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RAINFALL INTENSITY - DURATION - FREQUENCY RELATIONSHIP FOR NORTHERN OMAN

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ABSTRACT

For the proper and economical design of storm sewer systems, drainage facilities for highways, flood protection works and other related structures RIDF relationship is an essential input parameter. The construction of this relationship is primarily based on the availability of short duration rainfall measurements for sufficient period of time. Unfortunately such long time data are only available in few countries while in many other places are scarce. In Oman there is considerable lack of such data since measurements of short duration rainfall commenced at 11 sites in 1973. The present study analyzed the available data measured at 20 stations located at different places in northern Oman for the period 1973-1983 inclusive and the station year approach was then applied to extend the record length and both the log Pearson type III and the type I extremal frequency distribution functions were used to construct the RIDF curves and the best fit equations of these curves

were obtained. Ratios of the T year - t min rainfall to the 10 year - one hour rainfall were found to be in close agreement with those ratios given by Bell (3) and which are applicable to several diverse places around the world.

2. INTRODUCTION

The design of drainage structures are dependent upon correlations between rainfall and peak surface runoff. Hydrologic analysis for this relationship involves as many direct measurements as feasible, estimates of conditions that are not directly measurable, and calculations of the probable occurence of rainfall based on past records. The three features of rainfall fundamental to hydrologic problems are intensity, duration and frequency (1). Hydrologist are normaly concerned with rainfall intensity and not rainfall depth observed within different durations. The rainfall intensity duration frequency relationship (RIDF) is a transformation of the rainfall depth duration frequency relationship (RDDF), with the implicit understanding that the intensity of rainfall is constant during the specified duration (2).

The preparation of the RIDF curves are based on the analysis of long period measurements of short duration rainfall depth. Unfortunately such data are extremely scarce except for few countries. However, in such places where lack of data is considerable the hydrologist has two main options to obtain a more or less reliable RIDF curves. The first option is to apply the station year method to extend the limited data obtained by a single station. In this method of analysis it is assumed that data obtained from different stations are independent and from a meteorologically homogeneous area. The second option is to use RIDF relationship of other countries to develop the required relationship. Bell (3), Reich (4), Hershfield, Weiss and Wilson (5) have demonstrated that United States rainfall relationships can be applied to other parts of the world. Bell (3) introduced a table for the ratios of the T year - t minute rainfall to 10 year - one hour rainfall for a range of duration between 5 minutes and 2 hours and for return periods between 2 and 100 years. Bell showed that these ratios are valid for diverse places as Alaska, South Africa, Hawaii, Puerto Rico, Australia and the contiguous United States. However, some departures would possibly occur in other places where local convective rainfall is less important in producing short duration extremes.

This latter method was applied by Goswami (6) to obtain RIDF map for India and by the U.S Weather Bureaue (7) to derive rainfall depths for airport drainage in north Africa. Wan (8) applied the station year concept using the available 6 years gauge data of 18 stations to get RIDF curves for each of four rainfall zones in Saudi Arabia and showed that ratios given by Bell are also valid for Saudi Arabia.

3. RAINFALL INTENSITY RELATIONSHIPS

Tremendous effort has been carried out since the begining of this century to present rainfall intensity formula. In the U.K Lloyd - Davis (9) was among the first to adopt the following hyperbolic relationship:

$$I = a / (t + b) \tag{1}$$

where I is the average rainfall over duration t, a and b are constants. Same form of equation (1) but with different values of a, b were used by Roseveare (10), and Steel (11).

Meyer (12) used the following formula which he claimed to be applicable for areas east of the Rockies in the U.S.A:

$$I = at / (t + b) \tag{2}$$

Escritt (13) proposed the following relationship:

$$I = a / t^m \tag{3}$$

in which a is a constant and m an exponent.

