Precipitation in the area of Łódź and the Łódź Voivodeship in the period 1961-2016

Precipitation has been analyzed by many scientists. The main aim of this study is to characterize precipitation against the background of atmospheric circulation in the Łódź Voivodeship and analysis of rainfall incidents on a local scale based on the network of measurement points in the Łódź agglomeration. Previous precipitation analyzes in this area will be extended and updated with the precipitation data from the beginning of the 21st century.

The distribution of average total precipitation in the period 1961-2015 shows their differentiation in the Łódź Province. The average annual total of precipitation in this multiannual period ranges from 550 mm in the north to 650 mm in the south of the study area. The highest precipitation occurs in July and the lowest in January. Precipitation varies considerably from season to season. The highest total occur in summer and are twice as high as in winter, which indicates a continental precipitation regime. Total precipitation in spring are characterized by the lowest spatial differentiation in the Łódź Province. Taking into account the precipitation efficiency (the average total per day with precipitation from all measurement points), it reached the highest values in the summer. Winter is characterized by twice lower values than in summer.

The high frequency of western advection of humid air masses from the Atlantic in the winter is the reason of the highest share of days with precipitation in the Łódź Voivodeship at this season.

The highest values of the 95th percentile occured in summer due to the frequent occurrence of convective rainfall.

Percentage deviation from the average long term annual total precipitation in the Łódź Voivodeship ranged on average from -50% to 50%. Winter was characterized by certain, 2-3-year-long excesses and shortages of precipitation occurring alternately. Percentage deviations from the perennial average in winter, on average, are twice as high as the deviations of the long term average annual total. In spring, the longest period of low precipitation occurred from the beginning of the 1960s to the beginning of the 1990s. A longer period in summer with a deficit of rainfall was recorded from the beginning of 1980s to the beginning of 1990s.
Summer rainfall above the norm occurred from the late 1960s to the early 1980s. In autumn, alternating decade-long excesses and shortages of precipitation were observed.

The standard deviation of precipitation in the Łódź Voivodeship tend to increase from north to south with the highest values in summer. The highest deviation values in summer may be the result of the high frequency of convective precipitation in this season. In winter, in turn, the standard deviation was the lowest, which may be caused by frequent but not very heavy rainfall.

In winter, the lowest variation in the daily total precipitation was recorded in the Łódź Province, in the multiyear period 1961-2015. This is probably due to the high frequency of low intensity precipitation from stratified clouds at this season. In summer, the diversity was the greatest, which may be caused by high frequency of precipitation from the *Cumulonimbus* clouds, which characterized by a high intensity, but a small spatial extent.

In winter and spring in most parts of the Łódź Voivodeship an increase in the annual rainfall was noted, when in summer and autumn the trend was reversed.

In all seasons the highest average daily total precipitation occurred during cyclonal types. Winter was characterized by the highest daily rainfalls during atmospheric circulation type Wc (west cyclonic). In summer, the average daily total precipitation were twice as high as in winter and were characterized by the highest values during the SEc and SWc atmospheric circulation. In all seasons, during the anticyclonal types, the lowest average daily total precipitation occurred with the minimum in the Na type, which was caused by the low humidity of the Arctic air masses flowing in from the north. In the Łódź Voivodeship precipitation is most common during north-west, west and south-west advections, which shows the great influence of the Atlantic Ocean in generating precipitation. The lowest frequency is characteristic of precipitation during advection from the directions: NE, E and SE, depending on the season, the reason being dry continental air masses transferred from the above directions. Precipitation of 1,1-5,0 mm (light rainfall) prevails in the histogram for the frequency of the total precipitation during the year, especially clearly visible during winter and autumn. In summer there is an increase in frequency of moderate (5,1-10,0 mm) and strong (>10,0 mm) rainfall, compared with other seasons, which is caused by an increase in frequency of intense convective rainfall.

The probability of precipitation in the Łódź Voivodeship is the highest during cyclonic circulation in all seasons, which is influenced by the atmospheric fronts and connected with fronts precipitation. In winter, the highest values of the probability of precipitation occurred during types: Wc, NWc, Nc and NEc. In spring, the probability of precipitation was highest
during types Wc and NWc. In summer, the rainfall was most likely to occur during the Ec type. In autumn, the probability of precipitation the highest during the Ec type, and then the highest amounts of precipitation were also obtained. Anticyclonic types were characterized by the lowest probability of precipitation in the Łódź Voivodeship with the minimum during the SEa type in spring, summer and autumn and the Sa type in winter. The influx of dry air masses from Asia Minor is not conducive for precipitation. In winter the highest probability of very light rainfall (0.1-1.0 mm) is visible, with maximum values during advection from the west. In all seasons, the lowest probability is characterized by the moderate (5.1-10.0 mm) and strong (>10.0 mm) precipitation, the highest values of which occur in summer. The greatest correlation between the occurrence of circulation macrotypes (NAO, EA, EA/WR, SCA and POL) with precipitation in the Łódź Voivodeship was recorded in autumn and winter. The SCA and POL macrotypes have the strongest impact on the average precipitation total in the Łódź Voivodeship, the weakest the EA/WR type. Weak correlations prevailed.

On the basis of selected rainfall incidents in the Łódź agglomeration, it was found that the rainfall genesis is the decisive factor that affects the precipitation intensity course. It was shown that the course of the precipitation layer from stratiform clouds was uniform. In the case of *Cumulonimbus* clouds, the course of the precipitation layer was more dynamic and the highest increases in the precipitation layer occurred from 30 to 75% of its duration.

During selected rainfall incidents in the area of Łódź, during the advections from selected directions (NW, W and SW) within 60 minutes, a clear differentiation of the spatial and temporal distribution of the average percentage of rainfall is observed. The highest average percentage of rainfall occurs on the leeward side of the city during the advection from the analyzed directions. During the influx of air masses from the west the highest rainfall intensity is in the eastern part of Łódź during 35-40 minutes of rainfall duration, in the case of advection of air masses from the south-west it is eastern or north-eastern part of the city during 40-45 and 45-50 minutes of rainfall duration, and in the north-west advection southern part of Łódź in 15-20 minutes of rainfall duration.

In the cool half-year during the influx of air masses from the most rainy directions (NW, S and SW) the highest values of the 95th percentile of the daily total precipitation were observed from the western and north-western part of Łódź and NW advection. In the warm half-year, the highest values of the 95th percentile occurred during the SW advections in the western, eastern and southern part of the city. In the peripheral zones of the city, the highest values of the 95th percentile of the daily total precipitation were observed, while in its center its lowest values were usually recorded.
The increase in the average of the annual air temperature in Poland causes a decrease in a frequency of long term rainfall, and consequently the phenomenon of drought has intensified in recent years. At the same time, an intensification of the intensive rainfall is observed, especially in summer. The dynamism of the above phenomena in recent years suggest that it is important to extent the analyzes of precipitation based on data from the beginning of the 21st century, which this work supplements.