Trends in Selected Characteristics of Precipitation in the Cities above 100,000 Residents in Poland, 1966-2016

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Abstract. Contemporary climate change causes an increase in the sensitivity of urban areas to the effects of this change, manifested in the increased threat of periods of both shortage and surplus of water or a higher probability of flood or drought occurrence. That is why Polish Ministry of the Environment is currently implementing project aimed at developing in major Polish cities with more than 100,000 inhabitants Urban Adaptation Plans that would reduce the city's vulnerability to climate change. One of the elements of preparing such plans is the assessment of the city's exposure to the effects of changes in rainfall conditions. Therefore, it is extremely important to know the trends of these changes. The analysis of the variability of selected precipitation characteristics was carried out for 24 Polish cities with more than 100,000 inhabitants. The tendencies of annual and seasonal precipitation changes, the number of days with precipitation, the number of days with extreme precipitation (events exceeding the 1971-2000 95th percentile of daily precipitation) as well as the fraction of annual total precipitation due to extreme precipitation have been characterized. Annual trends were calculated using standard linear regression method and its statistical significance at the 95% confidence level was assessed with the help of F Snedecor probability distribution. Changes in precipitation characteristics show mixed patterns. In the majority of analyzed cities, annual precipitation totals tend to decrease, however, there is no clear spatial pattern. In general, seasonal tendencies of summer and winter precipitation, and especially autumn precipitation, also show negative tendencies. However, the sums of precipitation in the spring season are generally characterized by positive tendencies. In the vast majority of analyzed cities, the number of days with precipitation decreases, as well as the number of days with extreme precipitation. Decreasing or stable precipitation together with increasing air temperature may result in water insecurity in many Polish cities.

1. Introduction
Poland is a country with 38 million inhabitants, of which over 60% live in cities. Cities are particularly sensitive to climate change due to population density, valuable housing and infrastructure. That is why the Polish Ministry of the Environment prepared a 'Strategic adaptation plan for sectors and areas sensitive to climate change by 2020 with a perspective up to 2030' [1]. This plan is addressed to cities with over 100,000 inhabitants and is to help them develop the Urban Adaptation Plans (UAP). Currently, 44 Polish cities take part in the project, of which 37 are cities with more than 100,000 inhabitants.
One of the elements of the UAP is to study climatic factors that threaten cities [2]. Atmospheric precipitation is one of such factors (both their surpluses and deficits), which can directly affect the functioning of the city, its society and economy. Investigating trends of changes in basic rainfall characteristics in selected Polish cities is not only cognitive but also application-related - it may make it easier for teams developing UAPs to assess the risk of hazards in cities caused by atmospheric precipitation. The investigations were based on the analysis of daily precipitation totals recorded at synoptic stations located in 24 Polish cities with population above 100,000 citizens (Figure 1). The choice of cities was determined by the availability of the homogeneous precipitation database originated from Institute of Meteorology and Water Management - National Research Institute with data since 1966.

Four indices of precipitation that enable the assessment of city's sensitivity to climate change manifested by changes in the characteristics of atmospheric precipitation were analyzed. The indices included annual and seasonal precipitation totals, annual and seasonal number of days with precipitation, annual and seasonal number of days with extreme precipitation (events exceeding the 1971-2000 95th percentile of daily precipitation) as well as the fraction of annual and seasonal total precipitation due to extreme precipitation. The first two aforementioned indices can be applied for evaluating the changing conditions of water resources replenishment crucial for cities’ water management [3]. The number of days with extreme precipitation, and the fraction of annual and seasonal total precipitation due to events exceeding the 1961-1990 95th percentile appropriately characterize the cases of extreme precipitation. The value of 95% quantile is a characteristic used in numerous publications [4,5,6,7] for establishing the threshold value above which a daily precipitation total is considered to be extreme. Rare extreme events tend to have the highest impact and cause the greatest damage to natural and managed systems and to human well-being [3]. Temporal trends in the above mentioned indices for the period 1966-2016 were evaluated by means of linear regression, while their statistical significance at the 95% confidence level was assessed with the F-Snedecor test.

