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# Drought flow analysis of the River Tigris at Baghdad

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**Abstract.** Some commonly used statistical distributions have been compared to find their applicability for describing minimum flows of the Tigris River at Baghdad gauging station. Drought flows with given return period have, thereafter, been predicted by these techniques. The mean of the estimated flows by the various distributions has been calculated to represent a design drought; upper and lower values estimated have been used to give an idea of variation in drought flow estimation. The methodology suggested herein may avoid the dilemma as to which distribution to select for drought flow estimation.

## *Analyse d'écoulement pendant les sécheresses pour le Tigre à Baghdad*

**Résumé.** On a comparé quelques distributions statistiques d'usage courant afin de pouvoir constater leur application en vue de faire une description des débits d'étiage du Tigre à la station de jaugeage qui se trouve à Baghdad. Après cela on a prédit les écoulements dans les périodes de sécheresse à une période de retour donnée en utilisant ces techniques. On a calculé la moyenne des écoulements estimés après les distributions diverses afin de représenter une sécheresse utilisée dans les calculs. Les valeurs plus hautes et plus basses en ont été utilisées pour donner un aperçu de la variation trouvée dans le calcul de l'écoulement pendant les sécheresses. La méthodologie qu'on suggère ici évitera peut-être de dilemme de devoir choisir la distribution la plus propice à l'estimation de l'écoulement pendant les périodes de sécheresse.

## INTRODUCTION

The use of statistical distributions for flood prediction purposes is well known. Low flows in rivers can also be represented by statistical distributions, but the number of such attempts in the literature seems to be limited. Gumbel (1958) discussed the use of the type III extreme value distribution for fitting to low flows. Ewart & Brutsaert (1972) applied this technique to study the generalized characteristics of drought flows of the lower Mekong River. Joseph (1970) studied the probability distribution of annual drought using certain distributions and tested their goodness of fit, but did not elaborate on the prediction of drought flow of rivers.

Drought can be defined in various ways (Hudson, 1964; Shen & Todorovic, 1976). In the present study, drought defined as minimum flow of five days (called five day drought) has been studied for the Tigris River at Baghdad. The data used for analysis have been made available from the records of the Ministry of Irrigation of Iraq. To the writers' knowledge, the only previous work on drought flow in Iraq has been done by Mujda (1979).

THEORETICAL DISTRIBUTIONS

The statistical distributions commonly used for low flow prediction at any gauging station are: normal, lognormal, square root normal, extreme value type I and type III, and gamma II (two parameter) distribution etc. The uses of these distributions in hydrology, have been well presented and discussed by Yevjevich (1972). Estimated frequencies derived from these distributions when fitted to the Baghdad data, are shown in Fig. 1 together with the histogram of observed data. To estimate the expected frequencies, data were divided into certain class intervals and the probability density for the mid value was calculated. This probability density was then multiplied by the product of number of years of record and class interval to get the expected frequencies. The details of these can be seen elsewhere (Mudja, 1979).

TESTING OF DISTRIBUTIONS

For a decision between distributions, statistics offer two principal ways, namely, test of fit and the likelihood ratio. The test of fit helps to decide the general suitability of a distribution but does not specify clearly the best choice between the distributions. On the other hand the likelihood ratio brings a decision for exactly one distribution. The distribution that gives greatest likelihood ratio is chosen as most suitable (Koberg & Eggers, 1973). It may be noted that the computation of likelihood ratio is fairly time consuming as compared with  $\chi^2$  testing or the Kolmogorov–Smirnov

