

# IDŐJÁRÁS

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## Statistical structure of the homogenized precipitation time series of Hungary

### Part 2: Statistics of days and areas with precipitation in Hungary

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**Abstract**— The database of the present examination is the homogenized and interpolated precipitation time series of Hungary, which is diurnal amounts of precipitation for the 1233 grid cells, covering the area of the country for 1971–2022, in the state of the database in 2023. Firstly, the diurnal amount of precipitation over the area of the country, which is the sum of precipitation that falls in each grid cell over the area of the country has been chosen as a variable to be analyzed. Its annual and monthly characteristics have been analyzed for different independent variables. Secondly, spatial characteristics of the diurnal amount of precipitation, that is its distribution among the grid cells have been examined as well. Based on the above time series, nationwide dry, nationwide rainy, and locally rainy/dry days can be distinguished. In this article, we examine the frequency and precipitation yield of both nationwide, and locally rainy days. Precipitation tendency of an area is measured by the frequency of rainy days on the area and their precipitation yield based on the statistics of rainy days per grid. Our basic goal is to explore the temporal and spatial distribution of rainy days nationwide and locally.

*Key-words:* nationwide rainy days, rainy days and areas

## 1. Introduction

The database of our study comprises the homogenized and interpolated precipitation time series of Hungary, specifically the daily precipitation totals for 1233 grids covering the country from 1971 to 2022, as of 2023 (*HungaroMet*, 2023). As a variable to be analyzed, we chose the daily precipitation falling on the territory of the country, i.e., the sum of the daily precipitation of all grids. We analyze the annual and monthly properties of this precipitation sum in the case of various independent variables. On the other hand, we also examine the properties of the spatial, i.e., grid-by-grid distribution of daily precipitation.

To analyze the temporal structure of different precipitation characteristics, we used the national daily precipitation time series, which consist of the daily precipitation amounts in all grids. Based on this time series, nationwide dry, nationwide rainy, and locally rainy/dry days can be distinguished. On a nationwide dry day, no measurable precipitation falls in any grid, and on a nationwide rainy day, there is precipitation in all of them. On a rainy/dry day, there is at least one grid, but fewer than all, in which measurable precipitation falls. The spatial structure of precipitation characteristics was explored by analyzing the rainy days per grid.

The frequency of 0 mm precipitation per day or grid is a measure of drought. In our previous article (*Tar et al.*, 2025) we analyzed the temporal and spatial statistical structure of nationwide dry and locally dry days.

In this article, we examine the frequency and precipitation yield of nationwide rainy days and rainy (nationwide or locally) days. The precipitation tendency of an area is measured by the frequency of rainy days on the area and their precipitation yield based on the statistics of rainy days per grid. That is, the area unit is 1 grid.

Our basic goal is to explore the temporal and spatial distribution of rainy days nationwide and locally.

## 2. Spatial and temporal statistics of rainy days

A rainy day/grid is defined as a day when/where the amount of precipitation exceeds 0.1 mm per day/grid. Statistical features of rainy grids per day and rainy days per grid have been analyzed in this chapter.

### 2.1. Nationwide rainy days

The days when there is precipitation in each grid that is the number of dry grids is 0 are the *nationwide rainy days*. Their number is 847, namely about half (51.2%) of the number of *nationwide dry days* and 4.5% of the total 18628 days of the studied period. It means that every 22nd day is a nationwide rainy day on average.

Nationwide rainy days are separated by locally rainy days and nationwide dry days. The length of the periods containing such days is between 0 and 171, it is 21 days on average during the studied period in good accordance with the previous estimation. The length of the above-mentioned period is 0 if a nationwide rainy day is followed by a similar day. The length of the intervals is between 0 and 10 days in 45% of the cases. Most of them have a length of 0 days, which is 12% of the total nationwide rainy days. It means that a nationwide rainy day is followed by a locally rainy day or a nationwide dry day with a higher (88%) probability in the time series.

Nationwide rainy days (RDC) provide more than a quarter (26.1%, 9,795,494 mm) of the total amount of precipitation (37,580,312 mm).

Most important statistics of the number of nationwide rainy days per year can be seen in *Table 1*.

*Table 1.* The most important statistics of the number of nationwide rainy days per year

average, days	<sup>1</sup> stand.dev., days	<sup>2</sup> coeff. of var.	median, days	<sup>3</sup> maximum, days	<sup>4</sup> minimum, days	mode, days
16.6	5.04	0.30	16	36	9	18

Legends: <sup>1</sup>: standard deviation; <sup>2</sup>: coefficient of variation; <sup>3</sup>: 2010; <sup>4</sup>: 1973, 1983;

There have been 16.6 nationwide rainy days on average per year during the studied period. Their annual number are between 36 (2010) and 9 (1973, 1983) days, respectively. All of them are between 26 and 9 days, except for the maximum. There is a weak linear trend in their temporal change with about a 1-day increase per 10 years.

Based on the values of the average, the median and the mode, the empirical distribution can be approximated with a normal distribution. It has been confirmed via a classification using 5-day-wide classes (*Fig. 1*). However, this way, there have been only 7 classes. Due to this, the degree of freedom of the  $\chi^2$ -test is 1 (because of contractions), which makes the 0.05 level of acceptance uncertain. It is visible that in 74.5% (38 years) of the studied period, the number of nationwide rainy days has been between 10 and 20 annually (*Fig. 1*).

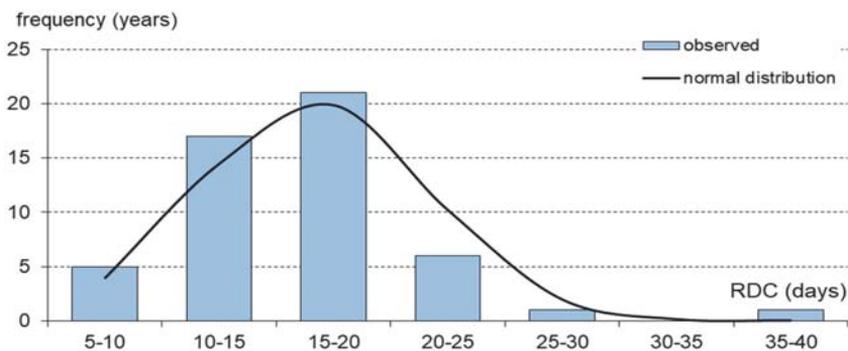


Fig. 1. Distribution of the annual number of nationwide rainy (RDC) days.

Annual precipitation yield of the nationwide rainy days has been examined, as well. The most important statistical characteristics of the precipitation on the 847 nationwide rainy days are presented in Table 2.

Table 2. The most important characteristics of precipitation on nationwide rainy days

<sup>1</sup> average, mm	<sup>2</sup> stand. dev. mm	<sup>3</sup> coeff. of var.	<sup>4</sup> minimum, mm	<sup>5</sup> maximum, mm	median, mm
11,564.9	6,077.5	0.53	1,754.0	38,613.9	10,310.8

Legends: <sup>1</sup>: precipitation per nationwide rainy day; <sup>2</sup>: standard deviation; <sup>3</sup>: coefficient of variation; <sup>4</sup>: December 13, 1998; <sup>5</sup>: May 15, 2010;

According to the table, the average precipitation on the nationwide rainy days (11,564.9 mm) is 5.73 times higher than the average precipitation per day during the total studied period (2,017.4 mm).

The mode can be determined from the frequency distribution of the precipitation (between 1,754 and 38,614 mm) of the nationwide rainy days unequivocally.

