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ANALYSIS OF RAINFALL DATA FROM EASTERN IRAN

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ABSTRACT

Extreme rainfall estimation is an important task in engineering design projects. They generate heavy floods which can be extremely damaging and even lead to loss of lives, so the prediction of perilous rainfall is important. These predictions should be done as precisely as possible; therefore it is useful to investigate and compare the results obtained using different method. In this study, two techniques for short duration rainfall have been analysed and intensity-duration-frequency (IDF) relationships developed that would help practicing hydrologist and engineers to cope-up the extreme floods. The annual maximum daily rainfall data from recent records, for the period 1985 to 2010 (Iranian calendar 1364 to 1388) were considered from two locations, i.e. Mashhad and Chabahar, situated in the east of Iran. The rainfall intensities for various return periods and annual maximum data series have been analysed using the Gumbel and the Generalized Logistic (GL) Distributions, and comparisons made between two approaches. The resulting information from Mashhad and Chabahar has been applied to extend and clarify previous intensity-duration-frequency (IDF) relationships. The results show plausible agreement with other IDF curves from different countries which are presented for comparison.

Keywords: Cumulative distribution, IDF curves, rainfall intensity, return period.

INTRODUCTION

Study of rainfall data corresponding to specific duration, frequency and intensity is an important aspect in the design of engineering projects. Flood phenomena can be extremely damaging and even lead to loss of lives, so prediction of extremes is important. These predictions should be done as precisely as possible; therefore it is useful to investigate and compare the results obtained using different methods.

In this study, annual maximum values of daily rainfall were obtained from the Islamic Republic of Iran Meteorological Organization (IRIMO) for two cities in eastern Iran, for the years listed in Table 1. Conclusions are drawn from these data about the different methods of analysis, and the resulting information is used to

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extend and confirm intensity-duration- frequency (IDF) relationships. These IDF graphs would be useful to calculate runoff from catchments by different methods such as rational or modified rational methods. A comparison is done for the 5 year return period for Mashhad and Chabahar with data from Northern Oman, London, and Kuala Lumpur to provide an international comparison, and to show that similar trends apply to IDF relationships for different locations.

Table 1. Rainfall data.

City	Dates (Iranian calendar)	Total years
Mashad	1991-2010 (1370 - 1388)	19
Chabahar	1985 - 2008 (1364 - 1386)	23

MATERIALS AND METHODS

The analysis is based on a single-site analysis approach, since the two locations are not considered sufficiently similar to be pooled together, thus data have been ranked and displayed using the Gringorten plotting position formula. Both the Gumbel and the Generalised, Logistic distributions have been used to analyze the series of annual maximum daily rainfall values, as described in the following sections.

The Gumbel or EV1 distribution

The Gumbel or extreme value type-1 (EV1) distribution has been recommended and can be used in the Flood Studies Report (NERC 1975) and described in texts such as Chadwick and Morfett (1998).

$$x = u + y_G \quad (1)$$

$$y_G = -\text{in}\{-\text{in}[F(x)]\} \quad (2)$$

The x and y_G parameters represent rainfall depth (mm) and the Gumbel reduced variety, respectively in this case. The two parameters u and α are location and scale parameters. F(x) is the cumulative distribution function, also known as the cumulative non-exceedance probability, and is related to the return period T by F=1-1/T.

One approach to determine the parameters u and α is to use least squares regression analysis of the displayed data. In the current study, the trend line from linear regression has been compared with the Gumbel line obtained by the method of moments.

From the mean $\bar{X}$ and standard deviation (s) of the data set, the parameters are obtained as follows by the method of moments, based on the properties of the Gumbel distribution:

$$u = x - 0.45s \qquad (3)$$

$$\alpha = 0.78s \qquad (4)$$

Therefore, for any given data set by plotting the values x versus the Gumbel reduced variety (y_G), a straight line would be obtained, either by moments using equations 3 and 4, or by the linear regression trend line. It could be seen that these results are similar but not identical.

