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Halil-River Basin Regional Flood Frequency Analysis Based on L-moment Approach

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Abstract: In the present study L-moment approach was used for flood frequency analysis in Halil-River basin. To identify the homogeneous regions, the Ward hierarchical cluster method was used. For independent testing of the cluster in the station for homogeneity, site data information was used. The Halil-River basins were divided in to two regions (region A and B) and parameters of the regional frequency distribution were evaluated by L-moment ratios. For the selection of appropriate distributions, L-moment diagram, goodness of fit test and plotting position methods were used. The results showed that in Halil-River basin, Generalized Pareto distribution for region A, Generalized extreme values, Pearson type III, Lognormal, Generalized Logistic and Generalized Pareto for region B are appropriate distributions. The relative Root Mean Square Error (rRMSE) between observed and estimated data in all stations was calculated. The results showed a good agreement between observed and estimated data. Regional model evaluated for determination of mean flood discharge magnitude by liner and multiple regression method.

Key words: Halil-River, homogeneity, L-moment, flood frequency analysis

Introduction

Estimation of extreme events is an important practical application in hydrology, especially because the planning and design of water resource projects and flood-plain management, which depend on the frequency and magnitude of peak discharges. Information on flood magnitudes and their frequencies is needed for design of hydraulic structures such as dams, spillways, road and railway bridges, culverts, urban drainage systems, flood plain zoning, economic evaluation of flood protection projects etc (Kumar *et al*., 2003). Regional flood frequency analysis is usually applied when no local data at a site of interest are available, or the data are insufficient for a reliable estimation of flood quantiles for the required return period. Regional flood frequency analysis has three major components, namely, delineation of homogeneous region, determination of appropriate probability density function, (or frequency curves), of the observed data and the development of a regional flood frequency model, such as a relationship between flows of different return periods, basin characteristics and climatic data. This study includes identification of homogeneous regions based on cluster analysis of site characteristics, identification of suitable regional frequency distribution and development of a regional flood frequency models.

L-moments

Recently, Hosking (1990) has defined L-moments approaches, which are analogous to conventional moments and can be expressed in terms of linear combinations of order statistics. Basically, L-moments are linear functions of Probability-Weighted Moments (PWMs) (Sankarasubramania and Srinivasan, 1999). Procedures based on PWM and L-moment, are equivalent

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but L-moment is more convenient, because they are directly interpretable as measure of the scale and of the shape of probability distributions (Mckerchur, 1994). L-moments are robust to outliers and virtitually unbiased for small samples, making them suitable for flood frequency analysis (Adamowski, 2000; Lee and Meang, 2003). Similar to conventional moments, the purpose of L-moments and probability-weighted moments is to summaries theoretical distribution and observed samples. Greenwood summarizes the theory of PWM and defined them as below (Schulze and Smithers, 2002):

$$\beta_r = E\{X[F_X(x)^r\} \qquad (1)$$

where β_r is the rth order PWM and $F_X(x)$ is the cumulative distribution function (cdf) of X. Unbiased sample estimators (β_j) of the first four PWMs are given as:

$$\beta_0 = m = \frac{1}{n}\sum_{j=1}^{n} X_j \; \beta_1 = \sum_{j=1}^{n-1}[\frac{n-j}{n(n-1)}]X_{(j)} \; \beta_2 = \sum_{j=1}^{n-2}[\frac{(n-j)(n-j-2)}{n(n-1)(n-2)}]X_{(j)}$$
$$\beta_3 = \sum_{j=1}^{n-3}[\frac{(n-j)(n-j-1)(n-j-2)}{n(n-1)(n-2)(n-3)}]X_{(j)} \qquad (2)$$

where $X_{(j)}$ represents the ranked Annual Maximum Series (AMS) with $X_{(1)}$ being the highest value and $X_{(n)}$ the lowest value, respectively. The first four L-moment are given as follow:

$$\lambda_1 = \beta_0 \; \lambda_2 = 2\beta_1 - \beta_0 \; \lambda_3 = 6\beta_2 - 6\beta_1 + \beta_0 \; \lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \qquad (3)$$