Mirril (14) adopted the following more advanced formula which considers the frequency of occourence (f):

$$I = k f^x / t^n \tag{4}$$

values of k, x and n were given for any location east of the 101 st meridian in the United States. Later in the U.K. Dillon (15) used a similar formula which reads:

$$I = a\ (f/t^3)^m \tag{5}$$

A more general equation may take the following form:

$$I = af^m\ /\ (t + b)^n \tag{6}$$

Equation (6) was used by McIllwraith (16) to fit Australian data and by Collinge (17) for the British Isles. Chow (18) listed 24 rainfall intesnity formulae similar to equation (6) and which were applicable to different areas in the U.S.A.

In the USSR Maksimov (19) proposed the following equation:

$$I = a\ /\ (t+1)^n \tag{7}$$

However, the simpler form of equations (1) and (3) continued to dominate in engineering practice (2). Also, in the U.S.A the above equations have been superseded by the extended rainfall frequency study prepared by Yarnell (20) and which was presented in the form of a series of maps for several combinations of return periods and durations. This work was updated by Hershfield (21) who compiled the available data from about 4000 stations to prepare rainfall frequency atlas of 49 maps for the U.S showing rainfall depths for various frequencies and durations. In the U.K similar approach was followed and substantial data bank for rainfall recods were analysed and a computerised version for constructing RDDF curves was introduced by the National Water Council and Department of the Environment (22). In this approach the 5 year - 60 minute rainfall depth map was given for the U.K along with ratios to estimate rainfall depth corresponding to different durations and return periods at different locations.

4 AVAILABLE DATA FOR NORTHERN OMAN

Measurements of short duration rainfall in Oman commenced at 11 stations in 1973. These data have been subjected to rigorous quality control for the period 1973-1978 by Horn (23). More gauges were installed after 1973 but still the available data are considered extremely limited to carry out conventional frequency analysis for each site. Therefore, the present study applies the station year concept in order to extend the available record length of the 20 recording stations in northern Oman. The data of those stations are considered independent and all stations are assumed to be located in a meteorologically homogeneous area and will therefore experience similar rainfall frequencies. The stations are also widely enough separated so that the total of rainfall records at all stations will be assumed similar to the records of any single station for a period equivalent to the sum of periods at all individual stations.

For each of the 20 stations extreme annual rainfall intensity corresponding to durations of 15 min, 30 min, 1 hr, 3 hr and 6 hr were extracted for the available data up to year 1983 and table (1) shows the list of the 20 stations along with number of recorded years for each duration and which were used in the present frequency analysis.

Table (1) Stations and Numbers of Years For Different Durations Used in the Present Study

Station	15 m	30 m	1 hr	3 hr	6 hr	Period
1. Dar Sait	5	5	5	5	3	78-83
2. Nizwa	9	9	9	6	2	74-83
3. Saiq	8	8	7	5	4	76-83
4. Mgafaz	7	7	6	5	3	78-83
5. Mudhaybi	2	2	2	2	1	82-83
6. Ibra	7	6	4	4	2	77-83
7. Wadi Bani Khalib	3	3	2	2	2	80-83
8. Tahwa	2	2	2	2	2	82-83
9. Wafi	6	6	4	3	3	77-83
10. Rumais c.	2	2	2	2	1	82-83
11. Rumais F.	2	3	4	4	2	75-79
12. Rustaq.	10	9	10	5	1	74-83
13. Mazara	2	2	1	1	-	77-78
14. Izki	2	2	2	2	1	82-83
15. Tanam	5	5	4	3	2	77-83
16. Hyal	2	2	2	2	2	82-83
17. Sohar	2	3	2	2	1	77-82
18. Daqiq	2	2	2	2	2	82-83
19. Kitnah	2	2	2	2	1	82-83
20. W. Hayl	2	2	2	1	1	82-83
Sum	82	82	74	60	36	