The maximum of the distribution (140 days, 16.5% of the total nationwide rainy days) is in the 6,000–8,000 mm interval. Therefore, the mode is about 7,000 mm (Fig. 2).

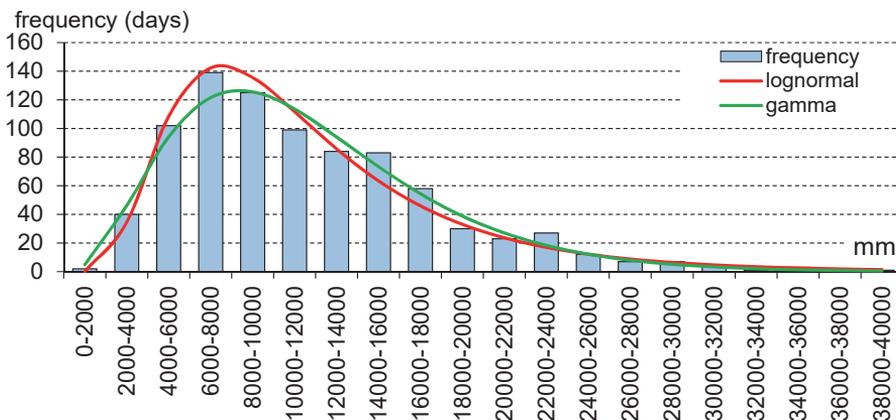


Fig. 2. Frequency distribution and approximation of rainfall on nationwide rainy days with the lognormal and gamma distributions.

The observed frequencies have been approximated with lognormal and gamma distributions. The lognormal distribution fits the empirical frequencies at a 0.05 significance level. Since the gamma distribution is frequently applied in climate statistics, especially in modeling parameters related to precipitation (Dobosi and Felméry, 1971; Dévényi and Gulyás, 1988; Matyasovszki, 2002), an approximation has been made with this distribution, as well. According to the  $\chi^2$ -test, it has provided a better fit than the previous one, but the significance level has not improved.

The relationship between the annual number and annual amount of precipitation of nationwide rainy days has also been studied. Fig. 3 shows a strong linear relationship between these parameters, according to the *Miller-test* (Miller, 1997; Hadnagy, 2020; 2023) at a significance level of 0.01, with a correlation coefficient of  $r=0.8932$ . According to the regression coefficient, a change of 1 day in the number of nationwide rainy days results in a change of 12,036 mm in the precipitation of these days, on average. Based on the determination coefficient, the *number* of nationwide rainy days determines the *amount of rainfall* of these days in 80%.

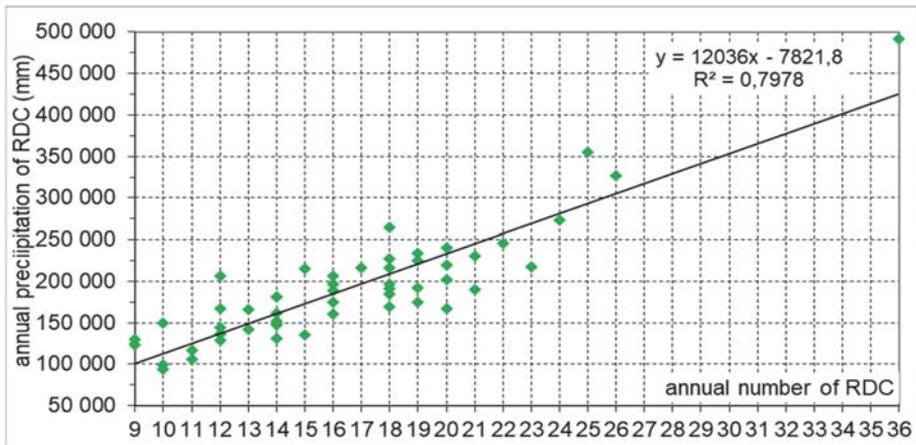


Fig. 3. Linear regression between the annual precipitation of nationwide rainy days and the annual number of such days

The relationships between the annual sums of the precipitation that fell nationwide and the precipitation that fell on rainy days nationwide have been examined also.

According to Fig. 4, the highest amount of precipitation fell in 2010 with 1,205,816 mm over the area of the country which is 3.2% of the total precipitation of the 51 years of the studied period. However, the absolute minimum of annual precipitation occurred in the next year with 515,299 mm (1.4%). Close to this, the precipitation in 2000 was 519,498 mm which can be considered as 1.4% as well. The maximum and minimum of the *precipitation of the nationwide rainy days* occurred in 2010 and 2011 also. Annual precipitation of the nationwide rainy days in 1981 and 2002 are close to the minimum. The ratio of the precipitation of nationwide rainy days compared to the annual precipitation is the second and third lowest as well in those years with 14.1% and 15.5%, respectively. The highest percentage occurred in 2010 too with 40.8%, but there are values close to it in the 2000's with 38.1% in 2016, 39.0% in 2000, and 39.5% in 2005. 26% of the annual precipitation fell on the nationwide rainy days on average during the studied period.

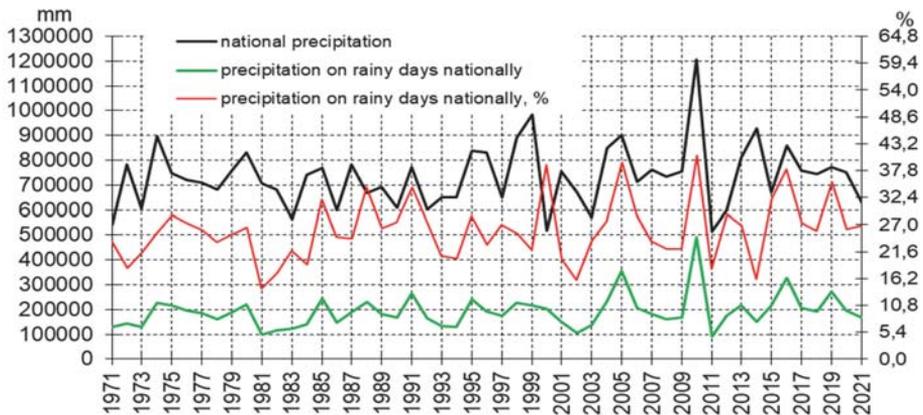


Fig. 4. The annual sums of the precipitation that fell nationwide and the precipitation that fell on rainy days nationwide, as well as the % values of the latter.

It has been examined also, whether the amount of precipitation or the number of nationwide rainy days has a stronger impact on the annual amount of precipitation. According to the linear regression between the annual amount of precipitation and the number and precipitation of nationwide rainy days, the correlation coefficients are  $r=0.7231$  for the precipitation and  $r=0.5880$  for the days. According to the *Miller-test* cited, both correlation coefficients are significantly different from 0. Their determination coefficients are 52% and 35%, respectively. Because of the strong relationship between the two variables (see Fig. 4), it cannot be stated that they determine the annual national amount of precipitation together in 87% anyway.

The “days” curve in Fig. 5 shows the monthly distribution of the number (847) of rainy days nationwide. It is visible, that nationwide precipitation has the highest probability in November followed by October, May, September, and December. Nationwide precipitation has the lowest probability in July. Seasonally, the ratio of nationwide rainy days is the following: *autumn*, 31.3%, *winter*, 26.2%, *spring*, 22.6%, *summer*, 19.8%. The second curve (*precipitation*) shows the annual trend of the amount of precipitation in % of all such daily precipitation amounts (9,795,494 mm). The similarity between the two curves proves the strong relationship that the monthly amount of precipitation of nationwide rainy days is determined by both the intensity of the precipitation and the number of such days. The determination coefficient is 65%.