Unbiased sample estimators of the first four L-moments are obtained by substituting the PWM sample estimators from Eq. (2) into Eq. (3). The first L-moment λ_0 is equal to the mean value of X. Finally, the L-moment ratios are calculated as:

$$L-\gamma = \tau_3 = \frac{\lambda_3}{\lambda_2} \; L-k = \tau_4 = \frac{\lambda_4}{\lambda_2} \; L-C_V = \tau_2 = \frac{\lambda_2}{\lambda_1} \qquad (4)$$

Sample estimates of L-moment ratios are obtained by substituting the L-moments in Eq. (4) with sample L-moments (Hosking and Wallis, 1997).

Index Flood

The T-year event X_T is defined as the event exceeded on average once every T years (Schulze and Smithers, 2002). When the annual maximum floods are distributed according to a specified frequency distribution with cdf, the T-year event can be calculated as Cadman *et al.* (2003):

$$X_T = F^{-1}(1-1/T) \qquad (5)$$

Regional frequency analysis methods, such as the index flood method, include information from nearly stations exhibiting similar statistical behavior as at the site under consideration in order to obtain more reliable estimates (Schulze and Smithers, 2002; Rakesh et al., 2003). Regional methods can also be used to obtain estimates at ungauged sites, which are important in region such as Halil-River basin, where the flow gaugaing network density is relatively low. Consider a homogeneous region with N sites, each site i having sample size n_i and observed AMS x_{ij}, j = 1,…,n_i The AMS from a homogeneous region are identically distributed except for a site-specific scaling factor and the index flood. At each site the AMS is normalized using the index flood as:

$$q_{ij} = Q_{ij} / \mu_i \tag{6}$$

Where μ_{ii} is the Mean Annual Flood (MAF) at site i, which is often used as the index flood. The sample L-moment ratios are estimated at each site and the regional record length weighted average L-moment ratios are calculated as:

$$\hat{\lambda}_r^R = \sum_{i=1}^{N} n_i \hat{\lambda}_r^{(i)} / \sum_{i=1}^{N} n_i \tag{7}$$

Where $\hat{\lambda}_r^{(i)}$ is the rth order sample L-moment ratio at site i and $\hat{\lambda}_r^R$ is the rth order regional average sample L-moment ratio. The parameters of a regional frequency distribution can be estimated using the method of L-moment ratios, as shown, for example, by Hosking and Wallis (1997). Finally, the T-year event at site i can be estimated as:

$$\hat{Q}_{T,i} = \hat{\mu}_i \hat{q}_T \tag{8}$$

Where $\hat{\mu}_i$ is the MAF at site i and $\hat{q}_T$ is the regional growth curve. The regional growth curve is the (1-1/T)-quantile of the regional distribution of the normalized AMS as defined through Eq. 8 (Hosking and Wallis, 1997).

Identification of Homogeneous Regions

In Halil-River basin six hydrometric sites, which have sufficient length record of data and are important for frequency analysis, were selected. For identification of homogeneous regions, Hosking and Wallis recommended using Ward's method, which is a hierarchical clustering method based on minimizing the Euclidean distance in site characteristics space within each cluster. The site characteristics selected in this study for each site included: Latitude (LAT) and longitude (LON) of the flow gauging weir, Mean Annual Flood (MAF), station area (AREA), altitude (ALT) and design storm intensity (ID). Table 1 shows the site characters for six stations in Halil-River basin. Using this method Halil-River basin divided to two regions (A and B). After identification of homogeneous regions, using Hosking's method discordancy measure (Di) of the sites was determinate in each region. Table 2 shows the L-moment ratios and discordances measure for region A and B stations. Figure 1 shows location of gauging sites and homogenous regions in Halil-River basin.

