Turk J Agric For
26 (2002) 47-55

Estimation of Instantaneous Peak Flows in Seyhan River Basin Using Regional Regression Procedures

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Received: 04.12.2000

Abstract: Multivariate procedures for estimating instantaneous flood flows for various return periods in Seyhan river basin are presented in the study. Procedures aim at developing regression equations uscable for the basin using annual peak instantaneous flows, climatic and morphometric charactcristics. It was determined that best subset analysis gave the highest determination coefficients (91.0%<R^2<95.0%) than stepwise analysis (84.23%<R^2<85.13%), principal component analysis and factor analysis (69.2%<R^2<71.0%). Climatic characteristic, basin area, and stream frequency are the most important characteristics in developed equations for the best subset analysis. In addition, the flood flow estimation capability of the best subset equations for the Seyhan river basin is demonstrated to be sufficient using statistical critcrion of prediction error. Flood estimates for a given return period can be done using the best subset equations of only three characteristics at an ungauged site in the Seyhan river basin without measuring any flow data.

Key Words: Instantaneous Flows, Flood, Climatic and Morphometric Characteristics, Best Subset Analysis, Multivariate Analyses, Regional Regression Equations

Seyhan Havzası Akarsularında Bölgesel Regresyon Yöntemleri ile Anlık Maksimum Akım Tahmini

Özet: Çalışmada Seyhan havzası için farklı yinelenme yıllarına ait anlık maksimum akımları tahmin etmede kullanılabilecek çok değişkenli yöntemler sunulmuştur. Bu yöntemler yıllık maksimum anlık akımları, iklim ve morfometrik karakteristikleri kullanarak havza için geçerli regresyon eşitliklerinin geliştirilmesini amaçlamaktadır. En yüksek belirleme katsayısının en iyi alt grup analizinden elde edildiği (%91.0<R^2<%95.0) ve sıralı çoklu regresyon analizinde (84.23%<R^2<85.13%), ana bileşkeler analizi ve faktör analizinde ise (69.2%<R^2<71.0%) bu katsayının daha düşük olduğu belirlenmiştir. En iyi alt grup analizinde geliştirilen denklemlerde iklim karakteristiği, havza alanı ve dere frekansının en önemli karakteristikler olduğu saptanmıştır. Ayrıca, en iyi alt grupta elde edilen denklemlerin hata testi istatistiksel kriteri sonucunda taşkınları tahmin etmede yeterli olduğu görülmüştür. Seyhan nehir havzasında ölçümü olmayan bir istasyonda herhangi bir akım verisi ölçmeksizin istenen bir yinelenme yılı için taşkın tahminleri sadece üç karakteristikli en iyi alt grup denklemleri kullanılarak yapılabilir.

Anahtar Sözcükler: Anlık Akım, Taşkın, Havza ve İklim Karakteristikleri, En İyi Alt Grup Regresyon Analizi, Çok Değişkenli Analizler, Bölgesel Regresyon Eşitlikleri

Introduction

Estimates of future flood magnitudes of a given return period in areas where no flow gauging stations exist or where gauge records are very short are required for the economical planning and design of river basin projects (Dalrymple, 1960). However, the method of estimation employed depends upon the quantity and quality of the available data and the nature and economic life of the project (Tülücü, 1996).

Flood records over a long period are not available for many catchments in Turkey. Based on limited data, investigations providing flood estimation equations may produce results with large errors. Therefore, in cases where limited records are available at or near the site of interest, regional studies, such as regional regression analysis, using morphometric and climatic characteristics of the basin, can be useful for estimating the flood flows. Many researchers have developed regional regression equations for estimating the flood flows of various return periods using flows and the climatic and morphometric characteristics and have found that different characteristics affect floods (Bilgin, 1981; Acreman, 1985; Horn, 1988; Driver and Troutman, 1989; Mimikou and Gordios, 1989; Garde and Kothyari, 1990; Pitlick, 1994).

