Engineering Journal of Qatar University, Vol. 4, 1991, p. 35 - 50.

RAINFALL CHARACTERIZATION IN AN ARID AREA

Abdallah S. Bazaraa and Shamim Ahmed
Department of Civil Engineering
Qatar University, Doha, Qatar.

ABSTRACT

The objective of this work is to characterize the rainfall in Doha which lies in an arid region. The rainfall data included daily rainfall depth since 1962 and the hyetographs of the individual storms since 1976. The rainfall is characterized by high variability and severe thunderstorms which are of limited geographical extent. Four probability distributions were used to fit the maximum rainfall in 24 hours and the annual rainfall depth. The extreme value distribution was found to have the best fit. The rainfall intensity-duration-frequency relationship has been developed which compares well with values obtained by other investigators in the Gulf area.

INTRODUCTION

A knowledge of the rainfall characteristics is of paramount importance in the design of hydrologic system whether the function of such a system is water control or water use and management. In some arid areas of the world failure to account for the drainage of storm water sometimes causes tremendous inconvenience. Presumably it was thought that an arid area hardly experiences any rain and therefore there is no need to worry about storm water.

The definition of arid region is somewhat vague, but where the potential water loss by evaporation and transpiration exceeds the amount of water supplied by precipitation may be called an arid area. The maximum precipitation for an arid area is not constant since it varies with the geographic location and the temperature. Extremely arid areas are those where precipitation totally lacks any rhythm and remains at zero for at least twelve consecutive months (Macmillan, 1982).

The purpose of this work is to characterize the rainfall in Doha which lies in an arid area. The rainfall data are analyzed to assess the variability and to develop relevant intensity-duration-frequency relationship with somewhat inadequate data. Doha is the capital of the State of Qatar, a peninsula in the Arabian Gulf. Since 1962 Doha International Airport meteorological station is operated by the Department of Meteorology of the Ministry of Communication and Transport and is considered to have the largest record in the State of Qatar. Available information include daily rainfall depth since 1962 and the hyetographs of the individual storms since 1976. Daily rainfall data is processed by the Department of Meteorology to produce the summary of annual rainfall depth, maximum rainfall in 24 hours and the number of rainfall days in a year with a depth exceeding 1 mm.

VARIABILITY OF RAINFALL

Annual rainfall depth, maximum rainfall depth, maximum rainfall in 24 hours and number of rainfall days for 28 years (1962-1989) are shown in Figures 1, 2 and 3 respectively. Maximum and minimum values are given in Table 1 together with the mean, the standard deviation and the coefficient of variation defined as the ratio of the standard deviation and the mean. These values indicate considerable variation in the rainfall amounts and events. The coefficient of variation of the rainfall depth was 0.85. A very high value compared to the coefficient of variation for well-watered regions of the world where this coefficient can be as low as 0.10.

Since the true mean is not known, it is interesting to notice the importance of the length of the record on estimating the mean. Table 2 shows the variation in the mean of annual rainfall depth for different record lengths together with the percentage deviation of that mean from the true mean taken as the mean of the whole record (28 years). It indicates that in order to obtain a reasonable estimate of the mean annual rainfall depth, at least ten years record is needed.

