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Regional Rainfall Frequency Analysis for the Luanhe Basin – by Using L-moments and Cluster Techniques

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Abstract

Flood frequency analysis is essentially a problem of information scarcity in arid and semi-arid regions. Practically in these regions, the length of records is usually too short to insure reliable quantile estimates. The density of rainfall station network of LuanHe basin is not enough for rainfall estimation at ungauged regions. Therefore, rainfall regionalization should be used to extend rainfall data to regions where rainfall data are not available. The aim of this study is to use cluster analysis and L-moment methods together to quantify regional rainfall patterns of LuanHe basin using annual rainfall of 17 stations for the period of 1932-1970. The cluster analysis follows "Ward's method" and shows seven regions of rainfall in Luanhe basin. The homogeneity test of L-moments shows that some of these regions are homogeneous. Using the goodness-of-fit test, Z^{Dist}, the regional frequency distribution functions for each group are then selected. In this study, five three parameter distributions generalized logistic (GLO), generalized extreme-value (GEV), generalized normal (GNO), Pearson type-3 (PE III) and generalized pareto distributions (GPA) were fitted to the four homogeneous regions. However, because of different rainfall generating mechanisms in the basin such as elevation, sea neighborhood and large atmospheric circulation systems, no parent distribution could be found for the entire basin.

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Keywords: Regionalization of rainfall, frequency distribution, statistical analysis, cluster analysis, Ward's method, L-moments

1. Introduction

Rainfall frequency analysis plays an important role in hydrologic and economic evaluation of water resources projects. It helps to estimate the return periods and their corresponding event magnitudes, thereby creating reasonable design criteria. The basic problem in rainfall studies is an information problem which can be approached through frequency analysis. The classical approach to rainfall

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frequency analysis is hampered by insufficient gauging network and insufficient data, especially when the interest is in estimating events of large return periods. At-site rainfall frequency analysis is the analysis in which only rainfall records from the subject site are used. More commonly, it will be necessary to carry out a regional analysis where rainfall records from a group of similar catchments are used. Regionalization or regional analyses are thought to compensate for the lack of temporal data.

Several methods are commonly used for the regionalization of hydro-climatic variables such as rainfall, stream flow, flood, drought, evapotranspiration and other components of the water cycle. Multivariate techniques, such as a cluster analysis (CA) and principal component analysis (PCA), are very common methods for classification (Romero et al., 1999; Singh, 1999; Ramos, 2001).

Since the introduction of L-moments by Hosking andWallis (1997), many studies have used L-moments for regionalization of hydroclimatic variables. For example this method is widely used for regional flood frequency analysis. Kjeldsen et al. (2002) applied L-moments for regional frequency analysis of annual maximum series of flood flows in KwaZulu-Natal Province of South Africa. Kumar and Chatterjee (2005) employed the L-moments to define homogenous regions within 13 gauging sites of the north Brahmaputra region of India.

The method of L-moments has also been used for regional low flow frequency analysis. Zaidman et al. (2003). The regional frequency distribution function for the extreme hydrologic drought periods in the southeastern arid region of Iran was investigated by Modarres and Sarhadi (2010).

The L-moments are also useful tools for regional annual rainfall frequency analysis. Guttman (1993) defined 104 homogenous regional rainfall groups across the USA using L-moments. Gonzalez and Valdes (2008) applied L-moments for regionalization of monthly rainfall in the Jucar River basin. Lee and Maeng (2003) applied L-moments for regional frequency analysis of extreme rainfall data across Korea. Di Balldassarre et al. (2006) used the L-moment method for regionalization of annual precipitation in northern central Italy. More recently, Yurekli et al. (2009) found GEV and LN3 distributions as the regional distribution functions for the maximum daily rainfall of Cekerec watershed, Turkey, through the L-moment approach.