In this paper, an attempt is made to develop regional flood prediction equations, which take as inputs the morphometric and climatological characteristics of the basin, for various return periods in the Seyhan river basin.

Materials

Flood Flow Data

The annual instantaneous flood peaks and the annual peak daily precipitation series varying from 15 to 56 and 14 to 67 years were picked for 13 runoff gauging (RS) and 55 precipitation gauging (PS) stations of the Seyhan river basin, respectively. Flow and precipitation data were taken from the publications of DSİ (1990 and 1994) and Topaloğlu (1999). Flow data are all free from regulation by any sizeable structure. Details of all RSs and PSs are given in Tables 1 and 2, respectively.

Map Data

There are different scaled maps such as 1:5,000, 1:25,000, 1:100,000 and 1:250,000 for the Seyhan river basin. However, 1:100,000 scaled maps provided by the University of Çukurova, Faculty of Engineering and Architecture, Department of Geological Engineering were used, taking the time of working into consideration.

Methods

Frequency Analysis

Frequency analysis was performed for each gauged site by employing a computer software package (Haktanır, 1991). In the analysis, the most common distributions such as Gumbel, Log-Logistic, Pearson-3, Log-Pearson-3 and Log-Normal-3 distributions were selected. The parameters of the distributions were estimated by the methods of moments (MOM) and the probability weighted moments (PWM), except the Log-Normal-3.

In the analysis, the Gringorten plotting position formula was used for examining the distributions. In addition, a detailed chi-squared goodness-of-fit test was performed both with equal-length sliced histograms and with equal-probability-area sliced histograms being repeated three times for three different but consecutively increasing slice numbers (Haktanır, 1991). Many references are also available about the probability distributions and their parameter estimation methods (Haktanır, 1991 and 1992).

Development of Database on Climatic and Morphometric Characteristics

The climatic and morphometric characteristics most often used to predict flood peak numbers are about a dozen (Thiessen, 1911; Horton, 1932; Strahler, 1964; Acreman, 1985). The selected climatic and morphometric characteristics which have been widely used in the development of regional models are the following: annual peak daily mean areal precipitation P_T; basin area A_B (the total area projected upon a horizontal plane, contributing overland flow to the channel segment); stream length L (the length of principal stream); Benson's slope BS (the slope between two points along the main channel

Table 1. Some characteristics of the selected runoff gauging stations

Gauge Numbers	Name of River	Years of Record	Elevation (m)	Ave. Runoff (m^3s^{-1})	Coef. of Variation	Gumbel Parameters Scale	Gumbel Parameters Location
1801	Goksu River	1936-91	665	198.38	0.61	0.00756	144.530
1802	Zamanti R.	1936-54	858	90.04	0.33	0.03571	75.598
1804	Zamanti R.	1941-55	1345	43.00	0.47	0.05063	33.003
1805	Goksu R.	1940-91	350	629.54	0.55	0.00335	462.680
1806	Zamanti R.	1961-79	347	325.47	0.67	0.00481	216.970
1812	Zamanti R.	1955-73	1425	40.17	0.40	0.06632	32.344
1817	Cakit C.	1964-85	150	94.69	0.46	0.02470	73.434
1818	Seyhan R.	1966-91	180	1175.90	0.51	0.00184	886.350
1820	Korkun C.	1970-91	170	154.59	0.72	0.00736	101.520
1821	Eglence C.	1971-86	75	261.44	0.50	0.00784	195.710
1822	Zamanti R.	1970-91	1270	80.67	0.37	0.03570	65.927
1823	Zamanti R.	1974-90	1451	48.65	0.61	0.03490	33.873
18-12	Korkun C.	1971-90	1109	51.03	0.60	0.03450	35.877