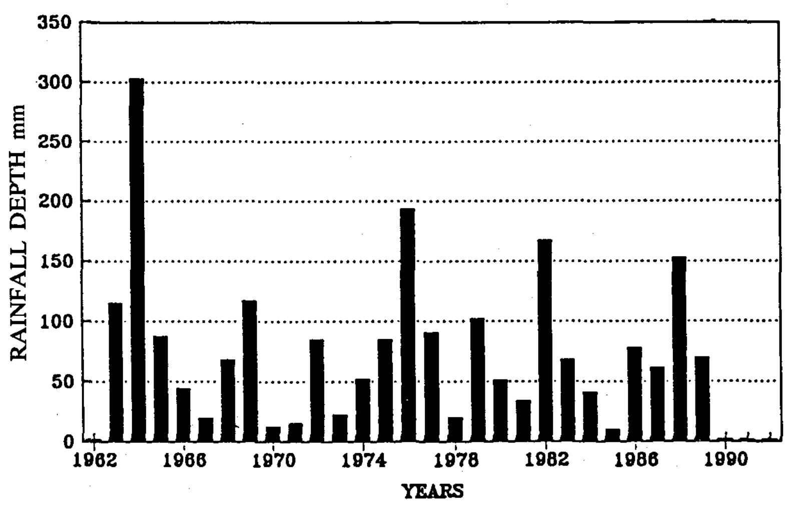

Fig. 1: Annual Rainfall Depth

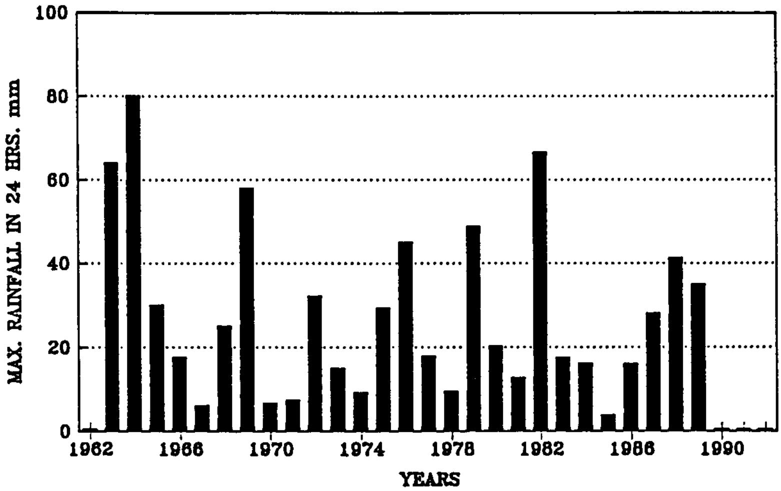

Fig. 2: Maximum Rainfall in 24 Hours

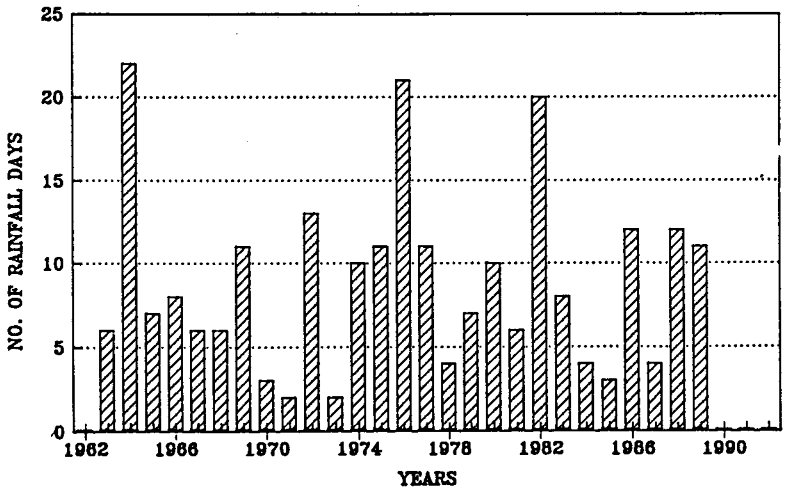

Fig. 3: Number of Rainfall Days (Rainfall Depth > 1 mm)

The mean anual rainfall depth for Doha is 77.2 mm, a small value compared to corresponding values for well watered areas of the world, (the average annual precipitation over the whole of the United Kingdom is of the order 1100 mm, 14 times that of Doha, and can be as high as 5000 mm in the mountainous regions of the North-West (Bartlett, 1981). From Figure 1, it is clear that in the years 1962, 1970, 1971 and 1985 the rainfall depth was less than 20% of the mean indicating relatively very dry years.

Table 1
Summary of Statistical Parameters for Rainfall Data (1962-1989), Doha-Qatar.

Variable	Maximum	Minimum	Mean	Max. Mean	Standard Deviation	Coeff. of Variation
Annual Depth (mm)	302.8	0.4	77.2	3.92	65.7	0.85
Maximum Rainfall in 24 hrs (mm)	80.1	0.2	27.1	2.96	20.9	0.77
No. of Rainfall Days in excess of 1 mm	22	zero	8.6	2.56	5.6	0.66

Table 2
Variation of the Mean Annual Rainfall Depth with the Length of the Record.

Period	Number of years	Mean (mm)	% Deviation of true mean
1962-1964	3	139.4	+ 80.5
1962-1967	6	94.8	+ 22.7
1962-1970	9	85.1	+ 10.2
1962-1973	12	74.0	− 4.2
1962-1976	15	81.2	+ 5.1
1962-1979	18	79.5	+ 2.9
1962-1982	21	80.1	+ 3.7
1962-1985	24	75.0	− 2.9
1962-1988	27	77.5	+ 0.33
1962-1989	28	77.24	zero

Figure 4 shows the average monthly variation in the rainfall. It indicates that the months of June, July, August and September are dry. Most of the rain occurs in winter and early spring. Roughly 65% of the annual rainfall occurs in January, February and March. By including the months of December and April this would account for 90% of the total rainfall. It is observed that most of the lightning and thunders occur in March and April. A tally of storms that have occurred since 1975 up to the end of 1989 (14 years) would indicate that 75.6% of the storms produced a depth less than 10 mm, while 24.4% of the storms produced a depth greater than 10

