Regional Flood Frequency Analysis Around Seyhan Basin

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ABSTRACT

In the 21st century, floods, which are frequent disasters due to the increasing temperature all over the world together with the global climate change, and consequently heavy, sudden precipitations and sudden snowmelt, cause great economic, ecological, and environmental damage and even loss of life. In addition, floods occur due to increased unauthorized construction in the floodplains, improperly applied river regulation studies, and especially incorrect determination of the design (project) discharge for the structures. In this study, according to the flow data obtained from the stations belonging to the Seyhan Basin, firstly several analyses were made for each station separately, then a regional analysis was made for all stations. Here, the annual maximum flow data for 8 different stations were obtained from the flow observation annuals of the General Directorate of State Hydraulic Works. For these data, compliance tests for various distributions were made based on a single station and flow estimations were made for each station in particular return periods by using the design discharge flood forecasting methods. Afterward, the regional flood frequency analysis was done by using several trend analysis methods. Then, a regional flood curve was obtained. In this way, a curve was found to obtain the current value even in the regions where there are no current records. Then, it has been determined that the regional curve fits successfully with the individual results when the individual and regional results are compared.

Keywords: flood frequency analysis, regional analysis, regional flood curve, trend analysis

INTRODUCTION

In rivers, water level and discharge change over time. During the periods when discharge and water level are so high, the flow can overflow the riverbed. Then, this phenomenon is called "flood". Floods may occur due to short-term heavy rains, snowmelt, dam break, or combinations of these. Besides, earthquakes, landslides, tides, and storm waves may cause floods. Then, these flood events can cause tremendous damage to the environment, and economy and, even carry a huge risk to life. Evaluating and analysing the water resources concerning the flood risk at the hydrological basins are necessary for protecting societies and the environmental systems. It is expected that climate change will be more effective in the future and will cause more frequent floods because of the increase in the precipitation amount, temperature, change in the snowmelt pattern, and evaporation processes. According to a study by (Lehner et al., 2006), 100-year floods will occur more frequently in northern and north-eastern Europe in 2070 due to global warming and climate change. For this reason, it has recently become more significant to do flood frequency analysis and determine design discharges. However, it is difficult to determine the design discharges mostly. Hence, some methods are improved for this problem. In the literature, there are several methods for flood frequency analysis and flood estimation. According to (Bayazıt, 1995) and (Önöz & Bayazıt, 2008), it is mentioned some methods are the relation between precipitation and flow (hydrograph analysis), empirical methods for small basins as Rational Method, Unit Hydrograph Method, and SCS(NRCS), Possible Maximum Flood Methods, and Regional Flood Frequency Analysis.

Purpose of the paper

In this study, it is aimed to obtain flow values depending on a return period by performing the Regional Flood Frequency Analysis and various statistical analyses regarding the flow data of the rivers around the Seyhan Basin, and thus to obtain design flow values even in areas without flow data. It is also stated in (Önöz & Bayazıt, 2008) as estimating the flood flow (design flow) corresponding to a return period (such as 50, 100, or 500 years) at a station. Besides, the regional analysis basically increases the number of data and decreases the statistical error due to the scarcity of samples. Homogeneity is important for regional analysis. Dimensionless statistical parameters of the flood discharge do not change for all stations in hydrologically homogeneous regions. Therefore, homogeneity tests are used to control whether the data at one station statistically differ from those other stations in the region (Önöz & Bayazıt, 2008).

MATERIALS AND METHODS

As related sections are mentioned in subtitles, several statistical methods are applied to 8 stations around the Seyhan basin according to river discharge data "River Flow Observation Yearbooks" from the General Directorate of State Hydraulic Works (D. S. İ. G. Müdürlüğü, 2019). Firstly, related statistical analyses such as flood frequency analysis, and flood discharge estimations (various distributions applied with compliancy tests) are applied to each station. Secondly, regional analysis is applied altogether according to the results of each station's analyses.

