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CHARACTERISTICS OF PRECIPITATION IN THE ATHENS AREA, GREECE

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SUMMARY

In this work, the characteristics of the long-term precipitation time series in Athens area (1891-2000). Statistical analysis shows that higher values of annual precipitation observed in the 1930s, while the lowest values were observed in the 1890s and 1980s. There is no significant trend in the annual precipitation time series. Moreover, the annual number of days with high precipitation (ANDHP) remains constant, during the investigated period. Spectral analysis by the Blackman-Tukey method that applied to the time series of ANDHP, showed in most cases peaks at frequencies corresponding to the following time periods: about 2.6 and 4.0 years.

KEYWORDS:
Precipitation, trends, precipitation statistics, Athens.

INTRODUCTION

The enhancement of the greenhouse effect, caused by the continuously increasing emissions of gases to the atmosphere, is expected to generate serious climatic changes. Precipitation trends may provide an additional indicator (together with temperature and sea-level pressure) in the evaluation of gases induced climatic change.

Precipitation variations are of interest in different fields of human economic activity, such as agriculture, water management, etc. Many researchers have carried out studies on precipitation using precipitation data measured at the National Observatory of Athens (NOA) [1-14].

There has been great interest recently in extremely low precipitation observed at the 10-year period 1981-1990, which created serious socio-economic problems in great urban areas.

The aim of this study was to perform some basic statistical analysis on the most long-term available record of precipitation data in Greece. The total number of days with large precipitation, as well as without any precipitation, over the urban Athens area during the examined 110-year period (1891-2000) was also investigated.

DATA AND METHODS

Daily precipitation values of homogeneous and continuous records, for a 110-year period (1891-2000), have been analyzed. The series of daily precipitation observations started in 1891 at the National Observatory of Athens (NOA), which is located on the Hill of Nymphs near the centre of Athens (λ=23^0 43’ E, ϕ=37^0 58’ N, h=107 m a.m.s.l.). In this work focus was laid on the descriptive presentation of these data as well as on the time-series analysis of the collected information.

Daily precipitation values are presented as mean ± standard deviation. Days with high values of total precipitation were those with precipitation greater than 10 mm, 20 mm or 30 mm. The constancy of variability of the time-series data was evaluated by the application of the modified Bartlett’s test [15], after controlling normal distribution of annual precipitation values using the Kolmogorov – Smirnov criterion [16]. The homogeneity of these time series was confirmed by comparing the ratio $S^2_{\max} / S^2_{\min}$ with theoretical values [17]. In order to examine the stability of the investigated record in terms of a comparison between the overall mean of the entire record and the means of certain parts of this record (the time series with annual precipitation values divided into five sub-periods, each of 22-year length), Cramer’s test [18] was applied. By the application of this test we determined whether the differences of the means are no larger than they would be compatible with a “null” hypothesis of randomness. A linear non-stationery regression model with first-order autoregressive errors (ARIMA) was applied in order to evaluate a trend in the time-series, after controlling for serial correlation and inequality of variances [19]. The selection of the best model was based on the Akaike's Information criterion [20]. Moreover, the investigation of systematic trends was achieved by the application of the Mann-Kendall rank statistic t [21, 22]. This non-parametric test is based on the number of all u(d) values, computed through an appropriate formula [22], and their graphical representation along the time axis connoted c_1. The sequential application to c_1 allows us to detect a change in the time series when u(d) becomes larger than 1.96 (significance level 0.05). In order to localize the beginning of the change, the same rule applied to the retrograde series, and the graphical representation of this ensemble connoted c_2. The intersection of the two curves c_1 and c_2 localized the change, provided that it is located between the critical values of the 0.05 significance level, which represents an abrupt climatic change [22]. Finally, the Blackman and Tukey method of spectral analysis [23] was applied to the time series of annual number of days with precipitation greater than or equal (GE) to 10 mm, 20 mm and 30 mm, separately, in order to reveal periodicities.

DATA ANALYSIS AND DISCUSSION

Annual precipitation

The analysis of the data showed that the maximum annual precipitation amount (612 mm) was observed during the year 1955, while the minimum one (115.7 mm) was observed during the year 1898. The overall mean of the entire precipitation time series was found 387.46 ± 94.35 mm, moreover the median value of the examined time series was 384.5 mm. The annual precipitation totals were normally distributed, according to the Kolmogorov – Smirnov criterion (Z = 0.56, significance level = 0.903), the coefficient of skewness (equal to -0.15), and the coefficient of kurtosis (equals to 3.0).

