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Stochastic analyses of maximum daily rainfall series recorded at two stations across the Mediterranean Sea

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Abstract Independence, stationarity, homogeneity, trend, and periodicity tests are applied on 48-year-long complete and 79-year-long incomplete maximum daily rainfall series recorded at Alexandria, Egypt, and on 61-year-long maximum daily rainfall series recorded at Antalya, Turkey, which are located at the southeastern and northeastern shores of the Mediterranean Sea. The results indicate no significant trend and no periodicity in mean, and both series are independent and homogeneous. Linear regression trend test applied to the 10 % highest part of the Alexandria series indicated a significant increasing trend. Next, frequency analysis is applied on each of these series by the probability distributions of Gumbel, general extreme-values, three-parameter log-normal, Pearson-3, log-Pearson-3, log-logistic, generalized Pareto, and Wakeby. The distributions, except for the generalized Pareto and Wakeby, pass the χ^2 and Kolmogorov–Smirnov goodness-of-fit tests at 90 % probability. By visual inspection of the plots of histograms together with the probability density functions, and by the results of the χ^2, Kolmogorov–Smirnov, and probability plot correlation coefficient tests, the general extreme-value distribution whose parameters are computed by the method of probability-weighted moments is deemed to be suitable for these two maximum daily rainfall series.

Keywords Maximum daily rainfall · Tests for trend · Independence · Stationarity · Homogeneity · Frequency analysis

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Introduction

Many studies in the last two decades indicate a change in climate in the twentieth century, which is expected to protract into the twenty-first century, caused mainly by release of excessive amounts of greenhouse gasses into the atmosphere since 1970s (e.g., Anderson et al. 2010; IPCC 2007, 2008, 2011; NZCCO 2008; Sen et al. 2012a, b). Yet, a few studies may be found arguing that various mechanisms of the planet will counter the anthropogenic effects somehow (e.g., Ball 1992; Nandargi and Dhar 2011). According to many publications, an increase in extreme precipitation is expected worldwide even at regions where annual average rainfall has a decreasing trend (e.g., Burn et al. 2011; Collins 2009; Douglas and Fairbank 2011; Fujibe et al. 2005; Groisman et al. 2005; Guo 2006; IPCC 2007, 2008, 2011; Kundzewicz et al. 2005; NZCCO 2008).

The Intergovernmental Panel on Climate Change, known by the acronym IPCC, is a unit comprised of experts established by the United Nations to organize evaluations of climate change information. The climatic simulation models such as ECHAM4 of Max Planck Institut für Meteorologie are executed on high-capacity computers with various emissions scenarios, and their effects on future meteorological events are predicted. A comment in chapter 2 of a technical paper by IPCC (IPCC 2008) is: "Theoretical and climate model studies suggest that, in a climate that is warming due to increasing greenhouse gases, a greater increase is expected in extreme precipitation, as compared to the mean. … It is very likely that heavy precipitation events will become more frequent."

In New Zealand, there are laws about the effects of the climate change on public utilities like storm water drainage systems and about the measures to be taken by regional councils and local authorities against those effects (NZCCO 2008). So, for New Zealand, the topic of climate

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change is not an issue to be disputed but rather a fact recognized by law. The effect of climate change on extreme rainfalls is quantified as increases in magnitudes of various return period rainfalls expressed in percentages 50 and 100 years later (e.g., Table 5.2 in NZCCO 2008).

In a recent study by Burn et al. (2011), the Mann–Kendall trend test is applied to annual maximum rainfalls of durations from 1 to 24 h in the State of British Columbia in Canada, and generally increasing trends in these series are detected. Fujibe et al. (2005) investigated the data of extreme rainfalls of three different durations: 1, 4, and 24 h recorded at 8, 46, and 61 stations in Japan, respectively, having continuous record lengths of at least 80 years within the period of 1898–2003 for determination of trends. In conclusion, an increasing trend in extreme precipitation all over Japan is detected.

One notices just a few studies, yet, containing results which express stationarity in floods and extreme rainfalls (e.g., Kundzewicz et al. 2005; Nandargi and Dhar 2011; Villarini et al. 2011). An interesting example is given by Douglas and Fairbank (2011), who, having applied the Mann–Kendall and the linear regression trend tests on annual maximum daily rainfall series recorded at 48 locations in northeastern America with an average record length of 80 years, say: "The trend analysis over the time period 1954–2005 indicated that annual maximum daily rainfall was amazingly stationary; …" They detected trend for the period 1954–2008 only when they included the last 3 years of the recorded data between 2005 and 2008 (Douglas and Fairbank 2011). Similarly, the last sentence of the paper by Nandargi and Dhar (2011) is: "Hence, it is somewhat baffling as to whether climate change has any impact on extreme rainfall events in the entire Himalayan region, especially, in the recent years of the period 2001–2007."

The annual maximum daily rainfall is the maximum of so many daily rainfalls occurring within a hydrologic year. So, in a recorded series of maximum daily rainfalls, there are as many elements as the length of record in years. On the geographical region enclosing the Mediterranean Sea, it is highly unlikely for the atmosphere to produce incessant rainstorms longer than 24 h. Therefore, the rainfall records in those countries flanking the Mediterranean Sea are taken for a maximum period of 1 day. The maximum daily rainfall is the major cause of intense floods in moderate-size and large watersheds, and therefore they deserve special attention. For example, for determination of flood inundation maps in wadis in arid regions as suggested by Sen et al. (2012a), the critical flood peak must be calculated which is dependent on plausible estimation of maximum daily rainfall. The objective of this study is to carry out a stochastic analysis on series of annual maximum daily rainfalls recorded at two important cities on the shores of the Mediterranean Sea, Alexandria in Egypt and Antalya in Turkey, in order to (1) look for a possible trend due to the effect of climate change, (2) check for independence, stationarity, homogeneity, and (3) apply frequency analysis to predict large return-period maximum daily rainfalls.

Materials and methods

Maximum daily rainfall series recorded at Alexandria and Antalya

The second largest city in Egypt, Alexandria, known as "The Pearl of the Mediterranean," has an atmosphere that is more Mediterranean than Middle Eastern; its ambience and cultural heritage distance it from the rest of the country, although it is actually only 225 km from Cairo. Alexandria has an arid climate (climate classification BWh by Köppen and Geiger 1936), but the prevailing north winds, blowing across the Mediterranean, gives the city a different climate from the desert hinterland. The city's climate shows Mediterranean characteristics, namely mild, variably rainy winters and hot summers that, at times, can be very humid; January and February are the coolest months, with daily maximum temperatures typically ranging from 12 °C to 18 °C and minimum temperatures that could reach 5 °C. Alexandria experiences violent storms, rain, and sometimes hail during the cooler months. July and August are the hottest and driest months of the year, with an average daily maximum temperature of 30 °C.

The climate of Antalya (Turkey) is typically Mediterranean, and the rainy season is from November to March. Air temperatures are in the interval of 30 °C–35 °C during the period June through September. December, January, and February are the coolest months, with daytime temperatures averaging about 15 °C and night-time temperatures always well above freezing (http://www.dmi.gov.tr).

Alexandria is located on the southeastern shore of the Mediterranean Sea at coordinates of 31.2°N and 29.92°E. Antalya is a city located at the northeastern shore of the Mediterranean Sea at coordinates of 36.9°N and 30.68°E. The birds-eye distance between them is 633 km, and their longitudinal positions are not too far apart as both are close to the 30°E meridian. Antalya is situated at the northern tip of the Antalya Gulf. The Taurus Mountain Range extends all along from the southwestern end of the Anatolian Peninsula to its southeastern end, paralleling the shoreline from a distance of about 20 to 30 km. There are no similar mountain ranges behind Alexandria, and she is on a fairly plain terrain. The map of this part of the Mediterranean Region is given in Fig. 1. Antalya is subjected to the orographic effects of the sea-ward slopes of 3,000-m-high Taurus Mountains surrounding her from all sides except for the sea direction.