Study Area

In this study, annual peak flow data from eight stations (D18A012, D18A017, D18A018, D18A023, E18A05, E18A025, E18A026, and E18A027) in the Seyhan basin were used in the regional flood frequency analysis. Figure 1 shows the location of the stations with red circles. Also, the properties of the stations are given in Table 1.

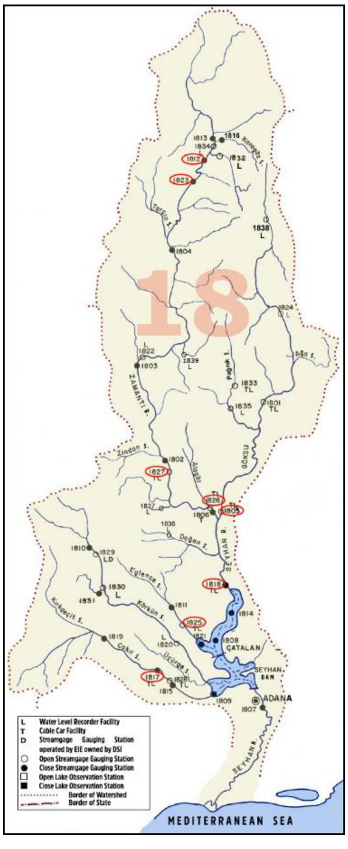

Figure 1: Seyhan Hydrological Basin (D. S. İ. G. Müdürlüğü, 2019)

Table 1: The Properties of The Stations (D. S. İ. G. Müdürlüğü, 2019)

Station No	**Name**	**Height (m)**	**Area (km^2)**	**Recorded Flow Data (year)**
D18A012	Körkün S. (Kamışlı)	1094	1065	38
D18A017	Sarız S. (Darıdere)	1548	202.7	31
D18A018	İnderesi (Hasan Çavuşlar)	1400	136	32
D18A023	Yağdeğleme Ç. (Yeniköy)	870	23.5	30
E18A005	Göksu (Gökdere)	312	4242.8	70
E18A025	Eğlence D. (EğriBük)	222	544.5	28
E18A026	Zamanti N. (Ergenuşağı)	360	8698.1	24
E18A027	Zamanti N. (Değirmenocağı)	740	7718	28

Analyses for Each Station

There are limited flood flow data for each station. In order to estimate the 100- and 500-years discharges for flood design, probability distributions are used and possible maximum floods are calculated. The most used probability distributions in flood hydrology area according to (Bayazıt, 1995) and (Önöz & Bayazıt, 2008) are used. Then, compliance tests are applied via a package software to the data and 3 common probability distributions fit to Seyhan Basin stations. These distributions are 3-parameters lognormal distribution, GEV (Generalized extreme value) distribution and Gumbel distribution.

3-Parameters Lognormal Distribution

Normal distribution is the most used distribution in statistics. Quantile function of normal distribution is:

$$X_p = \mu_x + z_p \sigma_x \quad (1)$$

Normal distribution table is used for Z_p, μ_x is mean value and σ_x is standard deviation. If the Y variable which is obtained by taking X variable's logarithm fits the normal distribution, distribution of X is lognormal distribution. In most cases the variable's logarithm does not fit normal distribution so X_0 lower bound is subtracted from the variable and then it fits the normal distribution.

$$X_p = exp(\mu_y + z_p \sigma_y) \quad (2)$$

$$Y = \ln(X - X_0) \quad (3)$$

$$X = X_0 + \exp(Y) \quad (4)$$

GEV Family

In hydrology, in most cases the highest and the lowest values of the flow rate, precipitation and etc. show similarity. According to (Gumbel, 1958), the random distributions of these kind of samples can be one of the extreme value distributions. In statistics it is accepted that if the sample goes infinity, distribution of the highest values of this sample converges to one of the extreme values distributions. There are three types of GEV distribution. In Turkey, GEV distributions are accepted as the most convenient distribution.

