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Regional Flood Frequency Analysis of the Basins of the East Mediterranean Region

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Abstract: Methods known as regional flood frequency analyses have often been used for providing records to be gathered and for determining different quantiles of flood in basins having an adequate runoff gauging station (RS) or no gauge. Regional flood frequency analyses including homogeneity test was applied to annual instantaneous peak flows of 50 RSs in 4 basins of the East Mediterranean region. Only 3 RSs were determined to be inhomogeneous. As a result, regional dimensionless flood frequency curves and variation of mean annual flood with drainage area were obtained. The determination coefficient of the mean annual flood prediction equation of the Seyhan basin was found to be very poor. Therefore, the basin was divided into 2 divisions. The determination coefficients of the 2 divisions were much greater. In addition, the flood flow estimation capability of the regional flood frequency analyses for ungauged areas in 4 basins of the East Mediterranean region is demonstrated to be generally sufficient using the statistical criterion of prediction error.

Key Words: Regional flood frequency analyses, Instantaneous flood peak, East Mediterranean region

Doğu Akdeniz Bölgesindeki Havzaların Bölgesel Taşkın Frekans Analizi

Özet: Yeterli sayıda veya hiç akım gözlem istasyonu (RS) bulunmayan havzalarda, taşkınların çeşitli yinelenmeli büyüklüklerinin saptanmasında mevcut kayıtların bir araya getirilmesini sağlayan ve bölgesel taşkın frekans analizi olarak bilinen yöntemler yaygın olarak kullanılmaktadır. Çalışmada, homojenlik testini de içeren bölgesel taşkın frekans analizi Doğu Akdeniz Bölgesi'nde bulunan dört havzaya ait 50 RS'deki yıllık anlık maksimum akımlara uygulanmış ve sadece 3 gözlem istasyonunun homojen olmadığı belirlenmiştir. Sonuç olarak, havza için bölgesel boyutsuz taşkın frekans eğrisi ile alan düzeltme eğrisi elde edilmiştir. Yıllık ortalama akım tahmin eşitliğinin belirleme katsayısının çok düşük bulunması nedeniyle Seyhan havzası iki alt havzaya bölünmüş ve sonuçta bu iki alt havza için daha yüksek belirleme katsayısı elde edilmiştir. Ayrıca, hata testi istatistiksel kriteri sonucunda bölgesel taşkın frekans analizinin Doğu Akdeniz Bölgesi'nde bulunan dört havzada ölçümü olmayan alanlarda taşkınları tahmin etmede genelde yeterli olduğu saptanmıştır.

Anahtar Sözcükler: Bölgesel Taşkın Frekans Analizi, Anlık Maksimum Akım, Doğu Akdeniz Bölgesi

Introduction

Estimation of the flooding potential at a site is needed for the design of river engineering works and urban planning. The best possible estimates are required not only of the cost of engineering works but also of the benefits. These engineering works require a reliable estimation of flood quantiles (QT) using reliable flood records measured at gauging stations. However, flood records at gauging stations are generally short and sparse, and the sampling errors correspondingly large. In addition, it is only rarely that flood frequency information is needed at a gauging station site, more often it is required at an ungauged site (Dalrymple, 1960; Meigh et al., 1997). Furthermore, if the length of the available streamflow gauging record at the site of interest is shorter than the return period of interest, obtaining an accurate estimation of QT becomes more complicated. Greater difficulty also occurs if there is no flow record available at the site of interest. All of these problems can be compensated for through the use of regional flood frequency analysis (RFFA).

RFFA can facilitate the estimation of the QT value at a location for which limited flow data exist. Another advantage of regional methods is that unusual events

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which occur in a small number of basins can be taken into account over a wider area where they might have occurred. Some RFFA methods, particularly Dalrymple's methods, assume that a region is set of gauging sites whose flood frequency behaviour is homogeneous in some quantifiable manner. RFFA exploits this homogeneity to produce quantile estimates which, in most cases, are more reliable than those obtainable from at-site data alone (Cunnane, 1988). Therefore, many researchers have used RFFA for estimating flood flows of various return periods (Horn, 1988; Garde and Kothyari, 1990; Pitlick, 1994). In addition it is to be expected that the more homogeneous a region the greater the gain in using regional instead of at-site estimation.