Table 2. Some properties of PSs within and nearby the Seyhan river basin

Name of Gauge Site	Years of Record	Number of Peaks Used	Elevation (m)	Ave. Prec. (mm)	Coef. of Variation	Gumbel Parameters Scale	Gumbel Parameters Location
Adana	1929-95	67	20	70.09	0.40	-0.04200	56.888
Afsin	1954-83	30	1180	32.54	0.23	0.15080	28.985
Akkisla	1964-87	24	1500	28.60	0.26	0.14410	24.920
Andirin	1953-83	31	1250	102.21	0.34	0.03170	85.273
Bakirdag	1960-81	22	1300	27.02	0.39	0.10170	21.841
Bor	1964-83	20	1100	22.62	0.38	0.12470	18.417
Bunyan	1957-87	31	1300	29.10	0.35	0.10970	24.210
Camardi	1969-82	14	1500	32.06	0.30	0.10330	27.126
Camliyayla	1967-86	20	628	82.82	0.28	0.04590	71.424
Cardak	1967-84	18	1175	46.59	0.39	0.05810	37.649
Catalan	1964-86	23	65	73.60	0.30	-0.04900	62.810
Ceyhan	1942-95	54	30	67.40	0.42	0.04120	54.038
Ciftehan	1967-82	16	1000	78.38	0.45	0.02890	60.562
Cokak	1969-87	19	1350	111.89	0.54	0.01740	81.962
Develi	1951-95	45	1180	28.06	0.34	0.11920	23.479
Dogankent	1968-87	20	20	76.97	0.43	0.03200	60.620
Elbasi	1965-87	23	1425	25.61	0.29	0.19410	20.867
Feke	1942-93	52	620	75.82	0.30	0.13270	69.383
Gemerek	1957-95	39	1173	27.37	0.27	0.15350	23.833
Gezi	1965-87	23	1250	28.79	0.37	0.10060	23.539
Goksun	1954-91	38	1344	45.35	0.30	0.08254	38.776
Gulek	1957-78	22	950	84.33	0.42	0.03065	67.143
Hacilar	1964-84	21	1500	34.92	0.28	0.10853	30.080
Haciali ciftl.	1963-79	17	12	69.63	0.46	0.03282	53.854
Imamoglu	1963-86	24	100	64.56	0.34	0.04901	53.753
Kadirli	1956-87	32	100	61.89	0.28	0.06433	53.528
Kamisli	1963-87	25	1225	66.37	0.60	0.06850	45.535
Karaisali	1957-95	39	400	99.60	0.42	0.02708	79.548
Karatas	1963-88	26	5	76.61	0.37	0.03825	62.696
Karsanti	1960-75	16	860	88.19	0.31	0.03320	28.920
Kaynar	1964-82	19	1550	27.63	0.34	0.11234	22.982
Konakli	1966-81	16	1265	29.24	0.27	0.12964	25.268
Kozan	1951-95	45	150	72.06	0.36	0.04436	59.744
Mansurlu	1964-85	22	1050	68.36	0.34	0.04669	57.077
Nigde	1935-95	61	1208	26.22	0.36	0.12286	21.727
Orensehir	1964-87	24	1600	28.61	0.32	0.11992	24.196
Pazaroren	1964-87	24	1500	29.73	0.35	0.10335	24.609
Pinarbasi	1950-95	46	1470	27.62	0.30	0.14080	23.734
Pozanti	1960-86	27	778	76.99	0.43	0.03342	61.034
Saimbeyli	1957-87	31	1100	65.49	0.38	0.04525	53.619
Sarioglan	1964-87	24	1150	31.38	0.25	0.13611	27.488
Sariz	1951-87	37	1500	34.32	0.40	0.08275	27.775
Sarkisla	1939-87	49	1180	26.63	0.34	0.12637	22.289
Talas	1970-86	17	1100	27.89	0.31	0.11845	23.524
Tanir	1968-88	21	1200	35.32	0.61	0.04931	24.672
Tarsus	1941-62	22	33	60.69	0.28	0.06275	52.291
Toklar	1965-83	19	1400	31.18	0.48	0.07053	23.782
Tomarza	1963-88	26	1400	29.10	0.37	0.10207	23.887
Tufanbeyli	1957-73	17	1350	36.94	0.38	0.07450	29.992
Tuzla	1966-87	22	10	78.45	0.45	0.03035	61.094
Ulukisla	1937-95	59	1451	27.03	0.34	0.12871	22.742
Yahyali	1969-87	19	1260	41.27	0.29	0.08934	35.433
Yazyurdu	1965-87	23	1750	27.49	0.27	0.14720	23.903
Yesilhisar	1957-87	31	1150	23.16	0.28	0.16946	19.988
Yumurtalik	1965-95	31	3	78.91	0.45	0.03151	61.863