One of the initial steps in regional rainfall frequency analysis involves identifying homogeneous regions. Regions are subsets of the entire collection of sites and consist of catchments at which extreme rainfall information is available or for which estimates extreme rainfall quantiles is required. A region can be considered to comprise a group of sites from which extreme rainfall information can be combined for improving the estimation of extreme quantile at any site in the region. The identification of an appropriate group of side is an important step in regional frequency analysis.

2. Data and scope of this study

Annual maximum rainfall amounts measured at 17 stations in Luanhe basin (area of 319000 square km, this is divided into two basins – jidong yan hai basin with area of 54400 square km, and tuhai majia he basin with area of 264600 sqiare km), with altitudes ranging from 32 to 1166 m a.s.l.. The data span the period of 1932-1970. , (Figure 1) illustrate the study area.

The study area refers to Luanhe basin located in Hebei-China, with the geographic coordinates from 112o ~ 120o East longitude and 35o ~ 43o North latitude. The hydrological and climatic data such as maximum annual rainfall series were obtained from Tianjin University-School of Civil Engineering-Department of Hydrology and water resources. Most of the gauging stations in this part have short data series with a large number of missing data. The selection of stations in the basin is made such that at least 7 years of historical rainfall data are available. The average record length for the stations was 20 years with range from 12 to 37 years. After the preliminary screening of the sites 17 gauging station were selected for this study.

This paper includes the following sections: in the next section, the L-moments and their characteristics are first defined and then applied for all rainfall data of Luanhe basin. In Section 4, a hierarchical cluster analysis is illustrated and applied to find initial rainfall groups. In Section 5, the method of L-moments is used to investigate the homogeneity of the initial groups and to identify a regional parent rainfall distribution for each group.

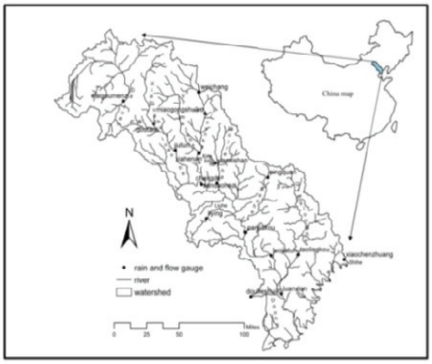

Fig. 1. The study area

3. L-moment approach

L-moments are alternative systems of describing the shape of a probability, which is used for summarizing the theoretical distribution of an observed sample of a random variable (X). Hosking and Wallis (1997) defined L-moments as linear functions of probability weighted moments (PWM), which are robust to outliers and virtually unbiased for small sample. Greenwood et al. (1979) defined PWM as:

$$\beta_r = E\{x[F(x)]^r\} \tag{1}$$

where F(x) is the cumulative distribution function (cdf) of X, and βr is the rth-order PWM. The first four L-moments related to the PWMs are calculated as the following (Hosking and Wallis, 1997):

$$\lambda_1 = \alpha_0 = \beta_0 \tag{2}$$

$$\lambda_2 = \alpha_0 - 2\alpha_1 = 2\beta_1 - \beta_0 \tag{3}$$

$$\lambda_3 = \alpha_0 + 6\alpha_1 + 6\alpha_2 = 6\beta_2 - 6\beta_1 + \beta_0 \tag{4}$$

$$\lambda_4 = \alpha_0 - 12\alpha_1 + 30\alpha_2 - 20\alpha_3 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \tag{5}$$

Different L-moment ratios can then be defined. λ1, is a measure of central tendency, τ=λ2/λ1 is a measure of scale and dispersion (or the L-Coefficient of variation, LCV), the ratio λ3/λ2 is referred to as τ3 or the measure of skewness (L- Coefficient of skewness, LCS), while the ratio λ4/λ2 is referred to as τ4, and it is the measure of kurtosis (L-Coefficient of kurtosis, LCK).

3.1. Moment ratio diagrams (MRDs)

Moment ratio diagrams are useful tools for discriminating between alternative distribution functions and selecting an approximate parent distribution. The theoretical relationships between τ3 and τ4 are summarized by Hosking and Wallis (1997). For selection of a suitable parametric distribution, the theoretical line of the best distribution must cross the mean of the sample points.

