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Statistical structure of the homogenized precipitation time series of Hungary

Part 1: Statistics of dry days and areas in Hungary

Károly Tar[1,*], **Sándor Szegedi**[1], **István Hadnagy**[2], **Tamás Tóth**[1]
and **István Lázár**[1]

[1]*University of Debrecen,*
Department of Meteorology,
H-4032 Egyetem tér 1, Debrecen, Hungary

[2]*Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education,*
Department of Biology and Chemistry,
UA-90200 Kossuth Square, 6, Beherove, Ukraine

**Corresponding Author E-mail: tarko47@gmail.com*

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Abstract— An exact statistical description of present and future climate requires a database representative in space and time. However, observation records – that is raw climatological time series – are loaded with inhomogeneities due to changes in the location of the weather stations and usage of different instruments and observation protocols. Datasets must be homogenized first, which means that previous measurement data must be adjusted to the present observation protocols, while missing data must be supplemented. The data base of the present examination is the homogenized precipitation time series of Hungary, that is diurnal amounts of precipitation for the 1233 grid cells which cover the area of the country over the period of 1971-2022 in the state of the database in 2023. Firstly, the diurnal amount of precipitation over the area of the country, that is the sum of precipitation what falls in each cell of the grid 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. In this article, after summarizing the climatic characteristics and the characteristics for the examined period of the total precipitation in Hungary, we analyze the spatial and temporal statistical properties of the daily dry grids and the dry days per grid. Dry days and grid cells are those when and where the daily precipitation amount is under 0.1 mm.

Key-words: nationally dry days, dry days and areas

1. Introduction – General spatial and temporal characteristics of the precipitation in Hungary

The amount of annual mean precipitation ranges between 500 and 800 mm over Hungary during the period between 1991 and 2020 with remarkable spatial differences and year-to-year fluctuations.

The spatial pattern of precipitation is formed by the maritime effect and the relief together (*Fig. 1*). The maximum occurs in the southwestern part of Transdanubia, where the maritime effect is the most emphasized (*Mersich et al.,* 2002, *Kocsis et al.,* 2018, *HungaroMet, 2024d*).

Other regions gaining high annual precipitation over 800 mm are the low-mountain ranges in Transdanubia and Northern Hungary over 700 meters above sea level. The minimum occurs over the low-lying central part of the Carpathian Basin on the Great Hungarian Plain with values between 500 and 550 mm (*Mersich et al.,* 2002, *Kocsis et al.,2018*, *HungaroMet, 2024d*).

Hungarian low-mountain ranges get higher amounts of precipitation than lowland regions due to orographic lift. There is a 35 mm increase in the annual mean precipitation amount with an increase of elevation of 100 meters on average (*Mersich et al.,*2002, *HungaroMet, 2024d*).

This anomaly is not symmetric over the mountain regions of Hungary, since positive anomaly occurs on the western sides of the mountain ranges facing the moist maritime air masses, while the eastern slopes are drier than the lowland areas due to the rain shadow effect of foehn winds.

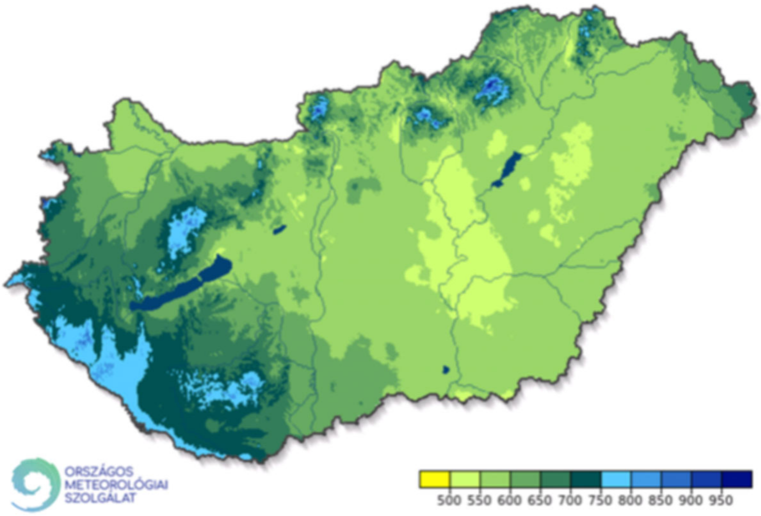

Fig. 1. Spatial pattern of annual mean precipitation during the normal period between 1991 and 2020 (*HungaroMet, 2024d*).

The minimum of the precipitation occurs between January and March due to low water vapor pressure of the cold air and the frequent dry, high pressure air masses from the Siberian high. The main maximum of the precipitation occurs between May and July due to the high water vapor content of the air, favorable conditions for convection, and the high cyclone activity in that period (*Mersich et al.,*2002, *Kocsis et al.,2018*, *HungaroMet, 2024d*).

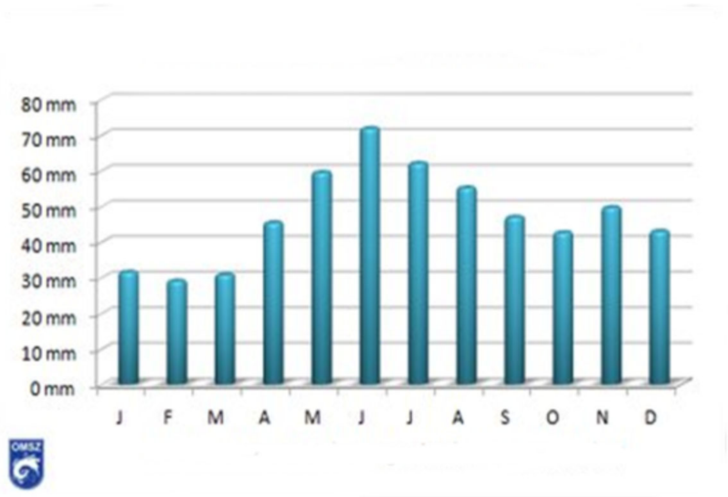

Fig. 2. Monthly mean precipitation during the normal period between 1971 and 2000. Based on homogenized, interpolated data (*HungaroMet, 2024d*).

There is a secondary precipitation maximum in the late autumn in the datasets before 2000 (*Fig. 2*). However, September and October have become considerably wetter since 2000 so the late autumn secondary maximum has disappeared, and there is a more or less gradual decrease of the monthly amounts of precipitation from August to December (*Fig. 3*, *HungaroMet, 2024d*). Autumn precipitation is caused mainly by warm fronts of mid-latitude cyclones formed over the western Mediterranean seas (*Mersich et al.,*2002).

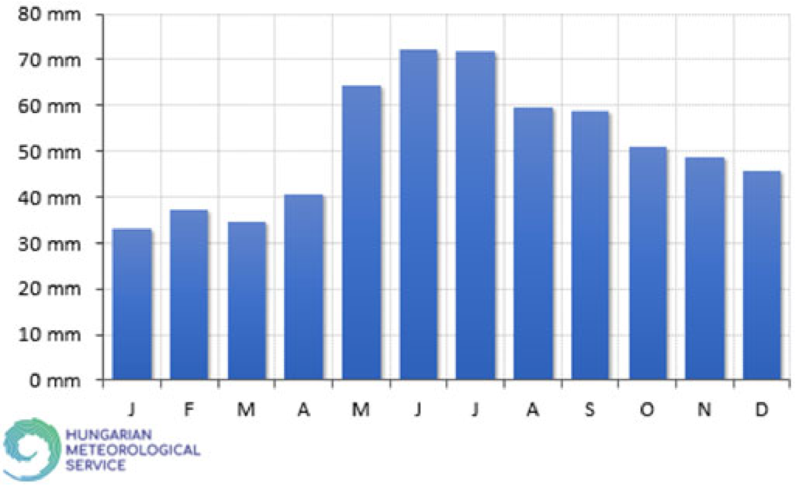

Fig. 3. Monthly mean precipitation during the normal period between 1991 and 2020 (*HungaroMet, 2024d*).

Among the meteorological parameters, precipitation shows the strongest variability on both spatial and temporal scales (*Gaál* and *Becsákné Tornay,* 2023, *Lakatos* and *Bihari,* 2011).