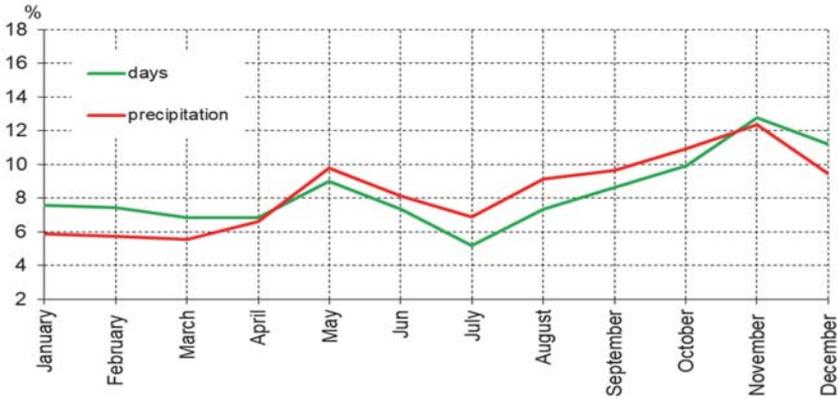


Fig. 5. The monthly distribution of rainy days nationwide (*days*) and the annual trend of the amount of precipitation in % of all such daily precipitation amounts (*precipitation*).

Fig. 6 shows the annual trend of the monthly number of nationwide rainy days (%1) as a percentage of the total number of months of the studied period (51\*31, 51\*30, ...). The absolute minimum is in July, when the relative frequency of nationwide rainy days is 3%. There are two local maxima in May with 5% and in November with 7%. The latter is the absolute maximum: the most nationwide rainy days occur in that month in Hungary.

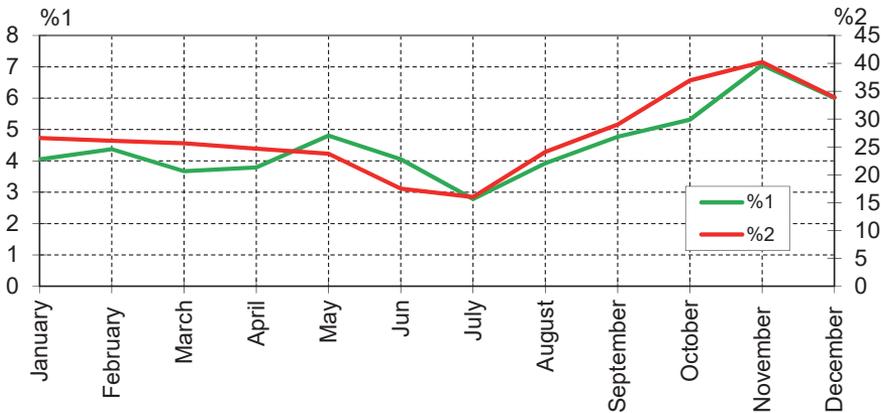


Fig. 6. Annual trend of the monthly number of nationwide rainy days (%1) and monthly precipitation (%2) nationwide.

The second curve in the figure (%2) shows the annual trend of the monthly precipitation nationwide as a percentage of the monthly precipitation amounts,

namely, it shows how the precipitation of the nationwide rainy days is related to the total monthly amount of precipitation. There are only two extremities of the curve now in harmony with the maximum and minimum of the first curve. According to this, the precipitation of the nationwide rainy days provides 16% and 40% of the total monthly precipitation in June and November, respectively.

## 2.2. Rainy days

The days when the national daily precipitation is not 0, namely it is more than 0.1 mm in one grid cell at least, are *rainy days*. The number of these days is 16,983 (all days are nationwide dry days numbers), 5% (847 days) of them are the nationwide rainy days. Rainy days (including nationwide rainy days), according to this definition, involve 91.2% of all days. Therefore, it is the probability of precipitation anywhere over the country during a day with a good approximation.

Most important statistical characteristics of the national daily precipitation (in all grids) of rainy days during the studied period are presented in *Table 3*. The average precipitation amount on rainy days is 2,203.5 mm/day, which is approximately 190 mm higher than the national average for the period, including nationwide dry days, too (*Tar et al., 2025*).

*Table 3.* Characteristics of the nationwide daily precipitation (in all grids) in the sample of rainy days

average, mm	<sup>1</sup> stand. dev., mm	<sup>2</sup> coeff. of var.	minimum, mm	maximum, mm	median, mm	mode, mm
2,203.5	3,820.2	1.73	0.1	3,8 613	524.7	0.28

Legends: <sup>1</sup>: standard deviation; <sup>2</sup>: coefficient of variation;

There is no significant difference between the variation coefficients, supposedly; while there is a significant difference between the values of the median and the mode, probably.

Based on the distribution of the sample, 92.4% of the precipitation amounts of rainy days are between 0.1 and 8,000 mm. Almost 50% of them fall in the 0.1–500 mm interval. In this interval, the highest frequency is between 0.1 and 100 mm (33.5%), and 14.5% is between 0.1 and 10 mm. In the latest interval, the maximum is in the 0.1-1 mm class, that is, the mode is in that interval.

The *annual number of rainy days* is alternating between 355 (1999, 2014) and 305 (1992). It is 333 days, on average. The standard deviation is 10.9 days, so the variation coefficient is 0.03, which is the lowest value among the parameters examined so far. It means that this characteristic is highly stable. The median is 332 days, while the mode is 330 days. It means that it is reasonable to approximate the distribution of the sample with the normal distribution.

Fig. 7 shows the observed and approximated frequencies. The approximation is very good according to the  $\chi^2$ -test; although it is uncertain because of the unification of classes, which was necessary to make the test executable.

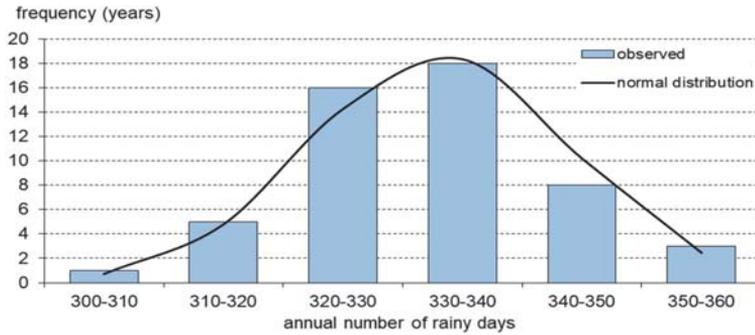


Fig. 7. Empirical distribution of annual rainy days and approximation to the normal distribution

Fig. 8 shows the linear stochastic relationship between the annual national precipitation sum (APA) and the number of rainy days (RDC), per year. As both variables have normal distribution, the significant difference of the correlation coefficient from 0 can be determined using the *t*-test (Vincze, 1975). According to the test, the  $r=0.4118$  correlation coefficient differs from 0 at a significance level of 0.01. This way, the two variables are considered as weakly correlated. Based on the determination coefficient ( $r^2$ ), the annual number of rainy days determines the annual national precipitation sum in about 17% only. It is determined by other factors, mainly the intensity of the precipitation in 83%. Based on the regression coefficient, a 1-day change in the number of rainy days.