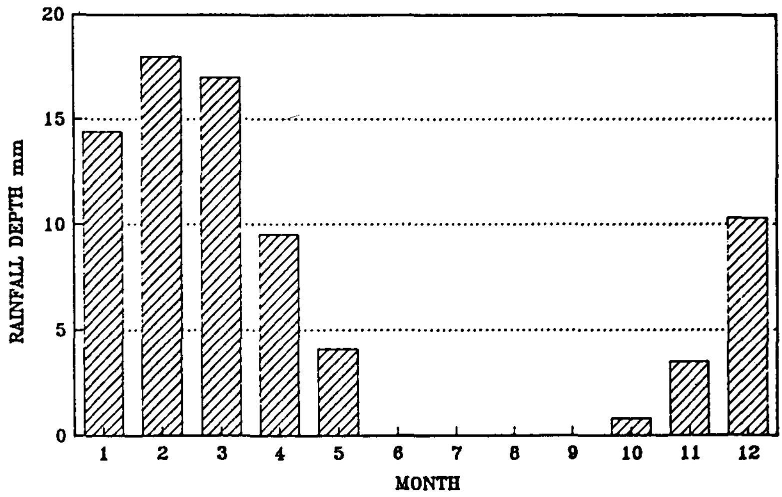

Fig. 4: Mean Monthly Rainfall Depth

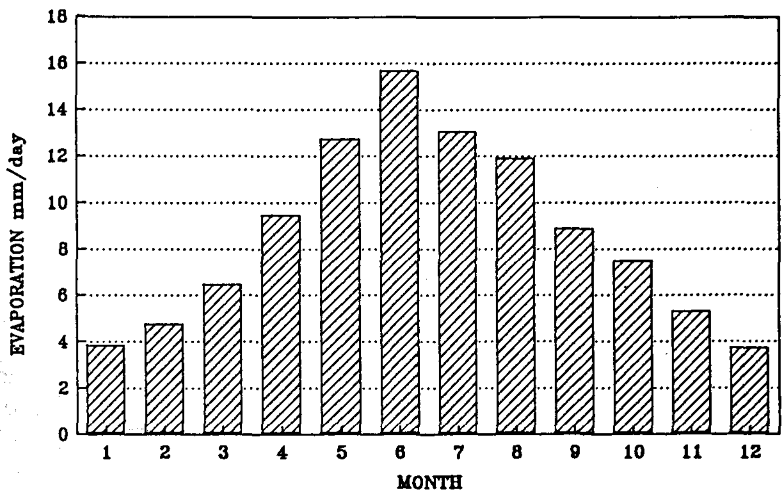

Fig. 5: Monthly Mean Daily Evaporation

mm out of which 10.7% of the storms produced a depth greater than 20 mm and 5.3% of the storms produced a depth greater than 30 mm.

A tally of those storms that produced a depth in excess of 10 mm would indicate that such storms usually occur in February and March. The probability of having at least one, two, three, four, and five storms in one year with a depth greater than 10 mm each is respectively 85.7%, 64.3%, 35.7%, 21.4% and 7.1%.

Standard pan evaporation data for the period 1976 to 1988 at the Doha International Airport were analyzed giving a mean daily rate of 8.6 mm/day with a standard deviation of 0.59. This would result in a coefficient of variation of 0.068, indicating less variability in pan evaporation. The annual average evaporation depth is 3,139 mm, more than forty times the annual rainfall depth. Figure 5 shows the variation of the average monthly evaporation rate during 1976 through 1988. Maximum evaporation of 15.7 mm/d occurs in June while the minimum rate of 3.7 mm/d occurs in December.

In 1978 a second climatological station was installed at the Doha Port within four kilometers from the main station at the International Airport. For comparison the annual rainfall depth, maximum rainfall depth in 24 hours and number of rainfall days having rainfall depth greater than 1 mm for the two stations over the period (1979-1989) are given in Table 3. This table includes the correlation coefficient, the y intercept and the slope of the regression line. The highest observed deviation in both the annual rainfall depth and the maximum rainfall in 24 hours between the two stations occurred in 1989. In general correlation of the maximum rainfall in 24 hours between the two stations is low as compared to the annual rainfall depth.

Table 3
Areal Variation of Rainfall Characteristics

Year		**Annual Rainfall Depth (mm)**		**Max. Rainfall in 24 hrs. (mm)**		**No. of Rainfall Days > 1 mm**	
		[2]x	[1]y	x	y	x	y
1979		101.9	107.4	48.8	34.3	7	9
1980		50.8	71.4	20.2	25.1	10	15
1981		33.8	31.1	12.7	12.1	6	6
1982		167.3	130.3	66.5	44.6	20	17
1983		68.1	59.8	17.5	24.1	8	8
1984		40.9	45.9	16.2	13.1	4	5
1985		9.7	11.4	3.8	8.6	3	2
1986		78.0	72.2	16.0	17.9	12	12
1987		61.3	65.9	28.0	37.5	4	2
1988		152.8	170.1	41.3	39.8	12	14
1989		69.7	129.7	34.9	104.0	11	11
Mean		75.85	81.38	27.81	32.83	8.82	9.18
Correlation Coefficient		0.879		0.517		0.909	
y intercept	(a)	15.26		12.17		0.88	
Slope	(b)	0.872		0.743		0.941	

[1]y : Doha Port Station
[2]x : Doha International Airport Station
$y = a + bx$

EXTREME-VALUE ANALYSIS

Hydrologic systems are sometimes impacted by severe storms. The magnitude of a storm is inversely related to its frequency of occurrence, very severe events occurring less frequently than moderate events. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions.

