the cold half of the year, the precipitation sum was also significantly influenced by the number of days with precipitation in lower classes.

*Table 6.* Correlations between the number of days with precipitation in a given class (mm) and the precipitation sum in the year and half-years in 1971-2010

| Meteorological station | Period | >0.1 | 0.1-1.0 | 1.1-5.0 | 5.1-10.0 | 10.0-20.0 | 20.1-30.0 | >30.0 |
|---|---|---|---|---|---|---|---|---|
| Stare Olesno | Year | 0.47* | 0.02 | 0.12 | 0.11 | 0.62* | 0.39* | 0.61* |
| | Apr-Sep | 0.57* | 0.28 | 0.01 | 0.30 | 0.56* | 0.51* | 0.56* |
| | Oct-Mar | 0.56* | -0.04 | 0.58* | 0.61* | 0.72* | 0.34* | 0.34* |
| Glubczyce | Year | 0.46* | 0.09 | 0.22 | 0.47* | 0.22 | 0.63* | 0.59* |
| | Apr-Sep | 0.46* | 0.01 | 0.32* | 0.29 | 0.34* | 0.55* | 0.60* |
| | Oct-Mar | 0.32* | 0.04 | 0.43* | 0.23 | 0.35* | 0.48* | -0.05 |
| Lapanow | Year | 0.51* | 0.25 | 0.20 | 0.48* | 0.34* | 0.40* | 0.74* |
| | Apr-Sep | 0.53* | 0.11 | 0.15 | 0.28 | 0.54* | 0.47* | 0.72* |
| | Oct-Mar | 0.72* | 0.36* | 0.38* | 0.49* | 0.64* | 0.46* | 0.22 |
| Tuchow | Year | 0.51* | 0.09 | 0.26 | 0.59* | 0.50* | 0.63* | 0.63* |
| | Apr-Sep | 0.63* | 0.07 | 0.34* | 0.32* | 0.57* | 0.56* | 0.31* |
| | Oct-Mar | 0.51* | 0.15 | 0.46* | 0.63* | 0.72* | 0.33* | 0.17 |

* significant correlation coefficient ($\alpha = 0.05$)

## *5. 5. Discussion*

The results presented show that in all the regions similar tendencies were observed in changes in the structure of the number of days with precipitation, with certain aspects of these tendencies modified by local environmental conditions. In the structure of the number of days with precipitation, days with precipitation sums < 5 mm, i.e., very light and light, are dominant. They show a statistically significant upward trend and, at the same time, little variation over the long term. This increase is observed mainly in the cold half of the year, both in the entire half-year and in some of its months. Moreover, the number of days with daily precipitation sums < 5 mm has a significant role in determining the precipitation sum, mainly in the cold half of the year. For days with higher daily precipitation sums, including for extreme precipitation, either no statistically significant trends in changes are observed or the trends are downward. *Lupikasza* (2010) summed up studies of changes in extreme precipitation in Europe and in Poland and found that 'during summer time, any positive trends in extreme precipitation observed in Europe are much weaker than those found in winter time and are mostly statistically insignificant. Indeed, significant negative trends have been identified in many areas of Europe in summer time' and 'during 1951–2006, decreasing trends in extreme precipitation indices dominated in both the warm and cool halves of the year and in the seasons in Poland.' The results of our study in southern Poland are thus consistent with the tendencies observed in *Lupikasza's* study (2010), as well as with results obtained by *Bartholy et al.* (2015) for Hungary, *Moberg et al.* (2006) and *Rodrigo* (2010) for Europe. At all stations, the number of days with precipitation > 10 mm showed either no statistically significant trends in changes or downward trends, and at the same time, the highest long-term variation. Moreover, days with precipitation > 10 mm have a significant role in determining the precipitation sums in the year and in half-years. In terms of water resources for agriculture, the tendencies presented indicate a direction of changes in the precipitation regime that can be considered unfavorable. The climate scenarios presented in the IPCC report *(Kirtman et al.,* 2013*)* suggest that in 2016–2035, in comparison with 1986–2005, seasonal precipitation sums in the regions studied in Poland will be about 5% lower in the summer and 5% higher in the winter. A significant factor is the considerably greater long-term variability in the number of days with precipitation > 10 mm than in the number of days with precipitation < 5 mm. In the cold half of the year, which covers the beginning and end of the growing season, we can expect the precipitation demands of crop plants to be met, while during most of the growing season we can expect a shortage, due to the lower number of days with precipitation, high variability in the frequency of days with high and extreme precipitation, and lower precipitation sums. Previous studies have shown that due to increased air temperature, in some mesoregions of Poland, rainfall deficits in the spring have been more frequent than the excessive rainfall for crops (*Skowera et al.,* 2014). The number of days with precipitation determines the distribution of precipitation supply over time. In the years 1971–2010, a downward tendency was observed in the number of precipitation spells in the warm half of the year (Glubczyce) and an increase in the cold half of the year (Lapanow and Tuchow) (*Skowera* and *Wojkowski,* 2015). Given that in the cold half of the year the number of days with very light precipitation increased while no increase was observed in the precipitation sum, we can conclude that the observed change in the structure of the number of days with precipitation did not translate to an increase in post-winter water resources for crop plants.

## *6. Conclusion*

Most studies of the number of days with precipitation focus on extreme precipitation, while precipitation with lower daily sums is overlooked.

The results presented regarding the structure of the number of days with precipitation in southern Poland demonstrate the significant role of the number of days with very light (0.1–1.0 mm) and light precipitation (1.1–5.0 mm) in determining precipitation sums (particularly in the cold half of the year) and water resources for agriculture. In the period 1971–2010, changes in precipitation sums showed no significant tendencies, but an increase was observed in the number of days with very light and light precipitation and a decrease in the number of days with 20.1–30.0 mm of precipitation. The magnitude of these changes varied between stations. In light of the anticipated climate changes in Europe, precipitation in southern Poland will undergo slight changes in the next few decades, similar to those observed until now, but with a tendency towards a decrease in precipitation in the summer and an increase in the winter. If the tendency in the change in the number of days with precipitation does not change, we can expect a further increase in the number of days with very light and light precipitation, particularly in the cold half of the year, and a decrease in the number of days with 20–30 mm of precipitation in the summer period.

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