Gumbel Distribution

If the independent variables fit same distribution and unlimited at upper boundary, then this distribution is called GEV type 1 or Gumbel Distribution. Cumulative distribution function for Gumbel Distribution is:

$$F_{(x)} = \exp\left[-\exp\left(-\frac{x-\xi}{\alpha}\right)\right] \quad (5)$$

Extreme Value Distribution

It is the general form of the GEV distributions and contains GEV I (Gumbel Distribution), GEV II and III. GEV II has a lower boundary and GEV III has an upper boundary. Cumulative distribution function for extreme value distribution is:

$$F_{(x)} = \exp\left[-\left(1-\frac{k(x-\xi)}{\alpha}\right)^{1/k}\right] \quad (6)$$

Mann-Kendall Test for Each Station

The Mann-Kendall test is widely used to evaluate trends in time series data like hydrological, climate, and environmental data. It is a non-parametric test that can be used for any type of distribution. The trend is controlled by the Null hypothesis(H_0) in the test. If there is a trend, the Alternative hypothesis(H_1) is used to understand the tendency of the trend in the data. However, an increase in the autocorrelation in the series decreases the probability of finding a no-trend hypothesis when the Mann-Kendall test is applied. (Storch 1995) suggested a method, Pre-whitening that is used to eliminate the effect of the autocorrelation in the series. After applying Pre-whitening, the Mann-Kendall test becomes more powerful to find out the no-trend series. Mann-Kendall test divides the time series data (X_1, X_2, X_3........X_n) into two groups (X_i, X_j). For $i<j$, the number of $Xi<Xj$ is called P, and the number of $Xi>Xj$ is called M. The statistic of the test is called S which is calculated by the subtraction of M from the P. The Kendall coefficient (τ) is used to determine the sequential association between two measured quantities.

$$\tau = S/[n(n-1)/2] \quad (7)$$

The significance of the statistic of the S can be standardized by using a normal distribution function.

$$Z = \begin{cases} \frac{S-1}{\sigma_S} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sigma_S} & S < 0 \end{cases} \quad (8)$$

$$\sigma_S = \sqrt{[n(n-1)(2n+5) - \sum_i t_i(t_i-1)(2t_i+5)]/18} \quad (9)$$

Regional Analyses

It is not always sufficient to use the values measured at a single station when determining the statistical properties of a random variable such as the flood discharge. In case of a small number of available data, it is useful to consider the measurement results of stations in a region homogeneous with the station in question. For this, it is necessary to determine the statistically homogeneous region. It is accepted that the dimensionless statistical parameters of the flood discharge do not change in such a region. The statistical analysis of data from all stations in a statistically homogeneous region is called regional analysis. In order to make a common calculation for all stations statistically, common years included in all stations are taken. Missing years are ignored. Besides, before the homogenization in the regional analysis, the Mann-Kendall and Pre-Whitening trend tests mentioned in the previous sections were also performed for the regional trend analysis. Thus, it is aimed to determine whether there is a common trend among the stations of the mentioned basin.

RESULTS

The results of the flood frequency analysis and regional analysis of 8 stations in the Seyhan Basin, which were mentioned in the previous section, are given below.

Results for Each Station

These analyses per station were also made for many distributions apart from the three distributions table as shown below. However, as mentioned before the GEV distribution that gave the best results for all stations, i.e. regionally, was found in the compliancy tests made through a package program. Moreover, Gumbel and 3P Lognormal distributions were found suitable. Then, all suitable results for all stations are shown in Table 2. Subsequently, the results of each station for GEV distribution are shown in the following figures. Group 1 shows the first 4 stations and Group 2 the rest of the 4. These groups were created according to the regional analysis. It will be mentioned later.

