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RAINFALL INTENSITY VARIATION FOR OBSERVED DATA AND DERIVED DATA - A CASE STUDY OF IMPHAL

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ABSTRACT

For estimation of runoff especially for urban areas short duration rainfalls are necessary. However especially in developing countries like India availability of short duration rainfalls is scarce and data available is mostly for daily rainfall data. In such cases determination of design rainfall is becoming an approximation and thus leading to frequent failure of drainage network and subsequent floods. In the absence of short duration rainfall data[1], data is generated for short durations like 1hr, 2hr, 3-hr, 6-hr and 12-hr rainfall values were obtained using an Indian Meteorological Department (IMD) empirical reduction formula is used in the absence of observed data (t-hour rainfall). Frequency analysis was then carried out to establish Intensity-Duration-Frequency (IDF) relationships. In the present study an attempt has made to find the difference of intensity of rainfalls obtained from observed data and derived data by taking Imphal rainfall data which is available for 15 min time interval.

Keywords: intensity duration frequency (IDF), gumbels EVD, location (μ) and scale (α) parameters.

INTRODUCTION

Flooding in the cities and the towns is a recent phenomenon caused by increasing incidence of heavy rainfall in a short period of time, indiscriminate encroachment of waterways, inadequate capacity of drains and lack of maintenance of the drainage infrastructure. Flooding in general and urban flooding in particular is not a un- known event in world and in India. The annual disasters from urban flooding are now much greater than the annual economic losses due to other disasters. This demanding re consideration of design of drainage system which in turn requires intensity of rainfall calculated depending upon short duration of rainfall.

Objective of the study

To check the deviation in estimation of rainfall intensity for different time of concentration (t_c) calculated depending upon observed short duration of rainfall and derived short duration of rainfall.

Details of study area

Imphal is the capital of Manipur state in India, located at 24°49′N 93°57′E/ 24.82°N 93.95°E. It has an average elevation of 786 metres (2578 feet). It is located in the extreme east of India. Imphal has a sub-tropical climate, a warm summer and a moderate monsoon season. July is the hottest month with temperatures averaging around 25°C (78°F), while January is the coldest with average lows near 4°C (40°F). The city gets about 1320 mm (52 inches) of rain with June being the wettest month. The soil in Imphal is mainly made up of alluvial soils of recent origin.

Rainfall data

For the purpose of storm water designs analysis, 15 min duration rainfall data for period 1986 to 2009 was collected from India Meteorological Department, Guwahati Regional Meteorological Centre. Rainfall intensity is ranging from 5 mm/hr to 90 mm /hr and for the durations of 7.5 min to 180 min.

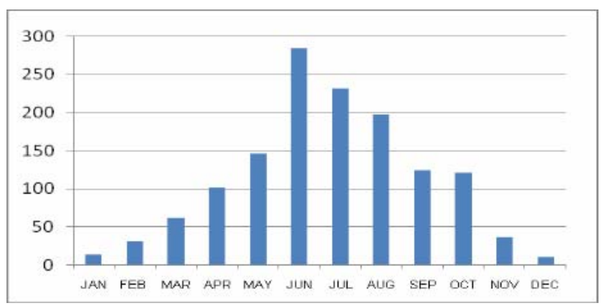

Figure-1

METHODOLOGY

Firstly rainfall data obtained for 15 min interval from IMD has analyzed by using CPHEEO method by considering 15min rainfall data first and then considering daily rainfall data for 1yr return period, 2yr return period and 5yr return period by using following methods:

- Analysis of rainfall data as prescribed by CPHEEO manual
- By using Gumbels extreme value distribution[2]

Results obtained are plotted and analyzed for variation.

a) Rainfall intensities of different durations ranging from 7.5min to 180 mins are derived from rainfall mass curves of Imphal IMD.

b) From daily maximum rainfall data, rainfall intensities of various durations are arrived at by using IMD reduction formula.

c) Frequency duration, intensity curves [3] area prepared by using CPHEEO method and Gumbels extreme value method and these results are compared the actual data for 1 hr rainfall.

Table-1. Analysis of 15 min rainfall data as prescribed in CPHEEO manual.

Frequency of storm for Imphal Rain Gauge Station															
Duration (in mins)	**Intensity** (mm/Hr)														
	<5	**5+**	**10+**	**15+**	**20+**	**25+**	**30+**	**35+**	**40+**	**45+**	**50+**	**55+**	**60+**	**75+**	**90+**
7.5	429	96	62	22	23	20	14	3	7	0	4	1	5	1	1
15	586	167	62	51	30	16	10	2	5	1	4	3	1	1	0
22.5	126	30	14	8	5	3	1	0	1	0	1	0	0	0	0
30	474	119	47	17	18	10	5	4	0	1	1	1	3	0	0
45	342	88	33	20	7	3	2	3	0	0	0	0	0	0	0
60	346	63	35	6	9	1	3	0	0	0	0	0	0	0	0
75	226	46	24	3	2	2	0	1	0	0	0	0	0	0	0
90	170	42	10	5	2	1	0	1	0	1	0	0	0	0	0
105	157	26	9	2	2	0	0	0	0	0	0	0	0	0	0
120	143	31	2	3	2	0	0	0	0	0	0	0	0	0	0
150	173	45	4	3	1	0	0	0	0	0	0	0	0	0	0
180	171	29	10	1	1	1	0	0	0	0	0	0	0	0	0
240	209	31	7	3	0	0	0	0	0	0	0	0	0	0	0
300	107	18	0	1	0	0	0	0	0	0	0	0	0	0	0
360	83	13	2	0	1	0	0	0	0	0	0	0	0	0	0
420	45	6	1	0	0	0	0	0	0	0	0	0	0	0	0
480	42	8	0	0	0	0	0	0	0	0	0	0	0	0	0
540	25	5	0	0	0	0	0	0	0	0	0	0	0	0	0
600	21	4	0	0	0	0	0	0	0	0	0	0	0	0	0
660	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0
720	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 720	40	2	0	0	0	0	0	0	0	0	0	0	0	0	0