Figs. 2 and 3 show MRDs of all rainfall data of Luanhe. Fig. 2 shows the MRD, L-skewness versus L-kurt. It appears that a GPA distribution would be the best distribution for the entire basin. The MRDs can also be used for the inspection of heterogeneity of a region (Stedinger et al., 1993) and are always preferred to product moment ratio diagrams for goodnessof-fit tests (Vogel and Fennessey, 1993; ARIDE, 1999). It is clear from Fig. 3 that the data points are widely scattered around the mean.

Therefore, we can conclude that the rainfall probabilistic behavior over the entire basin is not homogeneous. Hosking and Wallis (1997) introduced two statistics to identify the homogeneity of the region and to identify any discordant station within a region. These statistics are discussed in the following sections.

3.2. Homogeneity and discordancy test

3.2.1. DISCORDENCY TEST

Discordancy measure, Di, is based on the L-moments and can be used to determine an unusual site. Di, is defined as:

$$D_i = \frac{1}{3}(u_i - \bar{u})^T s^{-1}(u_i - \bar{u}) \qquad (6)$$

where ui is the vector of L-moments, LCv, LCs and LCk, for a site i;

$$S = (N_s - 1)^{-1} \sum_{i=1}^{N_s}(u_i - \bar{u})(u_i - \bar{u})^T \qquad (7)$$

$$\bar{u} = {N_s}^{-1} \sum_{i=1}^{N_s} u_i \qquad (8)$$

NS is the total number of sites. If the Di exceeds 3, the site is considered as a discordant station.

The D statistic for all 17 stations was calculated. Results show that the critical value, Di=3 is exceeded at one station. This station is located near Bohai Sea and in the highlands of luanhe basin. However, only one station is discordant within the groups (see Section 5.1). Figs. 2&3. Show MRDs of all rainfall data of Luanhe

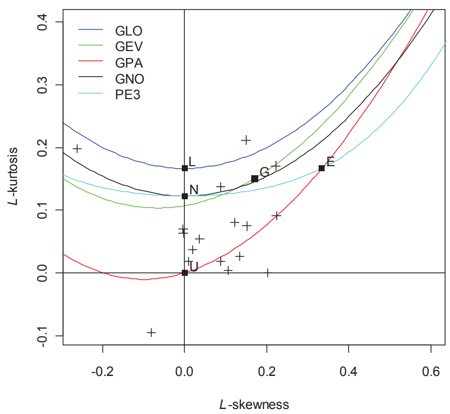

Fig. 2. LCv – L-skewness moment ratio diagramfor all station

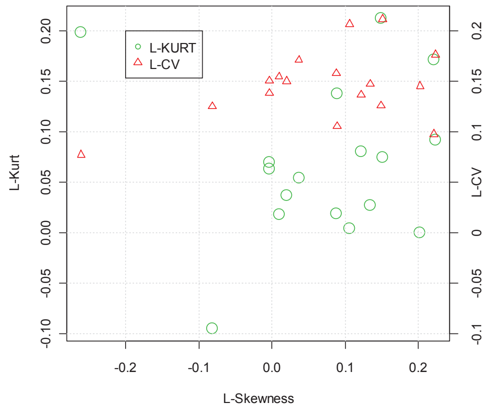

Fig. 3. Lmoment ratio diagram for Luanhe data

3.2.2. HOMOGENEITY MEASURE (H)

Hosking and Wallis (1997) derived heterogeneity statistics for estimation of the degree of heterogeneity in a group of sites. For heterogeneity test of a group, a four parameter kappa distribution is fitted to the regional data set generated from series of 500 equivalent region data by numerical simulation. The test compares the variability of the L-Statistics of actual region to those of the simulated series.