Table 2: Each Station Results as Estimated Discharges according to Individual Analysis (m^3/s) (Önöz & Bayazıt, 2008)

Distributions	3P Lognormal D.		Gumbel D.		GEV D.	
Years	**100 years**	**500 years**	**100 years**	**500 years**	**100 years**	**500 years**
D18A012	169.9	265.6	202.8	272.9	149.3	267.3
D18A017	37.3	53.7	37.4	47.8	40.3	54.6
D18A018	194.1	279.03	159.7	204.2	219.5	371.4
D18A023	27.8	48.3	27.8	34.8	27.04	30.4
E18A005	1524.8	1952.5	1427.8	1773.7	1526.06	2005.1
E18A025	667.7	823.6	571.7	715.4	571.5	712.9
E18A026	779.2	996.3	729.7	908.3	865.3	1063.8
E18A027	36.8	44.3	35.4	43.2	35.06	42.5

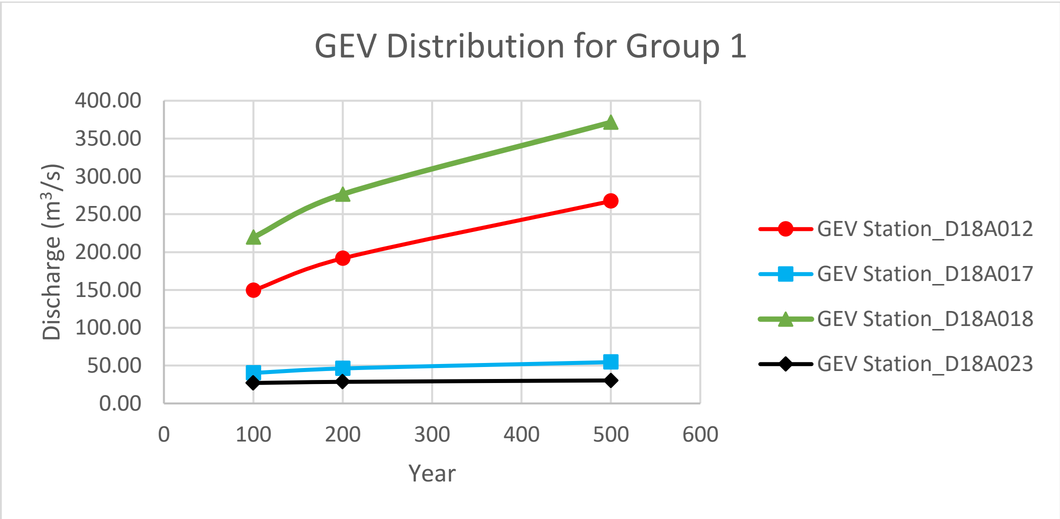

Figure 2: GEV Distribution Results of each station for Group 1 (Önöz & Bayazıt, 2008)

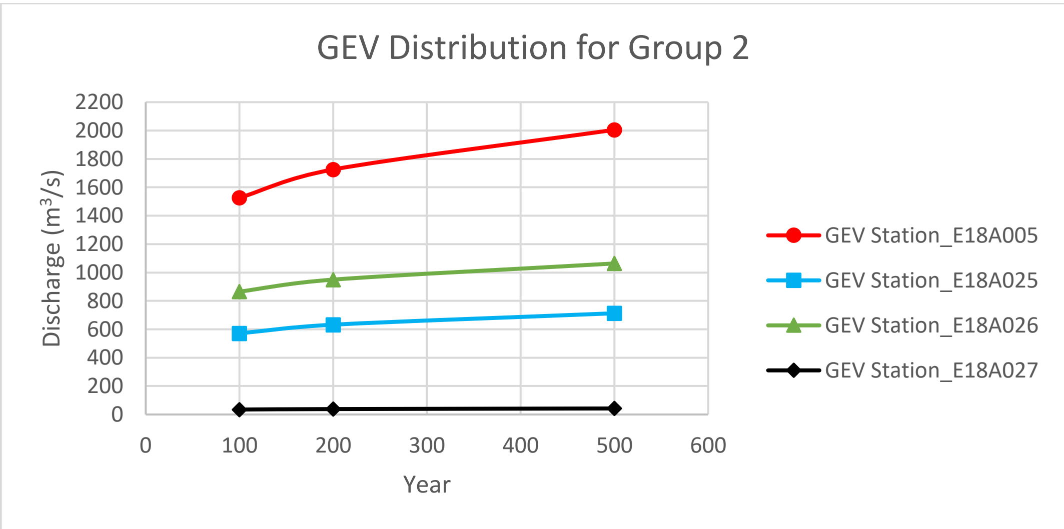

Figure 3: GEV Distribution Results of each station for Group 2 (Önöz & Bayazıt, 2008)

Mann-Kendall Test Results for Each Station

After overcoming the effect of autocorrelation, the H_0 hypothesis is approved by all stations.

