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Regional daily maximum rainfall estimation for Cekerek Watershed by L-moments

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ABSTRACT: The estimation of maximum daily rainfall (PDmax) is usually required for the estimation of design flood (the maximum flood that any hydraulic structure can safely pass). However, PDmax estimation is usually required for watersheds where rainfall data are either not available or only available in short periods from various sites and so are unsuitable for maximum daily rainfall estimation. In this study, the regional PDmax of the Cekerek watershed in Turkey is estimated using the method of l-moments using 17 rainfall stations in the region. The discordant test for outlier stations showed no discordant station in the region. Applying the homogeneity measure, H_i, the homogeneous region was identified. To find the best regional distribution, the Z^{DIST} goodness-of-fit test was applied. This test introduced two distributions as the candidates for regional parent distributions; Generalized Extreme Values (GEV) and 3-parameter Log Normal (LOGN3) distributions. The LOGN3 distribution was selected as the best regional distribution as it has the smaller absolute value of the statistics (Z^{DIST}) based on the goodness-of-fit-test. Copyright © 2009 Royal Meteorological Society

KEY WORDS PDmax; regionalization; l-moments; GEV; LOGN3; cekerek watershed

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1. Introduction

Extreme events play a key role in atmospheric, climatic and hydrological analysis and have received considerable attention in literature (Coles, 2001). Studying the probability of the distribution of such events has been central to research studies of these extreme events to the present time (Loaiciga and Marino, 1991; Coles, 2001). Considering the probabilistic behaviour of extreme hydrological events is essential in the design of water-related structures, in agriculture, weather modification and monitoring, erosion control and climate change (Svensson and Rakhecha, 1998).

A common problem in hydrology and water resources planning and management is that of estimating the magnitude of rare events such as daily maximum rainfall at sites where maximum rainfall data are either not available or are insufficient for reliable design. Regional frequency analysis uses data from several sites to estimate quantiles of underlying variables, here daily maximum rainfall, at each site in the region of consideration. This analysis, called regional frequency analysis or pooled frequency analysis, involves the identification of the region, or finding the sites that belong to a region, testing the homogeneity of the proposed region and choice of the regional frequency distribution (Sveinsson *et al*., 2002; Durrans and Kirby, 2004). Different methods of regionalization have been developed in the field of hydrology, among which the method of l-moments (Hosking and Wallis, 1997) is the most popular one. Lee and Maeng (2003) estimated the design rainfall through the l-moment approach by using annual maximum daily rainfall from 38 Korean rainfall stations. They considered the generalized extreme value (GEV), generalized logistic (GLO) and generalized pareto (GP) distributions to select appropriate probability distribution fitted to annual maximum rainfalls, and their aptness was judged by using L-moment diagram and Kolmogorov–Smirnov test. The GEV and GLO distributions were decided as appropriate distributions.

Park *et al*. (2001) used the Wakeby distribution (WAD) with the method of l-moment on two time series of annual maxima of daily precipitation and annual maxima of 2-day precipitation at 61 gauging stations over South Korea. Isopluvial maps belonging to the quantiles estimated from the WAD for several return periods were obtained. The l-moments method was applied to fit the regional distribution of annual maximum rainfall in the Tokat region in Turkey, but no significant relationship between rainfall and elevation of the stations was found (Yurekli and Modarres, 2007). Therefore, they first decided to divide the region into two sub-regions but these sub-regions were not homogeneous. Their final decision was three sub-regions. The GEV for the first and third sub-regions and GLO for the second sub-region were determined as

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the best regional distributions. Schaefer (1990) carried out regional frequency analysis of annual maximum rainfall data by using index flood approach and probability weighted moments parameter estimates for the generalized extreme value (GEV) distribution. Climatologically the studied region was defined as homogeneous subregions in terms of mean annual precipitation (MAP). The coefficients of variation and skew belonging to the sub-regions were found to vary systematically with local value of the MAP. Naghavi and Yu (1995) obtained 25 synthesized stations by combining records from 92 rain gauges in Louisiana to provide a long period of records for reliable statistical analysis and identified the three climatologically homogeneous regions in Louisiana. The regional frequency analysis based on l-moment ratios was performed by using the annual maximum series from 25 synthesized stations and was identified the generalized extreme value (GEV) distribution as regional probability distribution. Regional general extreme value (GEV) growth curves based on l-moment approach of k-day extreme precipitation depths at 165 rain gauge stations in Belgium were obtained by Gellens (2002), by considering the periods of the calendar year and hydrologic summer and winter, and determined the at-site fractiles. This was made to extend the 1951–1995 observation period to the 1910–1995 reference period by combining regional approach and data extension procedure based on the fractiles method. It is emphasized that the mentioned procedure using the regional growth curve was efficient to generate missing extremes. Fowler and Kilsby (2003) obtained a generalized extreme value curve based on the l-moment approach for nine defined climatological regions to fulfil regional frequency analysis of 1-, 2-, 5- and 10-day annual maxima for 1961–2000 from 204 sites across the United Kingdom and examined temporal changes in the annual maxima with l-moments by a 10-year moving window and fixed decades. The bootstrap approach was used to assess uncertainty in the decadal growth curve and to define changes in distribution parameters and quantiles. It was concluded that there was a two-part change in annual maximum rainfalls of the mentioned period. Little change for 1 and 2-day annual maxima, and significant change in many regions for 5 and 10-day annual maxima were seen. Di Baldassarre *et al*. (2006) analyzed the annual series of precipitation maxima for storm duration ranging from 15 min to 1 day in northern central Italy by using an approach based on l-moment. The study was showed that there was a significant relationship between the statistical properties of rainfall extremes based on l-moment and the mean annual precipitation. An empirical regional model was developed to estimate the design storm in any location of study area. Casas *et al*. (2007) fitted the maximum daily rainfall annual series from 145 rain gauge stations in Catalonia to the Gumbel extreme value distribution function using the l-moments method of Hosking. They estimated the maximum daily precipitation for each gauge station corresponding to return periods between 2 and 500 years. They concluded that the stable and realistic estimates of daily precipitation with high return periods were provided by Gumbel distribution whose parameters were calculated l-moment, and that the predicted rainfall amounts by l-moment approach was closer to the actual values than from traditional technique (use of Gumbel function with the mean and standard deviation of data series). Lana *et al*. (2006) tested the Gumbel, generalized extreme value (GEV) and generalized pareto (GP) distributions for the series of annual extreme (AE) and