There are three heterogeneity measurements (Hi), namely H1, H2 and H3, that are calculated using the following equation:

$$H_i = (V_i - \mu_v)/\delta_v \quad (9)$$

where µV and σV are the mean and standard deviation of Nsim values of V, Nsim is the number of simulation data; Vobs, is calculated from the regional data and is based on the corresponding V-statistic, defined as follows:

$$V_1 = \sum_{i=1}^{N}(n_i(L - CV_i - \overline{LCV})^2)/\sum_{i=1}^{N} n_i \quad (10a)$$

$$V_2 = \sum_{i=1}^{N}\left(n_i[(L - CV_i - \overline{LCV})^2 + (\tau_{3i} - \bar{\tau})^2]^{1/2}\right)/\sum_{i=1}^{N} n_i \quad (10b)$$

$$V_3 = \sum_{i=1}^{N}(n_i[(\tau_{3i} - \overline{\tau_3})^2 + (\tau_{4i} - \overline{\tau_4})^2])^{1/2}/\sum_{i=1}^{N} n_i \quad (10c)$$

On the basis of Homogeneity measurements, a region is declared acceptably homogenous when H<1, possibly heterogeneous when 1≤H< 2 and definitely heterogeneous when H≥2.

The results of homogeneity tests, for the entire basin are shown in Table 1. Based on H1 measurement which has a much better discriminatory power than either H2 or H3 (Hosking and Wallis, 1997), it can be seen that the entire basin is not homogenous because the H1 is larger than the criteria value, H<1.

Table1. Tests for Hk and Z measures for the defined regions

Region	Heterogeneity measure			Goodness of fit	Distribution function
	H_1	H_2	H_3	$\lvert Z\rvert \le 1.64$	
HR	3.81	0.80	-0.16	-1.97	**GPA**

3.3. Goodness-of-fit measurement

The goodness-of-fit measurement is used to identify the regional parent distribution. This measurement, ZDist, judges the difference between sample L-Kurtosis and population L-Kurtosis for the fitted distribution. The Z statistic has the form of goodness of fit and has approximately a standard Normal distribution.

The goodness-of-fit measure is defined as:

$$Z^{DIST} = (\tau_4^{DIST} - \overline{\tau_4} + \beta_4)/\sigma_4 \quad (11)$$

where "Dist" refers to the candidate distribution, τ4 is the average

L-Kurtosis value computed from the data of a given region, β4is the bias of the regional average sample L-Kurtosis, and τ4 DIST is the average L-Kurtosis value computed from simulation for a fitted distribution. A given distribution is declared a good fit if $|Z^{Dist}| \leqslant 1.64$. When more than one distribution qualifies for the goodness-of-fit measurement criteria, the preferred distribution will be the one that has the minimum $|Z^{Dist}|$ value. The criterion corresponds to acceptance of the hypothesized distribution at a confidence level of 90% (Hosking and Wallis, 1997).

The goodness-of-fit value ($|Z^{Dist}|$) for several distributions, Generalized Extreme Value (GEV), Generalized Logistic (GLO), Generalized Normal (GNO), Generalized Pareto (GPA) and Pearson Type 3 (P III) was calculated assuming the entire basin as a single region. The goodness-of-fit values are given in Table 2. It is observed from this table that none of the $|Z^{Dist}|$ is less than1.64. In other words, the entire basin cannot be considered as a homogeneous region and no parent distribution can be selected for rainfall in Luanhe basin.

It is quite clear that the basin is not homogenous because of large geographic and climate differences within the basin. So it is not surprising that the study area must be divided into homogenous groups by another method. For this purpose the popular cluster analysis (CA) is used in this study.

Table 2**.** Goodness-of-fit test measures (Z^{dist}) for the study area

Region	**Regional frequency distribution**				
	GLO	GEV	GNO	P- III	GPA
All stations	6.35	3.52	3.95	3.84	-1.97

4. Cluster analysis

The aim of using cluster analysis with hydrologic variables is to group observations or variables into clusters based on the high similarity of hydrologic features, such as geographical, physical, statistical or stochastic properties. In this way, each cluster contains the least variance of variables (smallest dissimilarity). Gottschalk (1985) applied cluster and principal component analysis to data from Sweden and found that cluster analysis is a suitable method to use on a national scale for a country with heterogeneous regions.