The short-cut Bartlett test of homogeneity of variance for annual total precipitation values, for the period 1891-2000, was applied by dividing the time series into k = 5 sub-periods with equal lengths (n = 22). Comparing the value of S^2_{max} / S^2_{min} ratio (equals to 1.63) with the critical value of 3.46 (for 0.05 significance level) we conclude that NOA has exhibited great precipitation homogeneity, which could attribute to the unchanged position since 1890 [6]. Table 1 shows the statistical characteristics and the results of Cramer's test, for each of the 22 years sub-period. The results suggest that non-randomness is present, and higher annual precipitation values were observed during 1935-1956 (415.86 ± 98.23 mm per year), while lower annual precipitation value was observed during 1979-2000 (368.43 ± 103.95 mm per year).

TABLE 1 - Statistical characteristics of each sub-period.

ID	Period	Mean (mm)	St. Dev. (mm)	Cramer's - t
1	1891-1912	371.80	102.99	-0.865
2	1913-1934	396.50	83.28	0.498
3	1935-1956	415.86	98.23	1.582
4	1957-1978	384.71	81.46	-0.151
5	1979-2000	368.43	103.95	-1.053

Figure 1 shows the annual precipitation time series along with 10-year moving average in the NOA station, for the investigated period (1891-2000). The applied time-series analysis showed that a statistically insignificant decreasing overall trend is evident (b-coefficient = -0.23, significance level = 0.57, AIC = 1219.16), after controlling for serial correlation and inequality of variances. Scrutiny of the time series in Figure 1 reveals that precipitation peaked at the end 1930s, in the early 1950s and has been declining since then. Several patterns emerged in annual total precipitation with three distinct regimes: a high precipitation regime during 1931-1940 (437.12 ± 100.34 mm per year), and significantly lower precipitation regime during 1891-1900 (325.98 ± 103.08 mm per year), and 1981-1990 (335.85 ± 105.93 mm per year). Three years: 1898 (115.7 mm), 1989 (150.3 mm), and 1990 (199.3 mm), were the three driest on record; and 57 years over this 110-year period had below-average precipitation.

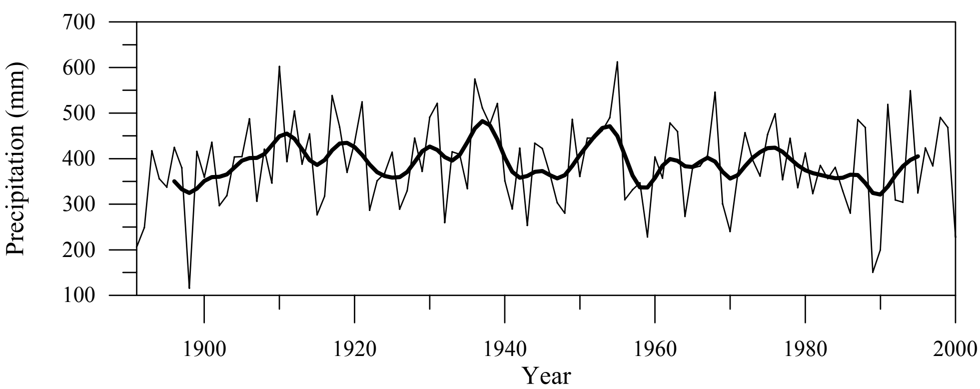

FIGURE 1 - The time series of precipitation at NOA, smoothed (bold line) using a 10-year moving average with binomial coefficient weights, for the period 1891-2000.

In order to study the seasonality of time series, three groups of months are considered. The first group (December, January, and February) may be considered as the main rainy period, the second group (May, June, July, August and September) as the dry period and the third one (March, April, October and November) as transitional period. Afterwards, a trend analysis was applied to these three periods. Both the rainy and the dry periods for the whole period present insignificant decreasing trend, equal to 12% and 32%, respectively (significance level > 0.05). On the contrary, the transitional period presents a significant increasing trend (significance level < 0.05) equal to 33%. Amanatidis et al. [10] observed increasing tendencies of precipitation, for the period 1926-1990, in NOA during the same transitional period, despite the decreasing trends at the annual values, as mentioned above. Katsoulis and Kambezidis [4] also observed increasing tendencies of precipitation, for the period 1951-1985, at the same station during the transitional period (represented by April and October), despite the significant decreasing trend of the annual values. They stated that these tendencies are indicative of an urban effect and support the theory of the mechanical effect of an extended urban area on precipitation enhancement by promoting the atmospheric instability. Goldreich and Manes [24] also showed a marked increase of November precipitation in the rapidly growing Tel-Aviv area, Israel. They also ascribed this to an urban effect on the relatively unstable air masses that prevail in the early part of the rainy season in the eastern Mediterranean.