Generalized logistic distribution

The Flood Estimation Handbook (Reed *et al.* 1999) advocates the application of the Generalized Logistic (GL) distribution. The logistic reduced variety, yL, is defined as:

$$y_L = \text{in}\left(\frac{1-F}{F}\right) \text{ OR} \qquad (5)$$

$$y_L = \text{in}\ (1 - T) \text{ since } F=1-1/T$$

In this method the annual maximum variable Q is non-dimensionalised by its median Q_{MED} and the resulting curve is given as follows:

$$\frac{Q}{Q_{MED}} = 1 + \frac{\beta}{K}\left[1 - \left(\frac{1-F}{F}\right)^K\right] \qquad (6)$$

The parameters, *K* and *β*, are determined by L-moment ratios. Further details of the GL method can be found in Hosking and Wallis (1997) and Chadwick *et al.* (2004). Further practical comparison between the GL and Gumbel approaches is given in Marriott and Hames (2007), and both methods have been used in this study.

Analysis of daily rainfall data

Numerical values for Mashhad are illustrated graphically in Figures 1, 2 and in tabular form for return periods up to 100 years are given in Table 2. Results for Chabahar are shown in Figures 3, 4 and Table 3. There is little difference between the Gumbel results by the method of moments and those obtained by the linear regression trend lines, indicating that the Gringorten plotting position formula is appropriate for the Gumbel distribution. The GL curves all show an increasing gradient for higher flows and return periods, indicating that they will diverge from the Gumbel straight line for higher results. This is already apparent in the Chabahar results for T = 20 years upwards, but not so for the Mashad results in the range tabulated. For lower return periods the agreement is reassuring, but for higher return periods the divergence should be taken into account.

It can be noted here that extrapolation from 20 years to 100 years data is not recommended. Though, it is always desirable to use longer data sets for greater confidence and for the predictions of higher return periods. However, the data analyzed here are considered suitable for the lower return periods used in drainage design. Higher values are presented to compare the different methods, and should be treated with some caution. A further point to be noted is that climate change may have the effect on increasing future storm rainfall intensities. This is recognized for current design practice in the UK (DEFRA, 2006), with indicative sensitivity allowances in the range of $^{+}5$ to 30% recommended for testing future performances.

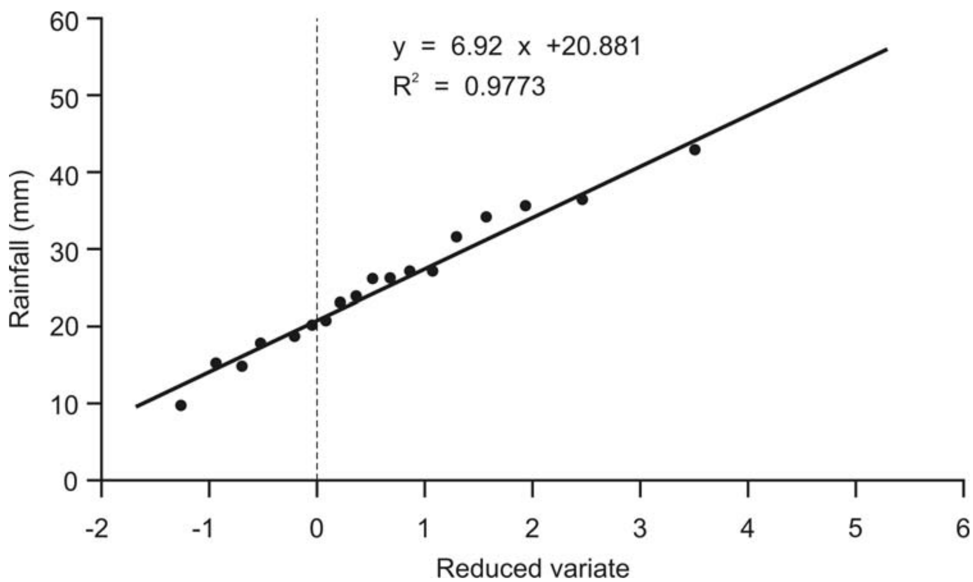

Figure 1. Gumbel distribution for daily rainfall data from Mashhad, showing the least squares trendline (linear regression line) through the displayed data.