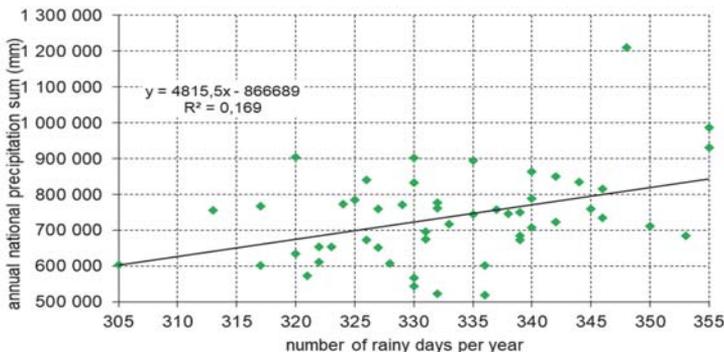
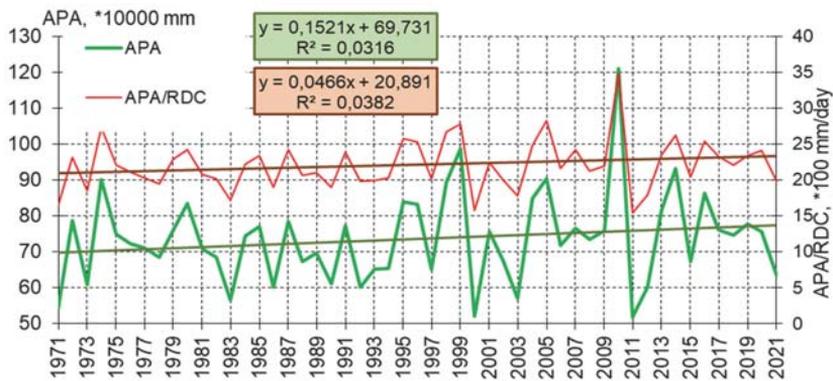


Fig. 8. Linear regression of the annual national precipitation sum (APA) and the number of rainy days (RDC) per year.

The annual precipitation intensities (APA/RDC), namely, the amount of precipitation of a rainy day (mm/day) have been calculated as well. It is between 1,541.9 (2011) and 3,475.9 (2010) mm/day. It is 2,210.2 mm/day on average and its standard deviation is 354,3 mm/day. Therefore, the variation coefficient is 0.16. The median is 2,200.9 mm/day, and the value of the mode is 2,300 estimated from the distribution. The conditions required for approximation using the normal distribution are given this way. Since both original variables have a normal distribution, the parameter derived from them can be considered as having a normal distribution as well without testing.

The times of the extreme values of the annual intensities are in coincidence with the minimum and maximum of the annual precipitation sums. The temporal pattern of APA/RDC is in harmony with the trend of APA; the trend lines are parallel, as it can be seen in *Fig. 9*.



*Fig. 9.* Time change of the annual precipitation amount (APA) and the annual precipitation intensity (APA/RDC)

The annual trend of rainy days, namely the distribution of their number per month, is presented in *Fig. 10*.

The first curve (%) shows the annual trend of the number of rainy days per month compared to the total number of rainy days (16,983). This data, with a standard deviation of 1.7%, gives the probability of having precipitation anywhere over the country (in any grid cells) on any days of a given month. This probability is around 9% in January and December, followed by May, June, and July with 8.5%. This probability is the lowest in September with 7.4% and February with 7.8%. Seasonal data are: winter: 25.8%, summer: 25.0%, spring: 24.8%, and autumn: 24.3%, respectively.

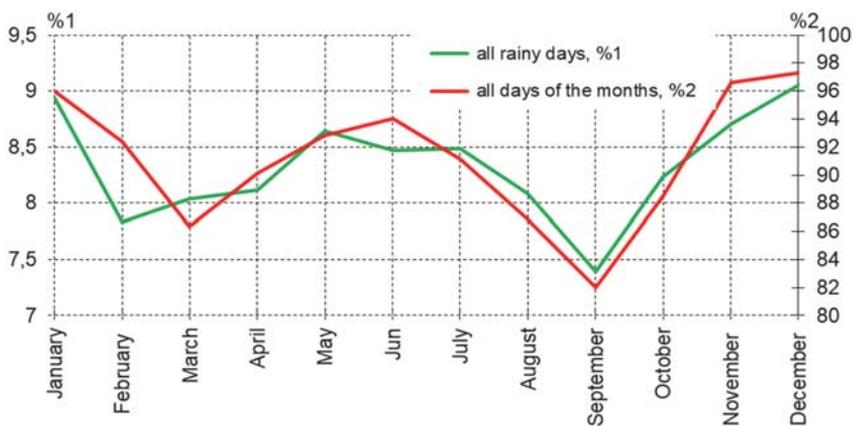


Fig. 10.

Annual trend of the number of rainy days per month as a percentage of all rainy days (%1) and of all days of the months included in the processing (%2)

There is no constant base of reference in the case of the second curve (%2) in Fig. 10, since the number of rainy days per month is given as a percentage of all days of the months included in the processing (51\*31, 51\*30,...). Therefore, the numbers show the percentage of rainy days somewhere/anywhere in the country within a month. These ratios are over 90% in November, December, January, and February (namely, in the late autumn and winter), and in April, May, June, and July, respectively. Consequently, there is a high probability of precipitation anywhere in the country on almost all days of these months. The occurrence of the studied phenomenon has a probability of less than 90% in the early spring, late summer, and early autumn, with a minimum of 82% in September.

### 2.3. The most important statistical characteristics of rainy days per grid cell

The spatial pattern of precipitation can be analyzed by studying the sum of rainy days per grid cell. The sum of rainy days per grid cell (the number of rainy grids) is 10,916,603, which is 47.5% of the total number of cases (22,968,324). 9.6% of the rainy grid cells are the grid cells of the nationwide rainy grids (847\*1,233=1,044,351). The most important statistical characteristics of the sum of rainy days per grid ( $DWP_g$ ) and their average number per year ( $DWP_g/year$ ) are given in Table 4.

There are 8,854 rainy days per grid cell on average, which is 0.08% of the number of all rainy grid cells (the number of rainy days in all grid cells is 10,916,603). The variation coefficient supports the relative stability of this

variable around the average. The number of values over and under the average are 640 (51.9%) and 592 (48.1%), respectively.

*Table 4.* The most important statistical characteristics of the sum of rainy days per grid ( $DWP_g$ ) and their average number per year ( $DWP_g/year$ )

<b>statistical characteristics</b>	<b><math>DWP_g</math></b>	<b><math>DWP_g/year</math></b>
average, days	8,854	174
<sup>1</sup> stand. dev., days	531	10
<sup>2</sup> coeff. of var.	0.06	0.06
<sup>3</sup> minimum, days	5,473	107
<sup>4</sup> maximum, days	10,142	199
median, days	8,878	174
mode, days	8,891	174

Legends: <sup>1</sup>: standard deviation; <sup>2</sup>: coefficient of variation;

<sup>3</sup>( $\varphi = 47.5$ ;  $\lambda = 16.8$ ); <sup>4</sup>( $\varphi = 47.8$ ;  $\lambda = 21.8$ ), ( $\varphi = 47.8$ ;  $\lambda = 21.9$ );

The spatial distribution of *rainy days* per grid cell is between 10,142 and 5,473 during the studied period. The increasing order of  $DWP_g$  values shows that the higher values are concentrated between the 20.8°E and 22.1°E longitudes and the 47.8°N and 48.4°N latitudes. This is more or less the same area that has been identified in our previous paper (*Tar et al., 2025*), since dry ( $DNP_g$ ) and rainy ( $DWP_g$ ) days per grid are complementary to each other. There is no such geographical concentration identified in the case of the lower values at the beginning of the line. The minimum with 29.4% occurs in the western part of the country, which is followed by a grid in the east with 29.7%.