There can be 200% differences in the annual amount of precipitation in two consecutive years (*Fig. 4).* Annual precipitation of the driest years is under 500 mm only, while there is 800–900 mm of precipitation in the rainiest years. There can be an absolute lack of precipitation in any month of the year (*HungaroMet*, 2024d). However, the mean number of rainy days is 120 that is every third day is rainy, theoretically. The length of the longest period without precipitation is 60 days. It is quite frequent to have 200–300 mm precipitation in one month during the summer season (*Bacsó,* 1953).

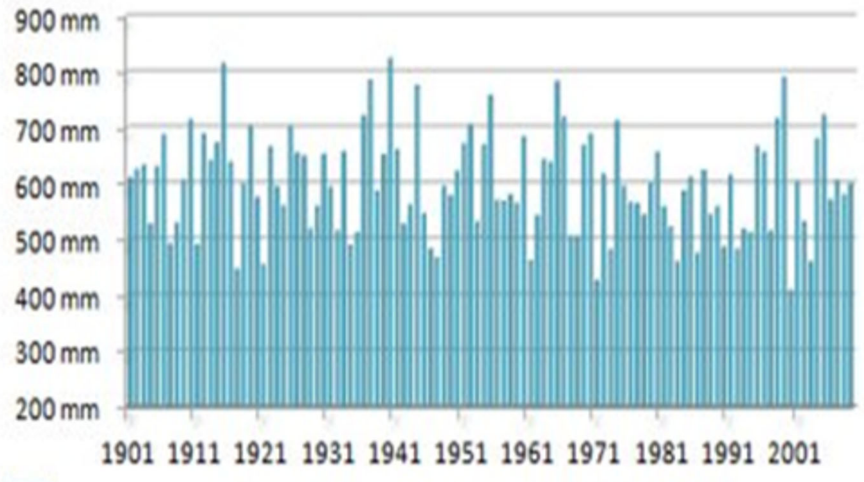

Fig. 4. Fluctuations of annual amounts of precipitation during the period between 1901 and 2009. Based on homogenized interpolated data (*HungaroMet*, 2024a).

Thunderstorms and hailstorms are summer phenomena typically in Hungary since they require high amount of moisture and energy in the atmosphere which is available during the period between the late spring and early autumn over the mid-latitudes. Thunderstorms are most frequent (more than 30 day annually) over the North Hungarian Mountain ranges, and the southeastern and northeastern parts of the Great Hungarian Plain, while the least thunderstorm (less than 20 per a year) occurs over the central part of the country (*Mersich et al.,*2002).

Low intensity rains are dominant by time span in Hungary: 75% of rainy days have intensities under 1 mm/hour. These rains provide only 30% of the total amount of precipitation. Medium intensity rains (1-5mm/hour) fall in 22% of rainy periods and provide 50% of the total amount of precipitation (*Mersich et al.,*2002).

High intensity rains (over 5 mm/hour) count for 2% of rainy periods but provides 20% of the total amount of precipitation. Most extreme precipitation events result in 150-200 mm of rain in 24 hours (*Mersich et al.,*2002).

It is a fundamental feature of the climate of Hungary that there is snow in the winters, although its amount fluctuates in a wide interval year by year. It not necessarily means the development of a snow cover in each year. There are 18–22 snowy days in the great Hungarian Plain, 25–30 snowy days in Transdanubia, and 50-60 snowy days in the hills over 700 meters above sea level on a multidecadal average (*Mersich et al.,*2002).

The least days with a snow cover occurs in the central Great Hungarian plain (30-35), where the amount of snow is the lowest, while the hilly regions have the longest periods of snow cover (*Fig. 5*).

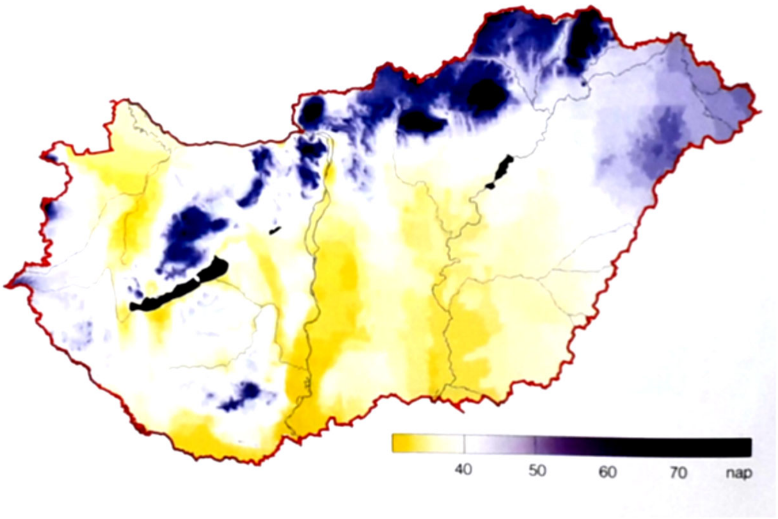

Fig. 5. Annual number of days with a snow cover given in days (*Mersich et al.,* 2002).

There are 40–45 days with a snow cover in most parts of Transdanubia due to the higher amount of snow precipitation despite slightly higher January mean temperatures. The number of days with a snow cover is over 50 in the hilly regions and reaches 100-120 over 700 meters above sea level (*Mersich et al.,*2002).

The great Hungarian Plain has the most extreme climate from the aspect of snow cover: there are winters when there is no snow cover, while there are winters when there are 80–100 days with a snow cover on the other hand (*Mersich et al.,*2002).

Another important climatic parameter is the thickness of the snow cover. It has an increasing tendency from the center of the Carpathian Basin towards its margins as well. It reaches 15–20 cm only over the cold but less snowy Great Hungarian Plain. It is around 25–40 cm over the milder and snowier Transdanubia and is over 50 cm over 500 m above sea level (*Mersich et al.,*2002).

Climate change has a remarkable impact on precipitation conditions in Hungary, however, depending on the time scale and region of focus the changes are different. For the whole country there was a moderate decrease in the annual amount of precipitation during the period between 1901 and 2020 (*Fig. 6*). The strongest decline of 20% occurred in the spring (*Kocsis* and *Anda,* 2018).The decrease is more emphasized over the western part of the country, while there was a slight increase in the eastern half of the country (*HungaroMet,* 2024b). There is a significant decrease of 17 days in the number of precipitation days during the period between 1901 and 2020. However, the number of days with precipitation over 20 mm increased during the same period. Daily intensities increased in the summer season during this period as well, which suggests more intenseprecipitation events (*HungaroMet*, 2024c).

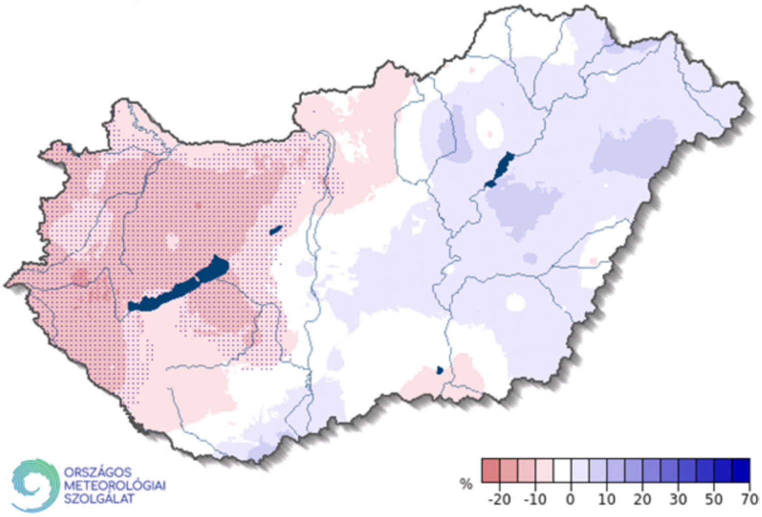

Fig. 6. Changes in the annual amount of precipitation (%) during the period between 1901 and 2020 (*HungaroMet*, 2024b).

Nevertheless, there was an increase in the annual amount of precipitation during the 1881–2020 period over most of the country (*Fig. 7*). The increase is the most remarkable over the central and northern parts of the country, where it can reach an 50% excess (*HungaroMet,* 2024b). The intensity and frequency of extremities has already been increased during the second half of the 20th century (*Barhtoly* and *Pongrácz,* 2007). The year 2010 was the wettest and 2011 the driest since 1901 with annual amount of precipitation of 959 mm and 407 mm, respectively (*Pongrácz et al.,* 2014).