Four types of probability distributions namely: the normal distribution, the log normal distribution, log Pearson type III distribution and the extreme value (Gumbel) distribution were fitted to the annual series of maximum rainfall in 24 hours over the period of 1962-1988. In order to perform the analysis, an order (m) is assigned to each individual recorded event according to the magnitude (m=1 for the highest rainfall in 24 hrs). The probability of an event of the same magnitude or higher occurring may then be calculated by:

$$P = (m/N+1)$$

where N is the total number of events recorded in the data series, herein 27 years. The calculated frequency of an event of the same magnitude or higher is given by;

$$Tr = (1/p)$$

Tr is called the return period or the recurrence interval and is defined again as the average time interval between storms that are equal to or greater than a specific value.

The arranged data for the maximum rainfall in 24 hours annual series together with the corresponding probability of excedence (p) is plotted on log-probability paper as shown on Figure 6. Procedures to fit the four probability distributions to the data are clearly outlined in Prashun (1987) and Chow *et al.* (1988). The goodness of fit for the four distributions was tested using the Chi-square test statistics (Chow *et al.*, 1988 and Haan, 1977). The same steps were followed for the total annual depth series. The results are presented in Figure 7. It was found that the extreme value (Gumbel) distribution provided the best fit for the two series. The calculated skewness coefficient required by the log-Pearson type-III distribution for the two series was close to (−2.0). The curves representing this distribution both on Figures 6 and 7 correspond to a skewness coefficient of (−1.0). The later value provided a better fit for the data values of the larger magnitude and lower probability of exceedence. This end of the series is of more concern.

It is clear from Figures 6 and 7 that the normal distribution deviates from the data points at its two ends, i.e. extreme low and high values. The normal distribution provided a better fit for the annual total rainfall series than the annual maximum

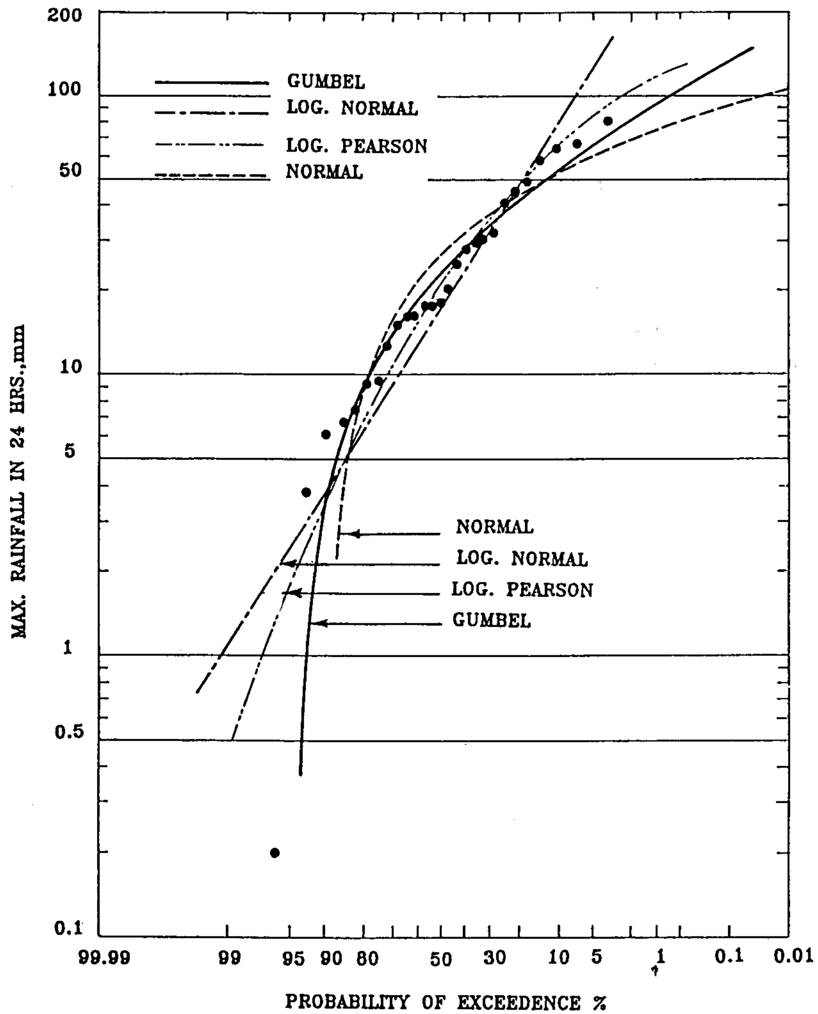

Fig. 6: Probability Distributions of the Maximum Rainfall in 24 Hours

rainfall in 24 hours. The problem with most hydrologic data is that an equal spread does not occur above and below the mean. The lower side is limited to the range from the mean to zero, while there is theoretically no limitation on the upper range. This contributes to what is called a skewed distribution.