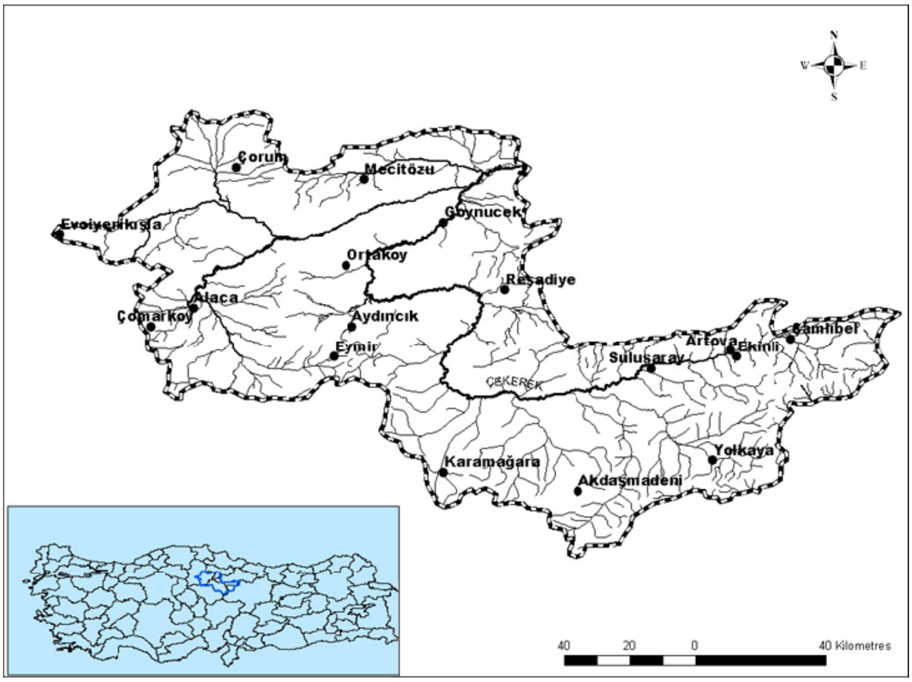

Figure 1. Rainfall gauge station over Cekerek watershed. This figure is available in colour online at www.interscience.wiley.com/ma

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partial duration (PD) constituted by taking into consideration daily rain amount thresholds of 0.1, 1.0 and 5.0 mm day^{-1} for 39 rain gauges in Catalonia (NE Spain). The GEV for AE sampling strategy, the GP for PD sampling strategy were usually much more convenient.

The objective of the present study is to regionalize the annual daily maximum rainfall from the Cekerek watershed and estimate the maximum daily rainfall (PDmax) by using the l-moments method.

2. Cekerek watershed

In the present study, the annual daily maximum rainfall (PDmax) from 17 raingauge stations in the Cekerek watershed, managed by the Turkish State Meteorological Service and General Directorate of State Hydraulic Works, was used (Figure 1). The annual maximum rainfall series for the rain gauge stations in the study were constituted by selecting a value of maximum daily rainfall for each year among daily rainfall depths recorded in the year. As there is lack of data in daily rainfall records of the 17 stations for some years (1988 for Goynucek, 1990 for Aydincik, Akdagmadeni and Artova, 1986 and 1997 for Eymir, 1970 for Evciyenikısla, 1966 for Comarkoy, 1979 for Yolkaya, 1959 for Karamagara, 1989 for Ortakoy, 1967 for Ekinli, 1968 for Zresadiye, 1989, 1990 and 1997 for Sulusaray) these years were not taken into consideration. The Çekerek Stream watershed lies between 39°30′ and 40°45′N and 35°15′ and 36°15′E. This area covers approximately 1 165 440 ha which is about 1.5% of Turkey's total area. The study area is located on the north Anatolia fault line and tectonic movement affects the characteristics of the watershed. The Çekerek Stream is formed by the confluence of small streams that originate from the Kizik, Dinar, Çali and Kavak hills, near the Çamlibel district. The Çekerek Stream is approximately 276 km in length. The stream drains into the Yesilirmak River near Kayabasi. Water quality of the stream is C_2S_1 (low salinity-low sodium) (Anonymous, 1970), which can be used for irrigation purposes for plants with moderate salt tolerance in most cases without special practices for salinity control (Chhabra, 1996).

3. l-moments

Hosking and Wallis (1997) defined l-moments as a linear combination of Probability Weighted Moments