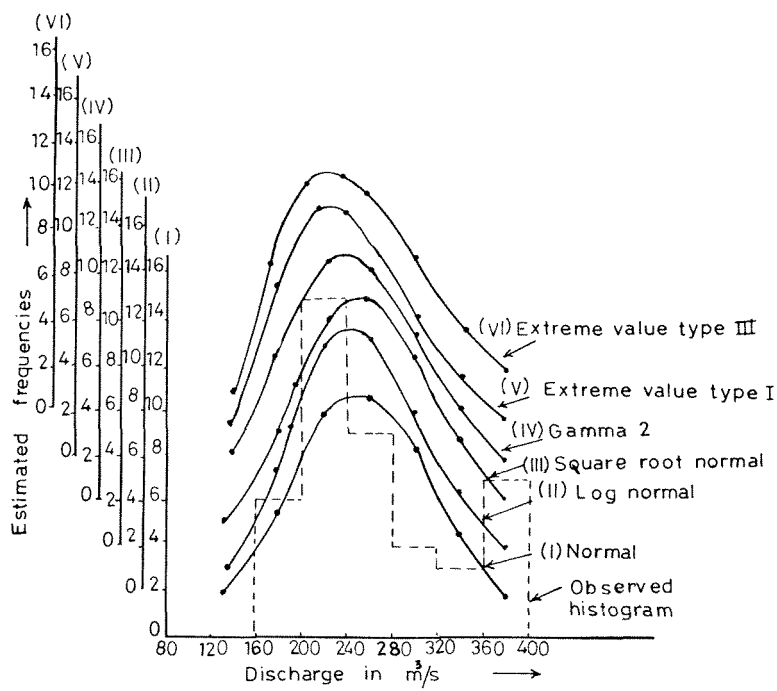


FIG. 1. Estimated frequencies at Baghdad by various distributions.

test. Joseph (1970) used a skewness–kurtosis relationship as a test criterion but the results he obtained were the same as those of test of fit.

Mean, standard deviation and coefficient of skewness, etc. were calculated for the ungrouped data without dividing them into different class intervals. However, for  $\chi^2$  testing, data were divided into intervals of 40 m<sup>3</sup>/s. The characteristic parameters needed for testing the Tigris data at Baghdad are given in Table 1. In Table 2 the results of the three types of testing are shown. It is obvious from Table 2 that  $\chi^2$  accepted all but one distribution as being suitable. The Kolmogorov–Smirnov test rejected none, but the likelihood ratio selected the extreme value type I distribution as the most suitable. The extreme value type I distribution is not normally chosen for drought flow analysis as it has no lower bound, indicating that the choice based on likelihood ratio may not be a realistic one; for this reason, Gumbel (1958) himself used the type III distribution for drought flow analysis of the Colorado River.

TABLE 1. Characteristic parameters for River Tigris at Baghdad

| Parameters             | Grouped data | Ungrouped data | Parameters                 | Grouped data | Ungrouped data |
|------------------------|--------------|----------------|----------------------------|--------------|----------------|
| $\bar{Q}$              | 255.450      | 261.00         | $\bar{y}_n$                | 0.546        | 0.54           |
| $\sigma$               | 65.910       | 64.51          | $\bar{\sigma}_n$           | 1.151        | 1.15           |
| $\sqrt{\beta_1}$       | 0.988        | 0.55           | $\alpha_1$                 | 1.573        | 2.12           |
| $\sqrt{\bar{Q}}$       | 16.114       | 14.04          | $A$                        | 0.175        | 0.26           |
| $\sigma\sqrt{\bar{Q}}$ | 1.968        | 1.96           | $B$                        | 1.716        | 2.28           |
| $\ln \bar{Q}$          | 2.408        | 2.40           | $u_1 = \bar{Q} + \sigma A$ | 266.990      | 277.83         |
| $\sigma_{\ln \bar{Q}}$ | 0.104        | 0.10           | $\zeta = Q\sigma(B - A)$   | 153.910      | 130.63         |