In this paper an attempt is made to develop regional flood frequency curves and variation curves of mean annual flood with drainage area for ungauged sites, which take as inputs annual instantaneous maximum flows of basins of the East Mediterranean region, namely the basins of the Seyhan river, Ceyhan river, Hatay and the East Mediterranean sea, for various flood quantiles. An attempt is also made to compare the flood estimation of various flood quantiles using a statistical criterion.

Material

The annual instantaneous flood peaks, the highest event in a particular year, were picked for 50 runoff gauging stations (RSs) (n = 15-56) operated by the Electrical Power Resources Survey and Development Administration (EİE) and the State Hydraulic Works (DSİ) in the East Mediterranean region (DSİ, 1994). An annual series takes only 1 event from each year of the record. The difference between annual instantaneous flood peaks and flood peaks is that the second or third, etc., highest events in 1 year may be higher than the maximum event in another year and yet they are totally disregarded. If flood flows are being investigated, they should preferably be annual instantaneous flood peaks (Kite, 1988). Runoff data are all free from regulation by any sizeable structure and well distributed over the whole region. Details of all RSs are given in Table 1.

Method

There are several regional flood frequency models used in the literature (Dalrymple, 1960; Cunnane, 1988). Dalrymple's method is one of the most frequently used models and can be used to combine information from the stations that belong to a region. The methodology of Dalrymple's method is well known and will not be described here in detail, but the approach taken in the study is briefly described below.

The method consists of 7 parts: first, determination of suitable probability distribution; second, application of the homogeneity test to RSs in basins; third, standardisation of the flood flows for various T-year flood flows (QT) by dividing mean annual flood defined as a flood having a return period of 2.33 years ($Q_{2.33}$); fourth, determining average $QT/Q_{2.33}$ values for each return period and each basin; fifth, derivation of the regional dimensionless flood frequency curves following the first 4 steps; sixth, derivation of the regression relationship between $Q_{2.33}$ and drainage area; and seventh, model evaluation using a statistical criterion.

Frequency analysis

Many references are available about probability distributions and their parameter estimation methods (Haktanır, 1991; Haktanır, 1992). Hence only some limited information about frequency analysis is given. In frequency analysis the Gringorten plotting position formula is one of the most commonly used formulae (Topaloğlu et al., 2003). If the data conform to a Gumbel distribution the quantile function, denoted by QT, can be described as

$$QT = c + (\{-\ln [-\ln(1- 1/T)]\} / b) \quad (1)$$

where T is the return period, and b and c are the scale and location parameters, respectively.

Homogeneity Test

The criteria for the homogeneity test are limiting values for variations in the return period. If variations in the data fall within 95% confidence limits they are such as could have occurred by chance. Variations outside these limits are caused by samples coming from different populations. The test curves, which relate to 10-year flood, can be plotted from values given by Dalrymple (1960).

In order to perform the homogeneity test, the ratio of the 10-year flood to the mean annual flood, as represented by the 2.33 year return period, is computed from the preliminary frequency curves for each station and the mean of these ratios is determined. New values for each 10-year flood are computed in this ratio to the mean annual flood. The actual return periods of these discharges from the preliminary frequency curves are

Table 1. Some characteristics of the selected runoff gauging stations (DSİ, 1994).