upstream from the mouth of the basin at distances equal to 10 and 85% of the total main-channel length); the stream frequency SF (junctions km^{-2}, measured by counting channel junctions on the 1:100,000 map of each catchment and dividing by the drainage area); basin perimeter BP (the length of the basin circumference); basin length BL (the linear dimension of the basin parallel to the main channel from the measuring station to the drainage divide); bifurcation ratio RB (the ratio of number of segments of a given order (N_u) to the number of segments of the higher order (N_{u+1})); and the maximum basin relief MBR (the elevation difference between basin mouth and the highest point on the basin perimeter).

Multivariate Analyses

Many multivariate analyses have been used in hydrological studies, such as stepwise regression analysis, principal component regression analysis, factor analysis and best subset analysis. In the present study, only the usage of the best subset analysis was explained because it can offer separate regression solutions for each of a number of variable climatic and morphometric variables. The analysis involves the development of regression relations between the flood flows of various return periods and independent variables. There are excellent computer algorithms for selecting the best subsets of independent variables in regression. A popular one, developed by Minitab Inc. (1993), computes all possible regressions in determining the best subsets. Three criteria may be applied for determining these best subsets, namely, maximum R^2, maximum adjusted R^2 and Mallows Cp statistic. Only the usage of the maximum R^2 criterion is described below (Bek, 1978).

$$F_{bs} = \frac{(R^2_p - R^2_{p-i}) / (p-i)}{(1-R^2_p) / (n-p-1)} \qquad (1)$$

where R^2_p is the determination coefficient of the selected best subset; R^2_{p-i} is the determination coefficient of compared best subset; p and i are the degrees of freedom of the selected and compared regression model (number of independent variables), respectively; n-p-1 is the degree of freedom of error of the selected regression model.

If F_{bs} is less than $F_{table\ (p-i,\ n-p-1)}$ according to a 5% significance level, the number of independent variables in the selected regression model is sufficient.

Development of Regional Regression Equations

Multiple regression techniques have been used in the development of regional relationships between the climatic and morphometric characteristics and the peak flows of various return periods. The relationship was assumed to be of the multiplicative, non-linear form

$$Q_T = b_0 * A_1^{b1} * A_2^{b2} * \ldots\ldots * A_i^{bi} \qquad (2)$$

where Q_T is the estimated instantaneous flow (m^3/s) with a return period of T years; A_1, A_2,…., A_i are the climatic and morphometric characteristics; b_1, b_2, ….., b_i are the regression coefficients; and b_0 is constant.

To reduce the extreme range in values of the climatic and morphometric characteristics, and to linearize the form of equation (2), all data were transformed to logarithms before running analysis of best subset and multiple regression.

Model Evaluation Criterion

The statistical criterion employed for model evaluation was prediction error (PE). Although standards for model evaluation using statistics are not yet established (Loague, 1992), one would hope to have a value of this statistic as close as possible to 0.0. This statistical criterion was computed for each return period and RS using the formula below:

$$PE = n^{-1} \sum_{i=1}^{n} \left| (Y_i - \hat{Y}_i) / Y_i \right| * 100 \qquad (3)$$

where n is the number of estimates, Y_i is the true value and $\hat{Y}_i$ is the value of Q_T calculated from equation (2). Zrinji and Burn (1994) used the single station at-site extreme flow estimates at various return periods as the "true flow" values.

