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LOW FLOW FREQUENCY ANALYSIS OF THE NILÜFER RIVER AT THE GEÇITKÖY STATION, TURKEY

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Frequency analysis of low flows (critical drought flows) is the first step in surface water pollution control. In this study, a Type-3 Extremal (or Weibull) Distribution with a lower limit is applied to 7-day moving average minimum flows of the Nilüfer River at the Geçitköy station. For the Geçitköy low flows, it is shown that reliable and physically meaningful estimates of parameters should be obtained using estimation procedures satisfying these restrictions. A lower flow limit, X_0=0.20 m^3/sec, obtained by the method of iterative least squares, is a reliable and physically meaningful lower limit for the probability distribution of 7-day average minimum flows at Geçitköy.

INTRODUCTION

Low flows at rivers are of great importance from the environmental pollution point of view. Assessment of water quality standards in water pollution control studies requires information on critical drought flow in rivers because the most adverse conditions for water pollution control in rivers occur during drought seasons. Since the pollution load to rivers reaches a maximum during drought seasons, serious difficulties are faced in assessment of water quality standards.

Low flows can be considered as daily, weekly, monthly flows, or greater time periods. Flow rate used for design purposes is given by $Q\ (A, T)$ where A is the number of days used in the average and T is the interval in years over which the average is expected to occur, the so-called the return period. The minimum average of 7-day flow expected to occur once every 10 years, Q(7,10), is considered a design flow. It may be noted that the Q(7,10) is in general use as a design flow for water quality analysis, although there are exceptions. The choice of a minimum 7-day, 10-year flow is, of course, somewhat arbitrary, and selection of the appropriate design flow is the subject of continuing studies (Thomann and Mueller, 1987).

Furthermore, in the case of a water year from October of the previous year to the end of September of the current year, a single critical drought may be falsely estimated as two different droughts occurring in consecutive water years.

From previous studies (Eroglu and Öztürk, 1980, Öztürk, 1980), it is concluded that the wastewater treatment efficiency, X, is a function of river flow, Q.

$$X = f\,(Q) \tag{1}$$

Therefore, for rivers receiving wastewater, it is very important to determine the drought characteristics of river and design flows. In particular, the determination of Q(7,10) flows for rivers having intensive habitation and industrial activities near their water course are of great importance for effective water pollution monitoring and control.

River discharges can have low values in some period of the year and may even be dry, especially in semi-arid regions. This usually occurs during the summer months when irrigation has primary importance. Also, river discharge is important where wastewater enters the river during low flow periods from the dilution point of view. If the flow decreases under a certain low flow value, it has a direct effect on the aquatic life of the surface flow under consideration (Bulu et al.,1995).

TYPE-3 EXTREMAL DISTRIBUTION

The Type-3 Extremal or Weibull Distribution is one of the most suitable distributions for low flow analysis (Matalas, 1963, Kite,1977). The cumulative probability distribution is:

$$P(x) = \exp\{-(\frac{x - x_0}{ß - x_0})^{\alpha}\} \tag{2}$$

where x is discharge, a is scale parameter, ß is characteristic drought, and x_0 is the lower limit of x.

The probability density function is:

$$f\,(x) = \frac{\alpha}{ß - x_0}\{\frac{x - x_0}{ß - x_0}\}^{\alpha-1} \quad \exp\{-\frac{x - x_0}{ß - x_0}\}^{\alpha} \tag{3}$$

Commonly, the following transformation is used to simplify the cumulative probability and probability density equations.

$$y = \{\frac{x - x_0}{ß - x_0}\}^{\alpha} \tag{4}$$

$$P(x) = e^{-y} \tag{5}$$

$$f(x) = \frac{\alpha}{ß - x_0} y^{(\alpha-1)/\alpha} e^{-y} \tag{6}$$

Sample estimates of the parameters can be obtained by the method of moments and maximum likelihood. If two new variables are defined, A_a and B_a, such that A_a is the standardized difference between the characteristic value and the mean, and B_a is the standardized difference between the lower limit and the characteristic value, both A_a and B_a are functions of a only.

The Method of Moments gives the relationship between a and skewness coefficient, g1 as:

$$\gamma_1 = \{\Gamma(1+3/\alpha) - 3\Gamma(1+2/\alpha)\Gamma(1+1/\alpha) + 2\Gamma^3(1+1/\alpha)\}\, ß_\alpha{}^3 \tag{7}$$

where Γ is the incomplete gamma function and $ß_a$ is defined by

$$ß_\alpha = \frac{ß - x_0}{\sigma} = \{\Gamma(1+2/\alpha) - \Gamma^2(1+1/\alpha)\}^{-1/2} \tag{8}$$

From a sample size of n, the sample coefficient of skewness is computed by using the following equation.

$$\hat{\gamma}_1 = \frac{n\sum(x - x)^3}{(n-2)[\Sigma(x-x)^2]^{3/2}} \tag{9}$$

and used in Equation 7. Then, the parameter a can be computed. Kite (1972) has developed the following polynomial equation to calculate a directly from γ_1 for the range of γ_1 from –1.02 to +2.00.

$$\alpha = 1/[a_1 + a_2\gamma_1 + a_3\gamma_1{}^2 + a_4\gamma_1{}^3 + a_5\gamma_1{}^4] \tag{10}$$

The coefficients of the polynomial equation are: a_1= 0.2777757913, a_2= 0.3132617714, a_3=0.0575670910, a_4= -0.0013038566, and a_5= -0.0081523408.