TABLE 2. Statistical test for the distributions

| Name of distribution   | $\chi^2_0 = 7.815$ |          | $\Delta_0 = 0.20$ |          | Likelihood ratio |         |
|------------------------|--------------------|----------|-------------------|----------|------------------|---------|
|                        | $\chi^2$           | Remark   | $\Delta$          | Remark   | Likelihood ratio | Remark  |
| Normal                 | 7.955              | Rejected | 0.115             | Accepted | 0.0255           |         |
| Square root normal     | 7.121              | Accepted | 0.12              | Accepted | 0.0867           |         |
| Lognormal              | 6.150              | Accepted | 0.094             | Accepted | 0.3431           |         |
|                        | (lowest)           |          | (lowest)          |          |                  |         |
| Gamma II               | 7.550              | Accepted | 0.1018            | Accepted | 0.0680           |         |
| Extreme value type I   | 7.016              | Accepted | 0.1041            | Accepted | 1.0000           | Highest |
| Extreme value type III | 6.817              | Accepted | 0.0940            | Accepted | 0.0129           |         |

$\chi^2_0$  = Critical value of  $\chi^2$ .  
 $\Delta = \max |(b_i - c_i)/N|$ .  
 $b_i$  = Observed frequency.  
 $c_i$  = Expected frequency.  
 $N$  = Total number of years of record.  
 $\Delta_0$  = Critical value of  $\Delta$  for Kolmogorov–Smirnov test.

## ESTIMATION OF DESIGN DROUGHT FLOW

In the previous section, analysis indicated clearly that a preference for a particular distribution could not be decisively achieved, therefore the writers propose the utilization of all the distributions that have passed the test of acceptance by  $\chi^2$ . The proposed idea is implemented by estimating an average value for the design drought flow from those obtained by the accepted distributions at the particular return period. A chart showing the results of the various drought flow estimates, at specified return periods, together with the average values should be prepared for the particular gauging station giving the designer a clear perspective of the variation of predictions and their average value.

Statistically, the idea of averaging may be open to criticism; however, from a practical point of view the writers believe that the proposition advocated is worthy of consideration due to the above explained reasoning.

Drought flow for various return periods for different distributions can be estimated from the following formulae (Mujda, 1979):  
normal distribution:

$$Q_T = \bar{Q} - K\sigma \quad (1)$$

lognormal distribution:

$$Q_T = \exp(\ln \bar{Q} - K\sigma_{\ln Q}) \quad (2)$$

square root normal distribution:

$$Q_T = (\sqrt{\bar{Q}} - K\sigma_{\sqrt{Q}})^2 \quad (3)$$

gamma II (two parameter):

$$Q_T = \bar{U}\sigma \quad (4)$$

extreme value distribution, type I:

$$Q_T = \bar{Q} + \left[ \frac{-\ln \ln T - \bar{y}_n}{\bar{\sigma}_n} \right] \sigma \quad (5)$$

extreme value distribution, type III:

$$Q_T = \zeta + (u_1 - \zeta) [\ln(T/T - 1)]^{1/\alpha_1} \quad (6)$$

where,  $Q_T$  is the magnitude of drought flow with a return period of  $T$  years;  $\bar{Q}$ ,  $\ln \bar{Q}$ ,  $\sqrt{\bar{Q}}$  are the mean of drought flows for natural values, logarithmically transformed,  $(\ln Q)$  and square-root-transformed values respectively;  $\sigma$ ,  $\sigma_{\ln Q}$ ,  $\sigma_{\sqrt{Q}}$  are the standard deviation of drought flows for natural, logarithmically transformed and square-root-transformed values respectively;  $K$  is a frequency factor;  $\bar{U}$  is a parameter of the incomplete gamma function;  $\bar{y}_n$  and  $\bar{\sigma}_n$  are the mean and standard deviations of reduced extremes to be obtained from Gumbel (p. 228) (1958);  $\zeta$ ,  $U_1$ ,  $\alpha_1$  are the functions of coefficient of skewness  $\sqrt{\beta_1}$  to be obtained from Gumbel (1958) (pp. 282–289) in terms of constants  $A$  and  $B$ .