According to climate change scenarios, an increasing tendency of the precipitation is projected for the autumn-winter months and a significant decrease is expected for the summer, while the annual sum is not expected to change considerably along with an increasing frequency of extreme precipitation events concentrated in the winter half year (*Gaál* and *Becsákné Tornay,* 2023, *Kocsis* and *Anda,* 2017, *Csáki et al.,* 2018, *Kocsis et al*., 2023).

Precipitation extremities are expected to result in increasing frequency of floods and droughts (*Birinyi et al.,*2023, *Gerhátné Kerényi,* 2018).

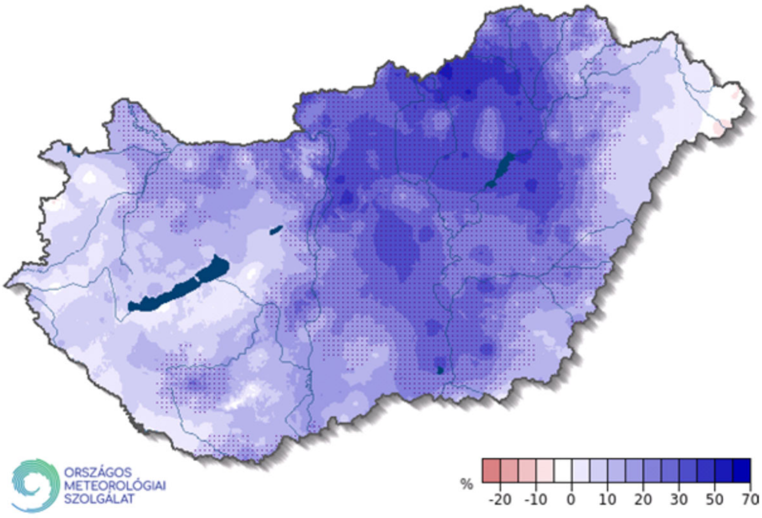

Fig. 7. Changes in the annual amount of precipitation (%) during the period between 1981 and 2020 (*HungaroMet,* 2024).

2. Material and methods

An exact statistical description of present and future climate requires a database representative in space and time. However, observation records – that is raw climatological time series – are loaded with inhomogeneities due to changes in the location of the weather stations and usage of different instruments and observation protocols. Datasets must be homogenized first, which means that previous measurement data must be adjusted to the present observation protocols, while missing data must be supplemented. Homogenization of Hungarian climatological datasets and supplementation of missing data have been carried out using the MASH (Multiple Analysis of Series for Homogenization) and MISH (Meteorological Interpolation based on Surface Homogenized Data Basis) methods (*Szentimrey*, 1999; *Szentimrey* and *Bihari*, 2007) developed at the Climatological department of the HungaroMet what providing homogenized, supplemented, and verified diurnal datasets. Gridded data sets have been produced by the MISH method. The papers of *Izsák et al.* (2021) and *Szentes* (2023) provide a good review on the different phases of the production of the climatological database. Both papers contain numerous references for other studies what deal with theoretical and practical problems of the different phases of the process. Authors would like to draw attention to the papers of *Izsák et al.* (2022), *Szentes et al.* (2023), and *Izsák et al.* (2024) from the newest literature on homogenization of precipitation time series. Besides a detailed description of the homogenization process of precipitation time series, the articles deal with the application of the method on different data sources.

The database of the present examination is the homogenized precipitation time series of Hungary, that is diurnal amounts of precipitation for the 1,233 grid cells which cover the area of the country over the period of 1971-2022 in the state of the database in 2023 (*HungaroMet*, 2023). According to the method of the homogenization there are 1,233 grid cells defined for the area of Hungary between the coordinates (45,7° N,16,1° E) and (48,6° N, 22,9° E).

Therefore, the data matrix contains 18,628*1,233 pieces of precipitation data. Firstly, the diurnal amount of precipitation over the area of the country, that is the sum of precipitation that falls in each cell of the grid 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.

Hereinafter, precipitation over a point of the country or what falls in the point of the country corresponds to these data.

3. Statistical characteristics of the diurnal amount of precipitation over the country

The 51 years long period involved in our study contains 18,628 days, that is *the diurnal amounts of precipitation* for the total 1,233 grid cells *for all days of the period*. These sums determine the diurnal amount of precipitation that falls over the country.

The total amount of precipitation during the study period (the sum of the precipitation of the 18,628 days) equals 37,580,312 mm that is this amount of water in liters/m^2 fell over the area of the country, more exactly over the area covered by the 1,233 grid cells. It is 736,869 mm on annual average on total, and it means 597.6 mm on spatial average (per one grid cell). Therefore, 597.6 mm is the amount of annual mean precipitation of Hungary for the study period.

The sum of rainfall in a day in the 1,233 grid cells is *the daily national precipitation total*. The most important statistical features of this time series (average, standard deviation, coefficient of variation, maximum, mode) are shown in *Table 1*.

Table 1. The most important statistical characteristics of daily national precipitation totals

average[*] **mm**	**stand. dev. mm**	**coeff. of var.**	**median mm**	**maximum**[**] **mm**	**mode**[***] **mm**
2,017.4	3,714.8	*1.84*	354.4	38,666	0.0

[*] average rainfall in a day in the covered area, [**] May 15, 2010, [***] see below

26.8% of the elements of the time series is over the average only. The maximum, occurred on May 15, 2010, is 0.1% of the sum of the elements.

98% of the daily national precipitation totals falls into the interval between 0 and 14,000 mm. Most of them (73.2%) is between 0 and 2,000 mm. 52.5% of the values within the interval between 0–2,000 mm is between 0 and 100 mm and 57% of these values is between 0 and 10 mm. *40% of the* latest category *is 0, which are the national dry days* of the time series when the daily national precipitation totals are under 0.1 mm. Therefore, 0 mm is the *mode* of the distribution that is the most probable daily amount of precipitation.

Monthly distribution of the national daily precipitation amount of the studied period is presented in *Fig. 8*. 44% of the total annual precipitation falls during May and the summer months. Average monthly national precipitation amounts are presented in *Fig. 8* as well. Annual courses are similar naturally: there is a maximum in June (12.2%, 72.3 mm) and a minimum in March (5.6%, 33.6 mm). There is an increasing trend between January and June and a decreasing one from June to December. Average monthly precipitation amounts are in accordance with the values derived from observation data of the period of 1991–2020 (see *Fig. 3*).

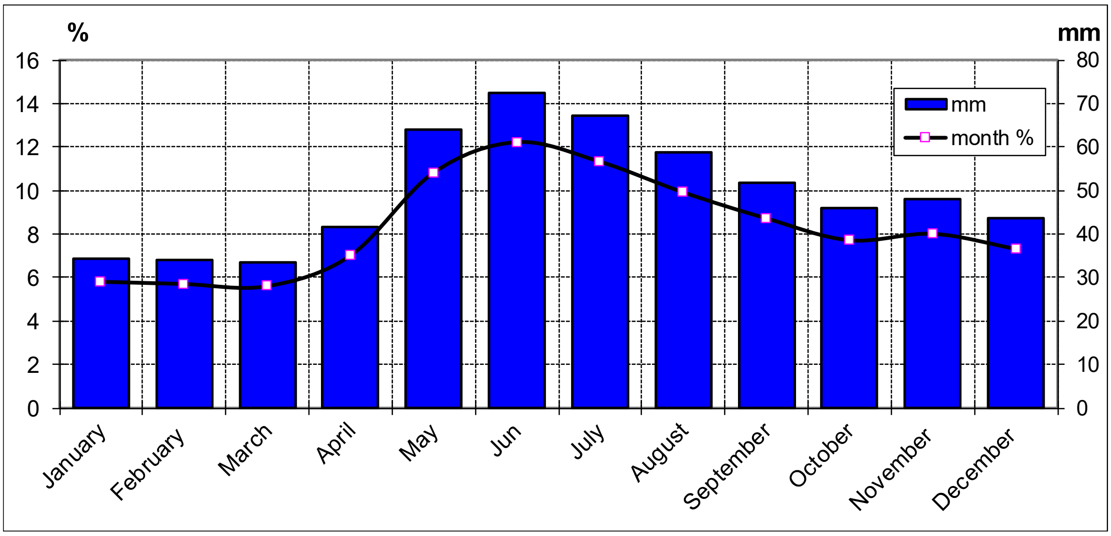

Fig. 8. Monthly distribution of the national daily precipitation amount (%) and the average monthly national precipitation amounts (mm), 1971–2021.