The rainfall gauging at Alexandria started as early as the 1900s. There are two 8-year discontinuities in the data, and

Fig. 1 Map showing the eastern part of the Mediterranean Sea and locations of Alexandria (Egypt) and Antalya (Turkey)

the periods of the available records are: 1900–1947, 1956–1979, and 1988–1994, each one being continuous in itself. All tests are applied on the first 48-year-long segment, but the linear regression test is applied to the series from the beginning till the end, taking into account the chronological positions of the missing years. And, the frequency analysis also is applied to the 79-element total series of Alexandria data. The Antalya data are complete over the period of 1950–2010. Table 1 gives the maximum daily rainfalls data recorded at these two cities.

Tests for trend

The plot of a series of a hydrologic variable versus time over the total length of the observation period is useful for visual investigation. A possible trend, a sudden change, and even a periodicity may reveal themselves by a careful visual observation of the plotted values. So, the figure of the magnitudes of a hydrological event versus time usually provides a qualitative evaluation. About the merit of plots in statistical analysis in general, Helsel and Hirsch (2002, ch. 2) say: "Graphs provide visual summaries of data which more quickly and completely describe essential information than do tables of numbers."

The Mann–Kendall, linear regression, and Spearman's rho tests are commonly applied for detecting trend in hydrologic series (e.g., Burn et al. 2011; Collins 2009; Douglas and Fairbank 2011; Ehsanzade et al. 2010; Fujibe et al. 2005; Groisman et al. 2005; Helsel and Hirsch 2002, ch. 12; Hipel and McLeod 1994, ch. 23; Onoz and Bayazit 2003; Rao et al. 2011; Yue et al. 2002). In this study, the first two of these are applied, being influenced by Yue et al. (2002) who showed that the Spearman's rho test gives results almost the same as the Mann–Kendall test.

Mann–Kendall trend test

The Mann–Kendall (M-K) statistic of a recorded series, which is ordered with respect to years, as originally proposed by

Table 1 Values of the maximum daily rainfalls (in mm) recorded at Alexandria (Egypt) and Antalya (turkey)

Maximum daily rainfalls (in mm) recorded at Alexandria, Egypt

Beginning year: 1900; number of records, 79

28.0	19.0	28.0	22.0	21.0	47.0	28.0	17.0	32.0	30.0	33.0	27.0
13.0	40.0	55.0	10.0	47.0	24.0	18.0	46.0	13.0	18.0	32.0	19.0
27.0	20.0	19.3	53.0	18.0	25.2	35.5	7.7	40.0	32.9	34.5	23.0
18.0	18.0	62.0	18.0	34.6	18.7	12.1	17.6	19.5	23.0	21.8	26.0
–	–	–	–	–	–	–	–	14.6	28.7	20.0	27.8
33.0	24.0	22.3	13.0	28.0	11.8	65.0	15.7	17.0	44.0	53.0	29.7
35.0	28.5	54.3	30.0	15.0	28.0	21.0	10.0	–	–	–	–
–	–	–	–	29.0	38.0	14.0	27.0	97.0	29.0	24.0	

Maximum daily rainfalls (in mm) recorded at Antalya, Turkey

Beginning year: 1950; number of records, 61

99.6	212.9	232.4	139.5	233.2	66.0	163.9	69.0	134.5	145.9	186.6	129.0
122.6	146.0	71.5	151.9	210.1	245.7	155.0	334.5	185.6	94.3	163.2	120.9
283.5	160.7	126.0	170.2	109.7	199.2	152.4	178.3	89.1	105.8	236.1	185.1
120.9	63.7	108.1	131.0	125.7	277.9	155.9	125.3	167.9	428.6	194.0	205.8
184.0	124.7	216.5	253.2	261.9	238.2	220.3	153.3	248.6	117.2	52.4	199.0
128.8											

Kendall (1975), is computed by (e.g., WMO 2009, ch.5):

$$S_{\mathrm{M-k}} = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}\left(x_i - x_j\right) \tag{1}$$

where sign($x_i - x_j$) assumes a value of +1 if $x_i > x_j$ and −1 if $x_i < x_j$, and n is the total number of elements of the series. The variance of $S_{\mathrm{M-K}}$ is given as:

$$\mathrm{Var}(S_{\mathrm{M-k}}) = [n \times (n-1) \times (2n+5)]/18 \tag{2}$$

The expected value of $S_{\mathrm{M-K}}$ is zero for an identically distributed random variable without trend (Kendall 1975). Therefore, the standardized variable given below obeys a standard normal distribution for sufficiently large series.

$$Z = (S_{\mathrm{M-K}} - 0) \Big/ [\mathrm{Var}(S_{\mathrm{M-k}})]^{0.5} \tag{3}$$

If the magnitude of the Z statistic computed by Eq. 3 remains within the interval: $-Z\mathrm{cr} < Z < Z\mathrm{cr}$, where Zcr is the critical value in the standard normal table for a tail probability equaling half of the probability level of rejection initially chosen by the analyst, then the hypothesis that Expectation[$S_{\mathrm{M-K}}$]=0 is true, which means there is no trend. The reason for halving the tail probability is because a two-sided confidence interval is evaluated for the Z statistic. Another way of deciding on the existence of trend by the Mann–Kendall test is to compute the probability of exceedence (Pex) of the Z statistic given by Eq. 3 and check if this Pex is greater or smaller than half of the critical level of probability (Pexcr). If Pex is smaller than Pexcr/2, this will indicate the existence of a trend. For an optimistic view, meaning, an initial tendency for rejecting trend, the critical probability is taken as a small value like 1 %. Conversely, for an analysis tending to accept the existence of trend, a fairly large probability, like 10 %, is assumed. It is noticed that, usually, a critical probability level of 5 % is adopted by relevant studies.

Linear regression trend test

This test is based on the idea that, if there is either an increasing or a decreasing significant trend in the magnitude of the investigated hydrologic variable, then its mean should be either increasing or decreasing with respect to years, and the slope term of the simple linear regression fitted to the chronological values of the recorded series will be statistically significant. In other words, the expected value of the slope coefficient should be different from zero, which means the two-sided confidence interval of the slope coefficient must not comprise zero, in order for a significant trend to exist. The regression line fitted to the variable suspected of having a trend over years is:

$$x = A + B \cdot (\mathrm{time}) \tag{4}$$

Where x is the hydrological variable in concern, maximum daily rainfall in this study, *time* is time in years, which takes on integer values from 1 to n for a complete series, B is the estimate of the population slope term β calculated out of the available recorded series, and A is the estimate of the population intercept α. The essence of this test is to check the hypothesis: if β, which is the Expected value of B ($\beta = E[B]$), is equal to zero? The intercept being zero or not does not affect the existence of trend. Assuming no trend, which means assuming $\beta=0$, the reduced variate in the two-sided confidence interval becomes (e.g., Ross 2004, ch. 9):

$$t = \left\{(n-2) \cdot \left[\sum_{i=1}^{n} (i - aai)^2\right]\right\}^{0.5} \cdot B \Bigg/ \left\{\sum_{i=1}^{n} [x_i - (A + B \cdot i)]^2\right\}^{0.5} \tag{5}$$

Where n is the total number of elements in the recorded series (series length in years), i is the ith year of record, being 1 for the first year regardless of its calendar value, which is the independent variable in the trend test by regression, and aai is the arithmetic average of integer numbers from 1 to n. If the t value computed by Eq. 5 turns out to be smaller than the critical t value taken from the Student's t distribution for half of a critical level of probability of exceedence (Pexcr) and degree of freedom of $n-2$, then the hypothesis that $\beta=0$ is correct, which means there is no trend. Conversely, if Pex of the absolute value of the magnitude of t computed by Eq. 5 given by the Student's t distribution for a degree of freedom of $n-2$ is greater than Pexcr/2, this means there is no trend. Both approaches lead to the same conclusion.

An unpublished study done by the authors in which all these five tests were applied on 175 series of daily maximum rainfalls recorded at rain-gauging stations all over Turkey having record lengths in the interval: $39 \leq n \leq 73$, revealed that both the M-K and linear regression (LR) tests agreed on 145 of these 175 series. The Mann–Kendall test and the other three tests which are summarized below necessarily must be applied on chronologically complete series of recorded hydrologic data. The LR test however can be applied to any series having discontinuities in records, provided that the years of the missing elements are known. This is because the independent variable in the LR model is the years, which are integer numbers from 1 up to the last year minus the first year of record, skipping the integer numbers of the missing years. So, this peculiarity of the LR method is a definite advantage of it over the M-K test for trend detection. Performing the regression computations with the actual numerical values of the years would reveal the same results, but usage of integers from 1 to (n+number of missing years) instead of 4-digit year numbers may be better for numerical stability in intermediate computations.