The dry ( $DNP_g$ ) and rainy ( $DWP_g$ ) days per grid are complementary to each other, so their sum is the total number of days of the studied period (18,628). In the case of annual averages, it is  $DNP_g/year + DWP_g/year = 365$  or 366, that is the number of days in a year. From this, according to the comments made in connection with *Fig. 8*, it follows that was described in the distribution analysis of the number of dry days per year ( $DNP_g/year$ , *Tar et al., 2025*), which also applies to the  $DWP_g/year$  characteristics. Therefore, the empirical frequencies cannot be acceptably approximated by the possible theoretical distributions.

The relationship between the annual average of rainy days per grid ( $DWP_g/year$ ) and the geographical coordinates of the grid cells ( $\varphi$ ,  $\lambda$ ) has also been examined using linear regression. Because of the above-mentioned relationships between the  $DNP_g/year$  and  $DWP_g/year$  characteristics and the statements in *Tar et al. (2025)*, correlation coefficients differ significantly from 0, again. Therefore, the statements regarding *dry days* are also true for this case, considering the change in the sign of the correlation and regression coefficients. Based on the realistic stochastic relationship, we prepared the complement of

DNP<sub>g</sub>/year (Tar et al., 2025), a map showing the distribution of the annual average of rainy days per grid (DWP<sub>g</sub>/year) during the examined period (see Fig. 11).

The map of the spatial distribution of the annual average of rainy days per grid is the inverse of the map of the annual average of dry days per grid. According to this, the annual averages of rainy days per grid are the highest in the northeastern part of the country in the Nyírség, and the Hajdúság regions. Minima occur sporadically within the Hungarian Small Plain over the Hanság and the Rábaköz regions.

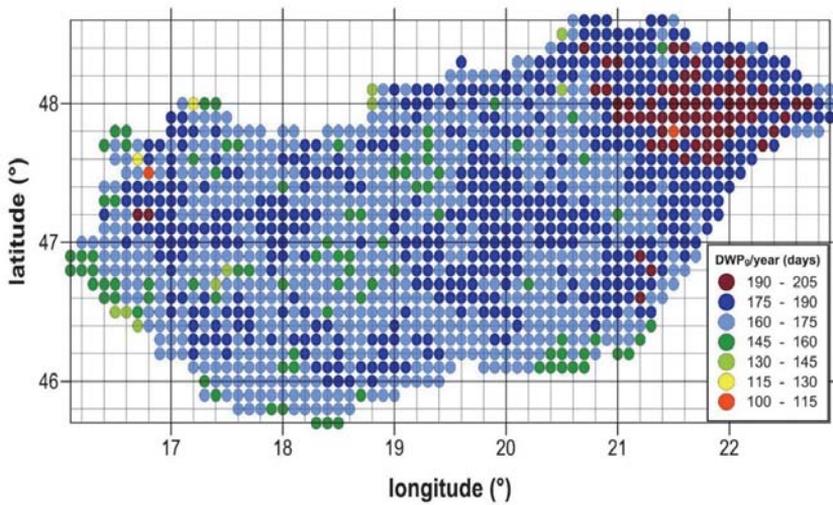


Fig. 11. Distribution of the annual average of rainy days per grid (DWP<sub>g</sub>/year) in the examined period.

#### 2.4. Statistics of the amount of precipitation per grid

The most important characteristics of the amount of precipitation per grid (APR<sub>g</sub>) and its annual average (APR<sub>g</sub>/year) during the studied period are shown in Table 5. The two coefficients of variation are equal trivially, which proves the relatively high stability of the measure of standard deviation around the average. Supposedly, there are some concentration points in the distribution of both datasets around some values. Values of the mode have been estimated from the distributions.

Table 5. The most important characteristics of the amount of precipitation per grid (APR<sub>g</sub>) and its annual average (APR<sub>g</sub>/year)

statistical characteristics	APR <sub>g</sub>	APR <sub>g</sub> /year
average, mm	30,478.8	597.6
<sup>1</sup> stand. dev., mm	3,292.6	64.6
<sup>2</sup> coeff. of var.	0.11	0.11
<sup>3</sup> minimum, mm	26,127.1	512,3
<sup>4</sup> maximum, mm	42,352.5	830,4
median, mm	29,456.4	577,6
<sup>5</sup> mode, mm	28,500.0	570.0

Legends: <sup>1</sup>: standard deviation; <sup>2</sup>: coefficient of variation;

<sup>3</sup>: ( $\varphi = 47.1$ ;  $\lambda = 20.3$ ); <sup>4</sup>: ( $\varphi = 48.1$ ;  $\lambda = 20.5$ ); <sup>5</sup>: from distribution

Frequency distribution of both data sets has been determined. Applying 1,000 mm classes for APR<sub>g</sub>, 46.7% of the values have been between 27,000 and 30,000 mm. The maximal frequency is 212 grid cells, and 17.2% of which falls into the 28,000-29,000 mm class; this way the mode is 28,500 mm. 20 mm classes have been applied in the case of the annual average of the precipitation amount per grid (Fig. 12). APR<sub>g</sub>/year values fall into the 520 and 600 mm class in 60.3% of the grid cells. The maximal frequency is 213 grid cells, and 17.3% of which is in the 560-580 mm class; so the mode is 570 mm. The coincidence of the latter with the previous results is due to the application of appropriate classes. Attempts have been made to approximate both distributions with the theoretical distributions used previously. Unfortunately, all these attempts have failed.

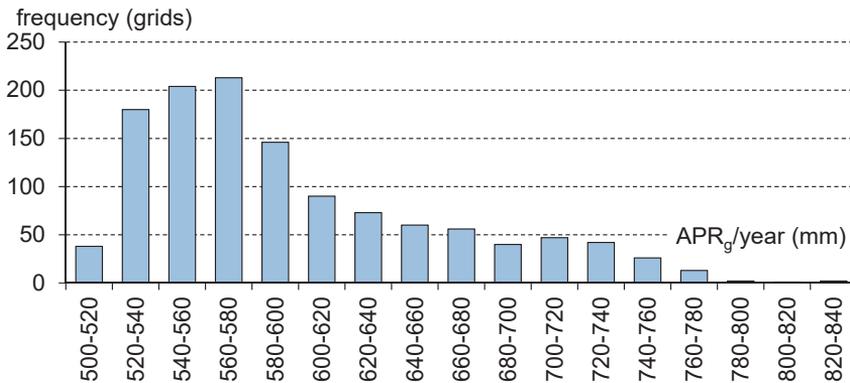


Fig. 12. Distribution of the annual average of precipitation per grid (APR<sub>g</sub>/year).

A detailed analysis of the distribution of the annual average precipitation per grid cell has been presented, as follows.

Adding the 500–520 mm class to the former four classes of between 520–600 mm and modifying the upper limit of the fourth to 597.6 mm, the number of grid cells, which have an average *annual precipitation amount, that is lower* than the nationwide average, can be determined. Their number is 765, which is 62% of all grids (namely, 62% of the total area of Hungary). 28,335.8 mm per grid on average, that is 57.7% of the total precipitation of the studied period has fallen in these five categories, which involves nearly the two-thirds of all grid cells. The annual mean precipitation (the average of  $APR_g/year$ ) is 555.6 mm in these grid cells. The geographic coordinates of these grid cells are  $\lambda=16.6^\circ E - 22.5^\circ E$  and  $\varphi=45.9^\circ N - 48.6^\circ N$ , that is, they are dispersed over almost the total area of the country. The distribution of the grid cells according to  $\lambda$  is wider, since the grids involved are spaced over 60 from the possible 69 lines of longitude, while, according to  $\varphi$ , they are spaced over 27 lines from the possible 30.