The next step was to subdivide the total time interval into 10-year periods and in evaluating the corresponding mean seasonal values and the corresponding percentage ever in the periods of 10-years (Table 2). The seasons defined classically, winter (December, January, February), spring (March, April, May) and so on. Table 2 confirms the well-known fact that the maximum precipitation recorded in fall and winter and amounts to about 73% of the total annual amount. Spring is less rainy than winter and the fall, while the summer is dry, contributed to approximately 6% of annual precipitation.

As shown in Figure 2, by the exception of a decrease of precipitation in 1958, no significant change was observed in the NOA annual precipitation series. The decreasing trends found in the precipitation records of the present study may attribute to atmospheric circulation variations, although no clear explanation could be given. Maheras and Kolyva-Mahera [6] showed that during the 92-year period (1894-1985), no climatic change and climatic trend appeared at NOA station. Amanatidis et al. [10, 11] by examining two precipitation records with different lengths (1926-1990 and 1951-1990, respectively), showed that the precipitation decreases, appeared at NOA station, were statistically insignificant (significance level < 0.05).

TABLE 2 - Seasonal mean precipitation values (mm) and percentages, along with the annual amounts (mm).

ID	Period	Winter	Spring	Summer	Fall	Year
1	1891-1900	147.3 (44.7%)	54.3 (16.5%)	23.9 (7.3%)	103.7 (31.5%)	326.0
2	1901-1910	169.7 (43.0%)	77.4 (19.6%)	40.2 (10.2%)	107.3 (27.2%)	402.2
3	1911-1920	175.0 (41.8%)	79.6 (19.0%)	24.5 (5.9%)	139.3 (33.3%)	414.6
4	1921-1930	174.5 (44.7%)	69.6 (17.8%)	20.0 (5.1%)	126.7 (32.4%)	387.0
5	1931-1940	205.4 (46.7%)	90.4 (20.5%)	29.6 (6.7%)	114.6 (26.1%)	437.1
6	1941-1950	152.2 (43.1%)	69.4 (19.6%)	31.2 (8.8%)	100.5 (28.5%)	362.0
7	1951-1960	147.0 (36.1%)	89.8 (22.1%)	18.1 (4.4%)	152.1 (37.4%)	407.3
8	1961-1970	184.1 (54.4%)	76.2 (19.5%)	15.2 (3.9%)	114.3 (29.4%)	382.4
9	1971-1980	164.7 (40.6%)	86.8 (21.4%)	20.3 (5.0%)	134.1 (33.0%)	407.8
10	1981-1990	133.8 (40.0%)	100.6 (30.0%)	20.0 (6.0%)	80.3 (24.0%)	335.9
11	1991-2000	154.8 (38.1%)	111.6 (27.4%)	21.4 (5.3%)	118.8 (29.2%)	400.0

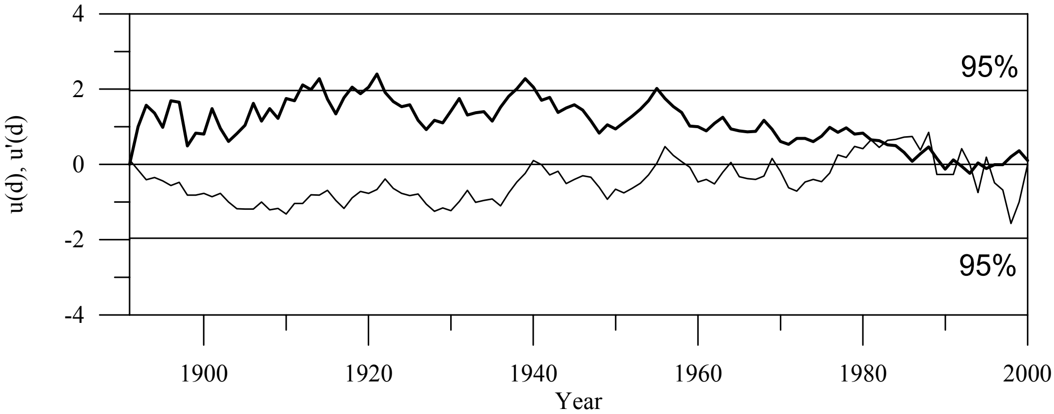

FIGURE 2 - Graphical approach of the Mann-Kendall rank statistic, t (c_1: heavy solid line, c_2: dashed line) of the annual precipitation, at NOA station. Dotted lines indicate the critical values for 0.05 significance level.