Having calculated the sample estimate a, $ß_a$, A_a and other parameters can be calculated by using the following equations.

$$A_\alpha = \frac{ß - \mu}{\sigma} = \{1 - \Gamma(1+1/\alpha)\}\, ß_\alpha \tag{11}$$

$$ß = \mu + A_\alpha \sigma \tag{12}$$

$$X_0 = ß - B_\alpha \sigma \tag{13}$$

If the skewness coefficient is greater than +2.00, a must be found by iterative solution of Equation 7. If the skewness coefficient is lower than –1.02, Equation 7 cannot be solved.

While the method of maximum likelihood and the method of least squares assure that the parameter X_0 is smaller than the observed minimum event, the method of moments may produce a lower limit greater than the smallest observed drought.

Since the method of maximum likelihood did not converge in iterations, it is excluded in this study, but the method of least squares (in an iterative form) yielded satisfactory results. This method is summarized as follows:

The reduced variable y_m in Equation 4 corresponding to the empirical plotting position P_m can be computed by

$$y_m = -\ln P_m \tag{14}$$

where $P_m = m/(n+1)$ is the empirical probability of flow in the m-th order, X_m.

Any reasonable choice of the lower limit, X_0, gives an expression between y_m and x_m

$$y_m = \left(\frac{1}{ß - x_0}\right)^{\alpha} (x_m - x_0)^{\alpha} \tag{15}$$

substituting

$$a = 1/(ß - x_0)^{\alpha};\ u_m = x_m - x_0 \tag{16}$$

in Equation 15 and taking logarithms of both sides, it reduces to a linear relationship between $V_m = \ln y_m$ and $Z_m = \ln u_m$

$$\hat{V}_m = A + \alpha Z_m \tag{17}$$

where $A = \ln a$ and A and a can easily be calculated through bivariate linear regression procedure. The sum of squares due to errors (the least squares function) is defined as:

$$LS(X_0, \alpha, ß) = \sum_{m=1}^{n} (V_m - \hat{V}_m)^2 \tag{18}$$

The LS function has a minimum in the parameter space. The set of parameters minimizing the LS function can easily be found by changing the lower limit incrementally between zero and observed minimum event magnitude.

APPLICATION

In this study, the daily dry period flows of the Nilüfer river at Geçitköy (Figure 1) in a dry period are used. The Geçitköy station is located 15 km northwest of Bursa, which is one of the largest industrial and population areas in Turkey. The drainage area of the Geçitköy is 1296.8 km^2.

The low flow period in this basin covers August, September and October. The 7-day moving average minimum flows are calculated by using daily data recorded at Geçitköy from 1954 to 1988. The sample mean, the standard deviation and skewness coefficient of 35-year long 7-day minimum flows are computed as 1.37 m^3/ sec, 0.42 m^3 /sec and 1.51 m^3 /sec.

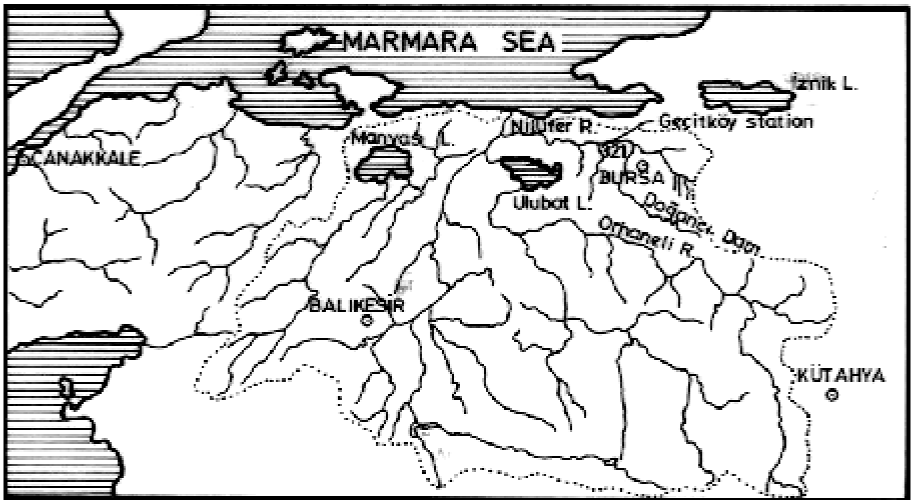

Figure 1. The drainage area of the Nilüfer River.