Heterogeneity Test

Hosking and Wallis (1997) proposed a statistical test based on L-moment ratios for testing the heterogeneity of the proposed regions. The test compares the between-site variation in sample L-CV with the expected variation for a homogeneous region. The method fits a four parameters kappa distribution to the regional average L-moment ratios. The estimated kappa distribution is used to generate 500 homogeneous regions with population parameters equal to the regional average sample L-moment ratios. The properties of the simulated homogeneous region are compared to the sample L-moment ratios as

$$H = (V_1 - \mu_{V1}) / \sigma_V \tag{9}$$

Table 1: Site characteristic for Halil-River stations

Station name	LAT	LON	ALT (m)	MAF (m^3 sec^{-1})	AREA (km^{-2})	ID (mm h^{-1})
Soltani	56.32	29.02	2070	79.24	935	6.2
Meydan	56.59	29.08	1880	97.24	631	7.5
Pol baft	56.37	29.14	2270	33.33	300	8.1
Henjan	56.57	29.15	2150	130.39	261	8.1
Konarueyeh	57.15	28.53	1400	427.87	7600	5.4
Cheshm Aroos	56.52	29.18	2460	24.37	83	10.5

Table 2: L-moment ratios and discordances measure for region A and B stations

Station name	Record length (year)	L-Cv	L-Skew	L-Kurt	Di
Region A					
Soltani	29	0.4968	0.2401	0.0441	0.44
Meydan	29	0.5078	0.3236	0.1558	1.00
Pol baft	29	0.4804	0.2608	0.0774	0.50
Henjan	29	0.0228	0.2105	0.5116	0.64
Region B					
Konarueyeh	29	0.6127	0.506	0.2232	1.00
Cheshm Aroos	29	0.4417	0.4344	0.2915	1.00

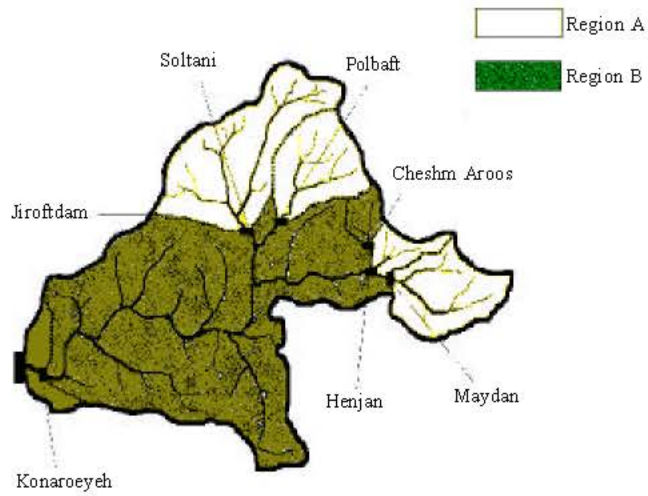

Fig. 1: Homogeneous regions (A and B) and Halil-River stations (Konarueyeh, Henjan, Maydan, Cheshm Aroos, Pol Baft and Soltani)

Where μ_V is the mean of simulated V values and σ_V is the standard deviation of simulated V values. For the sample and simulated regions, respectively, V is calculated as:

$$V = \{\sum_{i=1}^{N} n_i (t^{(i)} - t^R)^2 / \sum_{i=1}^{N} n_i\}^{\frac{1}{2}} \qquad (10)$$

Where N is the number of sites, n_i is the record length at site i, $t^{(i)}$ is the sample L-CV at site I and t^R is the regional average sample L-Cv. If H<1, the region can be regarded as 'acceptable homogeneous', $1 \leq H < 2$ is 'possible homogeneous' and $H \geq 2$ is 'definitely heterogeneous' (Hosking and Wallis, 1997).