Table 2. Mashad daily rainfall (mm) for various return periods, by different methods.

Return period T (years)	Logistic	Gumbel	Linear regression
2	23.50	23.33	23.42
5	30.58	30.87	31.26
10	35.18	35.86	36.45
20	39.76	40.64	41.43
50	46.05	46.84	47.88
100	51.11	51.48	52.71

Table 3. Chabahar daily rainfall (mm) for various return periods, by different methods.

Return period T	Logistic	Gumbel	Linear regression
2	30.40	29.10	29.33
5	51.47	50.69	51.54
10	67.57	64.99	66.25
20	85.54	78.70	80.36
50	113.61	96.45	98.62
100	139.11	109.75	112.30

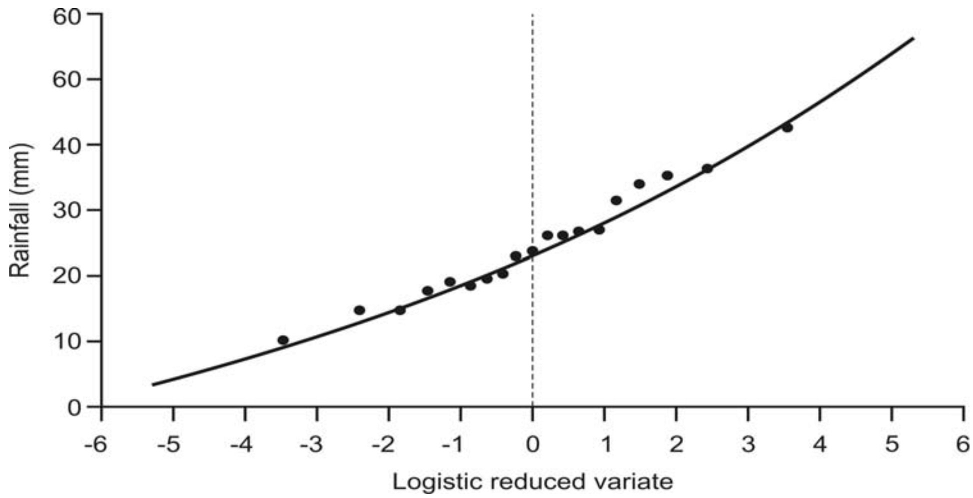

Figure 2. Generalised Logistic distribution curve for daily rainfall data from Mashhad.

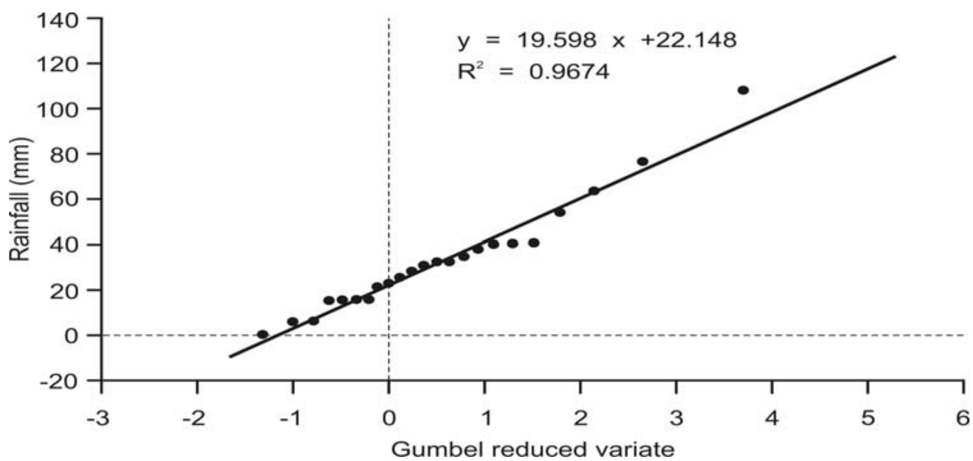

Figure 3. Gumbel distribution for daily rainfall data from Chabahar, showing the least squares trendline (linear regression line) through the displayed data.