Tests for independence, stationarity, and homogeneity

In relevant literature, one can find many statistical tests to check for a time series to be independent and identically distributed, stationary, and homogeneous (e.g., Helsel and Hirsch 2002; Kite 1977; Rao and Hamed 2000; WMO 2009). Practically, stationarity means independence from time. A hydrologic variable must be independent, stationary, and homogeneous in order to establish a relationship between its magnitude and its probability of exceedence (or non-exceedence) by applying a probability distribution to it, which is commonly known as frequency analysis. Otherwise, the serial effects need to be separated, the frequency analysis be carried out on the randomized series, and the temporal components be quantitatively superposed. Presence of trend causes deviation from this basic assumption. Significant serial correlation is another effect distorting the temporal independence. All the measured magnitudes of a random variable, which are elements of a sample series, must occur as governed by the same population probability distribution in order for them to be homogeneous. For example, all of the measured flood peaks must ideally be either extreme-rainfall-induced floods or snow-melt runoffs, and not combinations or even superpositions. Possible effect of 11-year sunspot cycles on hydrologic variables may be another cause jeopardizing true randomness. But, such cyclic effects are not detected on extreme quantities like annual instantaneous flood peaks and maximum daily rainfalls, usualy. If for some reason there is a periodic variation in the mean of a hydrologic variable, this deterministic component must be taken into account along with the random rule of the governing probability distribution.

In this study, next to the two trend tests, commonly used tests for independence, stationarity, and homogeneity are also applied, and brief information about them is given below.

Von-Neumann's test for independence

In order to test if the elements of a recorded series are realizations of independent occurrences, von Neumann in 1941 suggested the following statistic, known as von-Neumann's Q statistic (e.g., Bierkens 2006):

$$Q = \sum_{i=1}^{n-1} (x_{i+1} - x_i)^2 \Big/ \sum_{i=1}^{n} (x_i - aax)^2 \qquad (6)$$

Where x_i is the ith element of the sample series and aax is the arithmetic average of the series. Under the assumption that the x_i's are independent, the expected value of the Q statistic is equal to 2, and Q obeys a special distribution, whose critical values are given by Bierkens (2006, ch. 4) for commonly used tail probabilities. Alternatively, for large sample series, Q is approximately normally distributed with mean 2 and variance as given below.

$$\sigma_Q^2 = 4 \cdot (n-2) \Big/ \left(n^2 - 1\right) \qquad (7)$$

Therefore, for fairly large series, comparing the magnitude of the Q statistic computed by Eq. 6 with a critical value from its table yields the same result as comparing the Z statistic below with the critical value from the standard normal table versus a tail probability equaling Pexcr/2.

$$Z = (Q-2) \Big/ \left\{2 \cdot \left[(n-2) \Big/ \left(n^2-1\right)\right]^{0.5}\right\} \qquad (8)$$

Wald–Wolfowitz test for stationarity

In order to test if the elements of a recorded series are realizations of independent and stationary occurrences, as originally proposed by Wald and Wolfowitz in 1943, the following statistic, known as Wald–Wolfowitz's R statistic is suggested (e.g., Rao and Hamed 2000, ch. 1; WMO 2009, ch. 5).

$$R = \sum_{i=1}^{n-1} x_i \cdot x_{i+1} + x_1 \cdot x_n \qquad (9)$$

R is normally distributed with mean and variance given below.

$$\mu_R = \left(S_1^2 - S_2\right)/(n-1) \qquad (10)$$

$$\sigma_R^2 = \left(S_2^2 - S_4\right)/(n-1) - \mu_R^2 + \left(S_1^4 - 4\,S_1^2 S_2 + 4\,S_1 S_3 + S_2^2 - 2\,S_4\right)/(n-1)/(n-2) \qquad (11)$$

Where the terms S_j's are defined as $S_j = n \cdot MO_j$, in which MO_j is the jth moment with respect to the origin of the sample series, and μ_R and $\sigma_R{}^2$ are the mean and variance of R. Hence, the standardized variate is computed by

$$Z = (R - \mu_R)/\sigma_R \qquad (12)$$

If the magnitude of the Z statistic is smaller than the critical value (Zcr) given by the standard normal distribution for an exceedence probability equaling Pexcr/2 (Z<Zcr), then the null hypothesis is true and the series is assumed to be stationary. Or, if the exceedence probability of the absolute value of Z (Pex) is greater than half of the test exceedence probability (Pex>Pexcr/2), then the series is stationary. Both ways give the same result.

Mann–Whitney test for homogeneity

In order to test if the elements of a recorded series are realizations obeying the same population probability distribution, as originally proposed by Mann and Whitney in 1947, the following statistic, known as Mann–Whitney's U statistic is suggested (e.g., Rao and Hamed 2000, ch. 1; Helsel and Hirsch 2002, ch. 12; WMO 2009, ch. 5). First, the sample series is split into two pieces, such that $p \leq q$, p and q denoting the lengths of the first and the second parts, and next the original series is ranked in ascending order. Obviously, $p+q=n$. Secondly, the summation of the rank numbers of the first half of the series is computed, which is denoted by R. Thirdly, V and W statistics are computed as follows.

$$V = R - [p(p+1)]/2 \tag{13}$$

$$W = p \cdot q - V \tag{14}$$

V gives the number of times an element in the first segment follows an element of the second segment as both are in their original order. The magnitude of the Mann–Whitney's U statistic is the smaller one of V and W. For a series having more than 20 elements, U is approximately normally distributed with mean and variance given below.

$$\mu_U = p\,q/2 \tag{15}$$

$$\sigma_U^2 = p\,q \Big/ [n(n-1)] \left\{ \left[\left(n^3 - n \right)/12 \right] - \sum_{j=1}^{k} \left(T_j^3 - T_j \right)/12 \right\} \tag{16}$$

Here, T_j is the number of elements tied at the jth rank whose magnitudes are equal to each other, and k is the number of tied groups in the total ranked series. If there are m equal elements at any rank (m ties), then the arithmetic average of m integer rankings is ascribed to each one as its rank number. Hence, the standard variate is computed by

$$Z = (U - \mu_U)/\sigma_U \tag{17}$$

If the magnitude of the Z statistic computed by Eq. 17 is smaller than the critical value (Zcr) given by the standard normal distribution for an exceedence probability equaling Pexcr/2 (Z<Zcr), then the null hypothesis is true and the series is assumed to be homogeneous. Or, if the exceedence probability of the absolute value of Z (Pex) is greater than Pexcr/2 (Pex>Pexcr/2), then the series is homogeneous. Both ways give the same result.

The Mann–Whitney test is also applied to two sample series to check whether they can be assumed to come from a common population probability distribution. Assuming the lengths of the two series are p and q, the one having the shorter length becomes the first series, and the combined series having $p+q(=n)$ elements is then ranked in ascending order. In this case, R equals the summation of the rank numbers of the first series in the combined series. The rest of the computations and analyses are the same as above. The result in this case is the decision that the two sample series can be assumed to have a common probability distribution if the null hypothesis is accepted.

Spectral density plot for sun-spot effect periodicity

Assuming an annual hydrologic variable, like annual flows at a section of a natural stream, instantaneous maximum flow rate in a hydrologic year, the greatest one of so many tr-minute-duration rainfalls occurring within a hydrologic year period at a geographical location, etc., exhibits a deterministic periodic behavior in mean being affected by a few harmonics, the Fourier series depicting the periodic cycling of the mean can be written as (e.g., Kottegoda 1980, ch. 2; Yevjevich 1972, ch. 3)

$$\mu_t = \mu + \sum_{i=1}^{P/2-1} \alpha_i \sin(2\pi\, i\, t/P) + \sum_{i=1}^{P/2-1} \beta_i \cos(2\pi\, i\, t/P) \tag{18}$$

Where i's are harmonics, t is time in years, α_i and β_i are Fourier coefficients, and P must be even.