Name of Basin	Gauge Numbers	Name of Rivers	Name of Gauge Site	Drainage Area (km^2)	Years of Record	Number of Peaks Used (year)
The East Mediterranean Sea (TEM)	17-07**	Pamuk	Ketbükü	552	1972-1990	19
	17-11**	Efrenk	Hamzabeyli	410	1969-1990	22
	17-14**	Göksu	Görmel Köp.	2156	1972-1990	19
	17-16**	Göksu	Kravga Köp.	2994	1974-1990	17
	17-17**	Göksu	Gödrüp	364	1968-1990	22*
	1701	Kadıncık	Karageçit	422.4	1937-1967	31
	1704	Göksu	Selamlı	4372	1947-1965	19
	1708	Tarsus	Murat Köp.	1416	1961-1993	33
	1712	Göksu	Bucakkışla	2689.2	1962-1992	31
	1714	Göksu	Karahacılı	10065.2	1961-2001	41
	1717	Lamas	Kızılgeçit	1055.2	1967-1992	26
	1719	Ermenek	Kırıkkavak	3499.6	1970-1992	23
	1720	Göksu	Hamam	4304	1966-1992	27
	1721	Anamur	Ala Köp.	313.2	1969-1992	24
Seyhan	1801	Göksu	Himmetli	2683.2	1936-1991	56
	1802	Zamantı	Farata	7615.2	1936-1954	19
	1804	Zamantı	Söğütlü	4800.8	1941-1955	15
	1805	Göksu	Gökdere	4492.8	1940-1991	52
	1806	Zamantı	Ergenuşağı	8920.8	1961-1979	19
	1812	Zamantı	Pınarbaşı	2708.0	1955-1973	19
	1817	Çakıt	Arapali	1609.6	1964-1985	17
	1818	Seyhan	Üçtepe	14484.0	1966-1991	25
	1820	Körkün	Hacılı Köp.	1460.7	1970-1991	22
	1821	Eğlence	Sarımehmetli	664.0	1971-1986	16
	1822	Zamantı	Fıraktin Köp.	6528.0	1970-1991	22
	1823	Zamantı	Emeğil	2847.2	1974-1990	17
	18-12**	Körkün	Kamışlı	1107.2	1971-1990	19
Hatay	19-04**	Bohsın	Bohsın	238.4	1964-1990	27
	19-06**	Afrin	Afrin Köp.	601	1975-1989	15
	19-09**	Asi	Çoğurlu	21734	1969-1994	25*
	19-12**	Tahtaköprü	Girit	501	1975-1992	18
	1905	Karasu	Torun Köp.	1768	1954-2001	48
	1906	Afrin	Mütrüflü	2764.4	1954-2001	47*
	1907	Asi	Demir Köp.	16170.	1953-2001	48*
	1908	Asi	Antakya	22624.4	1950-2001	49*
Ceyhan	20-07**	Hurman	Kuş Kayası	2084	1967-1989	23
	20-16**	Kömür	Alıçlıbucak	291	1963-1989	27
	20-17**	Aksu	Köprüağzı	1740	1971-1987	17
	2001	Ceyhan	Kılavuzlu	8484	1941-1990	50
	2004	Ceyhan	Misis	20466	1971-2001	31
	2005	Ceyhan	Akcıl	4202	1953-1990	36*
	2006	Göksun	Karaahmet	739.2	1954-1992	39
	2007	Sumbas	Çukur Köp.	620	1962-1992	30*
	2008	Savrun	Kadirli	444	1970-1992	23
	2009	Göksun	Poskoflu	1387.2	1954-1992	38*
	2010	Aksu	Kürtler Avşarı	3498.8	1961-1990	28*
	2012	Ceyhan	Ceyhan Köp.	19727.2	1954-1970	17
	2015	Hurman	Tanır	915.2	1957-1992	36
	2020	Ceyhan	Aslantat	14708.4	1966-2001	35*
	2022	Söğütlü	Han	428	1973-1992	20

* Incomplete data (3 years at most), ** Operated by DSİ

then plotted against the adjusted period of record. The convention is followed that the adjusted period of record is equal in length to the actual record plus half the number of years by which it is extended.

Model Evaluation Criterion

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

$$PE = n^{-1} \sum_{i=1}^{n} \left|(Y_i - \widehat{Y}_i) / Y_i\right| * 100 \qquad (2)$$

where n is the number of estimates, Y_i is the true value and $\hat{Y}_i$ is the value of QT calculated from equation (1). 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

Incomplete data from flood gauging stations given in Table 1 were considered to be consecutive because the missing years numbered 3 at most. It was also thought that the missing values completed would not change the regional curves much. Cunnane (1988) has emphasised that small departures from perfect homogeneity do not appreciably reduce the beneficial aspects of RFFA.