The figure on the temporal characteristics of the annual precipitation amount will be presented in part 2 of this article. According to *Fig. 9a,* the annual precipitation amount (APA) falls into the 740,000–820,000 mm interval in 15 years of the studied period, it is the mode of the distribution this way. The average and the median falls into this class as well, therefore a normal distribution can be assumed.

The values of the annual relative precipitation amount (ARA=annual precipitation / precipitation in the 51 years long period) are between 1.38% (2011) and 3.22% (2010). The secondary maximum was in 1999 with 2.63%, while the secondary minimum was in the following year again with 1.39%! Their average is 1.96%, standard deviation is 0.34%, so the variation coefficient is 0.17, while their median is 1.98%. The mode can be determined from the frequency distribution shown in *Fig. 9b*.

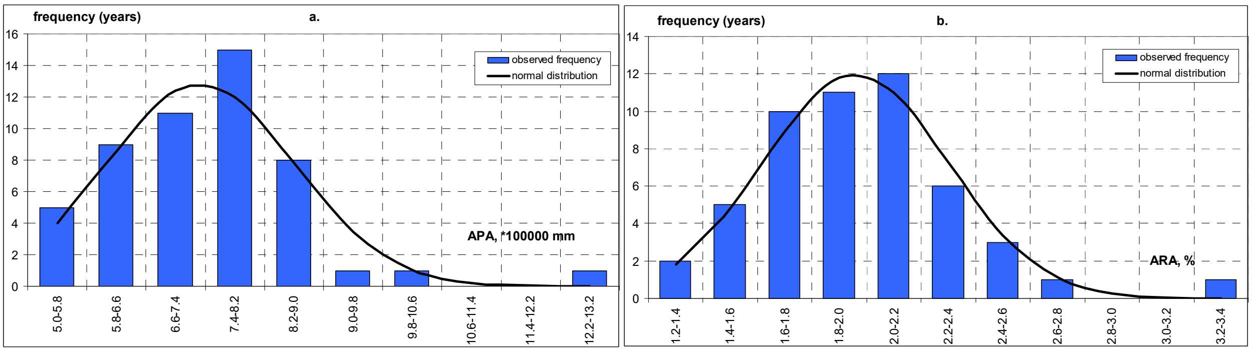

Fig. 9. Frequency distribution of the annual precipitation amount (a) and relative precipitation amount (b) and their approximation to the normal distribution.

On the base of *Fig. 9b,* the mode is about 2%, so we tried to approximate the empirical frequencies with the normal distribution. According to the χ^2 probe, the annual precipitation amount and relative precipitation amount can be approximated by the normal distribution at a high level of probability.

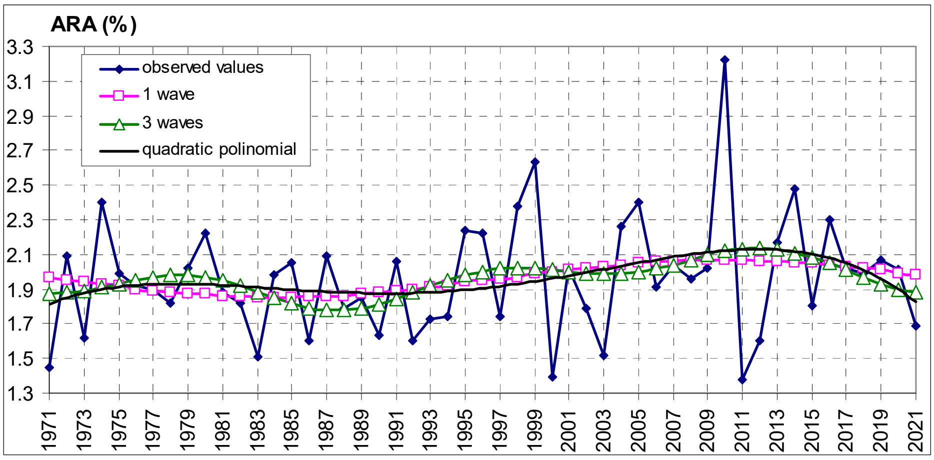

Fig. 10. Observed values of annual relative precipitation sums (ARA, %) and their approximation with quadratic and trigonometric polynomials.

Annual relative precipitation sums of the individual years (*observed data*) of the studied period are presented in *Fig. 10.* Analyzing the tendencies in annual relative precipitation sums during the studied period applying one direction analytic trends (linear, logarithmic, exponential etc.) would be counterproductive naturally, due to the relatively large difference between the extreme values (1.84%). Applying a fourth-degree polynomial results in a two-maximum curve, that is a double wave one can be presumed. Therefore, it is reasonable to carry out a period analysis on the time series.

The presumed periodicity has been examined approximating the observed annual values with trigonometric polynomials. The method is called harmonic analyses as well (see e.g., *Dobosi* and *Felméry*, 1971, *Huzsvai* and *Vincze*, 2012). An improved version of the method has been used in the present study. For detailed description of the method see: *Tar et al.* (2001, 2002), *Tar* and *Kircsi,* (2001), *Tar* (2004, 2007, 2014).

If we apply a four-element polynomial (a wave) to the observed values of the annual relative precipitation sums (ARA, %), then the expected value, E, of the amplitudes of the waves is 0.08. Using this method, the amplitudes for each wave, A_m, the A_m/E ratio refering to the suddenness of wave m, the goodness of the approximation, s_{0m}, and the root mean square error parameter, RMSE, have been determined.

The s_{0m} values show that all the four waves provide a rather weak approximation. Based on the amplitudes, the first wave with an amplitude of 51 years is real, what can be considered as obvious. The next is the third wave with a random period of 17 years. However, the periodicity has not been justified according to the nearly equal RMSE values.

The annual sign change (ΔARA) of relative precipitation amounts have been examined also. It is negative in 52% of the years that is the year-by-year decrease is larger by 4% than the increase. The so-called transition/conditional probabilities/relative frequencies have been calculated as well. Results are presented in *Table 2*.

Table 2. Conditional probabilities of the annual sign change (ΔARA) of relative precipitation amounts

		condition	
		ΔARA ≤0	**ΔARA >0**
conditional event	**ΔARA ≤0**	0.3462	*0.7083*
	ΔARA >0	*0.6154*	0.2917

According to the table, the probability of a sign change of the ΔARA difference is about twice as high as the perseverance of the sign.

The above results have been obtained using data for all the days and grid cells' precipitation data involved. In the following examinations, *dry* (no precipitation) and *rainy days and grids* have been distinguished. Dry and rainy days have been divided into two further subsets: *nationally and locally dry* and *nationally and locally rainy days,* respectively.

4. Temporal and spatial characteristics of dry days

Dry days and grid cells are those when and where the daily precipitation amount is under 0.1 mm. Statistical characteristics of daily dry grid cells and dry days by grid cells are dealt with in the following chapter.

4.1. Temporal statistics of nationally dry days

The beforementioned 40% is the ratio of the *nationally dry days,* when there was no more precipitation than 0.1 mm in any grid cells. It is 1645 days in total during the 51 years, that is 8.8% of the studied period. It means that every eleventh day is nationally dry on average. On the base of the abundant database of the study, it can be stated that it is the probability of a nationally dry day in Hungary. Therefore, there are dry and rainy grid cells (areas) within a day in most cases.

There are *locally* or *nationally rainy days* between the nationally dry days. These are the precipitation intervals with time spans from 0 to 199 days. Their length is 10.3 days on the average during the studied period in harmony with the previous estimation. It is 0 in the case, when a nationally dry day is followed by a similar day. The length of the precipitation periods is between 0 and 10 days in 74% of the cases. Most of them have a length of 0 days which is 45% of the nationally dry days. Thus, a nationally dry day is followed by a locally or nationally rainy day with a higher probability (55%) than by a nationally dry day.

The average of the annual number of nationally dry days (DDC) is 32.3, its standard deviation is 10.9, therefore, the variation coefficient is 0.34. The maximum is 61 days in 1992, while the minimum is 10 days in 1999 and 2014, the is median 33 days.