The *average annual precipitation amount is higher* than the nationwide average in the remaining 468 grid cells, which is 38% of the country's area. 3,3981.7 mm per grid on average, that is 42.3% of the total precipitation of the studied period has fallen into these grid cells. The average of  $APR_g/year$  is 666.3 mm in this case. The geographic coordinates of these grid cells are spaced in a wider line of longitude interval than the former ones: they are spaced  $\lambda=16.1^\circ - 22.9^\circ$  and  $\varphi=45.7^\circ - 48.6^\circ$ . The distribution of the grid cells according to  $\lambda$  covers an even wider interval, as they are spaced over 63 lines of longitude, while their distribution according to  $\varphi$  is spaced over 27 of the possible 30 again.

The following examination has been carried out to study the spatial pattern of the above-defined 765 and 468 grid cells.

Considering the *distribution according to  $\lambda$*  in the case of the  $APR_g/year \leq 597.6$  mm, there are 765 grid cells spaced over 60 lines of longitude, namely 12.85 grid cells per line of longitude on average. This value is presented in *Fig. 13 part a*, beside the values given for the lines of longitude. Values higher or equal to this, occur between  $18.6^\circ E$  and  $21.9^\circ E$ , namely, between the meridians that cross the northeastern corner of the Lake Velence and the town of Nagykálló. The 468 grid cells, where the average annual precipitation amount is higher than the nationwide average, are spaced over 63 lines of longitude, which means 7.4 grid cells per line (6 lines where there are no such grids are not involved in the average). According to *Fig. 13 a*, the grid cells with high precipitation amounts are concentrated along the lines of longitude that cross the Kőszegi Mountains, the towns of Szekszárd and Dunaújváros between the lines of  $16.4^\circ E$  and  $18.6^\circ E$  longitudes, respectively.

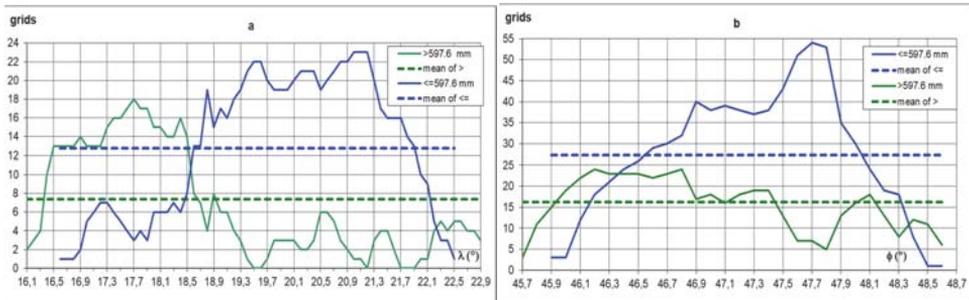


Fig. 13. Distribution of grids having an average annual precipitation amount that is lower or higher than the national average (597.6 mm), according to longitude (a:  $\lambda$ ) and latitude (b:  $\phi$ ).

In the case of the *distribution according to  $\phi$* , the 765 grid cells where the annual mean precipitation is under the nationwide average, are spaced over 28 lines of latitude, and the average is 27.3 grid cells per line. Values equal or higher than this are spaced between the 46.6°N and 48°N latitudes that is about between the lines of Lenti – Paks – Békéscsaba and Pétervására – Tiszalök – Baktalórántháza, according to Fig. 13 b. In the case of CSMg/year > 597.6 mm, 468 grid cells are spaced over 30 lines of latitude; namely, 15.6 grid cells per line of latitude. Based on Fig. 13 b, values higher than this are spaced between 45.9°N and 47.4°N, and 48°N and 48.1°N, which is between the lines that of Mohács - Kőszeg, and Budapest - Debrecen, respectively.

The results of the analyses above have been summarized in Fig. 14, which shows the spatial pattern of annual mean precipitation. The annual average of the rainfall per grid has a basically meridional-zonal distribution due to the strengthening continental effect from the west to the east on one hand, and the orographic effect on the other. The rainiest areas in southwest Transdanubia, the Central Transdanubian Mountains, Alpokalja, Mecsek, and the Bakony Mountains – where the Mediterranean effect is significant – get nearly twice as much precipitation than the Central Great Hungarian Plain, such as the regions of Jászság, Hortobágy, Nagyunság, and the plain between the Maros and Körös Rivers, and partly the Kiskunság. Due to the orographic effect, the amount of precipitation is over the nationwide average in the Transdanubian low mountains, the highest parts of the North Hungarian Mountains: Börzsöny, Mátra, Bükk, and Zemplén, and the Szatmár–Bereg Plain (due to the orographic effect of the northeastern Carpathians in the case of this latter one).

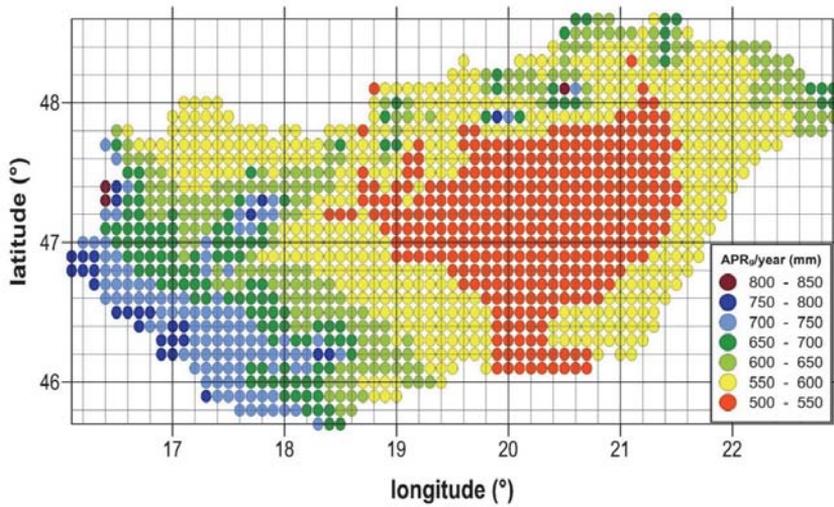


Fig. 14. Distribution of the annual average of the rainfall per grid ( $APR_g/year$ , mm) in the examined period

Values of the precipitation intensity per grid ( $IPR_g = APR_g / DWP_g$  given in mm/day) have been determined as well. Its most important statistical characteristics have been presented in Table 6.