In addition, of the 14 models, the probability distribution model of the Gumbel moments was considered applicable to the data according to the chi-squared goodness-of-fit test because the Gumbel model was found to be the best model 41 times from among the 50 RS models in the region (Topaloğlu et al., 2003).

Homogeneity Test

The homogeneity test was also performed for 50- and 100-year return period levels, although Dalrymple (1960) has suggested the homogeneity test be used for only the 10-year return period. Therefore, the flood flows of various return periods were determined using the parameters of Gumbel moments given in Table 2. However, only the results of the homogeneity test of the 10-year return period are given in Table 2.

The homogeneity test of the 10-year return period given in Figure 1 prepared using columns 8 and 9 of Table 2 showed that all data points fall within 95% confidence intervals except for the RSs of 17-16, 2007 and 2012. After excluding these 3 RSs from the 50 RSs the records of the remaining 47 RSs can be regarded as homogeneous and records from the stations in each basin may be grouped together to define a regional dimensionless flood frequency curve (RDFFC). Two of the excluding stations, except for the RSs of 17-16, were also found to be outside the confidence limits for the homogeneity tests of the 50- and 100-year return periods.

Derivation of Regional Dimensionless Flood Frequency Curve

The regional flood frequency curve has important implications for hydrologic processes. The slope of a frequency curve graphically represents the standard deviation of the flood frequency distribution, and the higher the slope, the greater the standard deviation in flood discharges (Pitlick, 1994).

The Gumbel distribution model was used for each basin to form the RDFFCs as shown in Figure 2 using average $QT/Q_{2.33}$ ratios for different QTs as calculated in column 6 in Table 2. However, the Seyhan basin was divided into 2 divisions since it gave a very poor determination coefficient, as can be seen from Table 3. The RDFFC associates a return period T with $QT/Q_{2.33}$ and this relation is assumed to be valid for all catchments in 1 region, or alternatively to represent the mean of the different relationships for the different catchments in the region.

Of these 4 basins, floods in the Ceyhan basin are the most variable, floods in Seyhan and the East Mediterranean (TEM) have less variability, and floods in Hatay are the least variable in the region. In other words, the RDFFCs showed that, depending on the region, floods that are unusual in a statistical sense (say, the 100-year flood, Q_{100}) may or may not be large relative to the mean annual flood, $Q_{2.33}$. In the Ceyhan basin, for example, Q_{100} is more than 3.4 times greater than $Q_{2.33}$, whereas in the Hatay basin, Q_{100} is less than 3 times greater than $Q_{2.33}$ (Figure 2). Pitlick (1994) classified these ratios as intermediate variable, and floods corresponding to these ratios were mostly produced by large-scale frontal precipitation as in the case of our region. Similar ratios

Table 2. Data for the homogeneity test of the 10-year return period.