Goodness-of-fit Test

The goodness-of-fit test described by Hosking and Wallis (1997) is based on a comparison between sample L-kurtosis and population L-kurtosis for different distributions. The test statistic is termed Z^{DIST} and given as follows:

$$Z^{DIST} = (\tau_4^{DIST} - t_4^R + B_4) / \sigma_4 \qquad (11)$$

Where DIST refer to a candidate distribution. τ_4^{DIST} is the population L-kurtosis of selected distribution, t_4^R is the regional average sample L-kurtosis and σ_4 is the standard deviation of regional average sample L-kurtosis. A four-parameter kappa distribution is fitted to the regional average sample

L-moment ratios. The kappa distribution was used to simulate 500 regions similar to the observed regions. From these simulated regions B_4 and σ_4 are estimated. Declare the fit to be adequate if Z^{DIST} is sufficiently close to zero, a reasonable reiteration for selection of suitable being $|Z^{DIST}|$ (Hosking and Wallis, 1997). The test described above applied to the four homogeneous regions. For each region the data were tested against the General Logistic (GLO), General Pareto (GPA), General Extreme Value (GEV), General Normal (GNO) and Pearson Type 3 (PE3) distribution. Table 3 shows the results.

Regional Flood Frequency Distribution

Several methods are available for selecting appropriate regional distributions. In this study the regional frequency distributions were selected based on the results of L-moment ratios as described by Hosking and Wallis (1997). Additionally probability plots (plotting position) were used to verify that the selected distributions provided a satisfactory description of the observed AMS.

L-moment Ratio Diagrams

An L-moment ratio diagram of L-kurtosis versus L-skewness compares sample estimates of the dimension less ratios with their population counterparts for ranges of statistical distributions include GLO, GEV, GNO, PE3 and GPA. L-moment diagrams are useful for discerning grouping of sites with similar flood frequency behavior and identifying the statistical distribution likely to adequately describe this behavior. Figure 2 shows the L-moment ratio diagram for homogeneous regions in Halil-River basin (A and B). As the sample L-moments, are unbiased, the sample points should be distributed above and below the theoretical line of a suitable distribution (Hosking and Wallis, 1997). From the above L-moment diagrams, it appears that the GPA distribution for region A and the GPA, GLO, GEV, PE3 and GNO for region B are appropriate.

Plotting Position

As pointed out by Hosking *et al.* (1985), comparison of different regional frequency distributions against observed data cannot be used to discriminate between different distributions, as the observed data represents only one of an infinite number of realizations of the 'true' underlying population (Schulze and Smithers, 2002). However, the probability plots may reveal tendencies such as systematic regional bias in the estimation of the extreme events. To assess how well the proposed regional frequency distribution fit to the observed AMS, the calculated X_T-T relationships for Konarueyeh station in region B are shown in Fig. 3. The empirical existence probability for the ordered observations $x_{(i)}$ were calculated using the median probability plotting position as described by Hosking and show below:

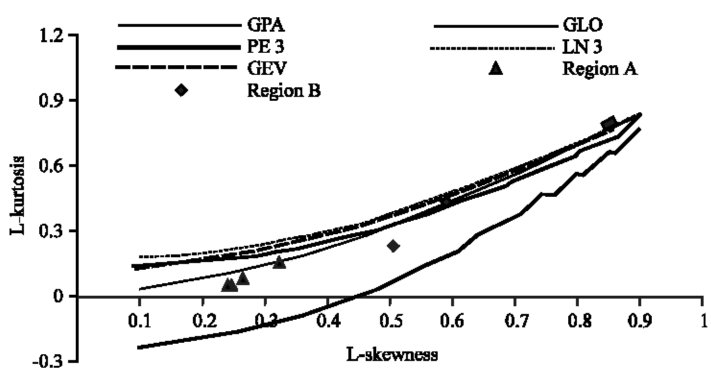

Fig. 2: L-moment ratio diagram for homogeneous regions (A and B) in Halil-River basin