In this study, the hierarchical cluster technique (described by Kaufman and Rousseuw, 1990) is applied in order to classify the synoptic rainfall stations into spatial groups. Several methods have been proposed for hierarchical cluster analysis, including single, average and complete linkage, and Ward's minimum variance method. Both the last two methods are widely used for classification of different climatic or hydrologic data (e.g. Jackson and Weinand (1995); Ramos, 2001). Nathan and McMahon (1990), Masoodian (1998) and Domroes et al. (1998) indicated that Ward's method gives better results than other methods of classification. Therefore, Ward's method is used for cluster analysis of rainfall data in Luanhe basin.

In Ward's method, the distance between two clusters is calculated as the sum of squares between two clusters, added up over all variables. At each cluster generation, the sum of squares is minimized. If CK and CL are two rainfall clusters that merged to form the cluster CM, the distance between the new cluster and another cluster CJ is:

$$d_{J.M} = \frac{\left((n_J+n_k)d_{Jk}+(n_J+n_L)d_{JL}-n_J d_{kL}\right)}{n_J+n_M} \qquad (12)$$

where n_J, n_K, n_L and nM are the number of the rainfall stations in clusters J, K, L and M, respectively, and d_{Jk}, d_{JL} and d_{KL} represent the distances between the rainfall observations in the clusters J and K, J and L, and K and L, respectively. On the basis of Ward's method, the selected stations of luanhe basin can be classified into seven groups. The pseudo t^2 and pseudo R^2 statistics are the criteria for selecting seven groups (SAS, 1999).

The largest two group's covers arid and semi arid central regions of Luanhe basin, the smallest three groups are nearest to Bohai Sea.

In the next section, L-moments are applied to check the homogeneity of these seven groups and to find the regional frequency distribution for each group.

5. L-moments for rainfall groups

5.1. Homogeneity and discordancy test

Using the FORTRAN computer program developed by Hosking and Wallis (1997), the homogeneity of the groups and the existence of any discordant station in each group are investigated at the first step.

L-moment statistics are calculated for all groups classified by cluster analysis and summarized in Table 3. The result of the discordance test for these seven groups indicates that there are no discordant stations within the groups except for the first group (G1). After removing the discordant station from the group, the discordance measurements recalculated and founded that the group do not exceed the critical value, Di=3, which means that there is no discordant station. The mean values of Di for this group are also given in Table 3.

Table 3. Descriptive statistics and L-moments of the rainfall at selected stations.

Regions	Number of stations	Mean of precipitations	Mean of STDEV	Mean of LCv	Mean of L-skewness	Mean of L-kurtoses	Mean of Di
G1	3	502.0442	65.3834	0.0998	-0.0405	0.0913	1.00
G2	4	506.7393	23.0229	0.1298	0.0675	0.1098	1.00
G3	1	469.3074	0	0.1364	0.1213	0.0804	1.00
G4	4	581.8564	93.49028	0.1634	0.120825	0.04115	1.00
G5	3	725.5438	54.92132	0.160967	0.044433	0.030167	1.00
G6	1	739.3	0	0.1761	0.2233	0.0915	1.00
G7	1	684.1588	0	0.2063	0.1054	0.0037	1.00

In the first group, Waigoumenzi Station is discordant. This station which is located in the highlands of the basin may be discordant due to the effects of erratic rainfall regime in the northern area, and it seems that its location at the margin of the basin; may be the main reasons of discordancy compared with other inland stations of the group.

The homogeneity statistics for each of these seven regions reveal that the homogeneous regions are limited to G2 and G5 regions which are acceptably homogenous. On the basis of H1 measurement, which is reported to be discriminatory and more powerful than H2 or H3 measurements (Hosking and Wallis, 1997), G1 and G4 groups are possibly heterogeneous regions while G3, G6 and G7 have only station in each group. If the one discordant station is removed from G1 region, H1 reduces to 0.94, which implies that the region considered as heterogeneous.