2. Results and discussion
The average annual rainfall totals in Poland are 623 mm [8]. Their spatial diversity is strongly dependent on the altitude. In the belt of the coasts the annual rainfall amounts to 530-550 mm, in lakelands it is
higher, exceeding 600mm. In the central Polish plains, it ranges from 500-600 mm, then grows in the highlands up to about 650-1000 mm, to reach the value above 1000 mm in the mountains (Table 1). The summer season precipitations prevail in Poland. From June to August, vast majority of Polish territory receives over 170-250 mm of rainfall, and the only exception among analysed cities is Bielsko Biała, where it reaches 356 mm. The sums of precipitation vary from 100 to 220 mm in the spring, and from 110 to 200 mm in the autumn. In winter, precipitation ranges from 85 to 135 mm in Poland.

The temporal tendencies of changes in annual sums of atmospheric precipitation, generally statistically insignificant, are characterized by high spatial variation. In southern and central Poland, the negative tendencies of annual sums of precipitation prevail, with a height of 1-3 mm·yr⁻¹. In Opole it is a statistically significant trend. The north and north-western part of the country is characterized by positive tendencies of changes in annual sums of precipitation, at the level of ca. 1 mm·yr⁻¹ (Table 1). The temporal tendencies of changes in precipitation sums in the spring season are characterized by high spatial variation, from -0.43 mm·yr⁻¹ in Plock to 0.69 mm·yr⁻¹ in Elblag, which is the only station with a statistically significant change trend (Table 1). In the spring season, two territorially uniform areas of positive but statistically insignificant trends in precipitation sums can be distinguished in Poland. These are the central coast, represented by the Gdynia, Gdansk and Elblag stations, and south-eastern Poland, represented by the Kielce, Lublin, Tarnow and Rzeszow stations. In the summer season, two areas with different temporal trends of changes in precipitation sums can be distinguished in Poland. In the southern part of Poland, up to Kalisz and Lodz, negative tendencies dominate with a statistically significant maximum change at -1.3 mm·yr⁻¹ in Opole. To the north of these stations the positive tendencies of changes in the sums of precipitation in the summer season prevail, however they are statistically insignificant. Precipitation in the autumn season is characterized by negative temporal tendencies in precipitation on almost all analyzed stations, with the exception of five stations located in southern Poland. In Opole, the trends of these changes, 0.7 mm·yr⁻¹, are statistically significant. In the winter season, negative temporal tendencies of precipitation in southern Poland can be observed, although a statistically significant decrease in seasonal sums of precipitation at the level of 0.7 mm·yr⁻¹ is observed only in Opole. Positive temporal trends in seasonal sums of winter precipitation occur north of the Kalisz station. However, the only statistically significant increase in winter precipitation, at the level of 0.6 mm·yr⁻¹ is observed in Warsaw.

The described tendencies of changes in annual and seasonal sums of precipitation are consistent with the observed changes described by [3], which showed the existence of generally statistically insignificant increases in annual and seasonal precipitation in the northern part of Poland and their decrease in the southern part.

The average annual number of days with precipitation (≥ 0.1 mm) in Poland varies within 150-180 days. [9] Spatial diversity of the annual number of days with precipitation in Poland is small. In central Poland, there are 150-160 days of precipitation per year, in the lakelands and highlands this characteristic rises to 170-190 days (Table 2). The highest number of days with precipitation, 45-50 days, is recorded in the winter season. In other seasons, the number of days with rainfall is slightly lower and varies from 35 to 45 days.

In general, the number of days with rainfall is decreasing in Poland. These temporal trends are characteristic for the year, spring, autumn and winter season and for the summer season in the southern part of Poland (Table 2). In this season, statistically significant positive trends, at the level of 0.18-0.25 day·yr⁻¹, characterize stations located in northern Poland. Gdansk is a city where positive trends in the number of days with precipitation are observed not only in summer (0.25 day·yr⁻¹) but also in the year (0.53 day·yr⁻¹) and in the winter season (0.20 day·yr⁻¹). However, in Zielona Gora, statistically significant negative trends are observed in the year (-0.35 day·yr⁻¹) and in the spring season (-0.14 day·yr⁻¹) and in the autumn season (-0.16 day·yr⁻¹). At the station in Opole, statistically significant negative trends on the level of -0.16 0.25 day·yr⁻¹ are observed in the summer and autumn seasons. At the station in Kielce a statistically significant decrease in the number of days with precipitation is noted in the spring season (-0.13 day·yr⁻¹), and the number of days with precipitation in the year (-0.41 day·yr⁻¹) also decreases.
Furthermore, a statistically significant decrease in the number of days with precipitation in the spring season is observed at the station in Gorzów Wlkp (-0.13 day yr\(^{-1}\)) and in the autumn season at stations in Torun, Warszawa and Łódź (-0.18, -0.17 and -0.13 days yr\(^{-1}\), respectively).