Table 3: Mann-Kendal Test Results Before Pre-Whitening for All Stations (Önöz & Bayazıt, 2008)

Station No	S	σ_S	$Z_{\alpha/2}$	Z	Trend Analysis
D18A012	-156	79.54	1.96	1.949	H_0 hypothesis is accepted.
D18A017	28	58.83	1.96	0.493	H_0 hypothesis is accepted.
D18A018	-48	61.65	1.96	0.762	H_0 hypothesis is accepted.
D18A023	80	56.02	1.96	1.450	H_0 hypothesis is accepted.
E18A005	-360	-0.149	1.96	1.820	H_0 hypothesis is accepted.
E18A025	34	50.58	1.96	0.652	H_0 hypothesis is accepted.
E18A026	-30	-0.11	1.96	0.719	H_0 hypothesis is accepted.
E18A027	59	50.61	1.96	1.146	H_0 hypothesis is accepted.

Table 4: Mann-Kendal Test Results After Pre-Whitening for All Stations (Önöz & Bayazıt, 2008)

Station No	S	σ_S	$Z_{\alpha/2}$	Z	Trend Analysis
D18A012	-108	76.46	1.96	1.399	H_0 hypothesis is accepted.
D18A017	37	56.04	1.96	0.642	H_0 hypothesis is accepted.
D18A018	-48	58.85	1.96	0.31	H_0 hypothesis is accepted.
D18A023	52	53.28	1.96	0.99	H_0 hypothesis is accepted.
E18A005	-342	-0.146	1.96	1.766	H_0 hypothesis is accepted.
E18A025	-13	45.37	1.96	0.265	H_0 hypothesis is accepted.
E18A026	-18	-0.07	1.96	0.422	H_0 hypothesis is accepted.
E18A027	89	47.96	1.96	1.835	H_0 hypothesis is accepted.

Results for Regional Analyses

As mentioned before, Mann-Kendall and Pre-Whitening trend tests are performed for the regional trend analysis. The results are shown in the table below. When these results are examined, the hypothesis is accepted as the *z* values calculated with and without cross-correlation between stations are smaller than the standard distribution of 1.96, that is, 5 percent. In other words, it is examined whether there is a common trend among the stations at the 5 percent significance level, and it is concluded that there is no trend at the specified significance level among these 8 stations in the Seyhan Basin. Besides, these trend tests are critical for the homogeneity and homogenization of the stations. That's why these tests are needed.

Table 5: Seyhan Basin Regional Trend Analysis Results (Önöz & Bayazıt, 2008)

$n_{all\_station}$	281	$\sigma_{Sm,}\ \rho_{mean}$	37.8011292
n_{mean}	35.125	ρ_{mean}	0.18304
S_k	-368	z_{mean}	1.216894865
S_m	-46	H_0	No Trend
σ_{Sm}	25.02744425		
z	1.837982318		

Subsequently, the regional flood frequency statistics parameters and results are given for the stations where the regional trend tests of the flow data are made. Then, these statistical parameters as the average, standard deviation, and variation coefficients of the annual maximum discharges of 8 stations belonging to the Seyhan basin are given below. Accordingly, boundary values are determined according to the analysis made according to the coefficients of variation of the stations.

Table 6: Seyhan Basin Regional Flood Frequency Analysis Statistical Parameters (Önöz & Bayazıt, 2008)

Station No	n	Standard Deviation	Average (Mean)	Coefficient of Variation
E18A025	28	114.201	213.482	0.535
E18A005	70	275.359	565.414	0.487
E18A026	24	139.500	284.583	0.490
D18A027	28	6.064	15.907	0.381
D18A018	32	37.185	48.625	0.765
D18A017	31	7.912	11.526	0.686
D18A012	38	32.085	42.895	0.748
D18A023	30	5.210	10.360	0.503

Table 7: Seyhan Basin Regional Flood Frequency Analysis Statistical Results (Önöz & Bayazıt, 2008)

C_v,mean	n,mean	min_C_v	max_C_v	Normal Distribution Variance	Boundary Values
0.574	**35.125**	0.381	0.765	0.007824311	0.401356

As seen from the results, the whole basin cannot be considered a homogeneous region. Therefore, the stations belonging to the basins were divided into 2 separate groups to determine the homogeneous regions.