The values of  $K$  in Equations 1, 2 and 3 can be found from tables of the

normal distribution. Values of  $\bar{U}$  in Equation 4 are calculated from Pearson's table (1921) for a given value of  $(\sigma/Q)$  and  $T$ . The relationship connecting them is given as:

$$I(\bar{U}, \bar{p}) = \frac{1}{\Gamma(\bar{p}+1)} \int_0^{U\sqrt{\bar{p}+1}} x^{\bar{p}} e^{-x} dx = \frac{1}{T} \quad (7)$$

It can be shown that  $p = [(Q/\sigma)^2 - 1]$  and  $x = Q\bar{Q}/\sigma^2$ . It may be noted that in all equations from 1 to 5, the probability  $p$ , has been considered as  $1/T$  since we are now interested in working out the probability of a drought flow being equal to or less than a specified value as against that of flood where the probability of a flood greater than or equal to some specified value is considered.

## DISCUSSION OF RESULTS

The estimated drought flows for various return periods calculated by using various distributions are given in Table 3. The average of these estimated values, and the highest and lowest values at chosen return periods are shown in Table 4.

The extreme value type I distribution was found most suitable by maximum likelihood ratio. However, this distribution also yielded results close to the average values of other distributions but for large return periods only.

The lognormal distribution gave the highest estimate of drought flows up to 40 years of return period, however beyond forty years, the extreme value type III distribution, invariably, predicted the highest values. On the other hand the square root normal distribution gave the lowest values for return periods greater than 30 years.

TABLE 3. Estimated drought flows, for various return periods, of the River Tigris at Baghdad (in  $m^3/s$ )

| Return period | Square root     | Lognormal<br>Eqn 2 | Gamma 2<br>Eqn 4 | Extreme value   | Extreme value     |
|---------------|-----------------|--------------------|------------------|-----------------|-------------------|
|               | normal<br>Eqn 3 |                    |                  | type I<br>Eqn 5 | type III<br>Eqn 6 |
| 10            | 182.9           | 185.6              | 182.2            | 176             | 181.6             |
| 20            | 164.3           | 171.8              | 164.0            | 161             | 166.7             |
| 30            | 155.5           | 162.3              | 155.5            | 154             | 160.5             |
| 40            | 148.7           | 157.2              | 150.0            | 149             | 156.7             |
| 50            | 144.4           | 153.8              | 145.7            | 146             | 154.0             |
| 60            | 140.2           | 150.5              | 142.5            | 143             | 152.1             |
| 70            | 137.4           | 148.3              | 139.0            | 141             | 150.6             |
| 80            | 135.6           | 146.9              | 137.5            | 139             | 149.4             |
| 100           | 131.5           | 143.7              | 134.2            | 137             | 147.5             |
| 200           | 120.5           | 135.2              | 124.2            | 128             | 142.8             |
| 400           | 110.8           | 127.8              | 115.6            | 122             | 139.4             |
| 500           | 107.9           | 125.3              | 112.7            | 120             | 138.5             |
| 600           | 105.1           | 123.6              | 110.5            | 118             | 137.9             |
| 800           | 102.3           | 121.4              | 107.5            | 115             | 136.9             |
| 1000          | 99.5            | 119.4              | 105.2            | 113             | 136.6             |

TABLE 4. Estimation of design drought flow together with highest and lowest predicted values at Baghdad