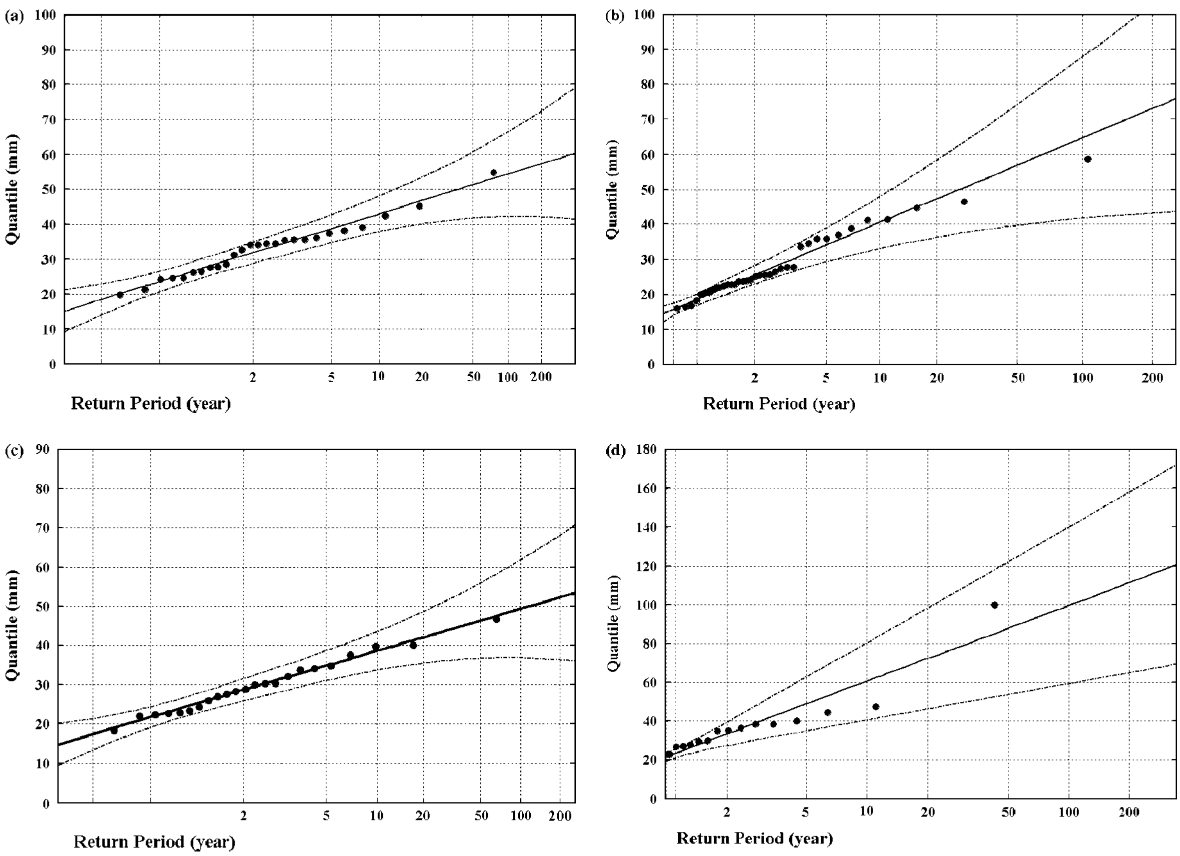

Figure 2. At-site cumulative distribution plotting position of selected stations. The theoretical distribution (solid line) and the upper and lower 95% confidence levels are also shown. (a) Akdagmadeni station, GEV distribution. (b) Alaca station, LOGN3 distribution. (c) Artova station, GEV distribution. (d) Aydincik station, exponential distribution. (e) Camlibel station, GEV distribution. (f) Comarkoy station, EV1 distribution. (g) Corum station, GEV distribution. (h) Ekinli station, EV1 distribution. (i) Evciyenikisla station, EV1 distribution. (j) Eymir station-EV1 distribution. (k) Goynucek station, EV1 distribution. (l) Karamagara station, LOGN3 distribution. (m) Mecitozu station- EV distribution. (n) Ortakoy station- EV1 distribution. (o) Sulusaray station- LOGN3 distribution. (p) Yolkaya station, EV1 distribution. (q) Zresadiye station, Log-Pearson III distribution.

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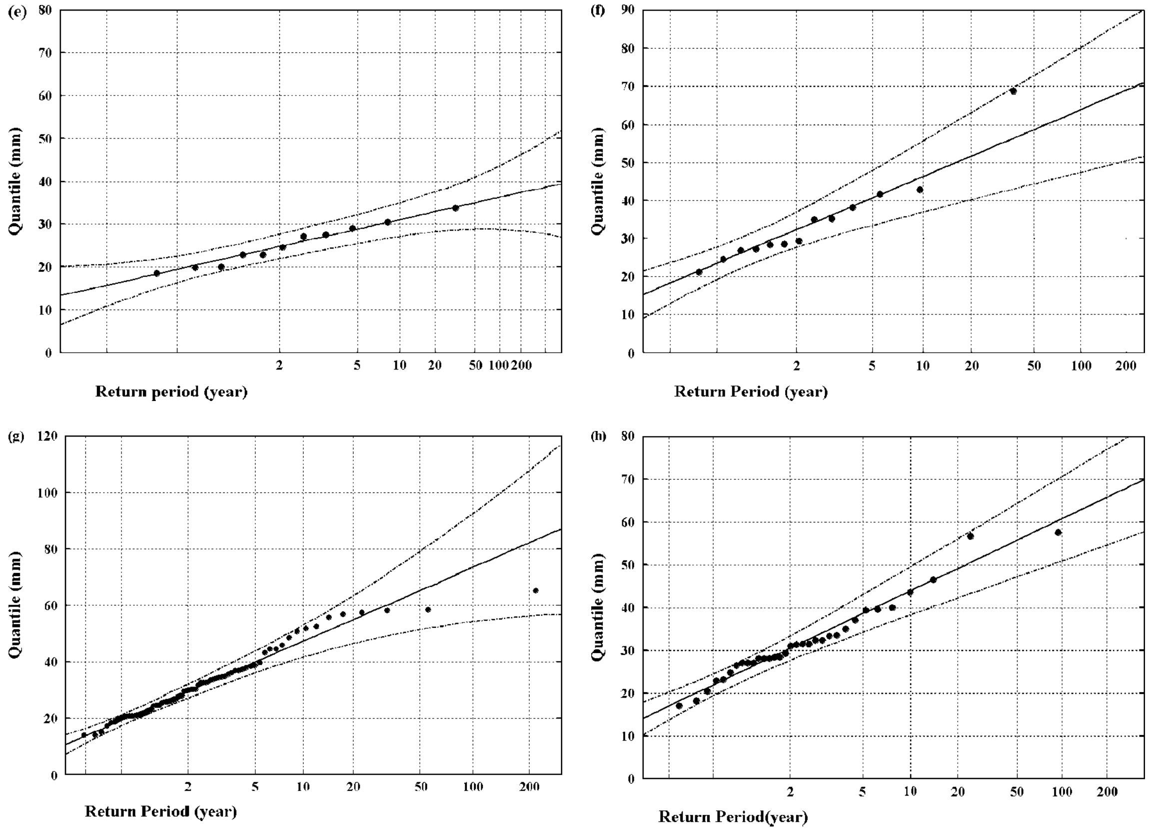

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introduced by Greenwood *et al.* (1979). Schaefer (1990) developed a regional procedure for annual maximum rainfall of the state of Washington based on l-moments and two regression curves relating the coefficient of variation and the coefficient of skewness of the data to mean annual precipitation.