5. FREQUENCY ANALYSIS OF SHORT DURATION RAINFALL

Several frequency distribution functions are avilable for the prediction of rainfall intensity corresponding to different return periods. In the present study five different frequency distribute functions were tested and it was found that the type I extremal (TIE) and the log Pearson type III (LPT3) were the best functions to fit northern Oman data. This was confirmed by the low value of the standard deviation and by the reasonable estimated rainfall intensity values corresponding to different durations and return periods. The other three functions were the 2 and 3 log normal distribution functions and the Pearson type III. Table (2) shows the estimated rainfall intensity values obtained by the TIE and LPT3 frequency distribution functions for durations from 15 minute up to 6 hours and for return periods between 5 and 100 years. The rainfall intensity values given in table (2) shows that values obtained by the TIE function are larger than those obtained by the LPT3 function for durations up to 1 hour and corresponding to return periods between 25 and 100 years. Meanwhile, both functions gave close values for durations up to 6 hours and corresponding to return period of 5 and 10 years while for durations of 3 and 6 hours correspondiong to return period of 25 to 100 years LPT3 values are slightly higher than TIE values.

Moreover rainfall intensity values given in table (2) were compared with the results given by Wheater and Bell (24) in their analysis for limited data of 11 stations in

Table (2) Rainfall Intensity values estimated by LPT3 and TIE.

T	t	I in mm/hr		$R_{T,t}/R_{10,1\,hr}$ [1]		Bell's [2]
Year	hour	LPT3	TIE	LPT3	TIE	value
5	0.25	77.00	73.60	50.67	47.56	49
5	0.50	51.71	50.88	68.06	65.75	67
5	1.00	30.25	30.43	79.63	78.65	85
5	3.00	11.12	12.01	87.81	93.12	
5	6.00	7.13	7.52	18.77	19.44	
10	0.25	93.05	91.62	61.23	59.20	57
10	0.50	63.79	63.79	83.96	82.44	79
10	1.00	37.99	38.69	100.00	100.00	100
10	3.00	14.72	15.15	116.24	117.47	
10	6.00	9.38	9.47	24.69	24.48	
25	0.25	109.21	114.38	71.87	73.91	67
25	0.50	77.11	80.10	101.49	103.91	93
25	1.00	46.73	49.14	123.01	127.01	118
25	3.00	20.04	19.11	158.25	148.18	
25	6.00	12.59	11.93	33.14	30.83	
50	0.25	118.66	131.27	78.09	84.82	75
50	0.50	85.65	92.20	112.73	119.15	105
50	1.00	52.43	56.89	138.01	147.04	132
50	3.00	24.60	22.05	194.26	170.97	
50	6.00	15.23	13.75	40.09	35.54	
100	0.25	126.30	148.03	83.11	95.65	85
100	0.50	93.12	104.22	122.56	134.69	117
100	1.00	57.49	64.58	151.33	166.92	148
100	3.00	29.68	24.05	234.38	186.48	
100	6.00	18.15	15.56	47.78	40.22	

1. $R_{T,t}/R_{10,1\,hr}$ is the ratio of the T year - t hour rainfall depth to the 10 year - 1 hr rainfall depth estimated by the present study.

2. Same as 1 above, but given by Bell (3).

northern Oman for the period 1973-1978 by applying the TIE frequency distribution function. The comparison revealed that for durations up to 3 hours and return periods up to 100 years the present study values predicted by the TIE function are higher by an average value of 8.04 %. Such deviations are expected since the present study utilized more than double the data which was available for Wheater and Bell. Furthermore ratios of the T year - t minute rainfall to the 10 year - one hour rainfall were determined for the results obtained by both LPT3 and TIE functions. Values of these ratios are listed in table (2) along with ratios given by Bell (3) and which were claimed to be applicable to diverse places around the world. It is clear from results shown in table (2) that ratios developed by both functions LPT3 and TIE for northern Oman data gave close values to those given by Bell. However LPT3 ratios are closer to Bell's values than TIE values as the average percentage difference between LPT3 and Bell's values is only 4.73 %.