Table 6. The most important statistical characteristics of the precipitation intensity per grid ( $APR_g / DWP_g$ )

average mm/day	<sup>1</sup> stand. dev., mm/day	<sup>2</sup> coeff. of var.	<sup>3</sup> minimum, mm/day	<sup>4</sup> maximum, mm/day	median, mm/day	<sup>5</sup> mode, mm/day
3.46	0.48	0.14	2.72	5.92	3.34	3.2

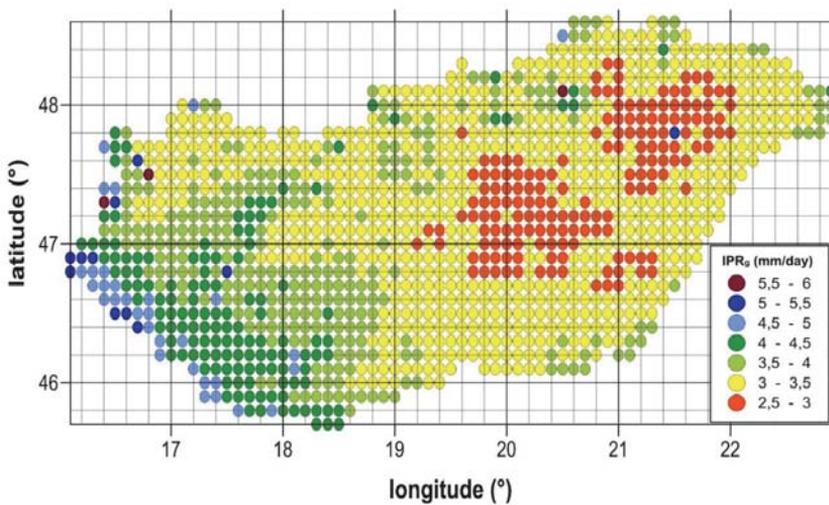
Legends: <sup>1</sup>: standard deviation; <sup>2</sup>: coefficient of variation; <sup>3</sup>: ( $\varphi = 47.1$ ;  $\lambda = 20.3$ );  
<sup>4</sup>: ( $\varphi = 48.1$ ;  $\lambda = 20.5$ ); <sup>5</sup>: from distribution

The location of the minimum and maximum of precipitation intensity per grid is in coincidence with the coordinates of the extreme values of rainy days per grid ( $DWP_g$ ), namely, this parameter has a stronger impact on it. The minimum is where the maximum  $DWP_g$  is, while the maximum is located where this parameter reaches its minimum. The spatial pattern is like that of dry days per grid ( $DNP_g$ ). These values have no direct relationship to the spatial pattern of  $DWP_g$ .

Linear correlation coefficients between the precipitation intensities per grid and the geographic coordinates ( $\varphi, \lambda$ ) of the grid cells can be considered

significant, since it is valid for both components ( $APR_g$  and  $DWP_g$ ). Now the correlation coefficients are  $r_\lambda = -0.6374$ , and  $r_\varphi = -0.3468$ . For  $DNP_g$ , the correlation coefficients are  $r_\lambda = -0.4308$ , and  $r_\varphi = -0.3357$ . Dependence on the longitude is stronger in both cases and stronger in the case of  $APR_g/DWP_g$  than for  $DNP_g$ . However, according to the regression coefficients of the precipitation intensity per grid ( $-0.1862$  and  $-0.2452$ ), changes in the latitude cause larger differences in the precipitation intensity per grid than changes in the longitude.

On the basis of the latter results, the map of spatial distribution of precipitation intensity per grid ( $IPR_g$ , mm/day) during the studied period has been compiled. The map is shown in *Fig. 15*.



*Fig. 15.* Spatial distribution of precipitation intensity per grids ( $IPR_g$ , mm/day) during the examined period.

Similarly to annual precipitation amounts, higher values can be found along the Dráva River and over the regions of the Central Transdanubian Mountains, the Alpokalja, and the highest areas of the Northern Central Mountains. Lowest values are concentrated in the central part of the Great Hungarian Plain over the regions of Jászság, Nagykunság, Hortobágy, Hajdúság, and Nyírség.

### ***3. Discussion and conclusions***

The database of the present study is the homogenized and interpolated precipitation time series of Hungary, namely diurnal precipitation data from the 1233 grid cells that cover the area of Hungary for the 1971–2022 period. The diurnal amount of nationwide precipitation, namely the sum of diurnal precipitation in all grid cells, has

been chosen as the studied variable. Firstly, the annual and monthly characteristics of this variable have been analyzed in the case of different independent variables. Secondly, spatial patterns of precipitation, or otherwise their distribution per grid cell has been analyzed as well. In our previous article (Tar et al., 2025), we analyzed the statistical structure of dry days and areas. We considered a day as dry when there was no measurable precipitation (greater than 0.1 mm). The dryness of an area was measured by the frequency of dry days there.

In this article, we explored the statistical structure of rainy days in four levels.

The days, when there is precipitation in each grid, namely the number of dry grids is 0, are the *nationwide rainy days*. Their number is 847, namely about half of the *nationwide dry days* and 4.5% of the total days of the studied period. It means that every 22nd day is a nationwide rainy day on average.

Nationwide rainy days are separated by locally rainy days and nationwide dry days. The length of the periods containing such days is between 0 and 171; it is 21 days on average during the studied period, in good accordance with the previous estimation. The length of the period is 0 if a nationwide rainy day is followed by a similar day. The length of the intervals is between 0 and 10 days in 45% of the cases. Most of them have a length of 0 day, which is 12% of the total nationwide rainy days. It means that a nationwide rainy day is followed by a locally rainy day or a nationwide dry day with a higher (88%) probability in the time series.

There have been 16.6 nationwide rainy days on annual average during the studied period. Their annual number are between 36 (2010) and 9 (1973, 1983), all of them are between 26 and 9, except for the maximum. There is a weak linear trend in their temporal change with about a 1-day increase per 10 years.

The average precipitation on the nationwide rainy days is 5.73 times higher than the average precipitation per day during the total studied period. The observed frequencies have been approximated with lognormal and gamma distributions. The lognormal distribution fits the empirical frequencies at a significance level of 0.05. Since the gamma distribution is frequently applied in climate statistics, especially in modeling parameters related to precipitation, an approximation has been made with this distribution, as well. According to the  $\chi^2$  test, it has provided a better fit than the previous one, but the significance level has not improved.

The relationship between the annual number and annual amount of precipitation of nationwide rainy days has also been studied. A strong linear relationship has been found according to the test applied at a significance level of 0.01 with a correlation coefficient of  $r=0.8932$ . According to the regression coefficient, a change of 1 day in the number of nationwide rainy days results in a change of 12,036 mm in the precipitation of these days on average. Based on the determination coefficient, the *number* of nationwide rainy days determines the *amount of rainfall* on these days in 80%.

The annual sums of the precipitation that fell nationwide and the precipitation that fell on rainy days nationwide has also been compared. The highest amount of precipitation fell in 2010 with 1,205,816 mm *over the area of*

*the country*, which is 3.2% of the total precipitation of the 51 years of the studied period. However, the absolute minimum of annual precipitation occurred in the next year with 515,299 mm (1.4%). The precipitation in 2000 is close to this with 519,498 mm, which can be considered as 1.4% as well. The maximum and minimum *precipitation of the nationwide rainy days* occurred both in 2010 and 2011. Annual precipitation of the nationwide rainy days in 1981 and 2002 is close to the minimum. The ratio of the precipitation of nationwide rainy days compared to the annual precipitation is the second and third lowest in these years with 14.1% and 15.5%, respectively. The highest percentage occurred in 2010, with 40.8%, but there are values close to it in the 2000's with 38.1% in 2016, 39.0% in 2000, and 39.5% in 2005. 26% of the annual precipitation fell on the nationwide rainy days on average, during the studied period.

The monthly distribution of the number (847) of rainy days nationwide has been studied as well. Nationwide precipitation has the highest probability in November followed by October, May, September, and December. Nationwide precipitation has the lowest probability in July. Seasonally, the decreasing order of the proportion of the ratio of nationwide rainy days is autumn, winter, spring, and summer. The annual course of the number of nationwide rainy days and the amount of precipitation per month is very similar. This shows the clear relationship that the amount of precipitation of monthly nationwide rainy days strongly depends on the number of such days in addition to the intensity of precipitation. However, the coefficient of determination in this case is 65%.