The station in groups G1is located in the highland of the basin. One, high, unusual rainfall event due to the effect of the See moisture may have influenced the statistical characteristics of annual rainfall such as the coefficients of variation and skewness and may have resulted in discordance of the above stations. These results indicate that the basic assumption of homogeneity in cluster analysis is different from those in frequency analysis. Therefore, it would be useful to test the homogeneity of each cluster by homogeneity measurement, Hi.

5.2. Regional distribution function

In this section, the regional rainfall frequency distribution function for each rainfall group is identified by the use of goodness-of-fit $|Z^{Dist}|$ statistics. The results of the goodness-of-fit test for common 3-parameter distributions, GLO, GEV, LN3, PIII and GPA distributions are shown in the Table 4. Except for G1 and G2 groups for which the GEV distributions are the best parent distributions, the GPA distribution the best distribution for other groups. However, it is clear that for the entire basin, none of the distributions could be selected as a parent distribution. It is an expectable result because of the complexity of rainfall generating mechanisms of Luanhe basin. The regional annual rainfall for each group at different return periods have been given in Table 5, using the regional distribution function. The 5%&95% confidence interval (CI) or the uncertainty bounds for the functions have also been calculated for each function according to Rao and Hamed (2000).

Table 4. The goodness-of-fit test measure (Zdist) for homogeneous rainfall groups within Luanhe basin.

distribution	Luan basin	G1	G2	G3	G4	G5	G6	G7
GLO	6.36	1.94	2.18	1.67	3.54	5.11	1.12	2.03
GEV	3.52	0.65	0.90	0.90	2.41	3.11	0.81	1.48
GNO	3.95	1.06	1.13	0.91	2.43	3.50	0.71	1.52
P-3	3.84	1.04	1.10	0.79	2.26	3.46	0.52	1.46
GPA	-1.97	-1.55	-1.54	-0.72	0.06	-0.56	0.09	0.37

Table 5. Regional rainfall estimations for rainfall groups of Luanhe basin.

Groups	Group1	Group2	Group3	Group4	Group5	Group6	Group7
Return period (year)	Best distribution						
	GEV	GEV	GPA	GPA	GPA	GPA	GPA
2	100.9	98.6	96.4	95.7	98.5	92.1	95.3
5	116.0	120.2	122.9	127.3	128.5	126.3	135.1
10	123.0	132.1	135.5	142.5	140.0	147.1	153.3

20	128.1	142.1	144.6	152.7	146.4	164.3	165.2
50	132.9	153.0	151.2	161.3	150.8	182.7	174.8
100	135.6	160.0	154.6	165.4	152.5	193.8	179.1
1000	140.8	177.5	159.8	171.5	154.3	219.0	185.4

6. Summary and conclusion

A set of rainfall time series for 17 synoptic stations across the basin is applied in this study to investigate the spatial pattern of rainfall frequency functions over the basin. The cluster and L-moment methods are used together in order to find the spatial rainfall regions and the regional rainfall frequency for each region, respectively.

The hierarchical Ward's method identifies seven fall regions over the basin. The spatial pattern of these regions indicates the effects of elevation, sea neighborhood and large atmospheric systems on rainfall spatial pattern in Luanhe basin. However, this paper suggests the use of the cluster analysis with L-moments to find the regional frequency distribution of rainfall in each region classified by cluster analysis.

As for the regional analysis the region should be homogeneous in terms of both rainfall amount (investigated by cluster analysis) and frequency distribution, the homogeneity measurement based on L-moments was used to find that these rainfall groups are homogeneous regions. Although most of the regions classified by cluster analysis were considered as homogeneous or possibly homogenous regions, some regions have discordant stations, the stations that are statistically different from other stations in a region. The difference may come from special effects of atmospheric circulation pattern or some rare events that may affect the statistical properties of rainfall during the record of data. Removing these stations may reduce the non-homogeneity of the region. Therefore at-site frequency analysis is required for rainfall frequency at these stations and it is necessary to investigate the reasons for their discordancy.