6.RAINFALL INTENESITY - DURATION - FREQUENCY EQUATION

The present study adopts the general form of equation (1) to represent the required RIDF relationship for northern Oman. Values of a and b were determined for each of the 5 return periods ranging from 5 to 100 years and which fitted the rainfall intensity values listed in table (2). In the obtained 5 equations rainfall intensity I is expressed in mm/hr and duration t in hours and each equation is only valid for the specified return period and for duration up to 3 hours. The estimated values of a and b are given in table (3) along with the standard error of estimate (SES) of each equation, max percentage error (MPE) and the average percentage error (APE) in estimating rainfall intensity I by the obtained best fit equation.

Table (3) Values of a and b for different return periods along with statistical analysis.

T year	a	b	SES	MPE %	APE %
5 LPT3 :	36.825	0.227	0.570	2.62	1.43
TIE :	39.467	0.285	0.344	- 1.19	0.60
10 LPT3 :	48.470	0.270	0.441	1.32	0.66
LIE :	50.375	0.299	0.385	- 1.16	0.58
25 LPT3 :	64.862	0.343	0.854	3.35	1.73
TIE :	64.138	0.310	0.492	1.40	0.76
50 LPT3 :	78.580	0.412	1.810	6.36	3.29
TIE :	74.300	0.315	0.593	1.65	0.91
100 LPT3 :	93.740	0.493	3.074	9.58	5.07
TIE :	86.602	0.307	1.256	3.86	1.99

Furthermore, both coefficients a and b were successfuly correlated to the return period T in years and the following are the best fitting equations which are applicable for return periods ranging from 5 to 100 years: for values fitted by the LPT3:

$$a = 23.16300 * T^{0.309844} \qquad (8)$$

(SES =1.721, CR=0.996, MPE=3.57 %, APE=2.56 %)

$$b = 0.148984 * T^{0.259676} \qquad (9)$$

(SES=2.420, CR=0.988, MPE=4.69 %, APE=3.64 %)

for values fitted by the TIE:

$$a = 27.79850 * T^{0.246243} \qquad (10)$$

(SES=0.000, CR=1.000, MPE=0.34 %, APE=0.21 %)

$$b = 0.278542 * T^{0.02691} \qquad (11)$$

(SES=0.006, CR=0.820, MPE=2.70 %, APE=1.89 %)

in which : SES is the standard error of estimate, CR is the correlation coefficient, MPE is the maximum percentage error and APE is the average percentage error of values obtained by equation.

Substituting equations (8) and (9) into equation (1) the following RIDF relationship is obtained based on data produced by the LPT3 distribution:

$$I=23.163 * T^{0.309844}/(t + 0.148984*T^{0.259676}) \qquad (12)$$

(SES = 2.654 mm/hr, MPE = 12.45 %, APE = 3.90 %)

Similarly substituting equations (10) and (11) into equation (1) the following RIDF relationship is obtained based on data produced by the TIE distribution:

$$I = 27.7985 * T^{0.246243} / (t+ 0.278542 * T^{0.02691}) \qquad (13)$$

(SES=2.137 mm/hr, MPE = 8.36 % , APE = 3.056 %)

in which I is the average rainfall intensity in mm/hr over duration t hours and corresponding to return period T years.

Both equations (12) and (13) are valid for durations up to 3 hours and return period up to 100 years. The low values of the SES and of the APE reflects the high accuracy of both equations.

It was found that for return period of 5 years, equation (12) will give rainfall intensity values slightly higher than values given by both LPT3 and TIE listed in table (2), while for return period of 10 years both equations (12) and (13) will estimate almost identical values. Moreover for return period between 25 and 100 years equation (13) predicts values slightly higher than those given by equation (12). Therefore, for design purposes the present study recommends the use of equation (12) for return periods up to 10 years while equation (13) to be applied for larger return periods up to 100 years.
Figure (1) and (2) show the plots of equations (12) and (13) respectively.