Daily precipitation

As we have already mentioned in the methodology section we, also, focused our interest on the annual number of days with “high” precipitation (ANDHP), along with 10-year moving average (Figure 3). If we use the cut-off point of 10 mm of daily precipitation in order to describe the ANDHP levels, we observed that the ANDHP ranged from 3 to 24 (12.69 ± 4.46 days), during the examined period. Using as cut-off point the value of 20 mm, we observed that the total number of days ranged from 0 to 11 (4.51 ± 2.39 days), during the investigating period. Finally, using a more extreme cut-off point, i.e. 30 mm, the ANDHP from 0 to 7 (1.70 ± 1.29 days). It is clear from Figure 3, that ANDHP peaked in the middle 1930s and has been declining since then.

Figure 4 shows the spectral estimates of the cut-off points in consideration in the periods range: infinity-2 years. (The units in the horizontal axis in these figures were originally in lags from 0 to 55. The lags then converted into time, in years, via the relation: time = 2*55/ number of lag, which for lag = 0 gives time = infinity years and for lag = 55, time = 2 years). The straight lines (heavy solid lines) in each figure represent the 95% confidence limits for the spectra. The spectral peaks standing out of their respective confidence limits infer confidence higher than 95% and therefore are of major statistical significance.

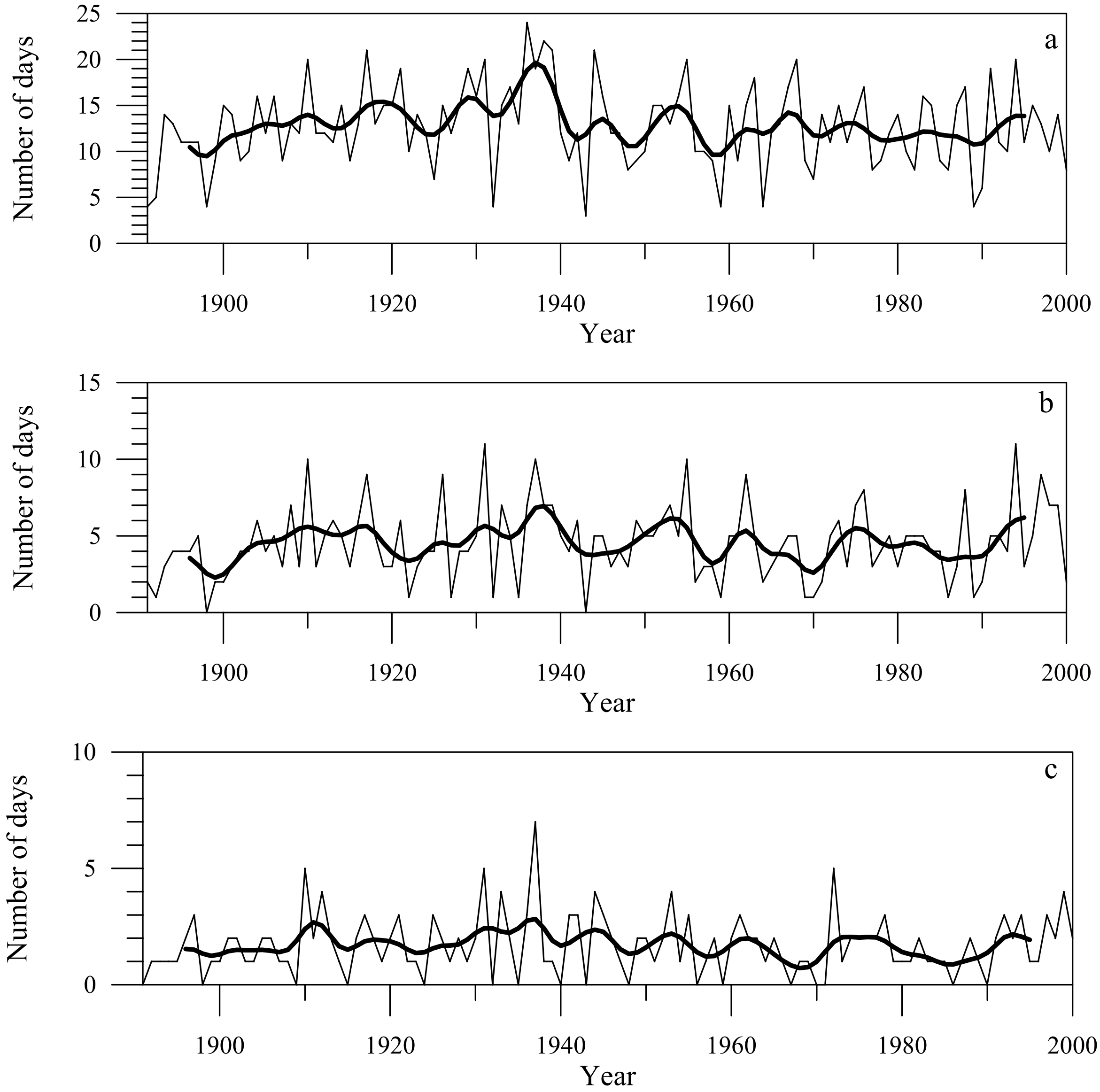

FIGURE 3 - Time series of annual number of days with precipitation greater than or equal to 10 mm (a), 20 mm (b), and 30 mm (c) per day, respectively, at NOA during the period 1891-2000. Smooth curve (bold line) represents a 10-year moving average as for Figure 1.