**Table 1.** The annual and seasonal mean precipitation totals (mm) at selected stations in Poland in the years 1966-2016, and the slope values (mm yr\(^{-1}\)) from the fitted regression equations. Statistically significant values are shown in boldface.

| Station  | Year mean (mm) | Year trend (mm yr\(^{-1}\)) | Spring mean (mm) | Spring trend (mm yr\(^{-1}\)) | Summer mean (mm) | Summer trend (mm yr\(^{-1}\)) | Autumn mean (mm) | Autumn trend (mm yr\(^{-1}\)) | Winter mean (mm) | Winter trend (mm yr\(^{-1}\)) |
|----------|----------------|-------------------------------|------------------|-------------------------------|------------------|-------------------------------|------------------|-------------------------------|------------------|-------------------------------|
| Szczecin | 549.1          | 1.09                          | 116.9            | -0.07                         | 175.0            | 0.65                          | 124.0            | -0.08                         | 108.3            | 0.38                          |
| Gdynia   | 529.2          | 0.70                          | 100.7            | 0.15                          | 173.5            | 0.44                          | 143.1            | 0.10                          | 88.3             | 0.26                          |
| Gdansk   | 548.7          | -0.14                         | 99.8             | 0.01                          | 189.9            | 0.06                          | 148.0            | -0.22                         | 85.0             | -0.17                         |
| Elblag   | 668.6          | 1.42                          | 119.3            | **0.69**                      | 218.7            | 0.19                          | 173.9            | -0.14                         | 118.1            | 0.39                          |
| Olsztyn  | 639.3          | -1.00                         | 125.0            | -0.10                         | 213.0            | -0.28                         | 155.2            | -0.62                         | 113.4            | 0.25                          |
| Gorzow Wlkp | 549.8       | -0.34                         | 115.9            | -0.18                         | 177.4            | -0.20                         | 120.0            | -0.23                         | 110.4            | 0.23                          |
| Zielona Gora | 583.7         | 0.31                          | 124.6            | -0.02                         | 194.9            | 0.50                          | 122.5            | -0.31                         | 114.8            | 0.03                          |
| Poznan   | 526.7          | 1.03                          | 112.0            | 0.36                          | 186.9            | 0.81                          | 109.4            | -0.41                         | 96.8             | 0.46                          |
| Torun    | 543.3          | 0.04                          | 108.5            | -0.11                         | 201.2            | 0.27                          | 117.0            | -0.08                         | 90.7             | 0.33                          |
| Plock    | 534.6          | -1.74                         | 112.5            | -0.43                         | 190.4            | -0.76                         | 112.3            | -0.53                         | 90.0             | -0.02                         |
| Bialystok| 599.1          | -0.18                         | 125.3            | 0.32                          | 207.4            | 0.18                          | 137.5            | -0.42                         | 97.3             | 0.01                          |
| Warszawa | 535.8          | 0.80                          | 111.8            | 0.21                          | 192.5            | 0.37                          | 116.6            | -0.34                         | 85.6             | **0.56**                      |
| Katowice | 727.8          | -0.85                         | 161.0            | -0.38                         | 255.1            | -0.69                         | 151.9            | 0.12                          | 121.9            | 0.08                          |
| Bielsko-Biala | 987.0      | -1.17                         | 224.0            | 0.46                          | 355.9            | -2.07                         | 196.8            | 0.71                          | 135.9            | -0.05                         |
| Krakow   | 679.0          | -0.63                         | 156.3            | -0.16                         | 242.8            | -0.68                         | 139.8            | 0.13                          | 103.3            | 0.02                          |
| Kielce   | 632.7          | -1.07                         | 134.2            | 0.17                          | 219.1            | -0.85                         | 130.1            | -0.20                         | 110.9            | -0.56                         |
| Lublin   | 595.6          | 0.15                          | 132.4            | 0.48                          | 204.9            | -0.52                         | 129.1            | -0.16                         | 96.2             | -0.01                         |
| Tarnow   | 734.1          | -0.62                         | 165.5            | 0.16                          | 271.5            | -0.94                         | 143.2            | 0.14                          | 102.9            | -0.13                         |
| Rzeszow  | 650.9          | 0.55                          | 149.8            | 0.59                          | 238.2            | -0.53                         | 132.9            | 0.38                          | 95.3             | -0.01                         |

*Spring: March, April, May; Summer: June, July, August; Autumn: September, October, November; Winter: December, January, February

Obtained results regarding the temporal trends of annual and seasonal changes in the number of days with precipitation in Poland in 1966-2016 are consistent with the results obtained by [10], who revealed areas of different change direction and pluvial conditions in Poland during the period 1951-2008, generally statistically insignificant.