Results and Discussion

Results of Frequency Analysis

Frequency analysis was performed for both RSs and PSs. Evaluation of both chi-squared tests indicated that, in general, Gumbel (MOM) probability distribution for both RSs and PSs was found to be the best model (Topaloğlu, 1999). Thus, the Gumbel probability distribution was considered applicable for all flood analyses in the basin. The flood flows of various return periods can be calculated using the Gumbel (MOM) parameters given in Table 1. Moreover, the hydrologic homogeneity test according to a 10-year recurrence interval (Dalrymple, 1960) showed that all points plot within 95% confidence limits. Therefore, the records are acceptably homogeneous.

Results of Measurement of Climatic and Morphometric Characteristics

All morphometric characteristics at each of the 13 gauged sites were measured twice from 1:100,000-scale topographic maps. Measurements of L and BP were obtained carefully using a cardboard strip due to the lack of a chartometer. Climatic characteristic was also calculated twice by drawing Thiessen polygons on a 1:400,000-scale map using a digital planimeter as reported by Thiessen (1911). The mean values of the morphometric and climatic characteristics are summarized in Tables 3 and 4, respectively. The independence of the climatic and morphometric characteristics was checked by testing the significance of their interrelationships. None of the characteristics were found to be significantly interrelated.

Results of Multivariate Analyses

A detailed review of best subset regression analysis for each return period from Table 5 showed that regression equations with three variables would be sufficient in estimating flood peaks for all return periods, based on the value of F-statistics given in equation (1) at a 5% significance level. These variables are the climate, the basin area, and the stream frequency. The

Table 3. Morphometric characteristics at 13 gauged sites. A_B: Basin area, L: Stream length, BS: Benson's slope, SF: Stream frequency, BP: Basin perimeter, BL: Basin length, R_B: Bifurcation ratio and MBR: Maximum basin relief

Sites	A_B (km^2)	L (km)	BS (m/km)	SF (n. jun./area)	BP (km)	BL (km)	R_B -	MBR (m)
1801	2683.2	125.0	8.11	0.0444	314.3	106.5	4.61	2310
1802	7615.2	263.8	1.42	0.0369	484.1	177.5	3.89	2117
1804	4800.8	142.7	1.96	0.0381	345.0	105.4	3.56	1361
1805	4492.8	186.8	7.30	0.0594	408.9	147.0	3.85	2625
1806	8920.8	317.4	3.70	0.0447	588.2	202.1	4.32	3278
1812	2708.0	79.6	1.76	0.0473	242.1	64.7	4.54	1281
1817	1609.6	89.7	14.80	0.0559	234.8	63.8	4.25	3374
1818	14484.0	367.2	4.54	0.0507	642.5	234.4	3.69	3281
1820	1460.7	103.8	17.60	0.0705	232.2	79.3	4.21	3418
1821	664.0	64.6	23.10	0.1476	137.2	57.4	2.93	3513
1822	6528.0	220.7	1.62	0.0357	440.5	147.7	3.84	1705
1823	2847.2	93.3	1.71	0.0460	244.3	73.0	4.58	1255
18-12	1107.2	60.1	13.00	0.0632	145.6	51.3	3.68	2479

Table 4. Annual peak daily mean areal precipitation values (mm) calculated from Thiessen polygons for various return periods (P_T) at 13 gauged sites