Gauge Number	Gumbel Parameters b*	Gumbel Parameters c*	2.33-Year Flood, $Q_{2.33}$ (m^3s^{-1})	10-Year Flood, Q_{10} (m^3s^{-1})	Ratio $Q_{10} : Q_{2.33}$ (-)	$Q_{2.33}$ x Ave. Ratio (m^3s^{-1})	T for Q of Column 7 (years)	Period of Record Adjusted (years)
1	2	3	4	5	6	7	8	9
17-07	0.0122760	87.078	134.21	270.39	2.01	241.58	7.20	30
17-11	0.0290330	46.311	66.24	123.82	1.87	119.23	9.00	32
17-14	0.0027921	512.820	720.04	1318.80	1.83	1296.08	9.40	30
17-16	0.0139570	224.670	266.13	385.91	1.45	479.03	35.50	29
17-17	0.0543050	42.631	53.29	84.07	1.58	95.91	18.00	32
1701	0.0180860	66.965	98.96	191.39	1.93	178.12	8.00	36
1704	0.0101180	168.380	225.56	390.79	1.73	406.02	11.60	30
1708	0.0040046	162.090	306.57	724.04	2.36	551.83	5.30	37
1712	0.0112830	193.470	244.75	392.92	1.61	440.55	16.80	36
1714	0.0034837	675.450	841.53	1321.42	1.57	1514.76	19.10	41
1717	0.0377570	22.626	37.95	82.23	2.17	68.31	6.20	34
1719	0.0036133	536.420	696.55	1159.22	1.66	1253.79	13.90	32
1720	0.0071997	262.500	342.86	575.06	1.68	617.15	13.40	34
1721	0.0076598	219.360	294.90	513.15	1.74	530.81	11.40	33
Ave. Ratio	-	-	-	-	1.80	-	-	-
1801	0.0075600	144.530	221.06	442.20	2.00	402.33	7.50	56
1802	0.0357100	75.598	91.80	138.62	1.51	167.08	27.00	38
1804	0.0506300	33.003	44.43	77.45	1.74	80.86	11.50	36
1805	0.0033500	462.680	635.39	1134.43	1.79	1156.42	10.70	54
1806	0.0048100	216.970	337.26	684.82	2.03	613.81	7.20	38
1812	0.0663200	32.344	41.07	66.28	1.61	74.74	17.00	38
1817	0.0247000	73.434	96.86	164.54	1.70	176.28	13.30	37
1818	0.0018400	886.350	1200.80	2109.38	1.76	2185.46	11.40	41
1820	0.0073600	101.520	180.13	407.28	2.26	327.84	5.80	39
1821	0.0078400	195.710	269.51	482.75	1.79	490.51	10.60	36
1822	0.0357000	65.927	82.13	128.96	1.57	149.48	20.00	39
1823	0.0349000	33.873	50.45	98.35	1.95	91.82	8.00	37
18-12	0.0345000	35.877	52.65	101.11	1.92	95.82	8.40	38
Ave. Ratio	-	-	-	-	1.82	-	-	-
19-04	0.0379170	27.634	42.89	86.98	2.03	75.06	6.60	38
19-06	0.0190290	67.516	97.92	185.78	1.90	171.36	7.80	32
19-09	0.0062885	440.900	532.91	798.75	1.50	932.59	22.50	37
19-12	0.0480830	50.751	62.78	97.55	1.55	109.87	17.00	34
1905	0.0211110	82.491	109.90	189.09	1.72	192.32	10.80	49
1906	0.0055949	139.590	243.00	541.81	2.23	425.26	5.50	48
1907	0.0200270	119.180	148.07	231.55	1.56	259.12	17.00	49
1908	0.0083982	296.790	365.68	564.75	1.54	639.95	18.30	49
Ave. Ratio	-	-	-	-	1.75	-	-	-
20-07	0.0171400	26.638	60.39	157.93	2.61	117.77	5.30	37
20-16	0.0829240	18.711	25.69	45.85	1.78	50.097	13.90	39
20-17	0.0086984	78.103	144.62	336.81	2.33	282.01	6.40	34
2001	0.0041721	427.840	566.52	967.22	1.71	1104.71	17.30	50
2004	0.0024936	774.180	1006.21	1676.64	1.67	1962.11	19.80	41
2005	0.0233160	84.767	109.58	181.28	1.65	213.69	20.50	43
2006	0.0383390	39.305	54.40	98.00	1.80	106.07	13.50	45
2007	0.0586560	49.818	59.68	88.18	1.48	116.38	50.00	40
2008	0.0092454	107.250	169.83	350.65	2.06	331.17	8.40	37
2009	0.0141640	55.537	96.39	214.42	2.22	187.95	7.00	44
2010	0.0077001	226.830	301.97	519.08	1.72	588.84	16.70	39
2012	0.0030074	902.490	1094.88	1650.77	1.51	2135.01	41.30	34
2015	0.0224620	23.488	49.25	123.67	2.51	96.03	5.70	43
2020	0.0019715	605.590	899.07	1747.04	1.94	1753.18	10.10	43
2022	0.0181090	45.478	77.43	169.75	2.19	150.99	7.20	35
Ave. Ratio	-	-	-	-	1.95	-	-	-

* b and c: the scale and location parameters of the Gumbel distribution, respectively.