Sample l-moments are calculated by substituting sample estimates of a_s and b_r in the following equations:

$$a_s = \hat{\alpha}_s = \frac{1}{n}\sum_{i=1}^{n}(1 - P_{i:n})^s x_i \qquad (1)$$

$$b_r = \hat{\beta}_r = \frac{1}{n}\sum_{i=1}^{n} P_{i:n}^r x_i \qquad (2)$$

where $P_{i:n}$ = plotting position and x_i is the *ith* observation. Plotting position is a tool for visual evaluation of compare sample and population frequency distribution. It is suggested to use $P_{i:n} = (i - 0.35)/n$ for generalized extreme value (GEV) and Generalized Pareto (Hosking and Wallis, 1997) as it gives better estimates of parameters than other plotting position formulae (Rao and Hamed, 2000). The l-moment ratios are then defined by Hosking (1997) in (3) and (4):

$$\tau = \lambda_1/\lambda_2 \qquad (3)$$

$$\tau_r = \lambda_r/\lambda_2 \; r \geq 3 \qquad (4)$$

where λ_1 is measure of the location, τ is measure of scale and dispersion (LCv), τ_3 is measure of skewness (LCs) and τ_4 is measure of kurtosis (LCk). The moment ratio diagram (MRD) is an easy way to identify regional homogeneity of a region. Rao and Hamed (2000) used MRD to identify homogenous regions of the Wabash river basin for flood frequency analysis. Kroll and Vogel (2002) used sample estimates of LCv versus LCs for 7-day low flows in the United States. An l-moment diagram provides a visual comparison of sample estimates to population values of l-moments (Stedinger *et al.*, 1993) and is always preferred to product moment ratio diagrams for goodness-of-fit test (Vogel and Fennessey, 1993).

4. Identification of an homogeneous region

In order to extend at-site frequency analysis of maximum rainfall to a region, an homogenous region should first be sought. Based on l-moments, there are two statistics which are used to stabilize an homogeneous region.

First, the study area and the PDmax series are checked to see whether or not the region has any discordant station. A station is called discordant when it has a different probabilistic behaviour comparing with other stations in the region. The discordancy measure, D, is calculated based on a vector $\mathbf{u}_i = [\tau_2^i, \tau_3^i, \tau_4^i]^{\mathrm{T}}$ related to sample l-moments of site i. The discordancy measure is then written as:

$$D_i = 3^{-1} N(\mathbf{u}_i - \overline{\mathbf{u}})^{\mathrm{T}} S^{-1}(\mathbf{u}_i - \overline{\mathbf{u}}) \qquad (5)$$

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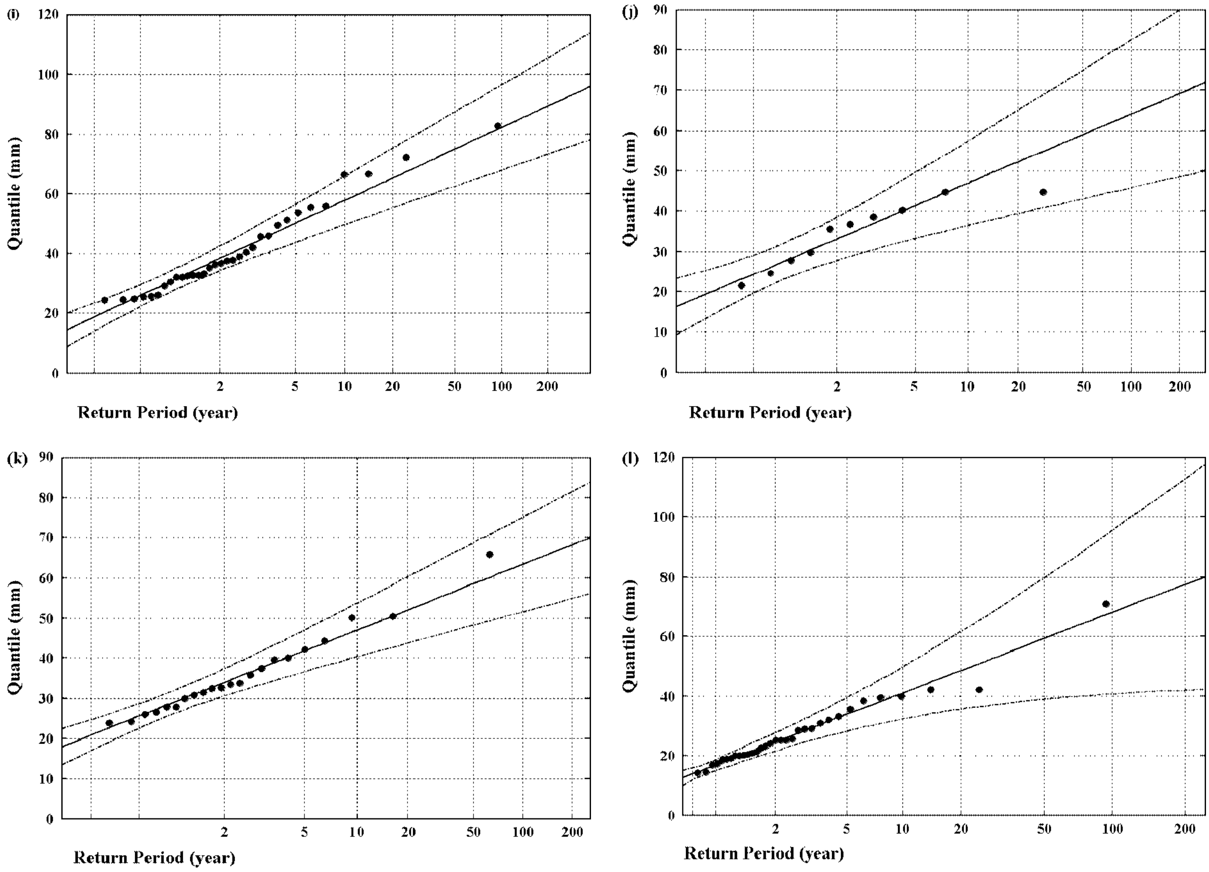

Figure 2. (*Continued*).

$$S = \sum_{i=1}^{N} (\mathbf{u}_i - \overline{\mathbf{u}})(\mathbf{u}_i - \overline{\mathbf{u}})^{\mathrm{T}} \tag{6}$$

N is the number of sites in a given group. Generally, any site with $D_i > 3$ is considered as discordant (Hosking and Wallis, 1993; Adamowski, 2000).