The quantity known as the spectral density is defined as (e.g., Kottegoda 1980, ch. 2; Yevjevich 1972, ch. 3):

$$S_k = \left[1 + 2 \sum_{j=1}^{M} r_j \cos(\pi\, k\, j/M) \right] /M,\ k = 1, 2, \ldots, M \tag{19}$$

Where M is a truncation point corresponding to the limiting frequency, and r_j is the j-lagged sample serial correlation coefficient, which is computed by the classic equation below.

$$r_j = \text{Covariance}\left(x_i, x_{i-j}\right) \Big/ \left\{ \left[\text{Variance}(x_i) \text{Variance}\left(x_{i-j}\right) \right]^{0.5} \right\} \tag{20}$$

Next, S_k is smoothed by the below equation, which is known as the Hanned spectral density, after J. von Hann, who suggested it originally.

$$S*_k = S_{k-1}/4 + S_k/2 + S_{k+1}/4 \tag{21}$$

The plot of $S*_k$ versus frequency $(f = 1/(2M/k), k = 1, 2, \ldots, M.)$ reveals sharp jumps for frequency values at which the series investigated has significant periodicity. For serially independent series, however, the $S^*_k - f$ plot exhibits a shape of irregularly zigzagging ups and downs in a fairly narrow band (various examples are given in Kottegoda 1980, ch. 2 and Yevjevich 1972, ch. 3). If the peaking values of an $S^*_k - f$ plot protrudes above the upper bound of the p% confidence interval ($C.I._{ub}$), then this means at that frequency and at the corresponding period there is significant periodicity of the investigated random variable. Usually, $p=90$ %, or 95 %, or 99 %, depending on the choice of the analyst. It has been shown that the quantity $\nu \cdot S^*_k$ is a random variable obeying a Chi^2 (χ^2) distribution with a degree of freedom of $\nu=(2.67)\cdot n/M$ (e.g., Kottegoda 1980, Ch. 2). Hence, by the classic confidence interval expression, the magnitude of the upper bound of the p% confidence interval is estimated by the below equation (e.g., Kottegoda 1980, ch. 2; Yevjevich 1972, ch. 3).

$$C.I._{ub} = \chi_{cr^2}/\mathrm{v} \tag{22}$$

Where, χ_{cr}^2 is the quantile of the random variable obeying the χ^2 distribution with a degree of freedom of ν having an exceedence probability of $(1-p)/2$ % for a p% confidence interval.

Results and discussion

Results of the trend, independence, homogeneity, and stationarity tests and discussion

All the tests considered in this study necessitate chronologically complete recorded series, the LR trend test being an exception to this rule. Therefore, the LR test for the Alexandria series is applied in two different manners in this study. First, the longest complete part, which is the first 48-year segment, is used together with the Antalya series for all the five tests of trend, independence, homogeneity, and stationarity, whose results are given in Table 2 with a critical probability level of 5 % (Pexcr=5 %). And next, the LR test was applied also on the 79-year-long series of Alexandria having two 8-year gaps between 1948 through 1955, and 1980 through 1987 (inclusive), whose results are given in Table 3. As seen in Table 2, the Antalya series is trend-free, independent, stationary, and homogeneous, and as can be seen by the numerical results, these are true even for Pexcr= 10 % also. While the 48-year-long complete part of the Alexandria series passes four of these five tests, it is not stationary according to the Wald–Wolfowitz test. Most relevant studies use 5 % probability for these tests. Choosing 1 % probability would increase the chance of decision for no-trend, independence, stationarity, and homogeneity, and naturally, the number of series investigated in a geographical region passing the tests increases with a choice of Pexcr=1 %. This is true with the Alexandria series also, which passes the Wald–Wolfowitz test at 1 %, while failing it at 5 %. According to Table 3, there is no significant trend in mean of the Alexandria maximum daily rainfalls even for Pexcr=10 %.

Figures 2 and 3 show the plots of the maximum daily rainfalls versus years recorded at Alexandria and Antalya. Visual inspection of Figs. 2 and 3 when they had the plots of the measured elements of the recorded series versus years only might suggest slightly increasing trend. The quantitative results of both the M-K and the LR tests, however, indicated no significant trend in both, even for Pexcr= 10 %. In short, both the 79-element maximum daily rainfalls series of Alexandria and 61-element series of Antalya exhibit no significant trend in mean, but the lines of these insignificant trends in means are still shown in Figs. 2 and 3.

Being influenced by (1) the comments in various relevant publications referred to in the "Introduction" section about an increasing trend in extreme precipitation being expected worldwide and by (2) the appearances of the plots of the measured points in Figs. 2 and 3, another linear regression test is applied to the extremes of the recorded elements. With this purpose, those elements of a recorded series which are greater than or equal to the quantile having approximately a 10-year return period (T) are chosen. Assuming the recorded series is fairly long, the classical California plotting position formula, which is $T \approx n/j$, where j is the rank number of the jth element in the series ordered in descending sequence and n is the total number of elements of the series (sample length), is used to separate those elements of the series having exceedence probabilities equal to or smaller than 10 % (Pex≤0.10). In other words, the element whose rank number is closest to $(0.1)\cdot n$ is determined, and those elements greater than or equal to it are separated as extreme events of the recorded series. Table 4 gives the results of the linear regression applied on six greater elements of the Antalya series and the results of that applied on nine greater elements of the Alexandria series, according to which the regression to the nine extreme elements of the 79-element Alexandria series indicates a highly significant increasing trend. This result concurs with the general comments about an increasing trend in extreme precipitation expected worldwide for Alexandria (Egypt). A similar result does not exist for Antalya, however, and the linear regression applied to the six greater elements of the 61-element Antalya series indicates no significant trend. The city of Antalya being located at the edge of Antalya Bay (Fig. 1) surrounded by high mountains from three sides may have reduced the impact of global climate change on Antalya maximum daily rainfall patterns and may have caused the rainfalls to be heavily affected by local, mainly orographic, conditions.

Table 2 Results of the Mann–Kendall and linear regression trend tests, von-Neumann independence, Wald–Wolfowitz stationarity, and Mann–Whitney homogeneity tests applied on the maximum daily rainfalls (in millimeters) series recorded at Alexandria (Egypt) and at Antalya (Turkey)

Maximum daily rainfalls (mm) recorded at Alexandria, Egypt
The number of elements in this series=48
Result of the Mann–Kendall trend test:
The M-K statistic and its standard deviation=101, 112.51
The standardized variate=0.898 and its tail probability=18.5 %
There is no trend because 18.5>2.5
Result of the linear regression trend test:
The coefficients of the linear regression: $X=A+B$*time are A=29.24, B=−0.094 correlation coefficient=−0.109
The t statistic of B=−0.742 and its tail probability=23.1 %
There is no trend because 23.1>2.5
Result of the von-Neumann independence test:
For a probability of 5 % the series is independent because von-Neumann's Q statistic is>the critical value 2.615>1.5351
Result of the Wald–Wolfowitz stationarity test:
The W-W statistic, its mean and SD are=0.32658E+05, 0.34650E+05, 0.97391E+03
The standardized variate=−2.045 and its tail probability=2.0 %
The series is not stationary because 2.0<2.5
Result of the Mann–Whitney homogeneity test:
The M-W statistic, its mean, and SD are=259.0, 288.00, 48.44
The standardized variate = −0.599 and its tail probability = 27.5 %
The series is homogeneous because 27.5>2.5

Maximum daily rainfalls (mm) recorded at Antalya, Turkey
The number of elements in this series=61
Result of the Mann–Kendall trend test:
The M-K statistic and its standard deviation=−207, 160.70
The standardized variate=1.288 and its tail probability = 9.9 %
There is no trend because 9.9>2.5
Result of the linear regression trend test:
The coefficients of the linear regression: $X=A+B$*time are A=149.53 B=0.630 correlation coefficient=0.162
The t statistic of B=1.258 and its tail probability=10.7 %
There is no trend because 10.7>2.5
Result of the von-Neumann independence test:
For a probability of 5 % the series is independent because von-Neumann's Q statistic is>the critical value, 1.803>1.5834
Result of the Wald–Wolfowitz stationarity test:
The W-W statistic, its mean, and SD are=0.17714E+07, 0.17387E+07, 0.35536E+05
The standardized variate=0.920 and its tail probability=17.9 %
The series is stationary because 17.9>2.5
Result of the Mann–Whitney homogeneity test
The M-W statistic, its mean, and SD are=423.5, 465.00, 69.32
The standardized variate=−0.599 and its tail probability=27.5 %