The value of 95% quantile is a characteristic used in numerous publications [4,5,6,7] for establishing the threshold value above which a daily precipitation total is considered to be extreme. At stations located in the Polish lowlands, the values of 95% quantile ranges between 14 and 18 mm (Table 3). In Bielsko-Biala, the value of 95% quantile is visibly higher, reaching 22.7 mm.
Spatial diversity of the number of days with precipitation above the 95% quantile in Poland is small, ranging between 5 and 6 days (Table 4). Most days with precipitation above the value of 95% quantile are recorded in the summer season (3-4 days). In the spring and autumn season, their number is similar, ca. 1 day. In winter, extreme rainfall is observed in Poland on average every five to ten years.

**Table 2.** The annual and seasonal mean number of days with precipitation at selected stations in Poland in the years 1966-2016, and the slope values (day yr\(^{-1}\)) from the fitted regression equations. Statistically significant values are shown in boldface.

| Station       | Year Mean | Trend | Spring Mean | Trend | Summer Mean | Trend | Autumn Mean | Trend | Winter Mean | Trend |
|---------------|-----------|-------|-------------|-------|-------------|-------|-------------|-------|-------------|-------|
| Szczecin      | 168.0     | 0.08  | 39.1        | -0.09 | 39.6        | **0.18** | 42.0        | -0.07 | 47.2        | 0.09  |
| Gdynia        | 169.8     | -0.62 | 37.9        | -0.07 | 38.8        | **0.21** | 44.1        | -0.08 | 48.8        | 0.02  |
| Gdansk        | 166.7     | **0.53** | 37.0  | 0.13 | 39.0        | **0.25** | 43.9        | -0.02 | 46.8        | **0.20** |
| Elblag        | 176.9     | 0.01  | 38.8        | 0.05  | 41.4        | **0.22** | 46.0        | 0.01  | 50.2        | 0.15  |
| Olsztyn       | 175.4     | -0.03 | 39.7        | -0.04 | 41.6        | 0.13  | 43.5        | -0.09 | 50.5        | -0.02 |
| Gorzow Wlkp   | 168.9     | -0.15 | 39.2        | -0.13 | 38.9        | 0.04  | 42.1        | -0.08 | 48.7        | 0.06  |
| Zielona Gora  | 173.7     | **-0.35** | 39.6  | **-0.14** | 39.9        | 0.06  | 42.9        | **-0.16** | 51.3        | -0.12 |
| Poznan        | 159.2     | -0.25 | 36.3        | -0.10 | 38.1        | 0.07  | 38.5        | -0.16 | 46.3        | -0.04 |
| Torun         | 165.3     | -0.24 | 37.4        | -0.06 | 39.5        | 0.09  | 40.9        | **-0.18** | 47.5        | -0.09 |
| Plock         | 163.4     | -0.13 | 38.1        | -0.05 | 38.9        | 0.01  | 39.6        | -0.09 | 46.8        | 0.04  |
| Bialystok     | 168.4     | -0.19 | 38.5        | -0.05 | 39.9        | 0.09  | 41.4        | -0.11 | 48.4        | -0.12 |
| Warszawa      | 158.6     | -0.25 | 37.3        | -0.08 | 36.9        | 0.02  | 38.2        | **-0.17** | 46.0        | -0.02 |
| Kalisz        | 154.9     | -0.06 | 35.8        | -0.01 | 38.1        | 0.05  | 37.0        | -0.08 | 44.0        | -0.01 |
| Lodz          | 170.4     | -0.29 | 39.9        | -0.10 | 40.0        | -0.02 | 40.8        | **-0.13** | 49.6        | -0.04 |
| Legnica       | 159.8     | -0.03 | 38.8        | -0.08 | 39.1        | 0.07  | 37.8        | -0.01 | 44.2        | 0.00  |
| Wroclaw       | 157.9     | -0.01 | 37.6        | -0.03 | 38.9        | 0.06  | 37.6        | -0.09 | 43.6        | 0.04  |
| Opole         | 166.1     | -0.50 | 39.6        | -0.09 | 40.8        | **-0.16** | 39.5        | **-0.16** | 46.3        | -0.07 |
| Katowice      | 179.2     | -0.34 | 43.0        | -0.11 | 42.8        | -0.05 | 41.9        | -0.13 | 51.5        | -0.02 |
| Bielsko-Biala | 183.2     | -0.15 | 46.7        | -0.03 | 46.0        | -0.11 | 42.0        | -0.02 | 48.4        | 0.05  |
| Krakow        | 172.1     | -0.02 | 42.3        | 0.00  | 41.9        | -0.05 | 39.7        | -0.02 | 48.1        | 0.07  |
| Kielce        | 178.1     | **-0.41** | 42.5  | **-0.13** | 41.7        | -0.07 | 43.1        | -0.13 | 50.6        | -0.09 |
| Lublin        | 172.3     | -0.31 | 41.9        | -0.04 | 39.5        | -0.05 | 40.6        | -0.10 | 50.1        | -0.10 |
| Tarnow        | 173.8     | -0.11 | 43.2        | 0.03  | 42.7        | -0.08 | 39.5        | -0.06 | 48.2        | 0.01  |
| Rzeszow       | 163.5     | -0.08 | 40.6        | 0.00  | 39.8        | -0.02 | 37.3        | -0.07 | 45.5        | 0.06  |
Table 3. Values of 95% quantile of daily precipitation [mm] at selected stations in Poland calculated for the normal season 1971-2000.