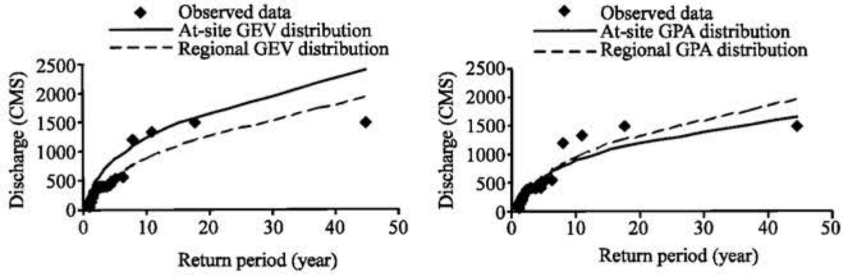

Fig. 3: Probability plot for Konarueyeh station in region B

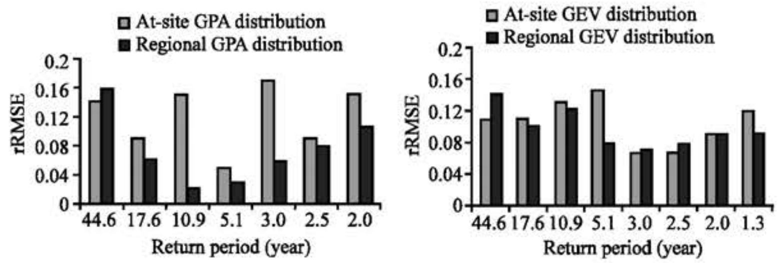

Fig. 4: rRMSE between computed and observed data for Konarueyeh station

Table 3: Regional parameters for the various distributions for the region B

	Parameters of the distribution			
GEV	$\xi = 0.455$		$\alpha = 0.426$	$k = -0.420$
GLO	$\xi = 0.634$		$\alpha = 0.355$	$k = -0.470$
GNO	$\xi = 0.596$		$\alpha = 0.605$	$k = -1.019$
PE3	$\mu = 1$		$\alpha = 1.178$	$k = 2.87$
WAK	$\xi = -0.093$	$\alpha = 0$	$\beta = 0$ $\gamma = 0.654$	$\delta = 0.279$

$$P[X > x_{(i)}] = i - .35 / n \tag{12}$$

From above three methods, goodness-of-fit test, L-moment ratio diagram and plotting position, the GPA distribution for region A and the GNO, GEV, GLO, GPA and PE3 distributions for region B were selected as regional frequency distributions.

Quantizes Estimation

After the regional distributions were selected, using these distributions the quantiles with different nonexceedance probability estimated for regions A and B in Halil-River basin. Table 3 shows the estimated value using GPA distribution in regions A and B.

The accuracy of estimated values (regional and at-site estimations) was determinate using relative Root Mean Squire Error (rRMSE). Figure 4 shows the rRMSE in Konarueyeh station. From these charts the rRMSE values in high return period are low. This indicates that both at-site and regional estimation procedure in high return period give accurate results.

Conclusions

In this study using site characteristic and Ward's method, hierarchical clustering method based on minimizing the Euclidean distance in site characteristics space within each cluster, the Halil-River basin divided into two acceptably homogeneous regions. The heterogeneity measures based on H_1 were -1.67 and 1.88 for regions A and B, respectively. The identification of suitable regional distribution for each of two regions was based on the L-moment diagram, a goodness-of-fit test and evaluated using probability plots. The GPA distribution for region A and PE3, GNO, GLO, GPA and GEV distributions for region B were suitable and selected. The rRMSE values between computed and observed data were obtained. These values in high return period were low and indicate that both at-site and regional estimation procedure in high return period give accurate results. Regional models for homogeneous regions was obtained using the multiple regression and step-wise method and with catchment and hydrologic characteristics.

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