In the second step, the homogeneity of the region is evaluated using homogeneity measures (H_1, H_2 and H_3) which are based on sample l-moments (LCv, LCs and LCk), respectively. The H_1, H_2 and H_3 homogeneity measures are based on the simulation of 500 homogeneous regions with population parameters equal to the regional average sample l-moment ratios (Hosking and Wallis, 1997; Tallaksen *et al.*, 2004). The heterogeneity (H) statistic and V statistic for the sample and simulated regions take the form, respectively:

$$H = (V_{\mathrm{obs}} - \mu_V)/\sigma_V \tag{7}$$

$$V_1 = \left\{ \sum_{i=1}^{N} n_i (\tau_2^i - \tau_2^R)^2 \Big/ \sum_{i=1}^{N} n_i \right\}^{1/2} \tag{8}$$

$$V_2 = \sum_{i=1}^{N} n_i \{(\tau_2^i - \tau_2^R)^2 + (\tau_3^i - \tau_3^R)^2\}^{1/2} \Big/ \sum_{i=1}^{N} n_i \tag{9}$$

$$V_3 = \sum_{i=1}^{N} n_i \{(\tau_3^i - \tau_3^R)^2 + (\tau_4^i - \tau_4^R)^2\}^{1/2} \Big/ \sum_{i=1}^{N} n_i \tag{10}$$

n_i is record length at site i, τ_2^i, τ_3^i and τ_4^i are the sample l-coefficient of variation (LCv), the sample l-coefficient of skewness (LCs) and the sample l-coefficient of kurtosis (LCk), respectively. The values, τ_2^R, τ_3^R and τ_4^R are the regional average sample LCv, the regional average sample LCs, and the regional average sample LCk, respectively, μ_V is the mean of simulated V values, σ_V is the standard deviation of simulated V values. The value of the H-statistic indicates that the region under consideration is acceptably homogeneous when $H < 1$, possibly heterogeneous when $1 \le H < 2$, and definitely heterogeneous when $H \ge 2$.

5. Choosing the regional frequency distributions

The regional frequency distribution is chosen based on the goodness-of-fit-test, Z^{DIST} (Tallaksen *et al.*, 2004). The statistics are written as:

$$Z^{\mathrm{DIST}} = (\tau_4^{\mathrm{DIST}} - \overline{\tau}_4 + \beta_4)/\sigma_4 \tag{11}$$

$$\beta_4 = N_{\mathrm{sim}}^{-1} \sum_{m=1}^{N_{\mathrm{sim}}} (\overline{\tau}_{4_{\mathrm{m}}} - \overline{\tau}_4) \tag{12}$$

$$\sigma_4 = \left\{ (N_{\mathrm{sim}} - 1)^{-1} \sum_{m=1}^{N_{\mathrm{sim}}} (\overline{\tau}_{4_{\mathrm{m}}} - \overline{\tau}_4)^2 - N_{\mathrm{sim}} \beta_4^2 \right\}^{1/2} \tag{13}$$