| Station     | 95% quantile | Station     | 95% quantile |
|-------------|--------------|-------------|--------------|
| Szczecin    | 13.70        | Kalisz      | 15.27        |
| Gdynia      | 15.00        | Lodz        | 14.65        |
| Gdansk      | 14.50        | Legnica     | 16.88        |
| Elblag      | 15.90        | Wroclaw     | 16.80        |
| Olsztyn     | 15.21        | Opole       | 16.10        |
| Gorzow Wlkp | 13.70        | Katowice    | 17.77        |
| Zielona Gora| 15.06        | Bielsko-Biala | 22.70       |
| Poznan      | 14.60        | Krakow      | 17.20        |
| Torun       | 15.20        | Kielce      | 15.30        |
| Plock       | 15.30        | Lublin      | 15.70        |
| Bialystok   | 14.80        | Tarnow      | 18.60        |
| Warszawa    | 16.02        | Rzeszow     | 17.36        |

In general, the number of days with precipitation above the 95% quantile does not show statistically significant trends in the analysed period, with two exceptions (Table 4). The existence of statistically significant positive trends was found only in Rzeszow in the autumn (0.03 day yr\(^{-1}\)) and negative trends was found in Plock in the summer (-0.04 day yr\(^{-1}\)). The obtained results are quite convergent with the results obtained by [11].

Table 4. The annual and seasonal mean number of days with extreme precipitation (defined as being above the 95% quantile calculated for the normal season 1971-2000) at selected stations in Poland in the years 1966-2016, and the slope values (day yr\(^{-1}\)) from the fitted regression equations. Statistically significant values are shown in boldface.