| Return period | Design drought<br>(average) | Predicted highest |                        | Predicted lowest |                      |
|---------------|-----------------------------|-------------------|------------------------|------------------|----------------------|
|               |                             | Value             | Distribution           | Value            | Distribution         |
| 10            | 181.7                       | 185.6             | Lognormal              | 176.0            | Extreme value type I |
| 20            | 165.6                       | 171.8             | Lognormal              | 161.0            | Extreme value type I |
| 30            | 157.4                       | 162.3             | Lognormal              | 154.0            | Extreme value type I |
| 40            | 152.3                       | 157.2             | Lognormal              | 148.7            | Square root normal   |
| 50            | 140.8                       | 154.0             | Extreme value type III | 144.4            | Square root normal   |
| 60            | 145.7                       | 152.0             | Extreme value type III | 140.2            | Square root normal   |
| 70            | 143.3                       | 150.6             | Extreme value type III | 137.4            | Square root normal   |
| 80            | 141.7                       | 149.4             | Extreme value type III | 135.6            | Square root normal   |
| 100           | 138.8                       | 147.5             | Extreme value type III | 131.5            | Square root normal   |
| 200           | 130.0                       | 142.5             | Extreme value type III | 120.5            | Square root normal   |
| 400           | 123.4                       | 139.4             | Extreme value type III | 110.8            | Square root normal   |
| 500           | 120.9                       | 138.5             | Extreme value type III | 107.9            | Square root normal   |
| 600           | 119.0                       | 137.9             | Extreme value type III | 105.1            | Square root normal   |
| 800           | 116.6                       | 136.9             | Extreme value type III | 102.3            | Square root normal   |
| 1000          | 114.7                       | 136.6             | Extreme value type III | 99.5             | Square root normal   |

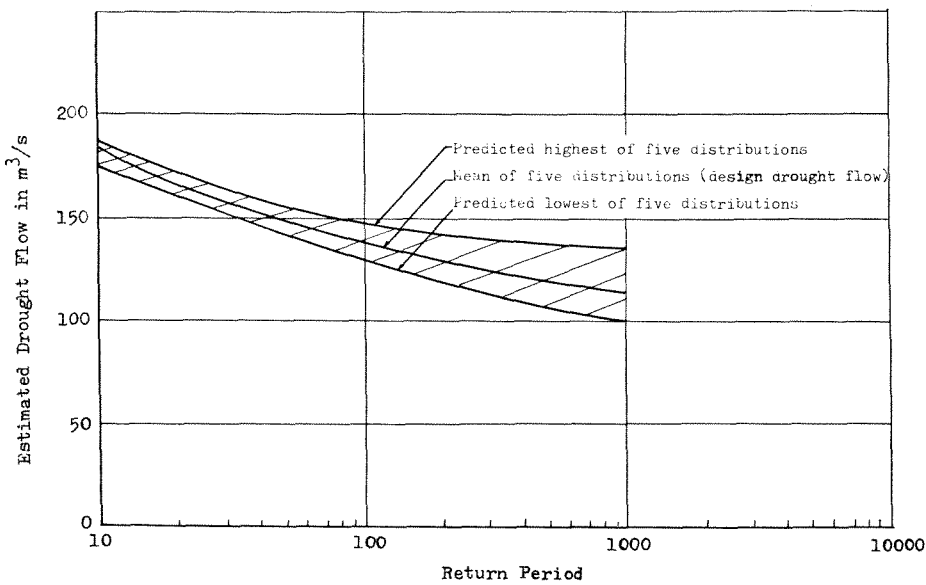


FIG. 2. Estimation of design drought flow for Baghdad.

The extreme value type III distribution specified, for the case studied, a lower bound for drought flow which was approximately 130 m<sup>3</sup>/s. Other distributions, however, predicted much lower values than this for the larger return periods. The estimated values are graphically presented in Fig. 2, where the design drought flow, and the highest and lowest estimated values are also indicated.

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## CONCLUSION

It was found that most of the popular distributions passed the test of acceptance by  $\chi^2$  testing. Thus the dilemma as to which distribution to choose was resolved by calculating the average of the estimated values for various return periods using all the acceptable distributions. The average values have been designated as design drought flow. A figure was then drawn showing estimated highest and lowest values calculated from those distributions accepted by the statistical test, together with the design drought flow. The figure drawn gives an idea of variation in drought flow estimation that could be obtained by choosing a distribution at random.

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