INTENSITY-DURATION-FREQUENCY RELATIONSHIP

One of the most important rainfall characteristics is the rainfall intensity, usually expressed in mm/hr. Average annual rainfall has only a limited bearing on the

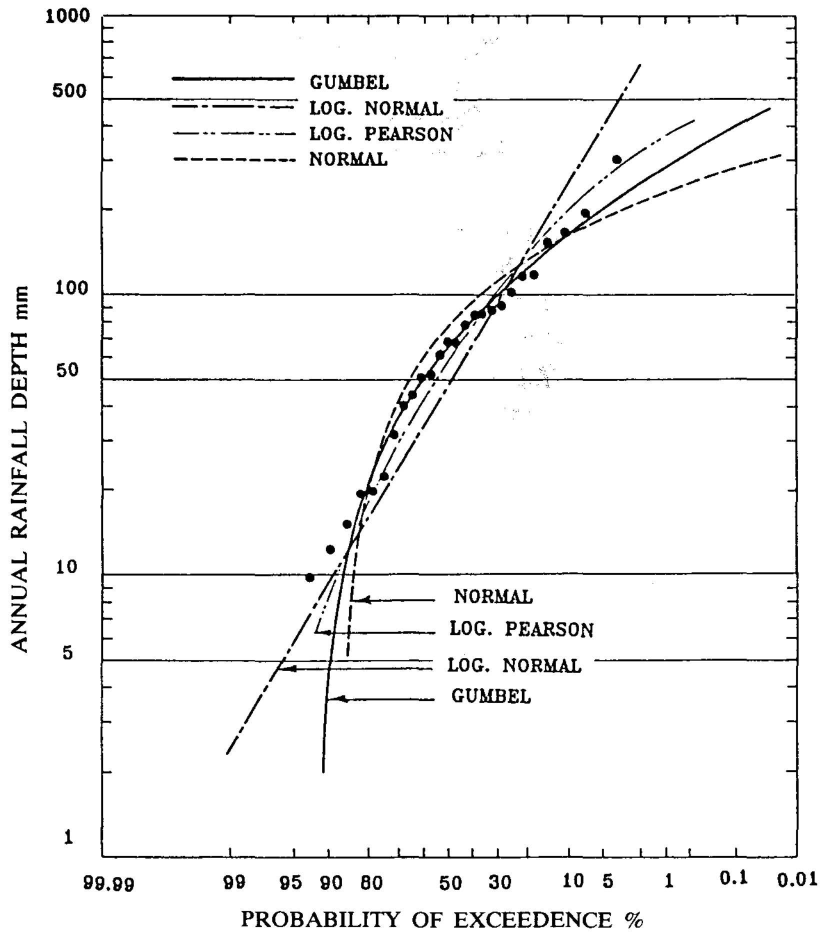

Fig. 7: Probability Distributions of the Annual Rainfall Depth

design of surface water sewerage schemes. Storms of high intensity generally last for fairly short periods and cover smaller areas. Therefore in applying statistical methods to rainfall data the analysis should include the intensity as well as the oveall depth. The analysis should provide the average period of time within which the depth of rainfall for a given duration will be equalled or exceeded.

In order to establish the relationship among rainfall intensity, duration and return period available rainfall hyetographs over the period 1977-1989 (13 years) were analyzed. Because of the limited number of rainfall events, it was not possible to determine the complete relationship using rigorous statistical procedures as outlined by Fair *et al.* (1977) and Chow *et al.* (1988). Therefore the procedure outlined in Al-Layla *et al.* (1980) was followed to determine the intensity-duration-frequency relationship with inadequate data. The procedure depends on the use of the coefficients given in Tables 4 and 5. While Table 4 relates the one-hour rainfall with different return periods to the one-hour, two year rainfall, Table 5 relates the rainfall of different durations to the one hour rainfall depth of the same return period.

The available hyetographs were scanned to determine the maximum rainfall depth that has occurred in one hour over 13 years. The storm on 12/3/1982 shown in Figure 8 produced the largest depth of 26 mm in one hour and was assigned a return period of 14 years. Figures 9 and 10 show the hyetographs of the storms which produced the second and third largest depth in one hour over 13 years. These depths were respectively 21 mm and 17.5 mm. The corresponding return periods would be then 7 and 5. Both the cumulative rainfall depth and intensity are portrayed on the hyetographs.

Table 4

Ratio of the 2 Yr, 1 Hr. Rainfall to the 1 Hr. Rainfall of Different Return Period*

Return Period (Years)	2	5	10	25	50	100
Ratio	1.00	1.35	1.60	1.87	2.10	2.32

* Al-Layla *et al.* (1980)

Table 5

Ratio of the 1 Hr, Rainfall Depth to the Rainfall Depth of Different Duration for the Same Return Period*.