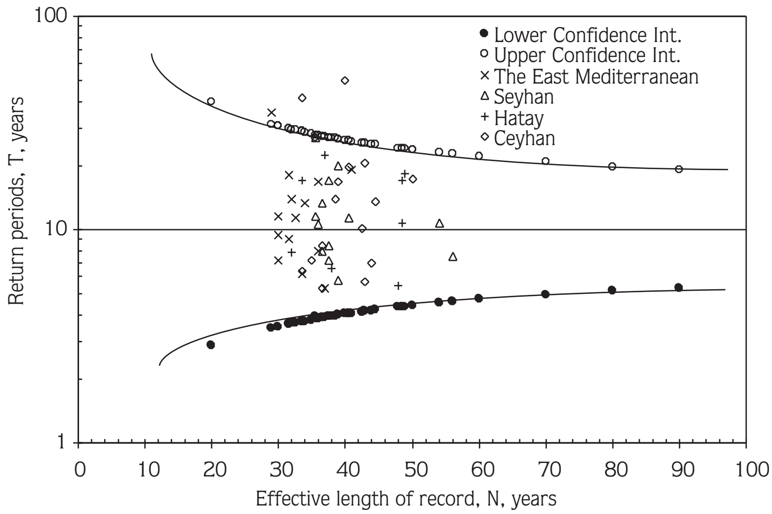

Figure 1. Homogeneity test for the 10-year return period.

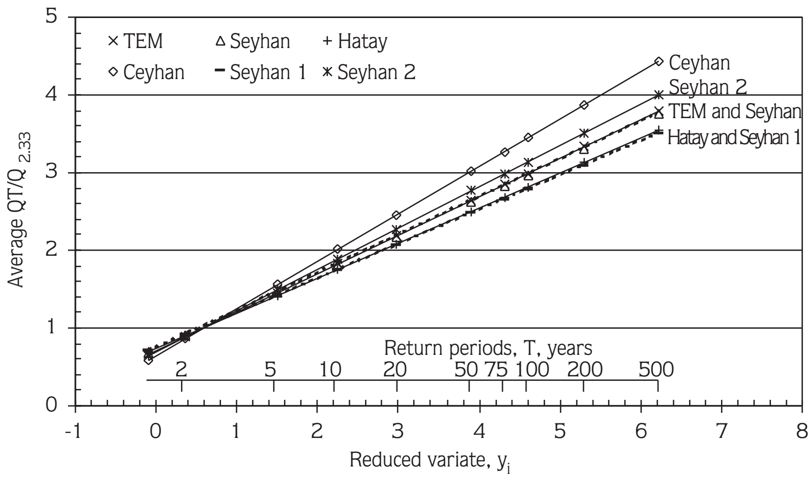

Figure 2. Regional flood frequency curves for 4 basins of the region.

Table 3. $Q_{2.33}$ prediction equations for basins.

Basins	Equations	r^2	r	n	r_{table} 5%	r_{table} 10%
TEM***	$Q_{2.33} = 2.528\ A^{0.610}$	0.479	0.692*	13	0.553	0.476
Hatay	$Q_{2.33} = 5.200\ A^{0.422}$	0.790	0.889*	8	0.707	0.622
Ceyhan	$Q_{2.33} = 0.585\ A^{0.727}$	0.740	0.860*	13	0.553	0.476
Seyhan	$Q_{2.33} = 6.070\ A^{0.390}$	0.106	0.326	13	0.553	0.476
Seyhan 1	$Q_{2.33} = 0.0019\ A^{1.245}$	0.641	0.801**	6	0.811	0.729
Seyhan 2	$Q_{2.33} = 0.487\ A^{0.801}$	0.594	0.771*	7	0.754	0.669

* Accepted for 5%, ** Accepted for 10%, *** TEM : The East Mediterranean

were also found for 10 geographical regions in Great Britain by the NERC (1975) and for 38 regions worldwide by Meigh et al. (1997). Pitlick (1994), however, determined this ratio at between 2 and 10 for 5 different regions. Meigh et al. (1997) concluded that the ratio of $Q_{100}/Q_{2.33}$ is lower for humid regions while it is higher for arid regions, reflecting the extreme year-to-year variability found in these basins. Thus, in a physical sense, it may be more appropriate to evaluate the magnitude of a rare flood by its ratio to the mean annual flood than by a statistical measure such as its return period.