The best regional distribution function for each group is also identified using the goodness-of-fit test measurement. This statistics reveals that the Generalized Pareto distribution, GPA, is the dominant distribution function for most of the rainfall regions except for the central arid zone of Luanhe basin, (G1) and the margins of Bohai Sea (G4) where GEV distributions can be selected as the parent distributions.

Although, the results give a parent distribution for each rainfall group, they do not support any parent frequency distribution function for the entire basin. This is the consequence of the combination of local rainfall factors such as elevation and topography with large different atmospheric systems.

In general, the climate regions of Luanhe basin are influenced by three major factors of sea neighborhood, elevation and large atmospheric systems. The cluster analysis may be a useful tool to find and classify the regions influenced by different atmospheric phenomenon and can show their effects on the amount of rainfall. However, the frequency distribution type of rainfall in these regions is not unique. In other words, the type of climate could not be represented by a unique distribution, at least for Luanhe basin. The application of cluster analysis together with L-moment method is highly recommended in different geographical and climate regions to prove the relationship between rainfall regimes and rainfall distribution functions.

References

[1]. Adamowski K. 2000. Regional analysis of annual maximum and partial duration flood data by nonparametric and L-moment methods. J. Hydrol., 229, 219-231.

[2]. Cunnane C. 1988. Methods and merits of regional flood frequency analysis. J. Hydrol., 100, 269-290.

[3]. Di Balldassarre, G., Castellarin, A., Brath, A., 2006. Relationships between statistics of rainfall extremes and mean annual precipitation: an application for design-storm estimation in northern central Italy. Hydrol. Earth Sys. Sci. 10, 589–601.

[4]. Domroes, M., Kaviani, M., Schaefer, D., 1998. An analysis of regional and intraannual precipitation variability over Iran using Multivariate Statistical Methods. Theor.

[5]. Gonzalez, J., Valdes, J.B., 2008. A regional monthly precipitation simulation model based on an L-moment smoothed statistical regionalization approach. J. Hydrol. 348, 27–39.

[6]. Gottschalk, L., 1985. Hydrological regionalization of Sweden. Hydrol. Sci. J. 30, 65–83.

[7]. Greenwood, J.A., Landwahr, J.M., Matalas, N.C., Wallis, J.R., 1979. Probability weighted moments: definition and relation to parameters of several distributions expressible in inverse form

[8]. Hosking J.R.M., Wallis J.R., Wood E.F. 1985, 1997.Estimation of the generalized extreme-value distribution by the method of probability-weighted moments. Technometrics, 27, 251-261.

[9]. Jackson, I.J., Weinand, H., 1995. Classification of tropical rainfall stations: a comparison of clustering techniques. Int. J. Climatol. 15, 985–994.

[10]. Kumar, R., Chatterjee, C., 2005. Regional flood frequency analysis using L-Moments for north Barhamputra region of India. J. Hydrol. Eng. ASCE 10, 1–7.

[11]. Nathan, R.J., McMahon, T.A., 1990. Identification of homogeneous regions for the purpose of regionalization. J. Hydrol. 121, 217–238.

[12]. Ramos, M.C., 2001. Divisive and hierarchical clustering techniques to analyze variability of rainfall distribution patterns in a Mediterranean region. J. Hydrol. 57, 123–138.

[13]. Singh, C.V., 1999. Principal components of monsoon rainfall in normal, flood and drought years over India. Int. J. Climatol. 19, 639–952.

[14]. Stedinger, J.R., Vogel, R.M., Foufoula–Georgiou, E., 1993. Frequency analysis of extreme events. In: Maidment, D.R. (Ed.), Hand book of hydrology. McGraw Hill, New York, NY. 18.1–18.66.

[15]. Yurekli, K., Modarres, R., Ozturk, F., 2009. Regional maximum rainfall estimation for Cekerec watershed by L-moments. Meteorol. Appl. 435–444.