The days when the national daily precipitation is not 0, namely it is more than 0.1 mm in one grid cell at least, are *rainy days*. The number of these days is 16,983 (all days are nationwide dry days), 5% of them are the nationwide rainy days. Rainy days, according to this definition, involve 91.2% of all days. Therefore, it is the probability of precipitation anywhere over the country during a day with a good approximation.

Average precipitation of rainy days is 2,203.5 mm/day, which is approximately 190 mm higher than the average for the whole studied period comprising the nationwide dry days. Based on the distribution of the sample, 92.4% of the precipitation amounts of rainy days are between 0.1 and 8,000 mm. Almost 50% of them fall in the 0.1-500 mm interval. In this interval, the highest frequency is between 0.1 and 100 mm (33.5%), and 14.5% is between 0.1 and 10 mm. In the latest interval, the maximum is in the 0.1-1 mm class, that is, the mode is in that interval.

The annual number of rainy days is alternating between 355 (1999, 2014) and 305 (1992). It is 333 on average. According to the variation coefficient, this characteristic is highly stable. Due to the small differences between the average, the median, and the mode, the approximation with the normal distribution has been successful.

The relationship between the annual national precipitation sum and the *number* of rainy days per year has been proved to be linear according to the *t*-test. According

to the test, the  $r=0.4118$  correlation coefficient differs from 0 at a significance level of 0.01. This way, the two variables are considered as weakly correlated. Based on the determination coefficient ( $r^2$ ), the annual number of rainy days determines the annual national precipitation sum in about 17% only. This parameter is determined by other factors, mainly the intensity of the precipitation, in 83%. Based on the regression coefficient, a 1-day change in the number of rainy days results in a 4,811 mm change in the annual mean nationwide precipitation amount.

Annual precipitation intensity, namely the amount of precipitation of a rainy day (mm/day), has also been calculated. Its value is between 1,541.9 (2011) and 3,475.9 (2010) mm/day. It is 2,210.2 mm/day, on average. Since both original variables have a normal distribution, the parameter derived from them can be considered normally distributed without testing.

The times of the extreme values of the annual intensities are in coincidence with the minimum and maximum of the annual precipitation sums. The temporal pattern of APA/RDC is in harmony with the trend of APA, the trend lines are parallel as in *Fig. 9*.

The ratio of the number of rainy days per month and all rainy days (16,983) gives the probability of having precipitation anywhere over the country (in any grid cells) on any days of a given month. This probability is around 9% in January and December, followed by May, June, and July with ~8.5%. This probability is the lowest in September with 7.4% and February with 7.8%. Seasonal data are as follows: winter: 25.8%, summer: 25.0%, spring: 24.8%, and autumn: 24.3%.

The number of rainy days per month, given as a percentage of all days included in the processing, shows the percentage of rainy days somewhere/anywhere in the country within a month. These ratios are over 90% in November, December, January, and February (namely, in the late autumn and winter), and April, May, June and July, respectively. Consequently, there is a quite high probability of precipitation anywhere in the country on almost all days of these months. The occurrence of the studied phenomenon has a probability of less than 90% in the early spring, late summer, and early autumn, while its minimum is 82% in September.

The spatial pattern of precipitation can be analyzed by studying the sum of rainy days per grid cell. The sum of rainy days per grid cell (the number of rainy grids) is 47.5% of the total number of cases. 9.6% of the rainy grid cells are the cells of the nationwide rainy grids.

The distribution of *rainy days* per grid cells is between 10,142 and 5,473 days, with an average of 8,854 days. Their annual minimum and maximum are 107 and 174 days, respectively.

The linear relationship between the annual average of rainy days per grid and the geographical coordinates of the grid cells has also been examined. Because dry and rainy days per grid cell are complementary to each other, the statements regarding *dry days* are true for this case, also considering the change in the sign of the correlation and regression coefficients. Based on the realistic stochastic

relationship, the map of the distribution of the annual average of rainy days per grid in the examined period has been compiled. The map of the spatial distribution of the annual average of rainy days per grid is the inverse of the map of the annual average of dry days per grid. According to this, the annual averages of rainy days per grid are the highest in the northeastern part of the country. Minima occur sporadically within the Small Hungarian Plain.

The amount of precipitation per grid, the extremities, its annual average, and the variation coefficient during the studied period prove the relatively high stability of this characteristic. Supposedly, the distribution of both datasets contains some concentration points around some values. The value of the mode has been estimated from the distributions.

Details of the distribution of the annual average precipitation per grid have been studied. In 60.3% of the grid cells, its values fall into the 520–600 mm class. The maximal frequency is 213 grid cells, which is 17.3% of the 560–580 mm class, so the mode is 570 mm. The amount of annual average precipitation in Hungary during the studied period was 597.6 mm.

The average annual precipitation amount is higher than the national average in 765 cells, which is 62% of all grids (that is 62% of the total area of Hungary), where 57.7% of the total precipitation of the studied period has fallen. The annual mean precipitation is 555.6 mm in these grid cells. The average annual precipitation amount is higher than the nationwide average in the remaining 468 grid cells, which is 38% of the area of the country. The annual mean precipitation is 666.3 mm in these grid cells. The geographic coordinates of these grids are spaced almost over the total area of Hungary.

Spatial distribution of these grid cells according to longitude and latitude has been examined to trace the concentration of precipitation along certain coordinates, that is, over some regions of Hungary.

We found that those grid cells, where the average annual precipitation amount is lower than the nationwide average, are spaced between the 18.6°E and 21.9°E longitudes. The 468 grid cells, where the average annual precipitation amount is higher than the nationwide average, are spaced west of these grids, between the 16.4°E and 18.6°E longitudes. Regarding the latitude-related distribution, the same intervals are spaced between the 46.6°N and 48°N, and 45.9°N and 47.4°N latitudes, with a much stronger overlap.

The spatial distribution of the annual average of the rainfall per grid cell is governed by the strengthening continental effect from the west to the east on one hand, and the orographic effect on the other. The rainiest areas in southwest Transdanubia get nearly twice as much precipitation as the Central Great Hungarian Plain. Due to the orographic effect, the precipitation amount is over the nationwide average in the highest parts of the Central Transdanubian Mountains and Northern Central Mountains, as well as the Szatmár–Bereg Plain (due to the orographic effect of the northeastern Carpathians, in this latter case).

Precipitation intensity per grid cell have also been determined. Their most important statistical characteristics are as follows: the average is 3.46, the minimum is 2.72, and the maximum is 5.92 mm/day, respectively.

The location of the minimum and maximum is now aligned with the extrema of the number of rainy days per grid. The minimum of the intensity is in the grid where the latter parameter has its maximum, and the maximum is where the latter parameter has its minimum. In other words, the intensity depends more strongly on the number of rainy days. The spatial distribution of intensity, therefore, approaches the spatial distribution of dry days per grid.

Linear correlation coefficients between the precipitation intensity per grid and the geographic coordinates of the grid cells differ from 0, since they are valid for both components. Zonal dependence is stronger than meridional again and stronger than in the case of dry days. However, according to the regression coefficients of the precipitation intensity per grid, changes in the latitude cause larger differences in the precipitation intensity per grid than changes in the longitude. Based on the latter results, the map of the spatial distribution of precipitation intensity per grid during the studied period has been compiled.

Similarly, to the annual precipitation amounts, higher values can be found along the Dráva River and over the regions of the Central Transdanubian Mountains, Alpokalja, and the highest areas of the Northern Central Mountains. At the same time, lowest values are concentrated into the central part of the Great Hungarian Plain, over the regions of Jászság, Nagykunság, Hortobágy, Hajdúság, and Nyírség.

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