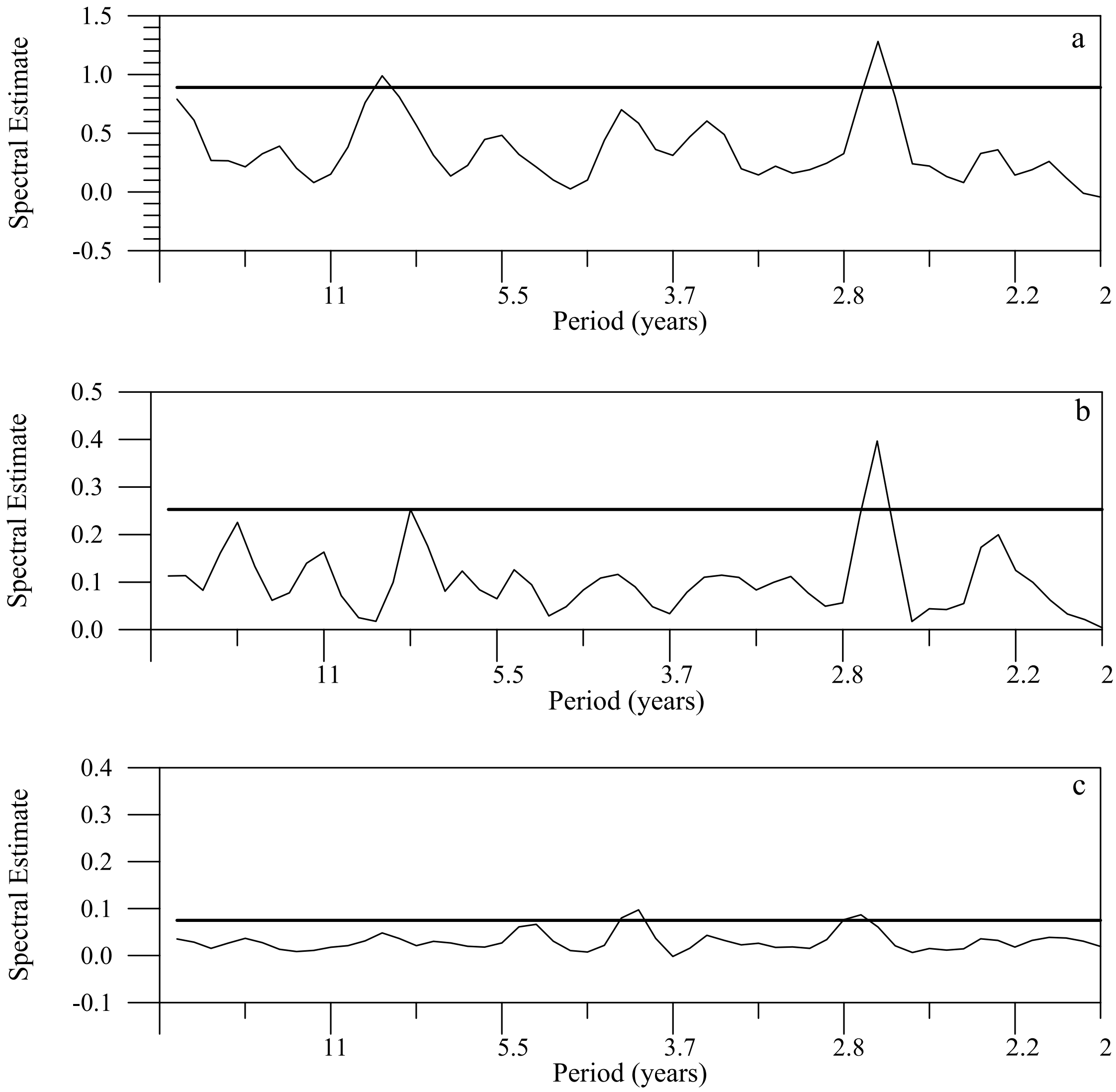

FIGURE 4 - Power spectrum of annual number of days with precipitation greater than or equal to 10 mm (a), 20 mm (b), and 30 mm (c). Straight lines (heavy solid lines) represent 95% confidence limits for the spectra.

Figure 4 shows the results of the application of spectral analysis. Concerning the spectrum of annual number of days with precipitation greater than or equal to 10 mm, 20 mm, and 30 mm, there are peaks significant at 95% confidence limit. Specifically, there are peaks at periods 2.6 and 8.5 years (Figure 4a), there is peak at period 2.6 (Figure 4b), there are peaks at periods 2.7-2.8 and 3.9 - 4.1 years (Figure 4c), respectively. Periodicities among 2-3 years could be related to the well-known quasi-biennial oscillation (QBO), which appeared in the tropics and detected in various meteorological parameters all over the world of the zonal wind. Other researchers have also found the 2-3 year precipitation periodicity in Athens [2, 5, 11]. The southern oscillation (SO) with periodicities among 3 and 5 years attributed to the atmospheric circulation in the tropical and subtropical Indian and South Pacific Ocean only defined in the spectrum of annual number of days with precipitation GE to 30 mm (Figure 4c). Similar periodicities were also found in the past for the eastern Mediterranean region [25], for Greece [11], while Metaxas et al. [26] related the occurrences of dry winters in Greece to extreme SO events. Additionally, periodicity greater than 8 years, which is not clearly related to any astrophysical phenomena - possibly produced by the interaction of the “10-12 year” solar cycle with long-term cycles [27, 28] - is defined in the spectrum of annual number of days with precipitation GE to 10 mm (Figure 4a). Similar periodicities were also found in the past in central Greece [11].