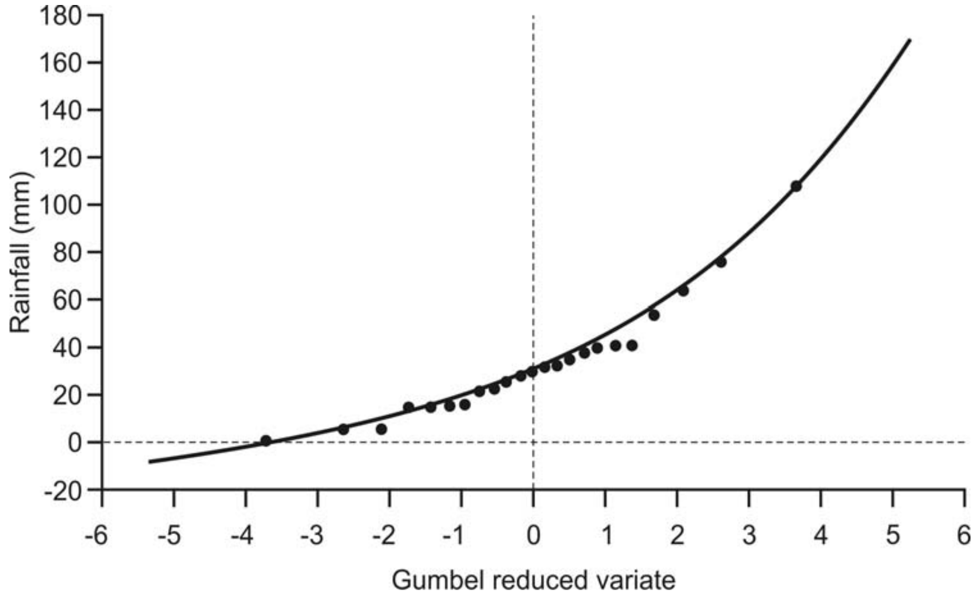

Figure 4. Generalised Logistic distribution curve for daily rainfall data from Chabahar.

Intensity-Duration-Frequency (IDF) analysis

Traditionally, the average rainfall intensity (I) and durations (D) relationships between have often been expressed in the form:

$$I = \frac{a}{D + b} \qquad (7)$$

Where a and b are locality constants. Shaw (1994) includes such a relationship for durations up to 2-3 hours and a related expression for rainfall depth R, which also features in the later edition of Shaw *et al.* (2011). Average intensity *I* is useful for engineering purposes in approaches such as the rational method or modified rational method for drainage design and this may easily be found from the equation:

$$I = \frac{R}{D} \qquad (8)$$

Wilson (1990) quotes relationship (7) for short durations, and for durations greater than two hours gives the following form:

$$I = \frac{R}{D^n} \qquad (9)$$

This may expressed in terms of logarithms as:

$$\text{Log } I = n - {*}\ \text{Log } D + \text{Log } C \qquad (10)$$

Amouzgar (2011) used equation (10) with logarithms to base 10 to extend IDF relationships as described in the following sections.

A further point to be made relates to the relationship between daily rainfall measurements and 24 hour values, because the storm period may not coincide exactly with the timing of daily readings. Wheater and Bell (1983) considered this error to be small, when considering isolated events generally occurring on a single daily record only and the same assumption has been made for this study.

In Malaysia, DID (2000) includes adjustment factors of 1.12 and 1.16 depending on location, and for 1 day data in the UK. Shaw *et al.* (2011) quoted a factor of 1.16 to convert fixed period rainfall totals to sliding duration equivalents. However, no such factor has been applied in the following sections.

Chabahar

Rainfall intensity for a range of return periods and different durations up to 3 hours duration are given in Table 4 from previous study (Zainudini and Marriott, 2010). The longer durations in that study produced anomalous results and have been revised in this study, by applying the rainfall intensity values for 24 hour duration found from the Gumbel results above. For example, the 5 year return period value of daily rainfall in Chabahar from Table 3 is 50.69 mm, which implies 2.11 mm/hr average rainfall intensity for 24 hour duration, subject to the assumptions described above. Similar results for a range of return periods and the associated equations are given in Table 5.