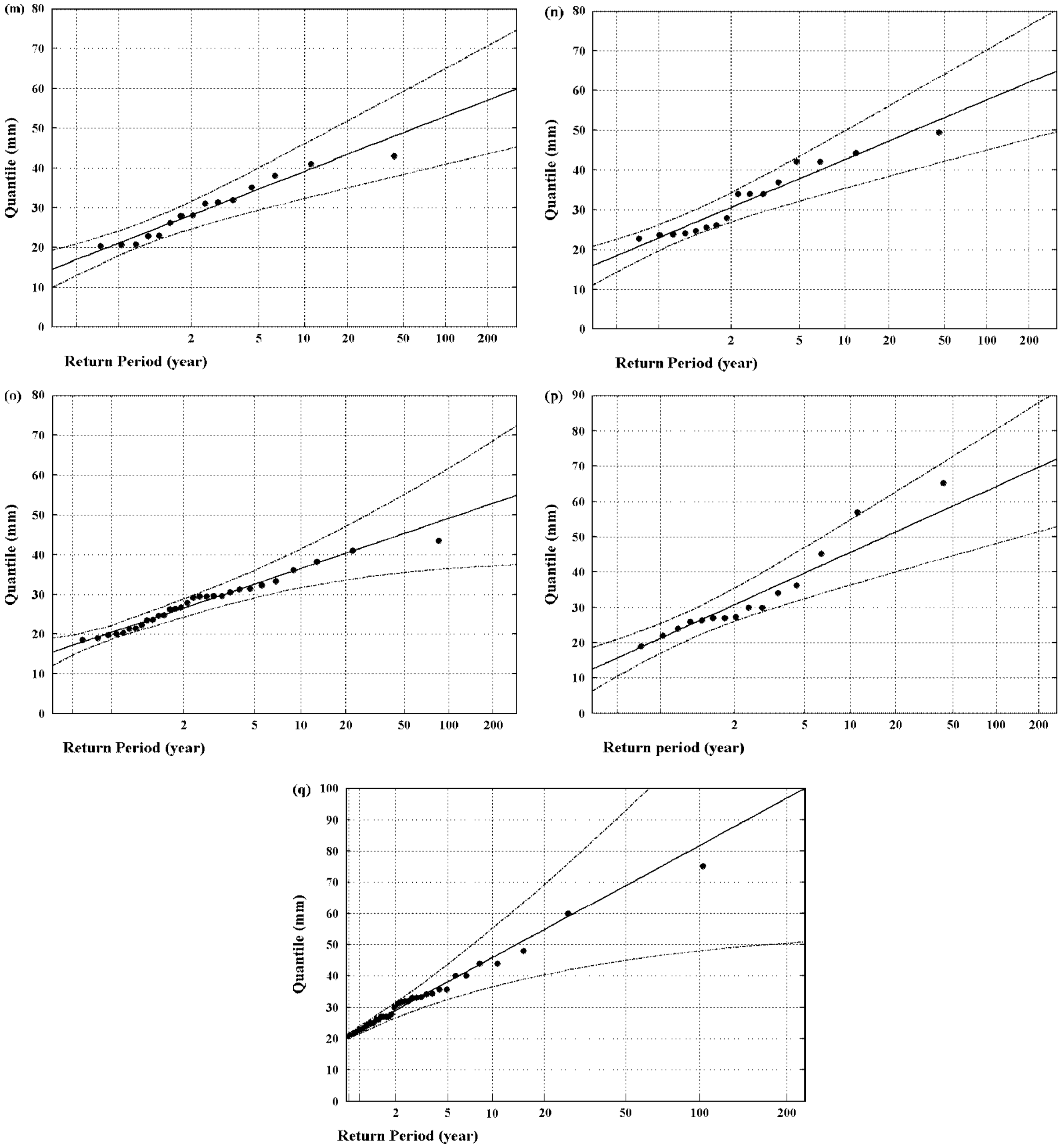

Figure 2. (*Continued*).

where DIST refers to a candidate statistical distribution, τ_4^{DIST} is the population l-kurtosis of selected distribution, $\overline{\tau}_4$ is the regional average sample l-kurtosis, β_4 is the bias of regional average sample l-kurtosis, σ_4 is the standard deviation of regional average sample l-kurtosis, and N_{sim} is realizations of a region with N sites. The four parameter Kappa distribution is used to simulate 500 regions similar to the actual region to estimate β_4 and σ_4. Hosking and Wallis (1997) imply that the four parameter Kappa distribution for simulations includes a special case the generalized logistic, generalized extreme values and generalized pareto distributions, therefore, this distribution has capability of representing many of distribution. They judged from simulations that the value of 500 for N_{sim} should usually be adequate. The parameters belonging to Kappa distribution were estimated by using the regional average l-moment ratios. The $|Z^{\mathrm{DIST}}| \leq 1.64$ should be for an appropriate regional distribution, but the distribution giving the minimum $|Z^{\mathrm{DIST}}|$ is considered as the best-fit distribution for the region.

6. Results and discussion

6.1. At-site frequency analysis

At-site probability plots of the selected stations are shown in Figure 2 using the plotting position formula $P_{i:n} = (i - 0.35)/n$. The best fitting at-site distribution is that in which the observations lie close to the straight line.

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The best distribution fitted to each individual station is selected based on the minimum Root Mean Square Error. Table I gives at-site quantile estimations for each individual station. They are estimated by the maximum likelihood method. The at-site estimation of PDmax values are also given in Figure 3.

The 95% confidence interval (CI) or the thin lines in Figure 2 are calculated for each distribution function according to Rao and Hamed (2000). In this figure, and for most of the stations, there are rare observations for high return periods, i.e. Tr > 50 year. That may be the reason of relatively short recording data or the reason of average climate condition in the region.

Before l-moment analysis, the physical characteristics of annual maximum rainfall are investigated. In Figure 4 the distribution of maximum, mean and standard deviation of annual maximum rainfall have been plotted against station elevation. The correlation coefficients between the elevation and three statistics of annual maximum rainfall are −0.24, −0.15 and 0.17, respectively, which are not statistically significant. This implies that physical properties can not be used for spatial classification of the study area. Thus, l-moments are taken into consideration for investigating spatial groups of the stations.

6.2. Regional frequency analysis

The MRDs of selected stations were first drawn to have an initial inspection of the region (Figure 5). The LCv–LCs diagram shows that the distribution of l-moments around the average is not too much. In other words, the region could be considered homogeneous according to visual inspection. In the LCs-LCk diagram, the stations have gathered around GEV and 3-parameter LOG Normal theoretical line (LOGN). However, discordancy and homogeneity tests should be implemented to judge whether the region is homogeneous or not.

Table II. L-moments and discordancy measure for selected stations.

Station	Sample size (year)	LCv	LCs	LCk	D_i
Goynucek	23	0.1615	0.2421	0.1907	0.08
Corum	76	0.2045	0.209	0.1276	2.21
Mecitozu	15	0.1488	0.1348	0.0204	0.49
Alaca	37	0.1823	0.2864	0.1642	0.19
Aydincik	15	0.2094	0.4677	0.4534	2.04
Akdagmadeni	26	0.1336	0.0813	0.1639	1.77
Eymir	10	0.1418	0.0892	0.0142	0.6
Evciyenikısla	33	0.1992	0.273	0.1333	0.83
Comarkoy	13	0.1828	0.3685	0.299	0.68
Yolkaya	15	0.2053	0.4095	0.2845	0.81
Karamagara	33	0.2085	0.2968	0.1908	1.02
Ortakoy	16	0.1538	0.2119	−0.0289	2.41
Ekinli	33	0.1564	0.207	0.2432	0.76
Zresadiye	36	0.1695	0.352	0.2448	1.06
Sulusaray	30	0.1334	0.1239	0.1127	0.51
Artova	23	0.1339	0.1392	0.1145	0.45
Camlibel	11	0.1551	−0.0825	−0.0233	1.08

LCv, the sample l-coefficient of variation; LCs, the sample l-coefficient of skewness; LCk, the sample l-coefficient of kurtosis; D_i, discordancy measure for site i.