Finally, we assessed the distribution of the total number of days with precipitation GE to 10, 20 or 30 mm, using the Kolmogorov – Smirnov criterion [16]. The analysis showed that the normal distribution describes the total number of days with precipitation GE to 10 mm (Z = 0.664, significance level = 0.770), GE to 20 mm (Z = 0.654, significance level = 0.770). Only the distribution of the total number of days with precipitation GE to 30 mm declines from the previous observation (Z = 2.079, significance level = 0.001).

CONCLUSIONS

The study of precipitation, in the Athens area for a long time period (1891-2000), has enabled us to characterize the homogeneity, the non-randomness, the tendency, and the temporal distribution for the last 110 years. The analysis revealed the following features.

(i) Data homogeneity and non-randomness are present in the examined time series of annual precipitation values.

(ii) Strong seasonal variation of precipitation (maximum during winter and minimum during summer) observed, which is typical of the Mediterranean climate. Higher precipitation amounts were recorded in fall and winter.

(iii) The trend of the annual precipitation remains, almost, constant, for the whole study period, as well as the numbers of days with high precipitation, i.e. greater or equal to 10, 20, 30 mm per day.

(iv) An increasing trend was found in the transitional season precipitation time series attributed to an urban effect in the precipitation series.

(v) Higher values of total annual precipitation were observed in the 1930s, while in the 1890s and 1980s the lowest values of total annual precipitation were observed.

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