The "observed" values curve shows the annual number of nationally dry days in *Fig. 11*. The maximum is 61 days in 1992 which is 17% of the total length of the year. According to the criteria defined by *Szentes* (2023) for the dry and rainy years, there was a durative dry period in the first half of the 1990s, peaking in 1992. Therefore, in the definition of dry years or the driest year, the annual number of nationally dry days can be a parameter. In our case (1971–2021), during the 1990s, the lowest annual precipitation was not in 1992 but in 2000 at the end of the decade.

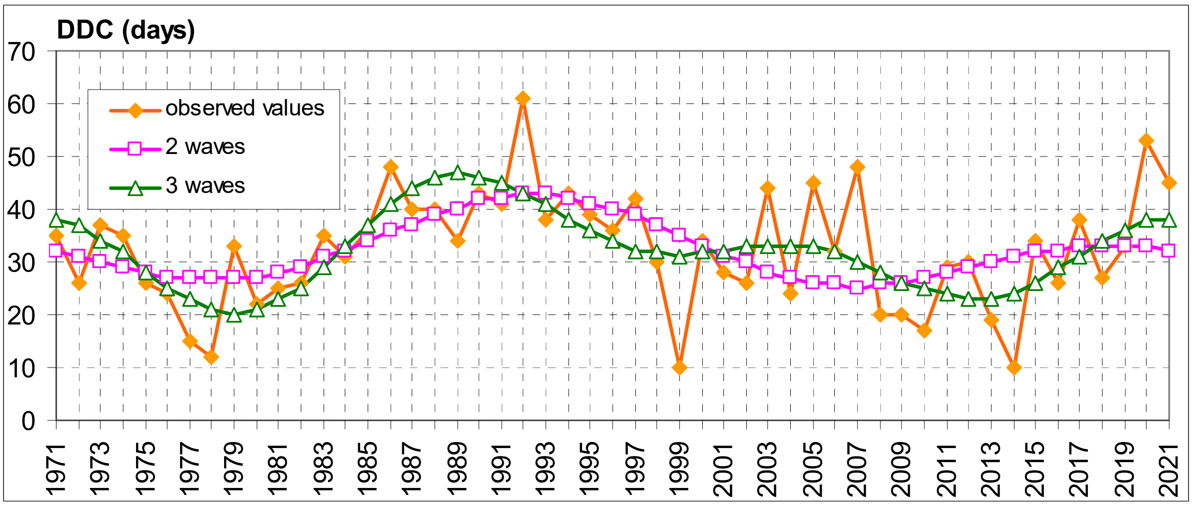

Fig. 11. Annual number of nationally dry days (DDC) and their approximation with trigonometric polynomials.

The 10 least nationally dry days occurred in 1999 and 2014. When examining the tendencies of nationally dry days, the application of one direction analytic trends (linear, logarithmic, exponential, etc.) would be counterproductive obviously, due to the relatively large difference between the extreme values (51 days). Therefore, it is reasonable to carry out a period analysis on the time series.

Carrying out the examinations detailed in the previous chapter, the following results have been achieved. In the case of the approximation with two waves, the 51/2=25.5 years period of the second wave; and in the case of the approximation with three waves, the 51/3=17 years period of the third wave can be considered as realistic. It can be seen in the corresponding curves of *Fig. 11*. In the case of the two waves approximation, the minima occur in the late 1970's and the mid 2000's with a periodicity of 25–28 years. The three waves curve has three local minima with a periodicity of about 18–16 years. Based on the highest A_3/E ratio, the *17 years period has been accepted*.

The *distribution of the number of nationally dry days per year* has been examined as well by a classification into five days long intervals/classes.

As it is visible in *Fig. 12,* the number of nationally dry days per year falls into the 25–30 and 30–35 classes most frequently in 10-10 years. Therefore, in 20 years (about 40%) of the studied period, the annual number of nationally dry days is between 25 and 35 days. On this basis, it can be assumed that the mode of distribution is the middle of this interval, that is 30 days. This way, the mode, the average, and the median are close to each other enough to make the approximation of the empirical distribution with a normal distribution possible. This approximation has been proved to be successful at a significance level of 0.05 according to the χ^2-test.

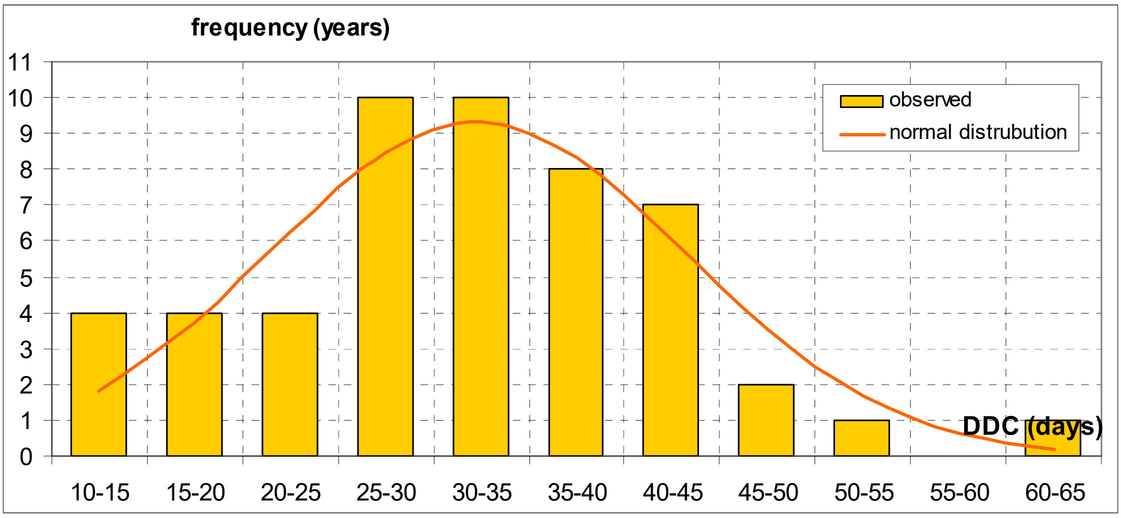

Fig. 12. Observed distribution of the number of nationally dry days (DDC) per year and its approximation to the normal distribution.

The increasing annual number of nationally dry days has a reducing effect on the annual amount of precipitation naturally. This stochastic relationship can be demonstrated most simply via a linear correlation presented in *Fig. 13*. The linear correlation coefficient is -0.4117.

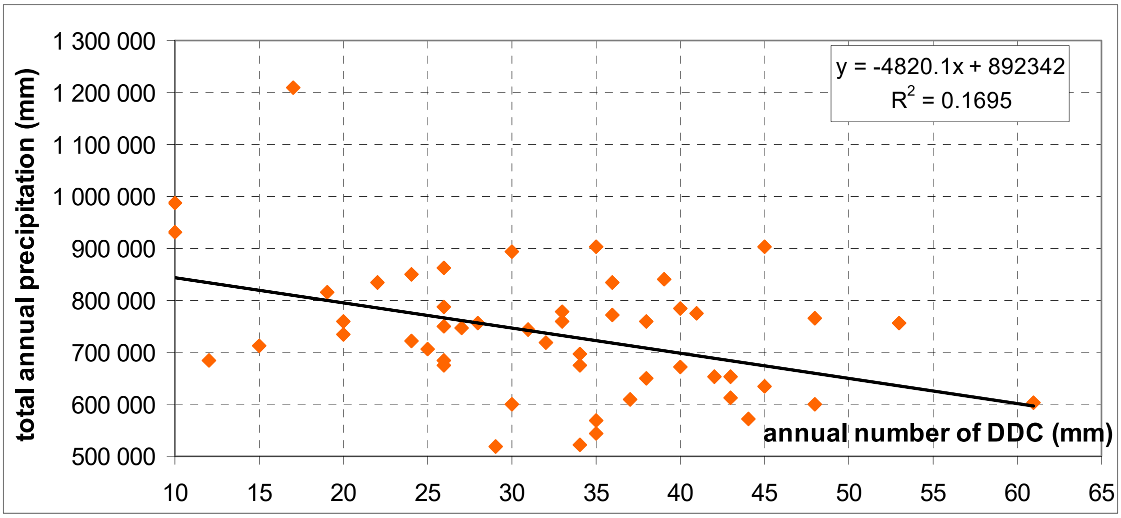

Fig. 13. Linear regression between the national annual precipitation and the number of nationally dry days per year.