7. Test for discordancy and homogeneity

For the purpose of regionalization, it is important to check the existence of discordant station and homogeneity of the region. Table II shows l-moments and discordancy measures, D_i, for the raingauge stations in the study

Table I. At-site annual maximum rainfall (mm) for different return periods.

Station number	Station name	Return period (year)					
		2	5	10	20	50	100
1	Goynucek	33.07	41.69	48.57	56.19	67.83	78.07
2	Corum	29.47	39.95	47.38	54.89	65.22	73.43
3	Mecitozu	28.23	34.78	38.97	42.88	47.8	51.37
4	Alaca	25.62	34.13	40.59	47.37	56.97	64.8
5	Aydincik	35.51	45.67	52.39	58.83	67.18	73.43
6	Akdagmadeni	31.9	38.85	43.05	46.82	51.32	54.44
7	Eymir	33.13	41.42	46.9	52.17	58.98	64.08
8	Evciyenikısla	38.31	50.07	57.85	65.31	74.98	82.22
9	Comarkoy	32.32	40.75	46.34	51.69	58.62	63.82
10	Yolkaya	30.72	39.69	45.63	51.33	58.7	64.23
11	Karamagara	24.51	33.45	40.67	48.75	61.21	72.3
12	Ortakoy	30.61	37.84	42.63	47.22	53.17	57.62
13	Ekinli	30.56	38.61	43.9	48.93	55.4	60.2
14	Zresadiye	30.61	37.84	42.63	47.22	53.17	57.62
15	Sulusaray	26.79	32.56	36.23	39.64	43.89	46.97
16	Artova	28.73	34.83	38.63	42.1	46.35	49.36
17	Camlibel	24.76	28.79	31.01	32.86	34.9	36.21

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region. As the D_i of all stations is smaller than three, no discordant station is observed in the region. The homogeneity measures, H_1, H_2 and H_3 are 0.65, 0.18 and 0.02, respectively. As all of these measures are less than one the region can be considered homogeneous. Thus, the stage after this step is to find the best regional distribution.

8. Goodness-of-fit-test

The goodness of fit test measure, $|Z^{DIST}|$, was calculated for five distributions, generalized logistic, generalized extreme values, generalized normal or 3-parameter log normal, Pearson type III and generalized Pareto distributions, which are 2.02, 0.47, 0.13, 1.23 and 3.25, respectively. Among these distributions, LOGN3 and GEV have the smallest values and could be considered as the regional distributions. The regional quantiles based on these two distributions are given in Table III.

Table IV shows error bounds and the average relative errors for regional LOGN3 and GEV distribution for each station. The results of regional frequency analysis are satisfactory as the average relative errors are small, within a range of 3.2 to 15.6 and 2.72 to 16.3, for LOGN3 and GEV distribution, respectively. On the other hand, the average relative errors for the entire region are 9.93 and 9.82 for GEV and LOGN3 distributions, respectively. Thus the regional frequency analysis is satisfactory and

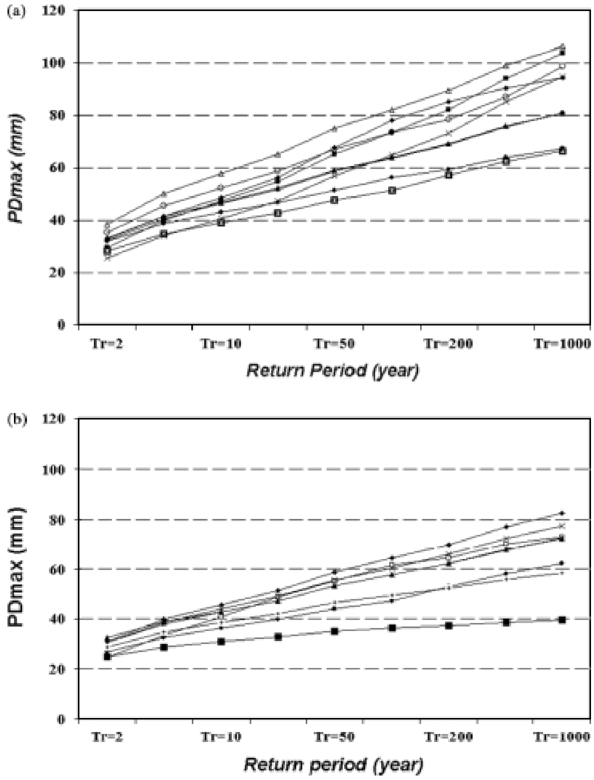

Figure 3. At-site maximum daily rainfall (PDmax) for eight different return periods (x-axis) at selected stations (lines) at Cekerek Watershed. Figure 3(a) and (b) show the first nine and the second eight stations ranked in Table II.

Table III. Regional annual maximum rainfall (mm) in different return periods for two distributions for Cekerek watershed.

Return period (year)	2	5	10	20	50	100
GEV	29.7	38.7	45.2	51.9	61.2	68.8
LOGN3	29.6	38.9	45.4	52	60.8	67.8

GEV, generalized extreme; LOGN3, 3-parameter log normal.

Table IV. Relative error (%) of regional annual maximum rainfall (mm) for each station.

Station	LOGN3		GEV	
	Error bounds	Average relative errors	Error bounds	Average relative errors
Goynucek	7.45–13.47	9.8	6.98–15.14	10.1
Corum	0.77–6.73	4.64	0.44–8.3	4.77
Mecitozu	4.95–25.3	15.57	4.62–24.23	15.42
Alaca	5.81–13.73	9.53	4.42–13.44	9.32
Aydincik	6.72–19.56	13.8	8.3–19.9	14.11
Akdagmadeni	0.38–20.8	9.9	0.13–19.7	9.7
Eymir	0.52–11.55	5.55	0.33–11.92	5.08
Evciyenikısla	5.5–21.3	13.7	6.2–22.1	14.1
Comarkoy	0.4–8.8	4.75	0.6–9.2	4.3
Yolkaya	0.95–6.64	3.12	0.5–5.26	2.72
Karamagara	0.02–17.4	8.7	0.67–17.2	9.1
Ortakoy	2.22–16.2	8.2	2.72–15.01	8.16
Ekinli	0.23–12.5	5.61	0.74–11.2	5.54
Zresadiye	2.32–16.2	8.4	2.72–15.01	8.16
Sulusaray	9.8–21.7	15.52	9.49–23.1	15.7
Artova	3.26–26.5	14.6	2.9–27.2	16.3
Camlibel	6.63–25.7	15.6	7.35–26.6	16.24

LOGN3, 3-parameter log normal; GEV, generalized extreme.