Table 3 Result of the linear regression trend test applied on all 79-element maximum daily rainfall series of Alexandria

The number of elements in this series=79
Result of the linear regression test:
The coefficients of the linear regression $X=A+B$*time are A=25.639, B=0.0561; correlation coefficient=0.106
The t statistic of B=0.930 and its tail probability=17.8 %
There is no trend because 17.8>2.5

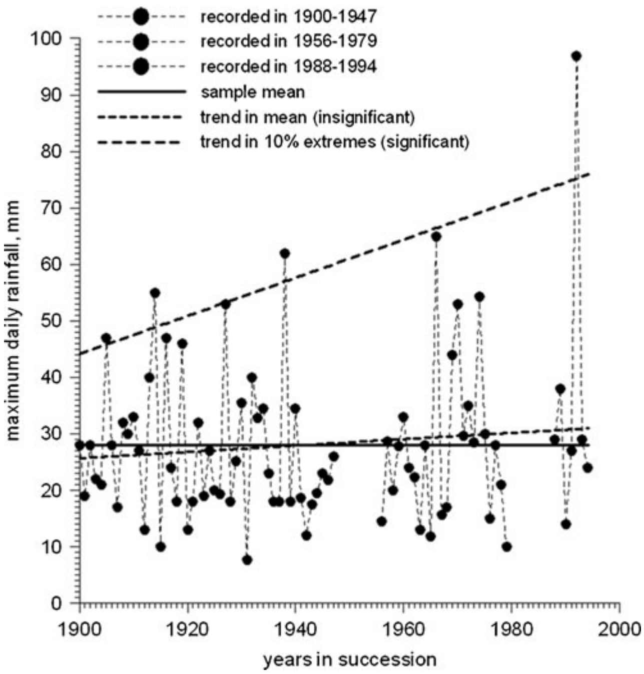

Fig. 2 Plots of (1) recorded maximum daily rainfall values at Alexandria (Egypt) over the period: 1900–1994, (2) sample mean of 79-element series, (3) trend line for the sample mean, which is statistically insignificant, (4) trend line for the quantiles having exceedence probabilities smaller than 10 %, which is statistically significant

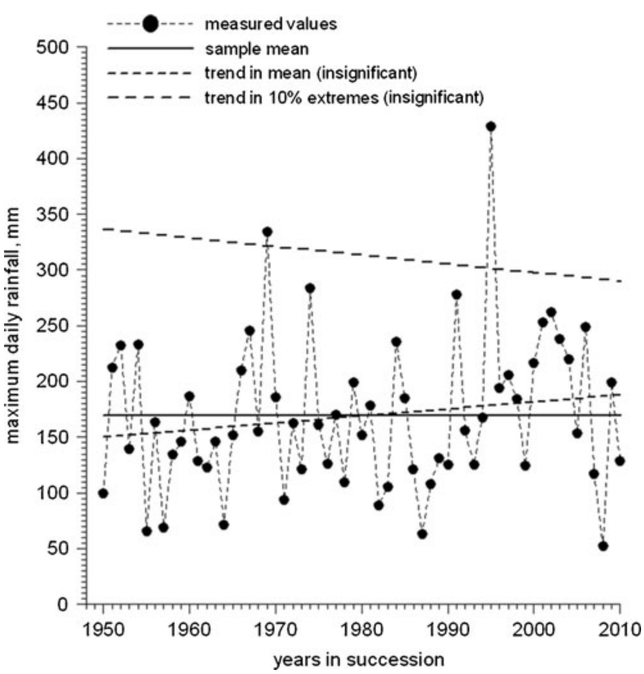

Fig. 3 Plots of (1) recorded maximum daily rainfall values at Antalya (Turkey) over the period: 1950–2010, (2) sample mean of 61-element series, (3) trend line for the sample mean, which is statistically insignificant, (4) trend line for the quantiles having exceedence probabilities smaller than 10 %, which is statistically insignificant

Next to the five tests applied individually on these two series, the Mann–Whitney homogeneity test was also applied to the combined series of the first part of Alexandria plus Antalya. Because the length of the first complete portion of the Alexandria data set is shorter than the length of the Antalya set, in combination, the 48-element Alexandria series was taken as the first series to which the 61-element Antalya series was attached as the ensuing second series. Actually, the 48 elements of the Alexandria series were divided by its arithmetic average, and the 61 elements of the Antalya series were divided by its arithmetic average prior to combining the two series, which is the regular procedure of this test actually. And by the symbols used herein, with two series of lengths p=48 and q=61, the Mann–Whitney homogeneity test was applied to this combined series of length n=p+q=109 also. As given in Table 5, according to the Mann–Whitney homogeneity test, the maximum daily rainfall series recorded at Alexandria and Antalya, although their means are appreciably different from each other, can be assumed to come from a common population probability distribution.

Spectral density plots for possible periodicity for sun-spot effect

The Hanned spectral density (S^*_k) versus frequency ($f = 1/(2M/k),\ k = 1, 2, \ldots, M$) relationship is computed separately for the 61-element Antalya maximum daily series and for the 48-element complete part of Alexandria series as summarized in the pertinent subsection above, with the purpose of detecting any possible period close to 11 years. Kottegoda (1980) recommends an integer value between n/10 and n/5 for M, which are 6 and 12 for Antalya, and 5 and 10 for Alexandria, respectively. Here, M is taken as 11 for both Alexandria and Antalya. Figures 4 and 5 show the diagrams of these relationships. Other values for M, up to 22, are also tried and the resultant diagrams are observed, which exhibit similar appearances. From Figs. 4 and 5, it is clear that there is no periodicity for a period about 11 years, whose frequency is f≈0.091, for both Antalya and Alexandria. For Alexandria, however, the spectral density diagram makes a small perturbation above the upper bound of 95 % confidence interval at a frequency of (1/2.7). Theoretically, this would suggest a periodicity with a period of 2.7 years. Because the extension of the spectral density line above the upper bound is not too high and because 2.7 is not a reasonable number like 3 or 4 years, it is believed that this slight perturbation cannot be taken as revelation of a serious periodicity. In a similar study, Iqbal et al. (2011) also found no periodicity related to the 11-year sun-spot cycles on rainfall series recorded at various cities in Pakistan.

Table 4 Results of the linear regression trend tests applied on those parts having elements with exceedence probabilities smaller than 10 % of the maximum daily rainfalls series of Alexandria (Egypt) and of Antalya (Turkey)

Maximum daily rainfalls (mm) recorded at Alexandria, Egypt
The number of elements in this series=79
The linear regression test is repeated on the truncated series
The truncation value is the magnitude of the quantile of the series having a probability of exceedence of approximately 0.10, which is=47.0 for this series. Hence, the elements and their dates of the truncated series are 1905, 47.0, 1914, 55.0, 1916, 47.0, 1927, 53.0, 1938, 62.0, 1966, 65.0, 1970, 53.0, 1974, 54.3, 1992, 97.0
The number of elements in the truncated series=9
Result of the linear regression test on the truncated series:
The coefficients of the linear regression $X=A+B$*time are A=43.828, B=0.3378, correlation coefficient=0.691
The t statistic of the slope coefficient=4.488
The tail probability of this t statistic=0.0 %
There is increasing trend because the slope coefficient is positive and 0.0<2.5
Maximum daily rainfalls (mm) recorded at Antalya, Turkey
The number of elements in this series=61
The linear regression test is repeated on the truncated series
The truncation value is the magnitude of the quantile of the series having a probability of exceedence of approximately 0.10, which is=253.2 for this series. Hence, the elements and their dates of the truncated series are 1969,334.5, 1974, 283.5, 1991, 277.9, 1995, 428.6, 2001, 253.2, 2002, 261.9
The number of elements in the truncated series=6
Result of the linear regression test on the truncated series:
The coefficients of the linear regression $X=A+B$*time are A=337.397, B=−0.7764 correlation coefficient=−0.164
The t statistic of B=−1.148 and its tail probability=2.8 %
There is no trend because 12.8>2.5