Table 8: Seyhan Basin Regional Flood Frequency Analysis Parameters as Homogenized Regions (Önöz & Bayazıt, 2008)

1st group	N	Standard Deviation	Mean	Coefficient of Variation (C_{v1})
D18A018	32	37.184565	48.625	0.764721131
D18A017	31	7.91206003	11.52645	0.686426343
D18A012	38	32.085266	42.89459	0.748002547
D18A023	30	5.20972433	10.36	0.502869144
2nd group	**N**	**Standard Deviation**	**Mean**	**Coefficient of Variation (C_{v2})**
E18A025	28	114.201372	213.4821	0.534945783
E18A005	70	275.358649	565.4143	0.487003346
E18A026	24	139.500325	284.5833	0.490191478
D18A027	28	6.06373119	15.90714	0.381195495

Table 9: Seyhan Basin Regional Flood Frequency Analysis Results as Homogenized Regions (1. Group) (Önöz & Bayazıt, 2008)

C_{v1},mean	n_1,mean	min_C_{v1}	max_C_{v1}	Boundary Values	
0.675504791	**32.75**	0.502869	0.764721	**0.449261**	**0.901749**

Table 10: Seyhan Basin Regional Flood Frequency Analysis Results as Homogenized Regions (2. Group) (Önöz & Bayazıt, 2008)

C_{v2},mean	n_2,mean	min_C_{v2}	max_C_{v2}	Boundary Values	
0.473334025	**37.5**	0.381195	0.534946	**0.344423**	**0.602245**

Based on the tables previously, the skewness coefficients remained within the boundary values, as can be seen when the data of the stations belonging to the basin are divided into 2 groups. Therefore, when we consider the basin as two separate groups, it is seen that the regions are homogeneous. In addition, the F test results in the table below show that the grouping at 0.05, 0.1, and 0.25 significance levels, respectively, is statistically significant. Therefore, the data belonging to 2 different groups are independent of each other. There is no relationship between them.

Table 11: Seyhan Basin Regional Flood Frequency Analysis F Test Results (Önöz & Bayazıt, 2008)

n_1-1	n_2-1	F	Table	H_0 rejects	MST	MSE	F	F Table (α=0.05)	Table (α=0.1)	Table (α=0.25)
32	37	2.036	1.76		0.0204	0.0186	1.097	5.99	3.78	1.62

Regional Flood Frequency Curve

The regional flood frequency curve is obtained by the standardization of the annual peak flows, i.e. the floods observed at all basin stations. These standardized flood discharges are defined as standard flood flows. These standard flood discharges are also obtained using the index-flood approach. In other words, when the annual (Q_{ij}) flood discharges at any station in a homogeneous region are standardized by dividing by the index-flood parameter of that station, it is assumed that the standard flood discharges fit the same probability distribution at all stations. As this index-flood parameter, the annual average flood discharge of station ($\overline{Q_{ij}}$) is generally used (Önöz & Bayazıt, 2008). Accordingly, the standard flood discharge defines as the equation below.

$$X_{ij} = \frac{Q_{ij}}{\overline{Q_{ij}}} \tag{10}$$

Besides, the index-flood procedures are a proper way to pool data comes from different stations which assumes of homogeneity in the region. The frequency distribution of the all the sites are the same although each site is characterized by a site-specific scaling factor. (Chebana and Quarda, 2009).