	Return Periods					
Sites	2.33	5	10	25	50	100
1801	53.96	72.07	86.83	105.47	119.30	133.03
1802	30.08	38.77	45.85	54.80	61.44	68.03
1804	28.81	36.65	43.03	51.10	57.08	63.02
1805	59.22	75.47	88.71	105.43	117.84	130.15
1806	33.78	43.79	51.95	62.25	69.90	77.49
1812	28.81	36.52	42.81	50.75	56.63	62.48
1817	61.37	82.75	100.15	122.14	138.46	154.65
1818	42.65	55.85	66.61	80.19	90.27	100.27
1820	47.19	60.46	71.28	84.94	95.08	105.14
1821	57.08	78.46	95.87	117.87	134.19	150.39
1822	29.06	37.54	44.44	53.16	59.63	66.05
1823	28.78	36.46	42.71	50.61	56.47	62.28
18-12	38.34	48.46	56.70	67.11	74.83	82.50

Table 5. Best subsets for return periods of 2.33, 5, 10, 25, 50 and 100 years. R^2: Determination coefficient, $R^2_{adj.}$: Adjusted determination coefficient, Cp: Mallows statistic, P_T: Annual peak daily mean areal precipitation, A_B: Basin area, L: Stream length, BS: Benson's slope, SF: Stream frequency, BP: Basin perimeter, BL: Basin length, R_B: Bifurcation ratio, MBR: Maximum basin relief.

Return Periods	Number of Variables, (p)	R^2	$R^2_{adj.}$	Cp	P_T	A_B	L	BS	SF	BP	BL	R_B	MBR
	1	49.4	44.9	465.0									*
	2	84.3	81.2	140.2					*	*			
	3	95.0	93.3	42.0	*	*			*				
	4	96.2	94.3	32.7	*	*			*			*	
2.33	5	97.2	95.2	25.0	*	*			*		*	*	
	6	98.5	97.1	14.8	*	*			*	*	*	*	
	7	99.3	98.3	9.7	*	*	*	*	*		*	*	
	8	99.7	99.0	8.0	*	*		*	*	*	*	*	*
	9	99.7	98.7	10.0	*	*	*	*	*	*	*	*	*
	1	50.5	46.0	946.8									*
	2	83.3	80.0	315.2					*	*			
	3	93.6	91.4	118.9	*	*			*				
	4	95.2	92.7	90.5	*	*			*			*	
5	5	96.4	93.9	67.8	*	*		*	*			*	
	6	98.3	96.7	33.0		*		*	*		*	*	*
	7	99.4	98.5	15.5	*	*		*	*		*	*	*
	8	99.8	99.5	8.0	*	*		*	*	*	*	*	*
	9	99.8	99.4	10.0	*	*	*	*	*	*	*	*	*
	1	50.9	46.5	1295.1									*
	2	82.8	79.4	450.3					*	*			
	3	92.7	90.3	188.7	*	*			*				
	4	94.5	91.7	143.4	*	*			*			*	
10	5	96.2	93.4	101.3	*	*		*	*			*	
	6	98.5	97.1	39.9		*		*	*		*	*	*
	7	99.4	98.6	18.5	*	*		*	*		*	*	*
	8	99.9	99.7	8.0	*	*		*	*	*	*	*	*
	9	99.9	99.5	10.0	*	*	*	*	*	*	*	*	*
	1	51.3	46.8	1595.7									*
	2	82.4	78.9	572.3				*			*		
	3	91.9	89.2	262.1	*	*			*				
	4	94.5	91.7	178.3				*	*	*			*
25	5	96.1	93.3	128.5		*	*	*	*		*		
	6	98.7	97.4	44.4		*		*	*		*	*	*
	7	99.5	98.7	20.8	*	*		*	*		*	*	*
	8	99.9	99.7	8.1	*	*		*	*	*	*	*	*
	9	99.9	99.6	10.0	*	*	*	*	*	*	*	*	*
	1	51.4	47.0	1724.5									*
	2	82.4	78.8	622.4				*			*		
	3	91.4	88.6	301.3	*	*			*				
	4	94.5	91.7	193.3				*	*	*			*
50	5	96.1	93.3	139.2		*	*	*	*		*		
	6	98.7	97.5	45.6		*		*	*		*	*	*
	7	99.5	98.8	21.6	*	*		*	*		*	*	*
	8	99.9	99.7	8.1	*	*		*	*	*	*	*	*
	9	99.9	99.7	10.0	*	*	*	*	*	*	*	*	*
	1	51.6	47.2	1796.6									*
	2	82.3	78.8	651.7				*			*		
	3	91.0	88.1	329.0	*	*			*				
	4	94.5	91.8	201.9				*	*	*			*
100	5	96.1	93.3	145.4		*	*	*	*		*		
	6	98.8	97.6	45.7		*		*	*		*	*	*
	7	99.5	98.8	21.9	*	*		*	*		*	*	*
	8	99.9	99.8	8.1	*	*		*	*	*	*	*	*
	9	99.9	99.7	10.0	*	*	*	*	*	*	*	*	*