Plots of histograms of the recorded series together with the probability density functions of candidate probability distributions

Although a flood peak or a maximum daily rainfall having an average return period (T) of 100 years sounds to be a hydrologic event of very extreme nature, actually it is not. For example, the probability of occurrence of a 100-year-return-period flood at least once at a hydraulic structure having an economical life of 100 years is 63 % and not 1 %. Therefore, in hydrologic design, estimation of extreme hydrologic events having return periods much greater than 100 years, like 10,000 years, and even longer, is often needed especially for important structures. For example, in Chapter 5 of a relevant report by the World Meteorological Organization (WMO 2009), it is stated that: “Design problems generally require information on very rare hydrological events, namely those with return periods much longer than 100 years.” Because the probability of exceedence (Pex) of maximum daily rainfalls at a location, for example, equals the inverse of the chosen

Table 5 Result of the Mann–Whitney homogeneity test applied on the maximum daily rainfalls (in millimeters) recorded at Alexandria (Egypt) and Antalya (Turkey)

Mann–Whitney test for checking if two sample series can be assumed to have a common population probability distribution
The first sample series is: Maximum daily rainfalls (mm) recorded at Alexandria, Egypt
Length, arithmetic average, variation coefficient, and skewness coefficient of the first sample series are p=48, AA=2.6925E+01, VC=0.452, SC=1.023
The second sample series is: Maximum daily rainfalls (mm) recorded at Antalya, Turkey
Length, arithmetic average, variation coefficient, and skewness coefficient of the second sample series are q=61, AA=1.6906E+02, VC=0.409, SC=1.039
Results of the Mann–Whitney homogeneity test:
The M-W statistic, its mean, and SD are=1397.0, 1464.00, 163.81
The standardized variate=−0.409 and its tail probability=34.1 %
The two series are homogeneous because 34.1>2.5

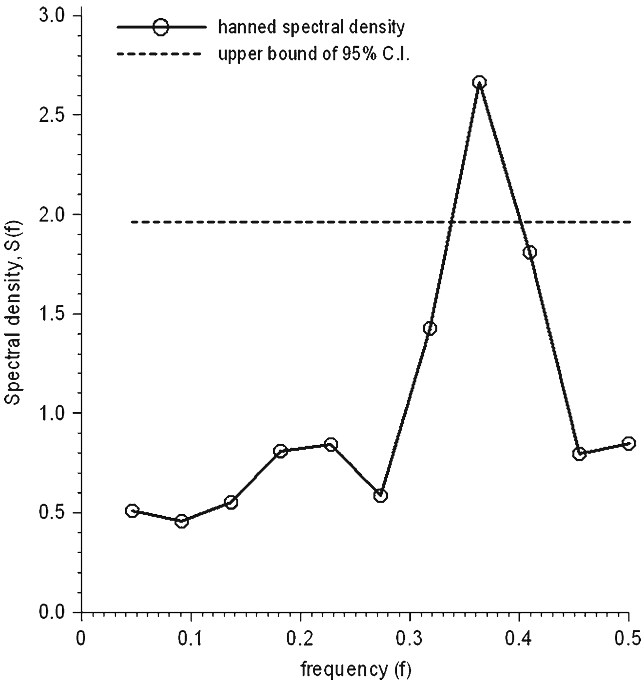

Fig. 4 Plot of Hanned spectral density for the 48-element complete part of the maximum daily rainfall values recorded at Alexandria (Egypt) over the period: 1900–1947

average return period (Pex$=1/T$) and the right-tail part, even the far right-tail part, of its density function of the chosen probability distribution has the governing effect on the extreme quantile. The plot of the histogram of the recorded series together with the plots of the scale-adjusted density functions of the candidate probability distributions gives a visual evaluation as to the suitability of the distributions to the measured series within its recorded range, which is a commonly applied practice of comparing candidate distributions, and many package computer programs provide these plots. Nevertheless, because the right-tail behavior of a probability distribution is more important on the magnitude of large return period events, it is commonly argued that the overall matching of a density function to the observed histogram in the recorded range cannot reflect the goodness of a probability distribution in estimating right-tail quantiles. Yet, both such a plot and its quantitative version, the χ^2 goodness-of-fit test, are still commonly used in helping to decide on a suitable probability distribution (e.g., Rao and Hamed 2000; Seckin et al. 2010). Briefly, the χ^2 goodness-of-fit test quantitatively compares the histogram of the recorded series with the histogram of the series of the same length given by a candidate probability distribution within the range of the recorded series. The histograms of the observed series are drawn concurrently with scale-adjusted density functions of the probability distributions considered. Because a distribution with different magnitudes for its parameters is actually another distribution, there are around 30 different distributions in this study. Drawing all of them on the same figure will create congestion and therefore, these plots are drawn with a few of them in one graph. Figure 6 shows the histogram of the 79-element maximum daily rainfall series recorded at Alexandria, and Fig. 7 shows the same information for the 61-element Antalya series. As

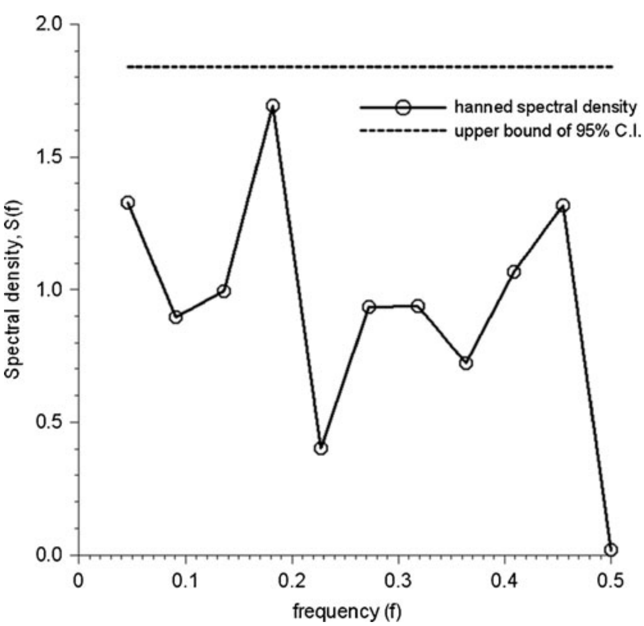

Fig. 5 Plot of Hanned spectral density for the 61-element (complete) series of the maximum daily rainfall values recorded at Antalya (Turkey) over the period: 1950–2010

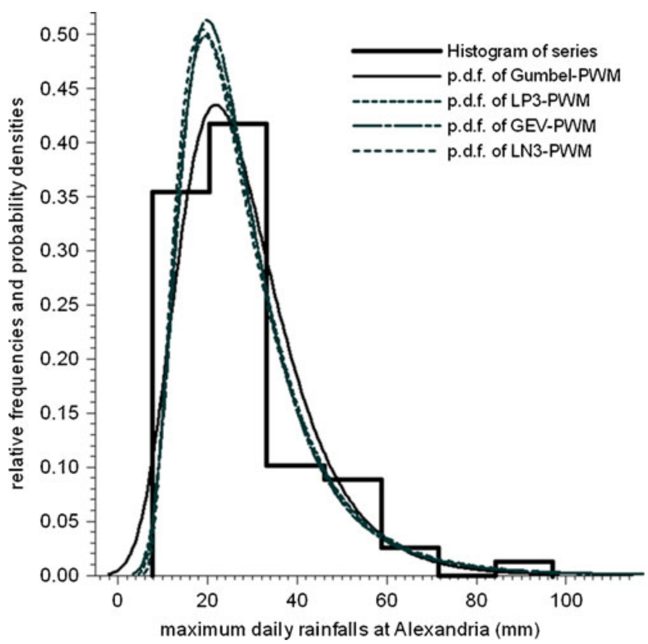

Fig. 6 Plots of (1) the *histogram* of the 79-element series of the maximum daily rainfalls recorded at Alexandria (Egypt), and (2) scale-adjusted probability density functions of the probability distributions deemed suitable in this study based on goodness-of-fit tests