The resulting IDF curves for Chabahar for return periods up to 100 years and rainfall duration up to 24 hours are illustrated in Fig. 5, and the 5 year data is included in Fig. 6. This provides a useful correction for the anomaly described in previous work.

Table 4. Point Rainfall intensities for a range of return periods in Chabahar, (Zainudini and Marriott, 2010).

Duration (hours)	Intensity (mm/hr)					
	T = 2	T = 5	T= 10	T= 25	T= 50	T= 100
0.25	53	74	88	105	118	131
0.5	36	53	65	79	90	101
1	22	35	44	55	63	71
3	9	14	18	22	25	28

Mashhad

Mashhad rainfall intensities for 5 year return period for short duration rainfall up to 6 hours is given in Table 6, (Alizadeh, 1997). From Table 2 the daily rainfall depth at 5 year return period by the Gumbel method in this study is 30.87 mm, which gives the 24 hour rainfall intensity as 1.29 mm/hr. According to this value and the data in Table 6, the following equation for intensity I (mm/hr) at Mashhad with 5 year return period is obtained for D>3 (hr):

$$\text{Log I}=-0.864\text{Log D}+1.303 \quad (11)$$

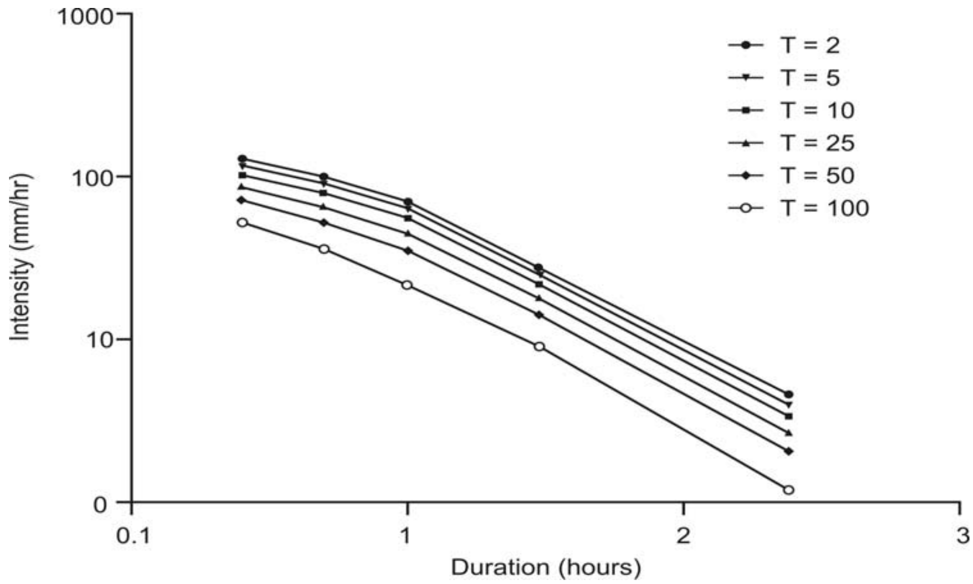

Figure 5. IDF Curves for Chabahar for return periods T = 2 to 100 years

Table 5. Equations to extend the IDF relationships from 3 to 24 hours for Chabahar.

T (Years)	Intensity (mm/hr)		
	D= 3 hr	D= 24 hr	Equation
2	9	1.25	Log 1=-0.965*Log D+1.415
5	14	2.11	Log 1=-0.910*Log D+1.580
10	18	2.71	Log 1=-0.911*Log D+1.690
25	22	3.46	Log 1=-0.890*Log D+1.767
50	25	4.02	Log 1=-0.879*Log D+1.817
100	28	4.57	Log 1=-0.872*Log D+1.863

This is applied in Fig. 6 which shows that this produces a plausible line.