determination coefficients of these three independent variables were calculated between 91% and 95% for all return periods. It was also found that R^2 became smaller as the return periods for the three independent variables increased. Adjusted R^2 values were calculated between 88.1 and 93.3%, which are quite close to the R^2 values for the three variables. Mallows Cp statistic was also calculated and it was evaluated that the three parameters in question would be sufficient in developing regional regression equations. One can also use more variables in estimating flood flow using best subset regression analysis. It should, however, be taken into consideration that this will be a costly and time-consuming affair.

A stepwise analysis was also performed in addition to best subset analysis. MBR, BL and L were the most important parameters in stepwise analysis. The determination coefficients, found to be 84.23%-85.13%, increased with decreasing return periods.

The data were also subjected to both a principal component analysis and a factor analysis (unrotated factor loadings) to assess the relative importance of the parameters with respect to their influence on flood flow behaviour. The first three factors accounted for approximately 58.0, 27.0 and 10.5%, respectively, of the total variability in the data for 6 return periods. The last 6 factors together explain less than 5% of the total variability. The analytical results and their interpretation of the first three factors showed that among the parameters that are related to flood flow, A_B, MBR and R_B are the ones that are most closely related to the process. Thus, in relating flood flow characteristics to basin morphology, only these parameters need be considered and the inclusion of additional parameters does not necessarily yield a better relationship and may result in redundancy. Moreover, multiple regression analysis using these three characteristics gave a determination coefficient between 69.2% and 71.0%, decreasing with the return period.

The first three factors were also subjected to rotation options and the resulting factor patterns showed that the additional rotations did not result in any improvement with regard to ease of interpretation of the major factors.

Furthermore, some of the results obtained by researchers in the last 20 years may be summarized as follows. Bilgin (1981) calculated R^2 to be between 70% and 75% using stream length, Benson's slope, drainage area, stream frequency, maximum daily precipitation and total annual precipitation for mean annual flow. Acreman (1985) developed a regression equation with an R^2 of 91.4% using drainage area, average annual rainfall, stream frequency, soil type index and fraction of the lake. Horn (1988) found a regression equation with an R^2 of 81.6%-96.1% using three variables, namely, drainage area, mean annual precipitation and percent forest cover. Driver and Troutman (1989) determined R^2 to be between 35% and 95% with only total storm rainfall and total contributing drainage area for 34 regions. Mimikou and Gordios (1989) found that stream frequency, drainage area, and the intensity of the 1-day rainfall of a 5-year return period were the variables that had the greatest effect on the mean instantaneous flood. Pitlick (1994) explained that the basin area and the mean precipitation with an R^2 of 96% were the most important independent variables for five basins. Asquith and Slade (1999) found that basin area, basin shape factor and stream slope are the most significant characters in natural basins in Texas.