Following the computational procedure proposed by Kite (1977) the moment estimators of the Weibull distribution are found as a = 1.1991, ß=1.414 m^3/sec and X_0=0.588 m^3/sec. This solution has no practical value since the lower boundary is greater than the observed smallest drought, 0.369 m^3/sec.

As a second alternative for computing reasonable parameters of the Weibull distribution, the method of iterative least squares is applied. The least squares function is computed for various values of the lower boundary. As show in Figure 2, the minimum of the least squares function is at X_0=0.20 m^3/sec. Other parameters corresponding to this lower boundary are estimated as a=1.765 and *ß*=1.54 m^3/sec.

Then the cumulative probability function is

$$P(x) = \exp[-(\frac{x-0.20}{1.54-0.20})^{1.765}] \tag{19}$$

Equation 19 and the sample points plotted on a standard normal probability paper according to Weibull's plotting positions, P_m=m/(n+1), are shown on Figure 3.

The estimated event magnitudes for the selected return periods are given in Table 1.

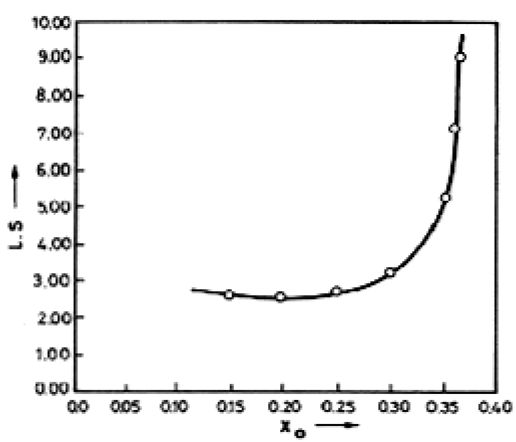

Figure 2. Graph of x_0 values against *LS* values.

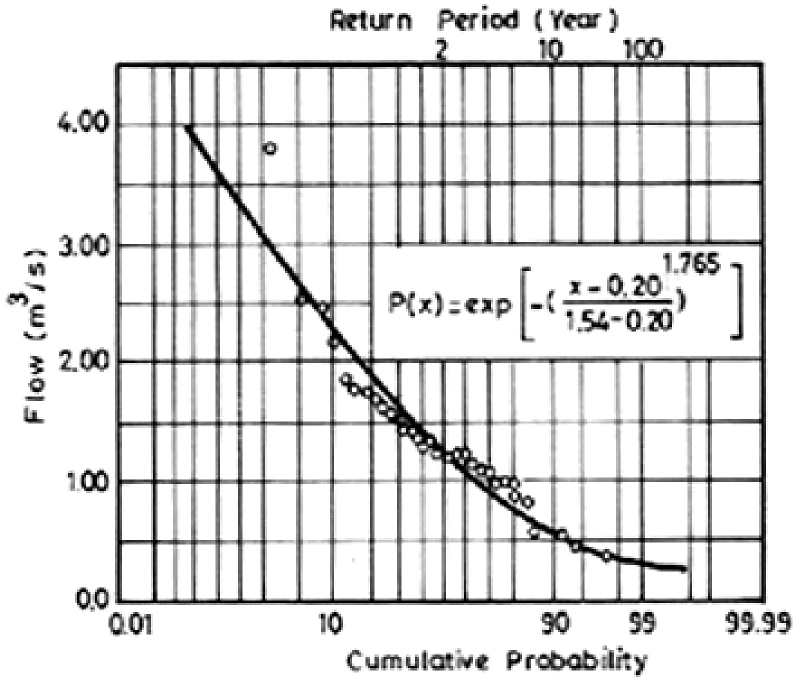

Figure 3. Flow cumulative probability curve of the Nilüfer River at the Geçitköy Station.

Table 1: The Estimated Event Magnitudes for the Selected Return Periods

Return Period (year)	Events (m^3/s)
2	1.290
5	0.770
*10	0.565
20	0.450
50	0.350
100	0.290

- Q(7.10)=0.565 m^3/s

RESULT AND CONCLUSIONS

In this study, it is shown that the average minimum flows for a specified time period should be defined on the basis of a low flow season instead of a water year.

For the Geçitköy low flows, it is shown that the required reliable and physically meaningful estimates of parameters should be obtained using estimation procedures satisfying these restrictions. The lower limit X_0=0.20 m^3/sec, obtained by the method of iterative least squares, is a reliable and physically meaningful lower limit for the probability distribution of 7-day average minimum flows at Geçitköy.

The Q(7,10) design event magnitude for the Nilüfer River at Geçitköy, which is traditionally used in surface water pollution and control studies, is estimated as 0.565 m^3/sec. As it can be seen from the numbers in Table 1, a small decrease in design event magnitude corresponds to a considerable increase on the return period.

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