7. CONCLUSIONS

Based on the analysis of the available short duration rainfall data measured at 20 stations located in northern Oman and which have been extended by the application of the station year concept the following principal conclusions may be listed:

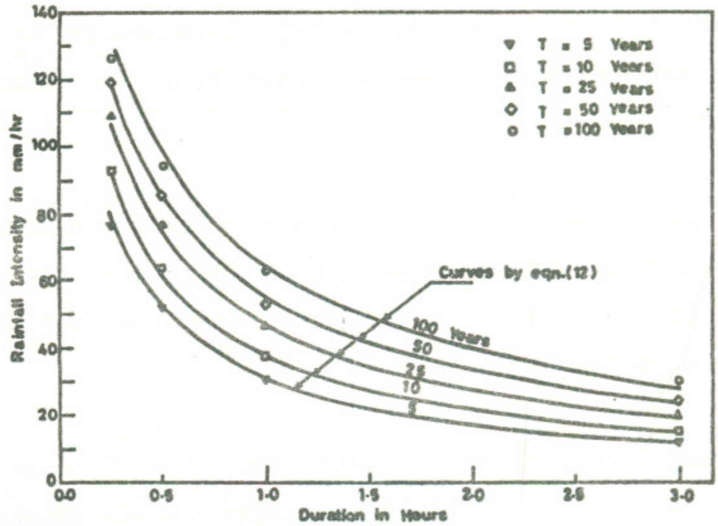

Fig.(1) Rainfall Intensity - Duration - Frequency Relationship For Northern Oman Obtained By The L P T 3 Function.

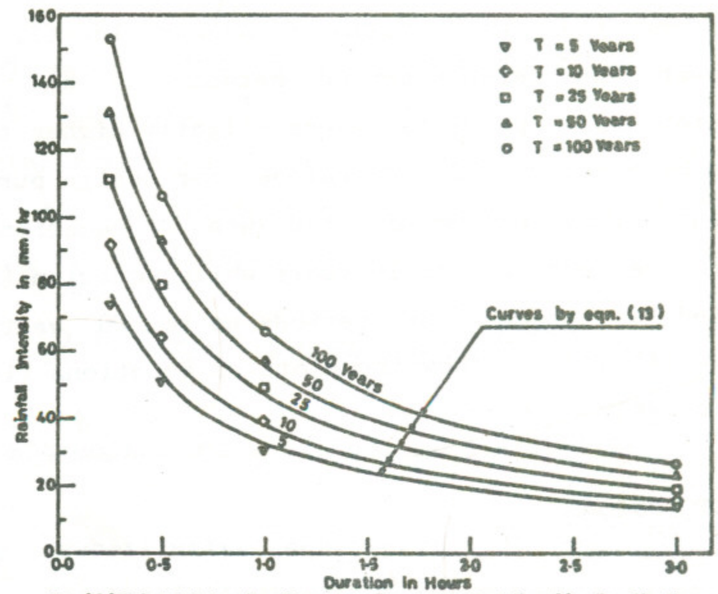

Fig.(2) Rainfall Intensity - Duration - Frequency Relationship For Northern Oman Obtained By The T 1 E Function.

1. The log Pearson type III and the type I extremal frequency distribution functions were the best among other 3 functions to fit the extended short duration rainfall data of northern Oman. Rainfall intensity values were given for five durations ranging from 15 minutes up to 6 hours and corresponding to return period ranging from 5 to 100 years.
2. Ratios of the T year - t minute rainfall depth to 10 year - 1 hour rainfall depth obtained by LPT3 function is in close agreement with ratios given by Bell and which are applicable to several diverse places around the world.
3. Accurate equations were developed to estimate design rainfall intensity corresponding to durations up to 3 hours and return period up to 100 years.

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NOTATIONS

APE = average percentage error

f = frequency of occurence

I = average rainfall intensity

LPT3 = log Pearson type 3 frequency distribution function

MPE = maximum percentage error

RIDF = rainfall intensity - duration - frequency

SES = standard error of estimate

T = return period

T1E = type 1 extremal frequency distribution function

t = duration

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