In this case, the standard flood discharges depending on the annual maximum flows of the stations in the Seyhan basin, for which the homogenization process was performed above, were calculated as the X_{ij} quantile values of each station by dividing the largest existing flows by the index-flood value. Afterward, to check whether there is a regional relationship between these data, the F test was applied to ensure homogeneity in the data. Depending on the homogeneity, the compliancy tests of the distribution of the quantiles of the following 2 different groups were carried out according to any known distribution with the help of a package program. As a result, it has been determined that all stations in the Seyhan basin are most suitable for the GEV distribution. Thus, the dimensionless coefficients (X_{ij}) (standard flood discharge values) for both groups were estimated for 10, 25, 50, 100, 200, and 500 years, respectively, depending on the GEV distribution. In other words, these coefficients were estimated in the relevant years by using the GEV distribution function. Afterward, the average (mean) values of these estimates are given in the tables below for both groups. In addition, the flood frequency curves of these two groups were drawn according to the years indicated as follows.

Table 12: X_quantile (Standard Flood Discharge) Values According to GEV Distribution of 1st Group (Önöz & Bayazıt, 2008)

1st Group					
Year	**D18A023**	**D18A017**	**D18A018**	**D18A012**	**All Stations**
T	X_quantile	X_quantile	X_quantile	X_quantile	Average of quantiles
10	1.9960	1.9331	1.912154005	1.753	1.898563501
25	2.2670	2.5324	2.756808148	2.586	2.535552037
50	2.4470	3.0041	3.550100699	3.424	3.106300175
100	2.6100	3.4963	4.513146887	4.502	3.780361722
200	2.7570	4.0118	5.685381512	5.893	4.586795378
500	2.9320	4.7324	7.637723601	8.373	5.9187809

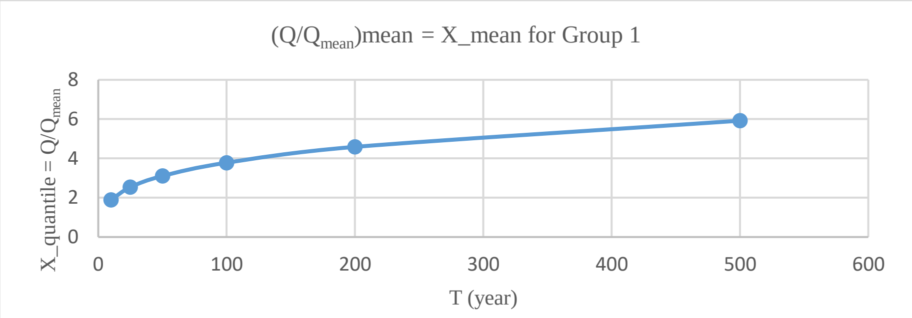

Figure 4: Regional Flood Frequency Curve for Group 1 (Önöz & Bayazıt, 2008)

Table 13: X_quantile Values according to GEV Distribution of Seyhan Basin 2nd Group (Önöz & Bayazıt, 2008)

2nd Group					
Year	**E18A025**	**E18A026**	**E18A027**	**E18A005**	**All Stations**
T	X_quantile	X_quantile	X_quantile	X_quantile	Average of quantiles
10	1.70295	2.062632	1.510077	1.632	1.72691475
25	2.097549	2.451893	1.792571	2.04	2.09550325
50	2.389016	2.745319	2.000047	2.362	2.3740955
100	2.677266	3.040554	2.204245	2.699	2.65526625
200	2.963414	3.338706	2.405982	3.052	2.9400255
500	3.339334	3.738252	2.669538	3.546	3.323281

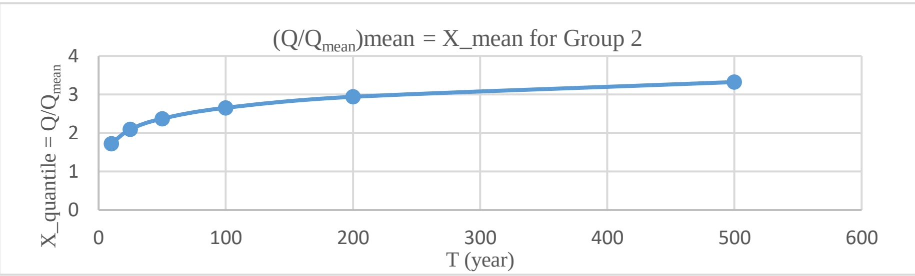

Figure 5: Regional Flood Frequency Curve for Group 2 (Önöz & Bayazıt, 2008)