It may also be concluded that the lower parts of all the flood frequency curves pass through almost the same point, especially for the return periods of 1 to 8 years in Figure 2. However, a considerable variation occurred in flood values starting with the 20-year return periods. The variation in flood values between the basins may be mainly due to response of the basins to the variability and diversity in extreme precipitation and basin characteristics. As can be seen from Figure 2, however, closer trends in flood frequency curves were determined between Seyhan and TEM.

Derivation of Mean Annual Flood Estimation Method

The mean annual flood, $Q_{2.33}$, for the site of interest was estimated, typically by a regression relationship between $Q_{2.33}$ and drainage area, A, as illustrated in Figure 3.

The regression lines between $Q_{2.33}$ and A for Hatay and Seyhan were found to be much closer to each other, while the TEM and Ceyhan data fall into separate fields.

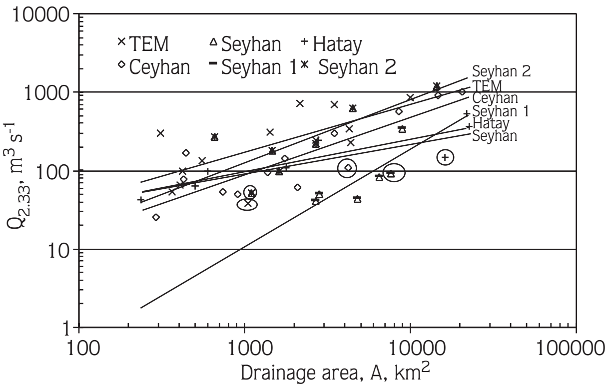

Figure 3. Variation of $Q_{2.33}$ with drainage area for basins.

The wide variation between individual curves may be largely explained by a variation in catchment size between the different regions. Basins having smaller drainage areas (<1000 km^2) tended to have steeper curves, such as TEM and Ceyhan, than those for larger areas. This makes hydrological sense, as there is a smaller probability of extreme rainfall occurring uniformly over a large area, and so large catchments tend to have a less extreme response than small ones (Meigh et al., 1997). The $Q_{2.33}$ prediction equations are given in Table 3. For each equation, the coefficient of determination (r^2) has been listed so that the quality of fit to the data can be judged by users.

In all 5 regions, values for r^2 ranged from 0.106 in the Seyhan basin to 0.790 in the Hatay basin. The value of r for the Seyhan basin is the only one rejected according to the correlation test of $r_{table,\ 0.05\ or\ 0.10,\ n-2}$ (Yurtsever, 1984). Further investigation of the $Q_{2.33}$ prediction equation should be carried out in this case (Meigh et al., 1997), especially when the determination coefficient is rather poor, by dividing the stations into a number of geographical groups and again searching for relationships between $Q_{2.33}$ and A. In the study, this suggested method was applied and the values for r^2 improved to 0.641 and 0.594 for the 2 divisions of Seyhan, namely Seyhan 1 and Seyhan 2, respectively. Seyhan 1 includes 6 RSs operated on the Zamantı river while Seyhan 2 covers the rest of the RSs in the Seyhan basin. RDFFCs for the 2 divisions were also developed and are given in Figure 2.

Model Evaluation Criterion

Each gauged site was assumed to be ungauged. In other words, the flood flows for various T-years from that site were not included in the data set used to derive the individual $Q_{2.33}$ regression relationships and RDFFC. In this way, the RFFA approach is realistically evaluated as an ungauged site extreme flow quantile estimation method. Thus, 47 different RDFFCs and $Q_{2.33}$ prediction equations were obtained.