Country	**Duration (Minutes)**					
	5	**10**	**15**	**30**	**60**	**120**
USA	0.29	0.45	0.57	0.79	1.00	1.25
Australia	0.30	—	0.57	0.78	1.00	1.24
USSR	0.32	—	0.55	0.79	1.00	1.30

* Al-Layla *et al.* (1980)

The intensity-duration-frequency relationship developed was based on the critical storm on 12/3/1982, (depth = 26 mm, duration = 60 min, return period = 14 yr). By interpolating the coefficients given in Table 4, the ratio of 1 hr, 14 yr rainfall

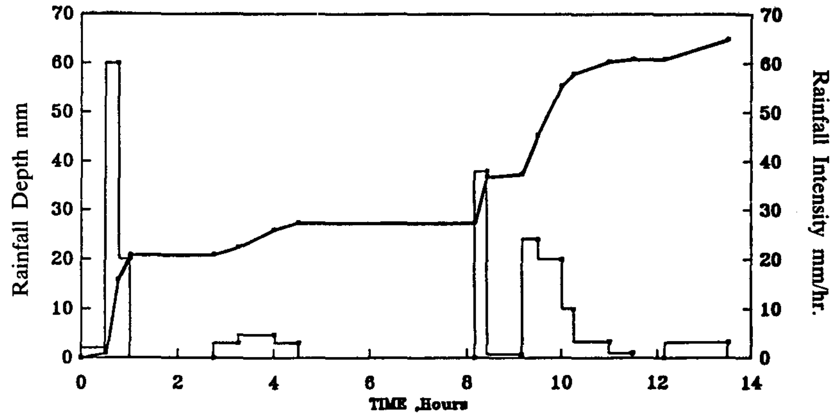

Fig. 8: Rainfall Hyetograph, 12/3/1982

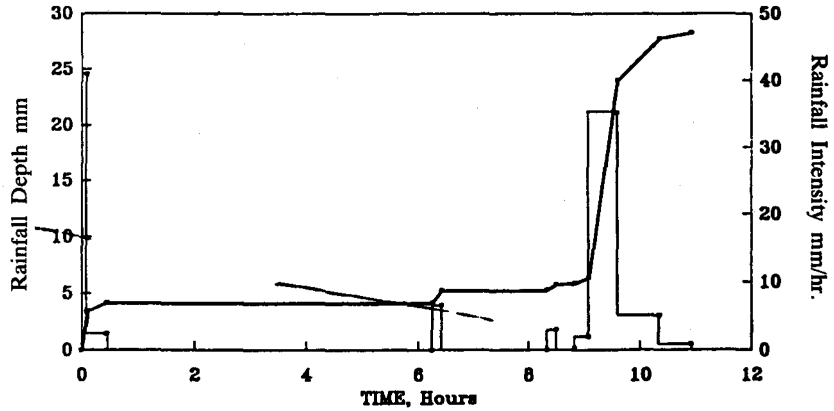

Fig. 9: Rainfall Hyetograph, 21/2/1988

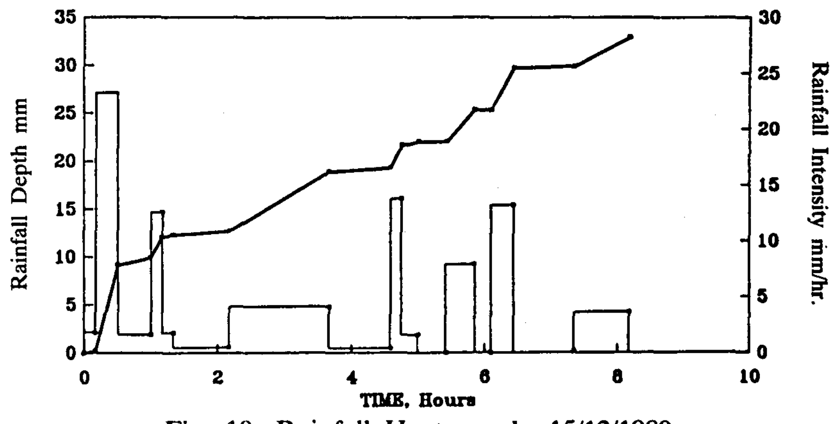

Fig. 10: Rainfall Hyetograph, 15/12/1989

to 1 hr, 2 yr rainfall is 1.70. Hence, the 1 hr, 2 yr rainfall depth is estimated as 15.3 mm. Similarly the 1 hr rainfall depths for 5, 10, 25, 50 and 100 year return periods were obtained. The ratios given in Table 5 for USA was used to determine the rainfall depths for different storm durations namely, 5, 10, 15, 30, 120 minutes based on the one-hour depth for each return period. The resulting depths are included in Table 6. The intensity-duration-frequency (IDF) relationship is obtained by dividing each depth by the corresponding duration.