To test the significance of the linear correlation coefficient, r, between the variables, the F-test used in variance analyses has been applied according to the interpretation of *Miller* (1997) and *Hadnagy* (2020, 2023).

The result of the test showed that the correlation coefficient r = -0.4117 differs from 0 at a significance level of 0.01. This way there is a weak correlation between the two variables (*Huzsvai* and *Vincze,* 2012). According to the interpretation of the determination coefficient (r^2), the number of nationally dry days per year explains the annual precipitation in about 17% during the studied period only. According to the regression coefficient, an increase of 1 day in the number of nationally dry days per year results in a decrease in the national annual precipitation of 4816 mm.

The monthly distribution of the 1645 nationally dry days per year is presented in the curve of "total DDC days" in *Fig. 14*. The other curve is a comparison between the monthly number of nationally dry days and the total number of days in a month (51*31 or 51*30, and 1441 in February). These ratios give the probability of a given day of a given month being nationally dry. Naturally, there is a strong linear correlation between the two quantities, since their calculation relies on a common mathematical base. It is visible that the *nationally driest month* is September, followed by March, August, and October, respectively. The number of nationally dry days is lower in all the three winter months than in all other months. Seasonally it is 30.9% in autumn, 29.2% in spring, 26.7% in summer and 13.2% in winter.

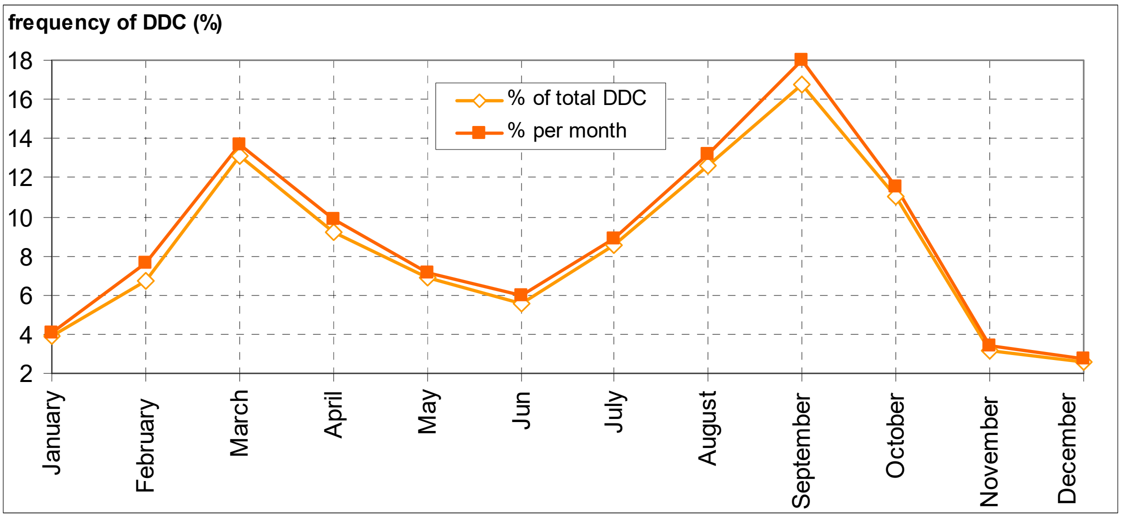

Fig. 14. Monthly distribution of nationally dry days.

4.2. *Statistical characteristics of daily dry grids*

Statistical characteristics of *daily dry grids* (0 to 1,233) have been studied also. There are 22,968,324 grid data from the 18,628 days of the 51 years of the studied period. The total number of *dry grids* is 12,051,721, that is more than half (52.5%) of the total number of cases. 16.8% of dry grids are the nationally dry grids (1,645*1,233=2,028,285).

The most important statistical characteristics of daily dry grids are shown in *Table 3*. According to the table, there has been no precipitation in more than half (52.5%) of the grids during the studied period. The value of the median is close to the average. Mode can be determined via examination of the distribution.

Table 3. Statistical characteristics of daily dry grids (pieces, *calculated*).

total	**average**	**stand. dev.**	**coeff. of var.**	**median**
12,051,721	647	448.3	*0.69*	667

Examining the distribution of the number of daily dry grids the following can be stated. The number of daily dry grids is under 100 in 18.3% of the cases (3,414 days), which is the highest frequency. However, almost as frequent (14.8%) is the case when almost all grids (1,200–1,233) are dry. The lowest frequency case is when the number of daily dry grids falls into the interval which involves the average (600–700).

It is probably a bimodal distribution. To judge this issue, a higher resolution classification of the 0–100 and 1,200–1,300 intervals has been established, shown in *Fig. 15*.

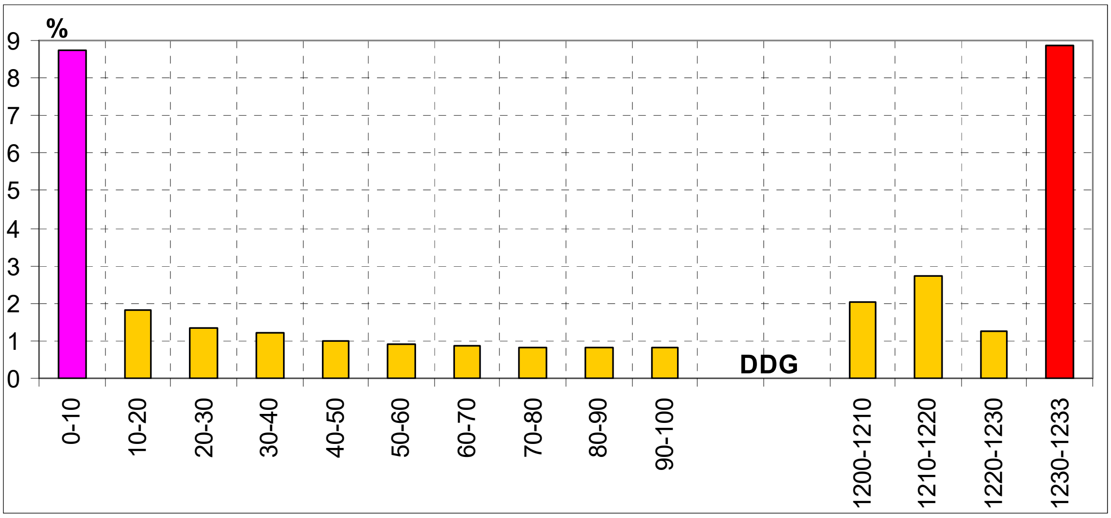

Fig. 15. Distribution of the number of daily dry grids (DDG, %) in the intervals 0–100 and 1200–1233.

The figure shows that the probability of the occurrence of less than 10 daily dry grid cells in a day (a rainy day with a high probability) is lower by 0.2% than the probability of the occurrence of a nearly nationally dry day only.

For the 1,233 grid cells that cover the area of the country, it has nearly equally maximal probability to have precipitation over less than 0.8% of the area of the country and to have no precipitation at all over 99.8% percent of the area of the country in a day according to *Fig. 15.*

The number of the *daily dry grids* (DDG, %) indicates the percentage of the area of the country, where there was no precipitation in a day. This ratio is between 0 % (*nationally rainy days*) and 100% (*nationally dry days*), obviously. There has been no precipitation over more than half of the studied period (52.5%), that is 5% higher than the ratio of the area, where there has been precipitation (47.5%) during the studied period. Further features of DDG_r are its standard deviation is 36.4%, its variation coefficient is 0.69, and the median is 54.1%, respectively.

The distribution of DDG_r is shown in *Fig. 16*. It is a bimodal distribution according to the figure. Having no precipitation over 90–100% of the area of the country in a day has the highest probability (24.8%). The case when this ratio is between 0 and 10% has the second highest probability (20%). The lowest probability case (6.3%) is when 40–50% of the country is dry (about half dry-half rainy).