| Station     | Year Mean | Trend | Spring Mean | Trend | Summer Mean | Trend | Autumn Mean | Trend | Winter Mean | Trend |
|-------------|-----------|-------|-------------|-------|-------------|-------|-------------|-------|-------------|-------|
| Szczecin    | 5.8       | 0.02  | 1.2         | -0.01 | 2.9         | 0.00  | 1.3         | 0.00  | 0.4         | 0.01  |
| Gdynia      | 5.0       | -0.01 | 0.7         | 0.00  | 2.6         | -0.02 | 1.4         | 0.00  | 0.2         | 0.00  |
| Gdansk      | 5.4       | -0.01 | 0.7         | -0.01 | 3.1         | -0.01 | 1.5         | 0.00  | 0.2         | 0.00  |
| Elblag      | 5.7       | -0.01 | 0.6         | 0.00  | 3.3         | -0.01 | 1.6         | 0.00  | 0.2         | 0.00  |
| Olsztyn     | 6.2       | -0.03 | 0.9         | 0.00  | 3.5         | -0.02 | 1.6         | -0.01 | 0.2         | 0.00  |
| Gorzow Wlkp | 6.0       | 0.02  | 1.1         | 0.02  | 3.1         | 0.00  | 1.2         | 0.00  | 0.5         | 0.00  |
| Zielona Gora| 5.7       | 0.00  | 1.0         | 0.01  | 3.3         | 0.00  | 1.1         | -0.01 | 0.3         | 0.00  |
| Poznan      | 5.3       | 0.01  | 1.1         | 0.01  | 3.1         | 0.02  | 0.9         | -0.02 | 0.2         | 0.01  |
| Torun       | 5.4       | 0.03  | 0.9         | 0.00  | 3.3         | 0.01  | 1.0         | 0.00  | 0.2         | 0.01  |
| Plock       | 5.0       | -0.04 | 0.9         | 0.00  | 3.0         | -0.04 | 0.9         | -0.01 | 0.2         | 0.00  |
| Bialystok   | 6.0       | 0.00  | 1.0         | 0.01  | 3.7         | 0.00  | 1.2         | 0.00  | 0.2         | 0.00  |
| Warszawa    | 4.9       | 0.01  | 0.8         | 0.02  | 2.9         | -0.01 | 1.0         | -0.01 | 0.2         | 0.00  |
| Kalisz      | 4.5       | -0.05 | 0.7         | -0.01 | 2.9         | -0.03 | 0.9         | -0.01 | 0.0         | 0.00  |
| Lodz        | 5.7       | 0.01  | 1.1         | 0.01  | 3.5         | 0.00  | 0.9         | 0.00  | 0.2         | 0.00  |
| Legnica     | 4.4       | -0.01 | 0.7         | -0.01 | 2.9         | 0.01  | 0.7         | -0.01 | 0.1         | 0.00  |
| Wroclaw     | 5.0       | 0.00  | 0.8         | 0.01  | 3.2         | -0.01 | 0.9         | 0.00  | 0.1         | 0.00  |
Table 4 (continued)

| Station     | Year | Spring | Summer | Autumn | Winter |
|-------------|------|--------|--------|--------|--------|
|             | Mean | Trend  | Mean   | Trend  | Mean   | Trend  | Mean   | Trend  | Mean   | Trend  |
| Szczecin    | 21.4 | 0.00   | 17.1   | -0.06  | 36.0   | -0.05  | 17.1   | 0.08   | 4.9    | 0.10   |
| Gdynia      | 20.9 | -0.05  | 12.2   | -0.01  | 34.6   | -0.34  | 18.6   | 0.12   | 3.6    | 0.04   |
| Gdansk      | 22.8 | -0.11  | 13.7   | -0.20  | 38.2   | **-0.31** | 19.5 | 0.03   | 2.9    | 0.03   |
| Elblag      | 19.7 | -0.10  | 9.6    | -0.01  | 34.6   | -0.24  | 18.3   | -0.08  | 3.6    | 0.08   |
| Olsztyn     | 21.9 | -0.02  | 13.2   | 0.01   | 36.1   | -0.11  | 20.2   | -0.11  | 4.4    | 0.18   |
| Gorzow Wlkp| 22.8 | 0.01   | 17.4   | **0.27** | 39.1   | -0.11  | 16.1   | 0.11   | 7.5    | 0.08   |
| Zielona Gora| 22.0 | 0.03   | 16.4   | 0.07   | 38.2   | 0.10   | 16.2   | -0.11  | 3.8    | -0.04  |
| Poznan      | 21.7 | 0.10   | 17.2   | 0.01   | 36.7   | 0.32   | 13.5   | -0.20  | 3.4    | 0.13   |
| Torun       | 23.2 | 0.11   | 15.4   | 0.02   | 38.4   | 0.09   | 17.7   | 0.19   | 3.1    | 0.13   |
| Plock       | 20.5 | -0.14  | 13.6   | -0.10  | 34.4   | -0.27  | 14.9   | -0.11  | 3.2    | 0.05   |
| Bialystok   | 22.1 | 0.06   | 14.0   | 0.22   | 39.4   | -0.01  | 16.1   | -0.03  | 2.4    | 0.00   |
| Warszawa    | 20.9 | 0.03   | 13.4   | 0.18   | 34.3   | -0.05  | 14.9   | -0.05  | 3.5    | 0.05   |
| Kalisz      | 19.3 | -0.17  | 11.4   | -0.16  | 34.2   | -0.14  | 15.0   | -0.17  | 0.3    | -0.01  |
| Lodz        | 22.3 | 0.06   | 17.1   | 0.22   | 38.9   | 0.09   | 14.2   | -0.05  | 2.9    | 0.03   |