Estimates of different flood quantiles of 5, 10, 20, 50, 75, 100, 200 and 500 years for that site were found by scaling its RDFFC as $QT/Q_{2.33}$ from Figure 2. Afterwards, these scale numbers were multiplied by the $Q_{2.33}$ value corresponding to the drainage area of that site using Figure 3 in order to calculate the various T-year flood flows ($Q_{2.33} * QT/Q_{2.33} = QT$) for that site. Finally, a general evaluation of the statistical criterion (Eq. 2) was made taking the means of RSs in each basin for each return period, and the results are given in Table 4.

Based on the results, values of mean PE for return periods were found to range from 49.37% to 81.67% for the region. TEM and Seyhan 2 showed much greater PE than did the others. The other basins, however, gave better PE results, generally lower than 60%, than those of these 2 basins. Furthermore, those that fell very far from the general trend of the data were investigated from Figure 3 to see if there were anomalies that indicated that the stations should not be included in the analysis. It was determined from the predictions that each basin has 1 RS increasing the mean PE. These are the RSs of 1717, 1907, 2005, 1802 and 18-12, which are circled in Figure 3. For these stations or ungauged areas having similar drainage area sizes, some other flood estimation techniques should be used to be able to obtain better flood estimation. By excluding these RSs from the mean PE calculation, estimation capability was improved by approximately 15% to 33% for the minimum and maximum PE values given in parentheses. Thus, the PE varied between 24.64 and 56.40 for the whole region. Potter (1953) and Horn (1988) calculated an estimation error varying between 0% and 67% for the 51 RSs and 50% and 100%, respectively, using regression equations including basin characteristics beyond the drainage area. Wharton et al. (1989) reported that PE varied between 1.57% and 267.6% by comparing the mean annual floods obtained from the Gumbel model with the estimation of mean annual flood using 6-variable regression equations for 72 FSs. Panu and Smith (1989) determined the average PE as 28% and 56% for various return periods for 21 RSs. Garde and Kothyari (1990) determined that the accuracy of the flood estimation equation was remarkably high because it resulted in a ±30% error.

Conclusions

The regression equations given in Table 3 can be of great value in providing flood estimates for ungauged sites in the region. However, the equations offer more reliable and rapid flood estimates in the region if they are not used for ungauged areas having similar drainage area sizes of the RSs of 1717, 1907, 2005, 1802 and 18-12 because they have low average PE, and area is the only variable needed to indicate the flood flow parameters at an ungauged site.

The initial purpose of carrying out the analyses was to derive an RDFFC that would be of immediate usefulness in practical applications. The methods are only suitable for preliminary estimates in the absence of substantial local data. Where other information, such as climatic data, or maps of geology, soils, land use or vegetation, is available, these provide additional clues. In addition, plots of $Q_{2.33}$ versus catchment area can not be used when additional variables are included. Neither could the results be used to reliably predict the $Q_{2.33}$ equation and flood frequency curve for other regions.

Table 4. General evaluation of statistical criterion of prediction error (PE), %.

Basins	Return Periods								Minimum	Maximum
	5	10	20	50	75	100	200	500	PE	PE
TEM*	78.14	78.29	78.51	78.80	78.91	78.98	79.15	79.33	78.14 (49.97)	79.33 (56.40)
Hatay	49.37	51.96	53.77	55.49	56.10	56.48	57.28	58.14	49.37 (24.64)	58.14 (27.90)
Ceyhan	56.36	55.87	55.77	55.78	55.81	55.83	55.89	55.97	55.77 (36.26)	56.36 (41.57)
Seyhan 1	58.80	61.69	63.69	65.60	66.26	66.68	67.57	68.52	58.80 (45.27)	68.52 (49.06)
Seyhan 2	79.14	79.96	80.49	80.98	81.14	81.24	81.45	81.67	79.14 (46.61)	81.67 (49.96)

* TEM: The East Mediterranean

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