Results of Multiple Regression Analysis

Multiple regression analysis was then used to develop regression equations for each return period according to the results of best subset analysis since higher R^2 values were obtained. The final regression equations for all return periods are in the form

$$Q_T = b_0 * P_T^{b1} * A_B^{b2} * SF^{b3} \quad (4)$$

The values of the parameters and the separate contribution of each selected variable to total variance (in parentheses) are given in Table 6. Basin area gave the highest contribution according to the separate contribution in all return periods.

Based on the results given in Table 6, streamflows in the study area are positively associated with independent variables, which means that flood flows are increasing functions of the climatic and morphometric characteristics. All the exponents of the characteristics were found to be hydrologically realistic and not spurious as mentioned by Meigh *et al.* (1997). It was also found that the importance of the climatic characteristic in the regression equations increased as the return periods increased. The other two, however, showed a decreasing importance with increasing return periods.

Table 6. Summary of regional regression equations and analysis of variance for each return period

Return Periods	Parameters of Reg. Equation			(Contribution to Total Variance)				R^2
	b_0	b_1	(%)	b_2	(%)	b_3	(%)	
2.33	0.0003800	2.17	(33.65)	1.36	(42.75)	2.10	(18.58)	95.0
5	0.0004677	2.08	(34.94)	1.35	(40.71)	2.12	(17.94)	93.6
10	0.0005495	2.03	(35.41)	1.35	(39.53)	2.13	(17.77)	92.7
25	0.0006457	1.97	(35.73)	1.35	(38.44)	2.15	(17.71)	91.9
50	0.0006918	1.94	(35.87)	1.34	(37.83)	2.16	(17.71)	91.4
100	0.0007413	1.92	(35.97)	1.34	(37.35)	2.17	(17.72)	91.0

Results of Model Evaluation Criterion

A general evaluation of the statistical criterion was made taking the means of 13 RSs for each return period, and the results are given in Table 7.

Based on the results, values of mean PE were found to vary between 20.24% and 34.07%. In addition, 1801, 1802 and especially 1817 and 1820 showed PE values much greater than 40%. Some other flood estimation techniques can also be used for these stations in order to obtain better estimates. The other stations, however, gave better PE values, generally lower than 30%, than that of these four stations. Mimikou and Gordios (1989) obtained a PE of 17.81% for the regression. Garde and Kothyari (1990) determined that the accuracy of the equation developed using morphometric characteristics is remarkably high because it resulted in a ±30% error. Linsley (1986) also emphasized that 30% errors are acceptable.

Conclusions

The regression equations given in Table 6 are of great value in providing flood estimates for ungauged sites in the Seyhan river basin. The best subset regression analysis offers more reliable and rapid flood estimates in the Seyhan river basin because they have low average PE values, and precipitation, area and the stream frequency are the only variables needed to indicate the flood flow parameters at an ungauged site. In applying regression equations for estimating flood flows in a basin, the values of the characteristics used should vary within their observed ranges.

Table 7. General evaluation of statistical criterion of prediction error

Return Periods	Gauge Numbers													Mean
	1801	1802	1804	1805	1806	1812	1817	1818	1820	1821	1822	1823	18-12	
2.33	34.50	24.35	33.61	3.56	19.25	4.49	60.01	5.29	30.59	13.25	2.43	14.31	17.48	20.24
5	42.47	27.63	22.40	11.39	32.02	1.10	60.25	12.00	47.40	17.90	1.52	27.32	30.30	25.67
10	40.12	44.11	30.19	9.16	29.99	10.19	76.17	5.34	48.66	31.57	10.06	25.47	29.16	30.02
25	42.20	50.26	29.20	13.33	32.37	11.84	77.68	5.67	52.48	35.95	13.72	28.05	32.25	32.69
50	47.37	40.90	18.47	22.01	39.14	4.34	66.35	14.17	57.38	29.93	6.26	34.59	38.14	32.23
100	46.27	47.96	21.79	20.77	37.98	8.32	72.91	11.38	57.18	36.60	11.10	33.48	37.19	34.07

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