The developed IDF relationship was compared to an IDF presented by Eccleston *et al.* (1981) which was based on a limited data (1972-1979) collected for three recording rainfall gauges at Rowdaht al Faras, Abu Nakhla, and Abu-Samara (three inland sites in the State of Qatar). The results are given in Table 7 together with the corresponding data for Bahrain, a neighboring state in the Gulf area known to have longer rainfall record of approximately fifty years.

As an independent check on the developed IDF relationship, the 1 hr, 5 yr rainfall depth from Table 6 is 20.6 mm. The corresponding values from the hyetographs of Figures 9 and 10 are a depth of 21 mm for 1 hr, 7 yr storm of 21/2/1988 and 17.5 mm for 1 hr, 5 yr storm of 15/12/1989.

In the absence of 1 hr rainfall records, one may use rainfall records of 24 hrs. which are generally available. The ratio between 2 yr, 1 hr rainfall to 2 yr, 24 hr rainfall varies between 0.35 to 0.5 (Al-Layla *et al.* 1980). An average value of 0.425 was used to convert the maximum rainfall in 24 hrs observed over a period of 28 years to 1 hr rainfall. The resulting 1 hr, 28 yr rainfall depth will be 34 mm. The ratio to convert 1 hr, 28 yr rainfall depth to 1 hr, 2 yr rainfall depth is obtained by interpolation from Table 4 as 1.9. This would give 1 hr, 2 yr depth of 17.9 mm compared to 15.3 mm as obtained from the critical storm of 12/3/1982.

Table 6

Depth-Duration-Frequency Relationship Based on the Critical Storm of 12/3/1982 (Doha-Qatar).

Return Period (Years)	Rainfall Depth (mm)					
	Duration (Minutes)					
	5	10	15	30	60	120
2	4.4	6.9	8.7	12.1	15.3	19.1
5	6.2	9.3	11.8	16.3	20.6	25.8
10	7.1	11.0	13.9	19.3	24.5	30.6
25	8.3	13.7	16.3	22.6	28.6	35.7
50	9.3	14.5	18.3	25.4	32.1	40.1
100	10.3	16.0	20.2	28.0	35.5	44.3

Table 7

Comparison of Rainfall Intensity-Duration-Frequency Relationships (Doha-Qatar)

Duration (Minutes)	Rainfall Intensity (mm/hr)															
	Return Period Tr (Years)															
	Tr = 2				Tr = 5				Tr = 10				Tr = 25			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
10	41.3	36	30	46.7	55.7	—	54	61.0	66.1	—	72	71.4	82.3	76.7	—	—
20	30.5	21	—	30.0	41.0	33	—	40.7	48.5	49	—	49.1	56.5	50.3	—	—
30	24.2	13	18	24.5	32.6	21	32	31.7	38.6	32	42	38.5	45.2	39.3	—	—
60	15.3	8	11	15.2	20.6	12	19	19.5	24.5	18	26	24.4	28.6	25.7	—	—
120	9.6	—	6.5	8.6	12.9	—	11	11.0	15.3	—	15	14.1	17.9	16.9	—	—

(1) Developed IDF based on the critical storm of 12/3/1982, inadequate data procedure.
(2) Eccleston *et al.*, (1981).
(3) Bahrain, Pencol (1981)
(4) U.K., Simple Ministry-type formulae, Bartlett (1981)

The intensity-duration-frequency relationship based on the critical storm of 12/3/1982 was fitted by an equation of the form;

$$i = \frac{C\ Tr^{m}}{(t+d)^{n}}$$

in which i is the rainfall intensity in mm/hr, Tr is the return period in years and t is the storm duration in minutes. C,m,d and n are fitting parameters. The best fit of the developed IDF relationship was for the following values of the parameters;

(C = 410, m = 0.206, d = 10, and n = 0.787)

The IDF relationship is shown in Figure 11. Table 7 includes also the rainfall IDF values relevant to the United Kingdom for comparison purposes. These values were computed using simple "Ministry-type" formulae based on work originally published by Norris in 1948 (Bartlett, 1981).