Comparison Between Individual and Regional Analysis for Stations D18A012 and EA18025

As seen from the figures below, the results obtained using the regional curve and individual analysis of the stations belonging to the two groups are given. Accordingly, the new orange curves obtained using the regional curve have been very successfully consistent with the individual analyses that have been made. Therefore, regional analysis can give successful results even if no stations exist.

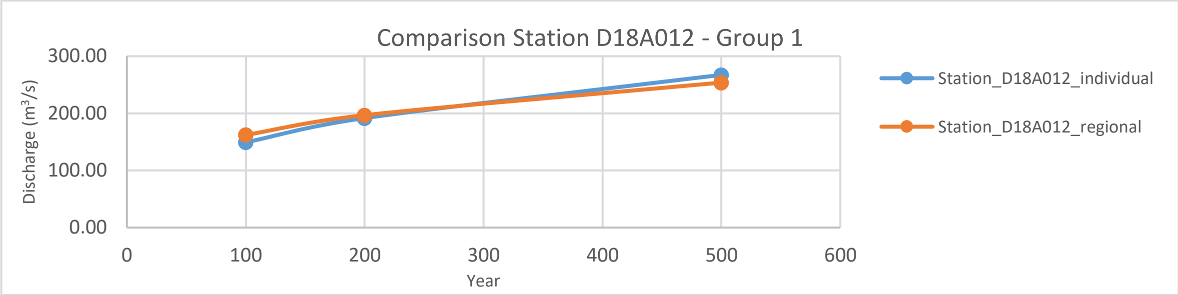

Figure 6: Comparison Between Individual and Regional Analysis for Stations D18A012 – Group 1 (Önöz & Bayazıt, 2008)

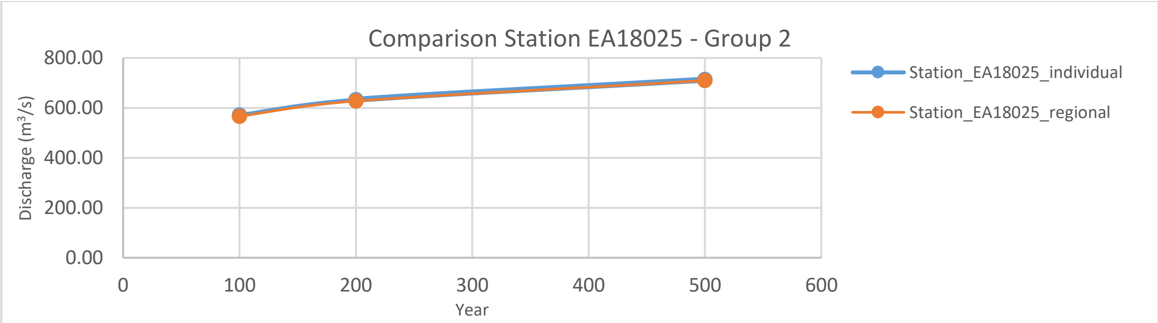

Figure 7: Comparison Between Individual and Regional Analysis for Stations E18A025 – Group 2 (Önöz & Bayazıt, 2008)

DISCUSSION AND CONCLUSION

Finally, graphs were drawn for the regional flow estimation values of the 8 stations analysed. In addition, graphs showing its relationship with other distributions were also drawn. As a result, in cases where there is sufficient data or no stations are not available in a basin, it has been reached that flow estimation can be made for those troubled areas from the regional flood frequency curves obtained from this regional analysis and the necessary analyses can be made for those regions. At this point, mainly it has shown that analysis can be done even if there is not enough information in a region thanks to the presence of statistical parameters such as mean, standard deviation, coefficient of variation, correlation coefficients, etc.

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