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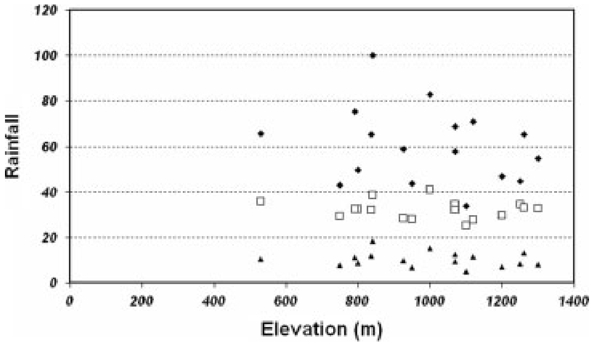

Figure 4. The observed maximum (black diamond), mean (squares) and standard deviation (triangles) of the annual maximum rainfall against the elevation of the station in Cekerek Watershed.

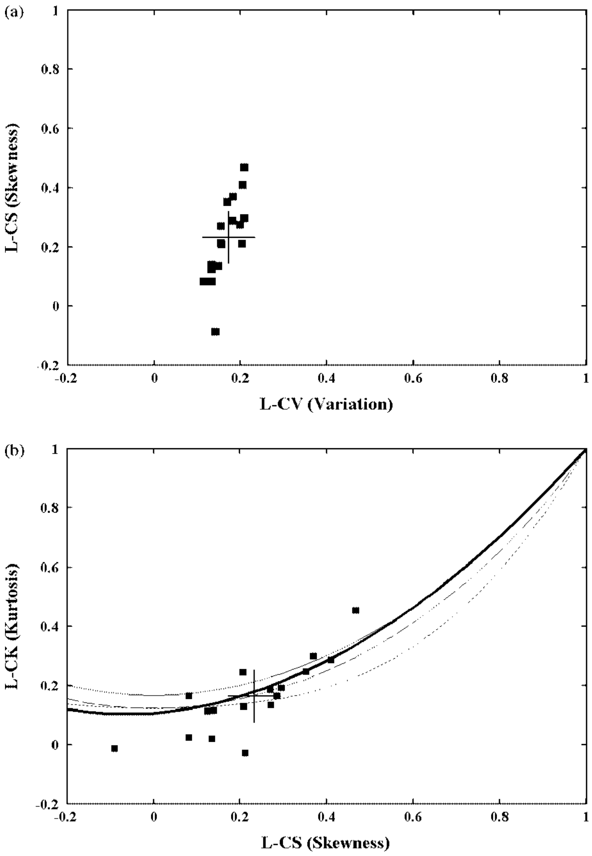

Figure 5. Moment ratio diagram for annual maximum rainfall of Cekerek watershed. The (+) shows the mean (a) L-CV *versus* L-CS. (b) L-CS *versus* L-CK.

LOGN3 distribution seems to perform the regional annual maximum rainfall better then GEV distribution. Besides, the LOGN3 probability distribution for quantile estimation related to annual maximum rainfall in Cekerek watershed should be used in return periods above 100 years. The GEV probability distribution were estimated the bigger quantiles in return period above 100 years, this is also very important for capacity and cost of any project belonging to a hydraulic structure. Therefore, because of overestimation of design flood or rainfall, the capacity and cost of hydraulic structure are going to be negatively affected.

9. Conclusions

In this study, annual maximum rainfall records of 17 stations in the Cekerek watershed, Turkey, were considered to find the best regional frequency distribution. Firstly, to detect whether spatial classification of the study area is carried out, the graph and the correlation coefficients belonging to the statistics (maximum, mean and standard deviation) of annual maximum rainfalls and station elevations were obtained. The graph and correlation coefficients showed that there was no significant relationship between the elevation and the statistics. As no physical relationship was significant in the Cekerek watershed, the method of l-moments was applied to regionalize annual maximum rainfall in the watershed.

Moment ratio diagrams (MRD) of selected stations were firstly drawn to have an initial inspection of the region. The l-coefficient of variation (LCv)- l-coefficient of skewness (LCs)-diagram showed that the region could be considered homogeneous according to visual inspection, but discordancy measures (D_i) were taken into account to check the existence of discordant station and homogeneity of the region. No discordant station is observed in the region. As all of the homogeneity measures, H_1, H_2 and H_3 were less than 1, the region can be considered homogeneous. The l-coefficient of skewness (LCs) l-coefficient of kurtosis (LCk) diagram showed that the stations gathered around Generalized Extreme Values (GEV) and 3-parameter Log Normal theoretical lines (LOGN3). Based on the goodness of fit test measure, Z^{DIST}, the smallest value among the probability distributions considered in the study had LOG3 and GEV distributions, respectively. Both LOGN3 and GEV distributions can be used in regional frequency analysis of annual maximum rainfall in the Cekerek watershed, but as the return period gradually increases, the difference between the quantiles from the distributions (LOGN3 and GEV) gets higher. Therefore, the LOGN3 probability distribution for regional frequency analysis of annual maximum rainfall in the Cekerek watershed should be used in return periods above 100 years. The GEV probability distribution were estimated the bigger quantiles in return period above 100 years, this is also very important for capacity and cost of any project belonging to a hydraulic structure. Therefore, because of overestimation of design flood or rainfall, the capacity and cost of hydraulic structures are going to be negatively affected. On the other hand, according to the average relative errors belonging to the entire region for LOGN3 and GEV distributions, LOGN3 probability distribution seemed to perform the regional annual maximum rainfalls better then GEV distribution.

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