IDF data from other countries

Some other rainfall intensities at 5 year return period are plotted in Figure 6 for making comparison with Iranian cities Mashhad and Chabahar. These data are from Northern Oman (Wheater and Bell, 1983), Kuala Lumpur (DID, 2000) and London (NWC, 1981).

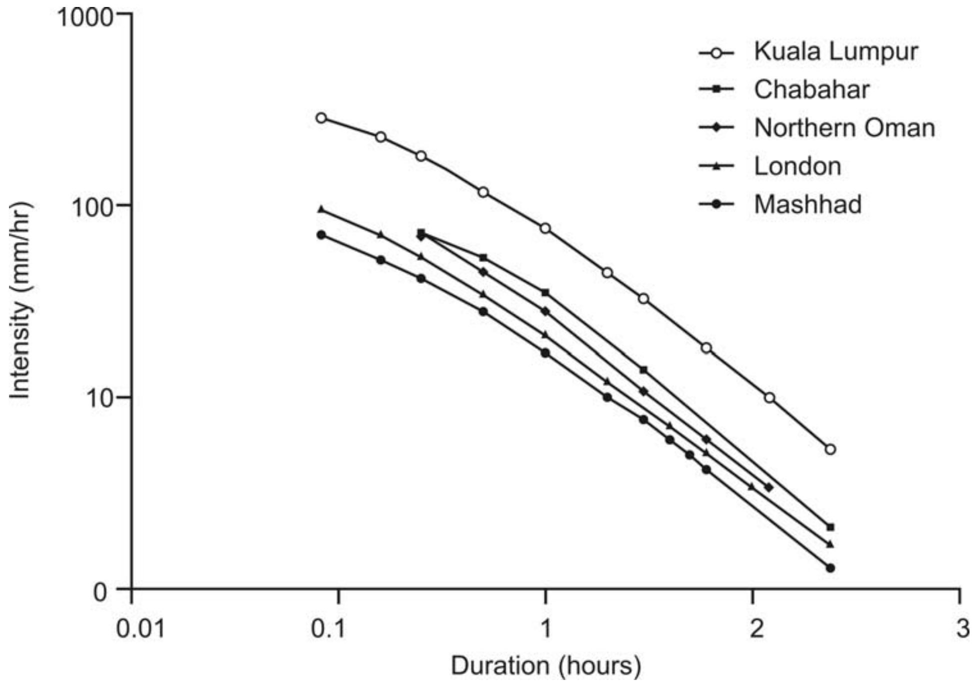

Figure 6. Intensity Duration Relationships for 5 year return period in various locations

Table 6. Point Rainfall intensities for 5 year return period in Mashhad, (Alizadeh, 1997).

Duration (hr), T= 5 (yrs)	Intensity (mm/hr)
0.083	70
0.167	52
0.25	42
0.5	28
1	17
2	10
3	7.8
4	6.0
5	5.0
6	4.2

As expected, the Kuala Lumpur (KL) curve displays the highest rainfall intensities as compared to data collected at Malaysia with a tropical climate. Surprisingly, the Chabahar city in an arid area with less than 120 mm average annual rainfall, takes the second place for intensity after KL. This is a useful reminder for design purposes that high intensity short duration rainfall may also occur in dry regions. Comparisons of the curves from different locations show a common trend, despite the considerable variation in climate of the locations.

CONCLUSION

In this study both the Gumbel and the Generalized Logistic methods show reasonable agreement for practical purposes, but for longer return periods the GL will produce higher values, particularly evident for the Chabahar data. But the focus here is mainly on the resulting IDF curves. For shorter return periods the simpler Gumbel method produces acceptable results. A new version of the IDF curves for Chabahar has been produced from these values, resolving a previous discrepancy. Further short duration data would still be useful.

The Mashhad IDF curve has also been extended, and the additional data shows good agreement with that previously published. The international data for comparison shows a common trend for IDF relationships.

Some caution is expressed regarding the extrapolation of data for longer return periods, and also regarding the impact of climate change on future rainfall intensities. As always, longer data sets would be desirable, to give greater confidence for longer return period predictions, and to monitor changes over time. The data presented here can be useful for civil engineering design calculations.

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