The average fraction of precipitation above the 95% quantile in the annual precipitation totals ranks from 19.3% to 24.8% in Kalisz and Bielsko Biala, respectively (Table 5). The highest fraction of precipitation above the 95% quantile in the seasonal precipitation is characteristic for summer (from 34.3% in Kalisz to 39.4% in Bialystok). In the spring, the contribution of extreme precipitation in seasonal precipitation totals ranges from 9.6% to 20.2% in Elblag and Bielsko Biala, respectively. In the autumn, these values change between 13.5% in Poznan to 20.6% in Bielsko Biala, and in winter from 0.3% in Kalisz to 7.5% in Gorzow Wlkp.

The observed trends in this characteristic are not statistically significant, with the exception of the increase of extreme precipitation in the sums of spring fall in Gorzow (0.27% yr⁻¹) and in the autumn season in Tarnów (0.53% yr⁻¹). The decrease in the fraction of precipitation above the 95% quantile in the sums of the summer fall in Gdansk (-0.31% yr⁻¹) is also found (table 5). The obtained results confirm the outcome of an earlier study [12], where the lack of statistically significant temporal trends of this precipitation index had been reported for central Europe.

Table 5. The mean values for the fraction of extreme precipitation (defined as being above the 95% quantile calculated for the normal season 1971-2000) [%] in the annual and seasonal precipitation total at selected stations in Poland in the years 1966-2016, and the slopes of fitted linear regression equations. Statistically significant values are shown in boldface.

| Station     | Year | Spring | Summer | Autumn | Winter |
|-------------|------|--------|--------|--------|--------|
|             | Mean | Trend  | Mean   | Trend  | Mean   | Trend  |
| Szczecin    | 21.4 | 0.00   | 17.1   | -0.06  | 36.0   | -0.05  |
| Gdynia      | 20.9 | -0.05  | 12.2   | -0.01  | 34.6   | -0.34  |
| Gdansk      | 22.8 | -0.11  | 13.7   | -0.20  | 38.2   | **-0.31** |
| Elblag      | 19.7 | -0.10  | 9.6    | -0.01  | 34.6   | -0.24  |
| Olsztyn     | 21.9 | -0.02  | 13.2   | 0.01   | 36.1   | -0.11  |
| Gorzow Wlkp| 22.8 | 0.01   | 17.4   | **0.27** | 39.1   | -0.11  |
| Zielona Gora| 22.0 | 0.03   | 16.4   | 0.07   | 38.2   | 0.10   |
| Poznan      | 21.7 | 0.10   | 17.2   | 0.01   | 36.7   | 0.32   |
| Torun       | 23.2 | 0.11   | 15.4   | 0.02   | 38.4   | 0.09   |
| Plock       | 20.5 | -0.14  | 13.6   | -0.10  | 34.4   | -0.27  |
| Bialystok   | 22.1 | 0.06   | 14.0   | 0.22   | 39.4   | -0.01  |
| Warszawa    | 20.9 | 0.03   | 13.4   | 0.18   | 34.3   | -0.05  |
| Kalisz      | 19.3 | -0.17  | 11.4   | -0.16  | 34.2   | -0.14  |
| Lodz        | 22.3 | 0.06   | 17.1   | 0.22   | 38.9   | 0.09   |
3. Conclusions
Pluvial characteristics variability is not coherent and reveals areas of different change direction during analysed period. In general, the analysis of changes in the basic characteristics of atmospheric precipitation in selected Polish cities with the population above 100,000 inhabitants in the period 1966-2016 confirmed the lack of statistically significant trends, with some outlined earlier in this paper exceptions.

The obtained results should not, however, dampen the vigilance of those responsible for the preparation of the Urban Adaptation Plans, because the increase in air temperature, including extreme temperatures, and increase in the number of heat waves have been observed in Poland since the second half of twentieth century [3, 10]. These trends will increase the demand for water, which, together with the simultaneous increase in evapotranspiration, can lead to increasing water shortages. Adaptation measures aimed at retaining rainwater in cities and increasing its retention are all the more important as the annual average air temperature over Europe is projected to increase by the end of the century (2071-2100) by 4.5° to 5.5° C under RCP4.5 and RCP8.5, respectively. At the same time annual precipitation is generally projected to increase in northern Europe and to decrease in southern Europe [3] and Poland lays on the borders of these two regions.

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