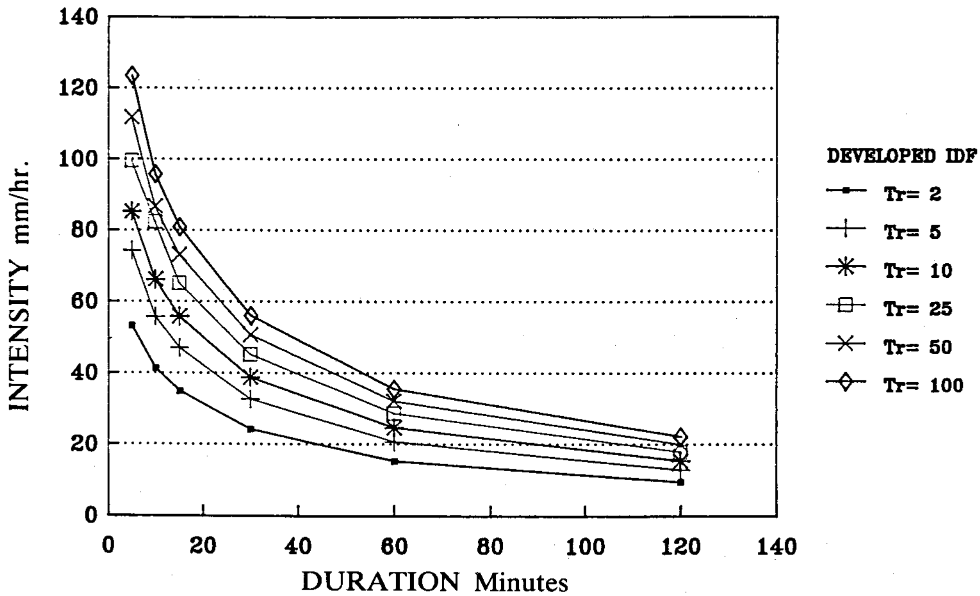

Fig. 11: Intensity-Duration-Frequency Relationship

CONCLUSIONS

The State of Qatar can be taken to represent an arid area since the average annual evaporation loss greatly exceeds the average annual rainfall gain. The mean annual rainfall depth based on a record of 28 years in Doha, the state capital, was

77.2 mm, while the maximum annual depth observed was 302.8 mm in 1964. There are only few days in the year when precipitation take place (8 to 9 days) between November and April. Thunder storms may occur once or twice a year and can contribute significantly to the total annual rainfall depth. The maximum rainfall in 24 hrs so far recorded was 80.1 mm.

The rainfall is characterized by high variability. In order to obtain a reasonable estimate of a representative mean of the annual rainfall depth the length of the record need to be at least ten years. Although the correlation of the annual rainfall depth and the number of rainfall days was adequate for two closely spaced stations, the correlation of the maximum rainfall in 24 hrs was not as good. This shows that severe thunderstorms are of limited geographic extent.

Four probability distributions were used to fit the maximum rainfall in 24 hrs and the annual rainfall depth. The (Gumbel) extreme-value distribution was found to have the best fit. The rainfall intensity-duration frequency (IDF) relationship for Doha has been developed based on the analysis of the hyetographs of few critical storms and compared with the maximum 24 hrs rainfall data. The developed relationship seems adequate when further compared with values obtained by other investigators for the State of Qatar and for Bahrain a neighbouring state in the Gulf area where longer rainfall record is available.

While the annual rainfall depth in an arid area can be small compared to well watered areas of the world, the intensities of the storms in an arid region may be high over short durations. Rainfall is scarce in an arid area but some events are severe and can cause inconvenience.

ACKNOWLEDGEMENT

We wish to acknowledge with thanks the help and cooperation extended by the Department of Meteorology, Ministry of Communication and Transport, State of Qatar, for providing the rainfall data.

REFERENCES

1. **Al-Layla, M.A., Ahmed, S.** and **Middlebrooks, E.J., 1980,** Handbook of Wastewater Collection and Treatment, Garland STPM Press, New York.
2. **Bartlett, R.E., 1981,** Surface Water Sewerage. Applied Science Publishers Ltd., London.
3. **Chow, V.T., Maidment, D.R.** and **Mays, L.W., 1988,** Applied Hydrology. McGraw Hill Book Company, New York.

4. Department of Meteorology, Ministry of Communication and Transport, Long Period Means and Extremes of Climatological Elements, Doha International Airport (1962-1989)., State of Qatar.

5. Department of Meteorology, Ministry of Communication and Transport, Long Period Means and Extremes of Climatological Elements, Doha Port (1962-1989), State of Qatar.

6. **Eccleston, B., Pikes, J.G.** and **Harhash, I., 1981,** The Water Resources of Qatar and Their Development. Technical Report No. 5, Ministry of Industry and Agriculture, State of Qatar.

7. **Fair, G.M., Geyer, J.C.** and **Okun, D.A., 1971,** Elements of Water Supply and Wastewater Disposal, John Wiley and Sons Inc., New York.

8. **Haan, C.T., 1977,** Statistical Methods in Hydrology. Iowa State University Press, Ames, Iowa.

9. Macmillan Family Encyclopedia, 1982, Macmillan, London.

10. **Prashun, A.L., 1987,** Fundamentals of Hydraulic Engineering. Hot Rinehart and Winston, New York.

11. **Pencol, J.T.** and **Sons, 1981,** Doha Storm Water and Land Drainage Master Plan. Draft Report, Ministry of Public Works, State of Qatar.

12. **Pilgrim, D.H., 1987,** (Editor), Australian Rainfall and Runoff, A Guide to Flood Estimation. The Institution of Engineers, Barton, Australia.

13. **Reich, B.M., 1963,** Short-Duration Rainfall-Intensity Estimates and Other Design Aids for Regions of Sparse Data. Journal of Hydrology, Vol. (1), pp. 3-28.

14. **Yevjevich, V., 1972,** Probability and Statistics in Hydrology. Water Resources Publications, Fort Colins, Colarado, USA.