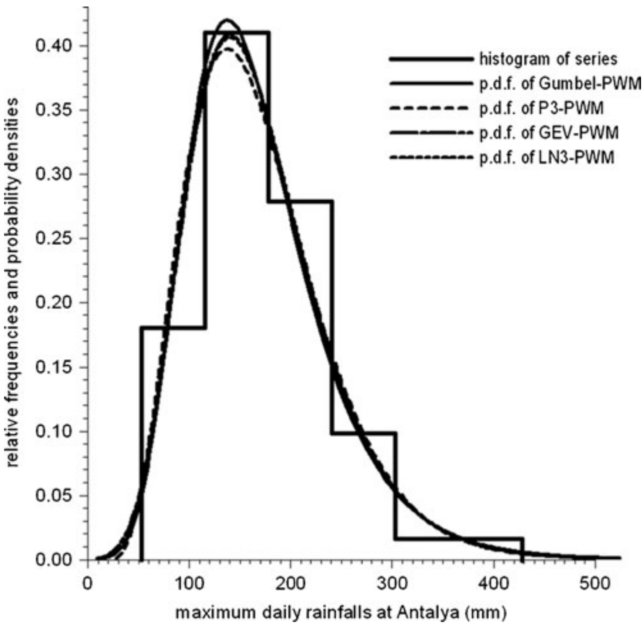

Fig. 7 Plots of (1) the histogram of the 61-element series of the maximum daily rainfalls recorded at Antalya (Turkey) and (2) scale-adjusted probability density functions of the probability distributions deemed suitable in this study based on goodness-of-fit tests

seen by the results presented so far, although they are on the northern and southern shores of the Mediterranean Sea at close longitudinal distance to each other, the sample means of these two series are much different from each other. This is probably because Alexandria is in an arid region on a fairly plane terrain whereas Antalya is in a humid region with a lot of orographic effect of 3,000-m-high Taurus Mountains surrounding Antalya.

Plots of sample L-kurtosis coefficient (L-KC) versus L-skewness coefficient (L-SC) together with theoretical plots L-KC versus L-SC of some probability distributions

A recent approach for choosing a suitable probability distribution for regionalized frequency analyses by the L-Moments method as developed by Hosking and Wallis (1997) depends on evaluation of closeness of the plotted points of sample L-kurtosis coefficients (L-KC) versus sample L-skewness coefficients (L-SC) to the plots of the same L-coefficients of the candidate probability distributions, which seems to have gained popularity (e.g., Karim and Chowdhury 1995; Kumar and Chatterjee 2005; Peel et al. 2001; Saf 2009; Seckin et al. 2011). The closeness of the sample points to the theoretical curves can be observed visually, and the quantitative evaluation of this is done by a statistic symbolized by Z^{DIST}, details of which are given in the book by Hosking and Wallis (1997).

The plot of the population L-KC versus L-SC is a curve for a three-parameter probability distribution, and it is a point for a two-parameter distribution. This plot is a surface and not a curve for a four- or a five-parameter distribution. Because mostly three-parameter distributions are used for hydrologic frequency analysis, however, the comparison of the population curves with the scatter of points plotted by sample L-coefficients is common. The three-parameter distributions of three-parameter log-normal (LN3), general extreme values (GEV), log-logistic (LL), Pearson-3 (P3), and log-Pearson-3 (LP3) are widely used, including this study, and a myriad of publications are available about them (e.g., Cunnane 1989; Rao and Hamed 2000; WMO 2009). Accordingly, the curves of the population L-KC versus L-SC for distributions of LN3, GEV, P3, and LL are drawn herein also and are shown in Fig. 8 along with two points formed by plotting sample L-KC versus L-SC for both Alexandria and Antalya maximum daily rainfall series. As can be seen in this figure, the sample point of Antalya series is close to the curve of the GEV distribution and to the point of the Gumbel distribution. By the classic goodness-of-fit tests of χ^2, Kolmogorov–Smirnov (K-S), and probability plot correlation coefficient, both the GEV and the Gumbel distributions by all four parameter estimation methods performed well. The magnitude of the sample skewness coefficient (SC) of the Antalya series is 1.04, and this is very close to the population SC of the Gumbel distribution, which is 1.14. Interestingly, closeness of the sample and population SCs, results of the classic goodness-of-fit tests, and the L-KC versus L-SC plots all are in agreement for the

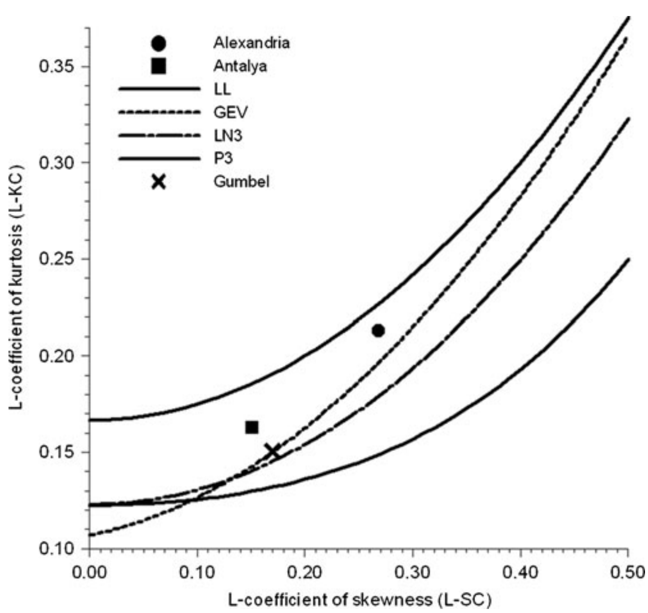

Fig. 8 Plots of (1) the sample L-coefficients of kurtosis versus skewness of the maximum daily rainfalls series of Alexandria (Egypt) and of Antalya (Turkey) and (2) the population L-coefficients of kurtosis versus skewness of four three-parameter probability distributions considered in this study

Antalya series. Because the Gumbel distribution is a special two-parameter version of the three-parameter GEV distribution, however, generally GEV should be preferred over Gumbel. Agreement of the results of the classic goodness-of-fit tests with the closeness of the points of sample L-KC versus L-SC to the curves of population L-KC versus L-SC does not always occur and is not a generalization. As seen in Fig. 8, for the Alexandria series also, the point of sample L-KC versus L-SC is close to the population curve of the GEV distribution. And it is close to the population curve of the LL distribution also.

Frequency analyses

Except for the Wald–Wolfowitz stationarity test on Alexandria series, both series passed all five tests. Hence, it can be concluded that according to the results of relevant tests, both of the fairly long maximum daily rainfall series recorded at Alexandria (Egypt) and Antalya (Turkey) are independent, homogeneous, trend-free, and non-periodic. Hence, classical frequency analyses are applied to both the 79-element maximum daily rainfall series of Alexandria and to the 61-element series of Antalya. Figures 9 and 10 show the frequency curves of quantiles versus average return periods by probability distributions judged herein to be more successful along with the elements of the series plotted by the Cunnane plotting position formula in a Gumbel graph paper.