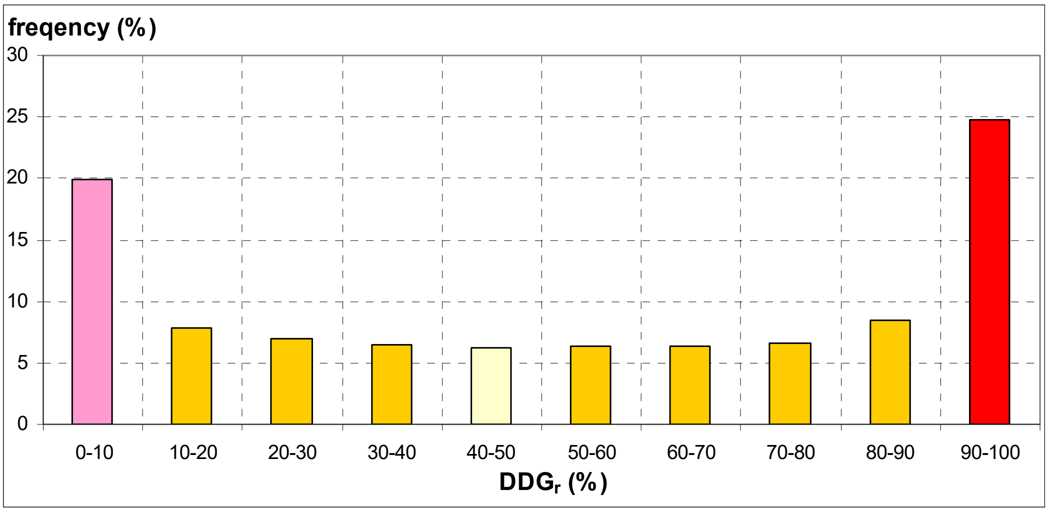

Fig. 16. Distribution of the relative number of dry grids per day (DDG_r, %).

The monthly distribution of dry grids as a percentage of the total number cases *(% of total*) is presented in *Fig. 17*. The driest month is October, followed by August, September, and March, respectively. The percentage is 26.8% in autumn, 25.2% in summer, 24.8% in spring, and 23.2% in winter. The second curve in the figure shows the total number of dry grids per a day of a month (*1 day per month*). Due to the common base, its annual course is in harmony with the previous one. However, the order is a bit different: October, September, August, and March. The values are higher than the average (647) in those months only. The standard deviation of the monthly data set is 67.2, that is the variation coefficient is 0.10. The spread (October-May), that is a measure of the annual fluctuation is 183, which is about 15% of the total number of grids. The average numbers of dry grids per a day are 607 in winter, 636 in spring, 647 in summer and 697 in autumn.

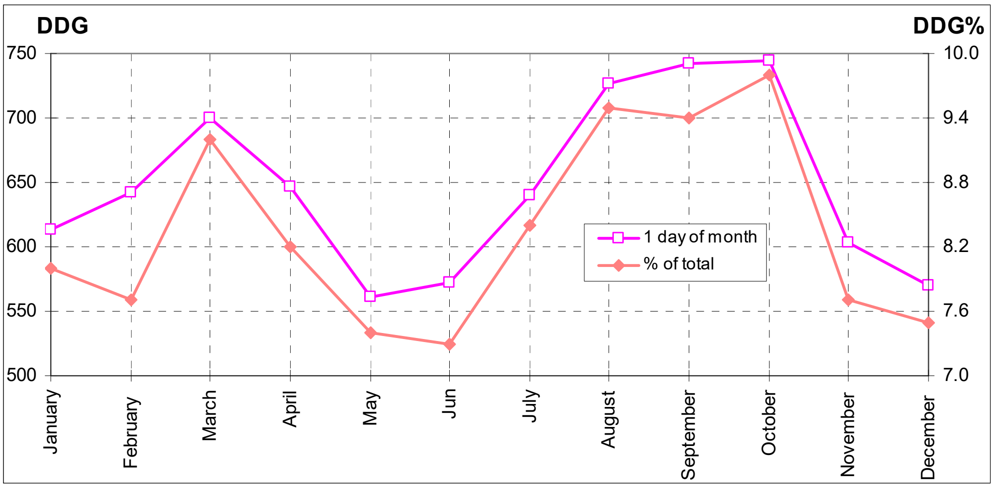

Fig. 17. The number of dry grids per day of the month (DDG, *1 day of month*) and the total number of dry grids per month as a % of their total number (DDG%, *% of total).*

4.3. Statistics of the dry days per grids

The most important statistical characteristics of the sum of dry days per grid (DNP_g) and their average number per year (DNP_g/year) are summarized in *Table 4*.

Table 4. The most important statistical characteristics of the sum of dry days per grid (DNPg) and their average number per year (DNPg/year).

	DNP_g	**DNP_g/year**
average, days	9,774	195
stand. dev., days	531	11
coeff. of var.	0.05	0.05
minimum, days	8,486	170
maximum, days	13,155	263
median, days	9,750	195
mode, days	9,737	195

There have been 9,774 dry days per grid on average, which is 0.08% of all dry grids (the number of dry days in all grids is 12,051,721). The variation coefficient indicates a relative stability of this variable around the average. The number of values over and under the average are 594 (48%), and 639 (52%), respectively.

(Spatial) distribution of *dry days* per grids have been fluctuating between 13,155 days and 8,486 days during the studied period. Our data show the strongest similarity to the map showing the annual average number of consecutive dry days during the 1991–2000 climatological normal period (*Szentes,* 2023).

The average, median, and mode of average number per year of dry days per grid are practically equal according to *Table 4.* Despite this, the approximation with normal distribution was not successful. It can be explained by that in our case, 74.5% of all cases fall into the average+standard deviation interval instead of 68.2% which is the requirement for the normal distribution (*Dobosi* and *Felméry*, 1971). Otherwise, this 74.5% can explain the value of the variation coefficient, i. e., the relative stability around the average. Attempts for the approximation with the lognormal and square lognormal distribution have not been successful also. According to the χ^2 test, the lognormal distribution provides the best approximation. However, there is a significant difference between the observed and the approximating values, which are higher than the level of acceptance. The opportunity of the approximation with the gamma distribution has been examined as well. The $\Gamma(p)$ function in the density function has shown an overflow due to the high value of the p parameter what made the gamma distribution inapplicable in our case.

As it has been discussed in the beginning of this chapter, it is expedient to examine the relationship between the annual average of dry days per grid (DNP_g/year) and the geographical coordinates (φ latitude and λ longitude) of the grids, that can be carried out most simply via a linear regression.

On the basis of analyses referred in Section 4.1, the relationship between the annual average of dry days per grid and the longitude and latitude of the grids is statistically real. The correlation coefficients are $r_\lambda = -0.4308$ (for longitude), $r_\varphi = -\ 0.3357$ (for latitude), that is the annual average of dry days per grid (its spatial distribution) is in a stronger stochastic relationship with the longitude (within a climate zone). There is a decreasing tendency in the values of DNP_g/year with the increase of both geographical coordinates. It is 2.8 days per 1 degree of longitude and almost twice as much, 5.2 days per 1 degree of latitude (meridionally), according to the steepness of the regression lines.

The realistic stochastic relationship discussed above makes it possible to present the results in a form of a map. Spatial distribution of dry days during the studied period is presented in *Fig. 18.* From the relative homogeneity of the map, the spots over the northeastern part of the Great Hungarian Plain, the Nyírség and Hajdúság emerge, where the annual number of dry days is minimal (160–175). Highest values appear sporadically within the Small Hungarian Plain over the Hanság and Rábaköz.

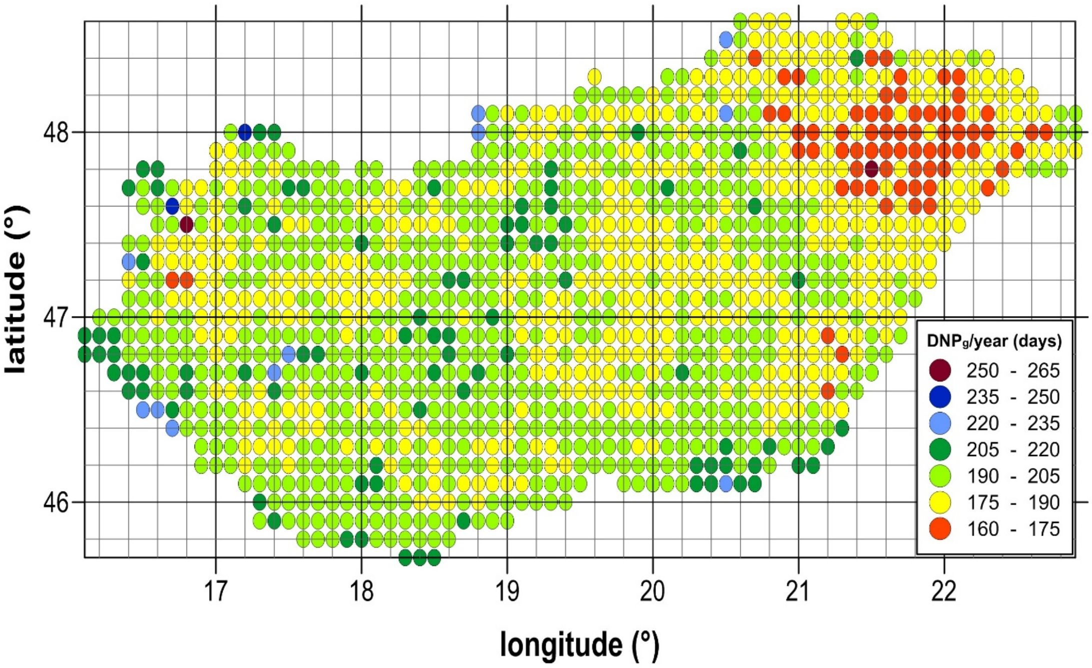

Fig. 18. Distribution of the annual average of dry days per grid (DNP$_g$/year) in the examined period.