In a relevant report by the World Meteorological Organization (Cunnane 1989), the probability distributions: Gumbel, LN2, LN3, GEV, LL (the same as generalized logistic), P3, LP3, generalized pareto (GP), and Wakeby are listed as distributions used for frequency analysis of both annual maximum flows and annual maximum rainfalls. In another relevant report by WMO (2009), the Halphen distribution is added to this list. The five-parameter Wakeby distribution is praised and considered as a parent distribution by some statistical arguments (e.g., Bobee and Rasmussen 1995; Hosking and Wallis 1997, p. 205). Because it does not have an analytical probability density function, both the methods of moments and maximum-likelihood are not available for the Wakeby distribution. Expressed by its five parameters, and in some cases four parameters, the quantile function (inverse of the cumulative distribution function) of the Wakeby distribution is suitable for the probability-weighted moments (PWM) method for computing the magnitudes of its parameters (Greenwood et al. 1979; Cunnane 1989). In a similar study, Chargui et al. (2012) applied the two-parameter log-normal and exponential distributions to extreme rainfalls series recorded in central Tunisia. In another similar study, Subyani (2011) applied frequency analyses on annual maximum daily rainfall series recorded at eight stations in western Saudi Arabia region using the Gumbel and log-Pearson-3 distributions and found that the Gumbel distribution was a better fit. In this study, frequency analysis on both the 79-element series of maximum daily rainfalls recorded at Alexandria and 61-

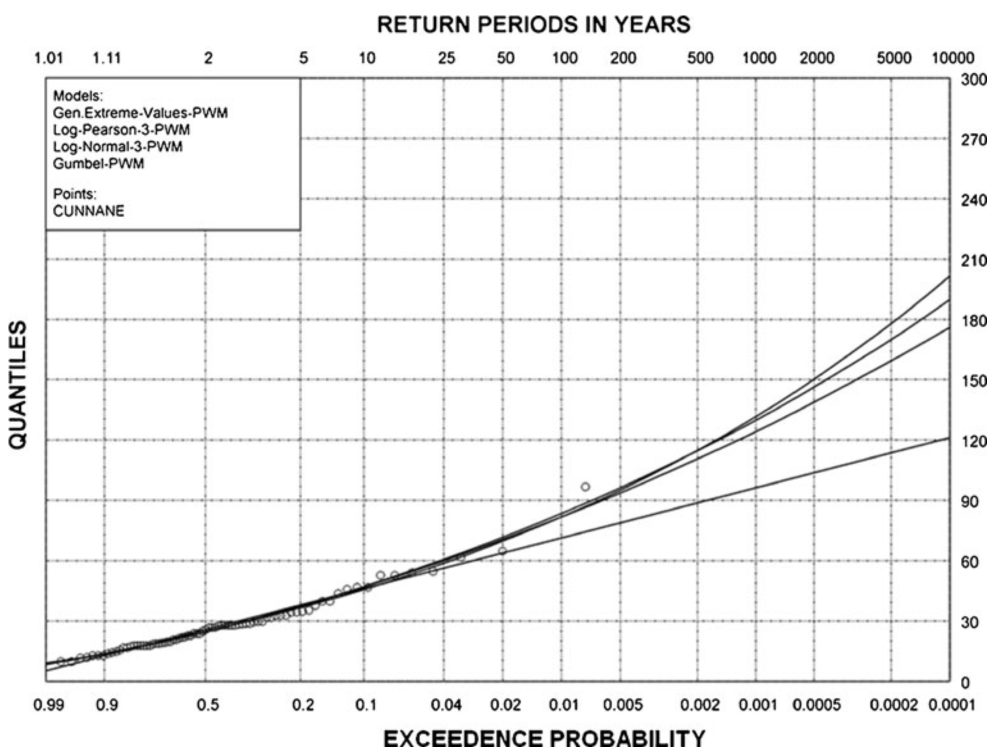

Fig. 9 Frequency curves of those probability distributions deemed suitable for the maximum daily series of Alexandria (Egypt) along with the recorded elements of the series plotted by the Cunnane plotting position formula

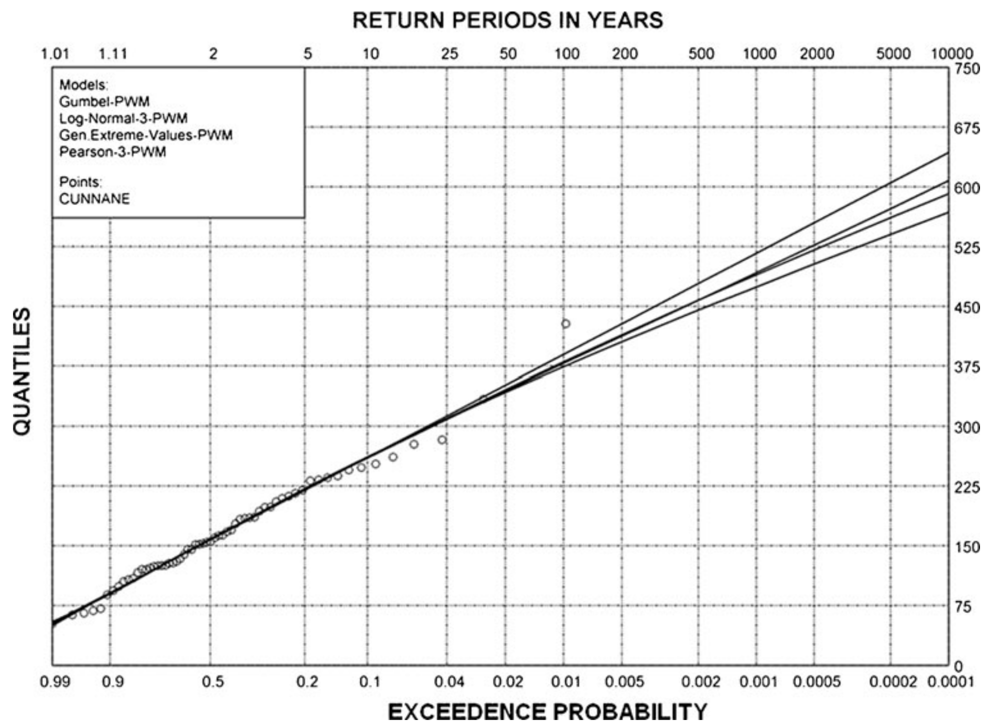

Fig. 10 Frequency curves of those probability distributions deemed suitable for the maximum daily series of Antalya (Turkey) along with the recorded elements of the series plotted by the Cunnane plotting position formula

element series recorded at Antalya is applied using almost all probability distributions recommended by WMO, which are: Gumbel, LN3, GEV, LL, P3, LP3, GP, and Wakeby. The parameters of these distributions are computed by the methods of moments, maximum-likelihood, and PWM, except Wakeby for which only the PWM method is applied by the method presented in Appendix 4 of the report by WMO (Cunnane 1989). Information can be found about these probability distributions and the parameter estimation methods in relevant literature (e.g., Bobee and Rasmussen 1995; Cunnane 1989; Haktanir and Horlacher 1993; Haktanir et al. 2010; Rao and Hamed 2000; WMO 2009). The results of the χ^2 and K-S tests indicate that all distributions except GP and Wakeby pass these goodness-of-fit tests at 90 % probability for the Antalya series and LN3, LL, P3, LP3, and GEV distributions with all parameter estimation methods pass the χ^2 and K-S tests at 90 % probability for the Alexandria series. In a similar study, Iqbal and Ali (2012) found the GEV distribution as the best-fit distribution for annual extreme rainfall series recorded at various cities of the Punjab Region.

Conclusions

According to commonly used statistical tests applied on continuous 48-year-long maximum daily rainfall series recorded at Alexandria (Egypt) and on continuous 61-year-long maximum daily rainfall series recorded at Antalya (Turkey), no trends are detected in both these series. The linear regression trend test applied on the 79-element maximum daily rainfall series recorded at Alexandria from 1900 through 1994 with two 8-year discontinuities in between also indicates no trend in it. But the linear regression test applied to 9 of 79 elements having exceedence probabilities smaller them 10 % indicates a highly significant increasing trend. Spectral density analysis applied on these series does not indicate any periodicity due to 11-year sun-spot cycles. Frequency analyses on these series indicate that the general extreme values probability distribution whose parameters are computed by the method of probability-weighted moments (GEV-PWM) is a suitable model for extrapolating to magnitudes of high return periods.

The sample mean of the maximum daily rainfall series of Antalya is about six times higher than that of Alexandria. These two locations are situated at the northeastern and southeastern shores of the Mediterranean Sea, and both are longitudinally very close to each other being very near to the 30° E meridian. Although they are at the crossing sides of the Mediterranean Sea, Alexandria is in an arid region, while Antalya is in a humid region, being about 633 km away from each other. The strong orographic effect of the 3,000-m-high Taurus Mountains range surrounding Antalya from three sides add considerably to this large difference in means.

The results of the Mann–Kendall and the linear regression trend tests indicate that the “impact of climate change” does not seem to have yet noticeably acted on the means of the maximum daily rainfall series of Antalya and Alexandria. But a statistically highly significant increasing trend in maximum daily rainfalls having return periods 10 years and longer is determined at Alexandria.

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