5. Discussion and conclusions

The database of the present study is the homogenized diurnal precipitation time series of Hungary on 1,233 grid cells covering the area of the country for the 1971–2022 period. Diurnal amount of national precipitation that is 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, that is its distribution per grid cells has been analyzed as well.

Based on the analyses of the total dataset (1,233 grid cells*18,626 days), the following conclusions have been drawn.

The amount of annual mean precipitation over Hungary is 597.6 mm during the studied period. The average and maximal diurnal amounts of precipitation are 2,017.4 mm and 38,666 mm (May 15, 2010), respectively.

98 % of diurnal precipitation amounts fall into the 0–14,000 mm interval, most of them (73.2%) is in the 0–2,000 mm category. 52.5% of the values is between 0 and 100 mm, and 57% of these values is between 0 and 10 mm. 40% of the latest category *is 0,* which are the national dry days of the time series when the daily national precipitation totals are under 0.1 mm. Therefore, 0 mm is the *mode* of the distribution that is the most probable daily amount of precipitation.

44% of annual precipitation falls in May and in the summer months. The maximum and minimum of the monthly mean national precipitation are in June with 72.3 mm and March with 33.6 mm.

The distribution of the annual amount of precipitation and annual relative amount of precipitation have been examined also. According to the χ^2 test, both parameters have a normal distribution with a high probability.

Trends of the relative amounts of precipitation in the different years has been examined as well. As the application of one direction analytic trends would be counterproductive, supposedly period testing has been carried out on the data. A weak wave has been found with a 17-year accidental periodicity, which means periodicity practically has not been proved the findings supported by other parameters too.

The annual changes in the sign of the distribution of the relative amounts of precipitation have been examined as well. It is negative in 52% of the years that is the year-by-year decrease is larger by 4% than the increase. Conditional probabilities show that the change of the sign year-by-year has about twice as high probability than the perseverance of the sign.

The number of *nationally dry days* is 1,645 days, therefore, every 11th day is nationally dry during the 51 years of the studied period. It is 8.8% of the total length of the period. It is the probability of a nationally dry day in Hungary with a good approximation.

There are *locally* or *nationally rainy days* between the nationally dry days. These are the precipitation intervals with time spans from 0 to 199 days. Their length is 10.3 days on the average during the studied period in harmony with the previous estimation. It is 0 in the case, when a nationally dry day is followed by a similar day. The length of the precipitation periods is between 0 and 10 days in 74% of the cases. Most of them have a length of 0 days which is 45% of the nationally dry days. Thus, a nationally dry day is followed by a locally or nationally rainy day with a higher probability (55%) than a nationally dry day.

The average of the annual number of nationally dry days is 32.3, its standard deviation is 10.9, therefore, the variation coefficient is 0.34. The maximum is 61 days in 1992, while the minimum is 10 days in 1999 and 2014, the median is 33 days.

Annual tendencies of nationally dry days have been examined by period testing again. The 17 years long wave has been accepted as real, since it has 3–3 local minima and maxima like the observed time series, and it is in the best agreement with the statistical requirements.

The distribution of the number of nationally dry days per year has been examined as well. The number of nationally dry days per year falls into the 25–30 and 30–35 classes most frequently in 10–10 years. Therefore, in 20 years (about 40%) of the studied period, the annual number of nationally dry days is between 25 and 35 days. On this basis, it can be assumed that the mode of distribution is the middle of this interval, that is 30 days. This way, the mode, the average, and the median are close to each other enough to make the approximation of the empirical distribution with a normal distribution possible. This approximation has been proved to be successful at a significance level of 0.05 according to the χ^2-test.

The reducing effect of increasing annual number of nationally dry days on the annual amount of precipitation can be demonstrated most simply via a linear regression. The linear correlation coefficient is $r = -0.4117$. The result of the F-test showed that the correlation coefficient $r = -0.4117$ at a significance level of 0.01 differs from 0. This way, there is a weak correlation between the two variables. According to the interpretation of the determination coefficient, the number of nationally dry days per year explains the annual precipitation in about 17% during the studied period only. According to the regression coefficient, an increase of 1 day in the number of nationally dry days per year results in a decrease in the national annual precipitation of 4,816 mm.

The monthly distribution of the 1,645 nationally dry days per year has been studied in two approximations. The monthly ratios give the probability of a given day of a given month being nationally dry. The *nationally driest month* is September, followed by March, August, and October, respectively. According to this the driest season is the autumn, followed by the spring, the summer, and the winter.

Statistical characteristics of *daily dry grids* have been studied also. The total number of *dry grids* is more than half (52.5%) of the total number of cases. 16.8% of dry grids are the nationally dry grids.

The average number of daily dry grid cells is 667, their standard deviation is 448.3, therefore, the variation coefficient is 0.69, and the median is 667 grid cells, respectively. Thus, there has been no precipitation in more than half (52.5%) of the grids during the studied period.

The number of daily dry grids is under 100 in 18.3% of the cases (3,414 days), which is the highest frequency. However, almost as frequent (14.8%) is the case when almost all grids are dry. The lowest frequency case is when the number of daily dry grids falls into the interval which involves the average (600–700). It is probably a bimodal distribution.

To judge this issue, a higher resolution (10 grid cells per class) classification of the 0–100 and 1,200–1,300 intervals has been established. Based on this, for the area of the country measured in grid cells, it has nearly equally maximal probability to have precipitation over less than 0.8% of the area of the country and to have no precipitation at all over 99.8% percent of the area of the country in a day.

Based on the comparison between the monthly numbers of dry grids to the total number cases the driest month is October, followed by August, September, and March, respectively. There are the same four months like in the case of nationally dry days but in a different order. The seasonal order is autumn, summer, spring and winter.

The number of dry grids per a day of a month has been determined also. The order is a bit different: October, September, August, and March. The values are higher than the annual average in those months only. The annual fluctuation (October-May) is 183, which is about 15% of the total number of grids. The average numbers of dry grids per a day are 697 in autumn, 647 in summer 636 in spring and 607 in winter.

Characteristics of dry days per grid cells (their spatial pattern) have been examined for the total studied period and its years. The average, the minimum and the maximum for the total period are 9,774, 8,486, and 13,155 days, while annually they are 195, 170, and 363 days. To map the spatial distribution, the stochastic relationships between the annual averages of dry days per grid geographical coordinates of the grids have been examined first.

The examination can be carried out most simply via a linear regression. Using the appropriate test it has been proved, that the relationship between the annual average of dry days per grid and the longitude and latitude of the grids is statistically real. The correlation coefficients are $r_\lambda = -0.4308$ (for longitude), $r_\varphi = -\ 0.3357$ (for latitude), that is the annual average of dry days per grid (its spatial distribution) is in a stronger stochastic relationship with the longitude. There is a decreasing tendency in the values with the increase of both geographical coordinates. It is 2.8 days per 1 degree of longitude and almost twice as much, 5.2 days per 1 degree of latitude (meridionally), according to the steepness of the regression lines.

The realistic stochastic relationship discussed above makes it possible to present the results in a form of a map. The most important information from the map are the following: the annual number of dry days is minimal (160–175) over the northeastern part of the Great Hungarian Pain, the Nyírség and Hajdúság. Highest values appear sporadically within the Small Hungarian Plain over the Hanság and Rábaköz.

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