Table-2. Analysis of frequency of storm for 1 year return period for Imphal Raingauge station (with 24 years data).

Duration		**Intensity** (mm/Hr)															i
In Mins	**In Hrs.**	**<=5**	**>5**	**> 10**	**> 15**	**> 20**	**> 25**	**> 30**	**> 35**	**> 40**	**> 45**	**> 50**	**> 55**	**> 60**	**> 75**	**> 90**	
7.5	0.13	5540	1495	645	385	235	145	80	55	37	30	23	16	8	3	1	**49.29**
15	0.25	4852	1236	509	284	161	89	54	33	19	18	13	8	2	1		**38.21**
22.5	0.38	3913	930	340	168	94	49	28	17	8	8	6	4				**31.82**
30	0.50	3724	867	309	149	83	43	25	15	7	7	5	4				**30.28**
45	0.75	3024	661	314	93	46	18	10	6	1	1						**23.93**
60	1.00	2526	513	154	59	31	11	5	3	1	1						**21.75**
75	1.25	2063	404	108	40	18	7	3	3	1	1						**18.64**
90	1.50	1755	323	75	31	13	4	2	2	1	1						**16.94**
105	1.75	1523	266	55	21	8	1										**14.56**
120	2.00	1327	227	42	17	6	1										**13.60**
150	2.50	1146	193	35	12	4	1										**12.39**
180	3.00	920	143	28	8	3	1										**10.17**
240	4.00	707	101	15	5	1											**9.48**
300	5.00	457	61	5	2	1											**8.30**
360	6.00	331	44	4	1	1											**7.50**
420	7.00	232	28	1													**5.74**
480	8.00	180	21														**4.91**
540	9.00	130	13														**4.53**
600	10.00	100	9														**4.18**
660	11.00	75	5														**3.64**
720	12.00	53	2														**2.84**
>720	> 12.00	42	2														**2.25**

In the similar way analysis of frequency of storm for 2 year return period and 5 year return period for Imphal Rain gauge station was carried out and the results for 1yr, 2yr and 5yr return periods are as follows;

SUMMARY OF RESULTS BY CPHEEO METHOD

The values of 't' (duration in minutes) and 'i' the (Intensity) for the return periods of 6 months, One year and 2 years are plotted from the available data and the values of the Intensities (i) can be determined for any given time of concentration, (t_c).

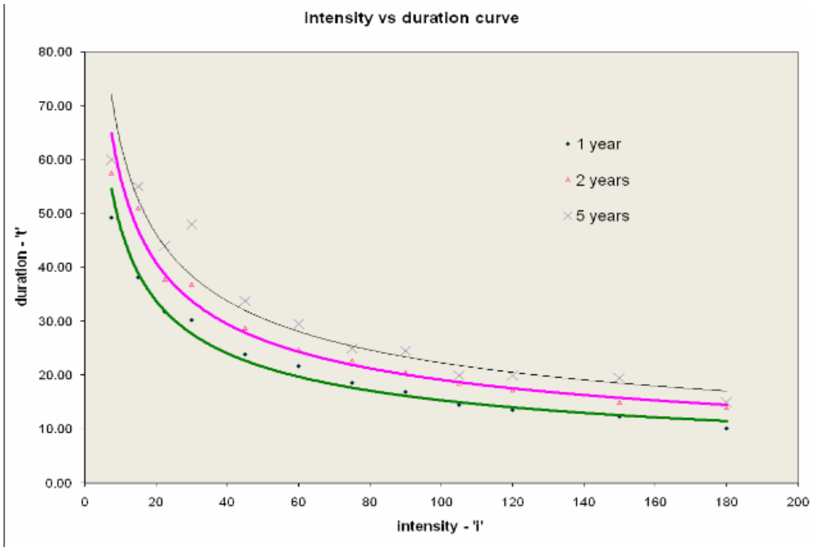

Figure-2. Intesity Duration Curve

Table-3. Design Intensity for Different durations by CPHEEO Method

Duration in minutes	intensity in mm/hr		
	1Yr	2 Yrs	5 Yrs
7.5	49.29	57.50	60.00
15	38.21	51.00	55.00
22.5	31.82	37.78	44.00
30	30.28	36.88	48.00
45	23.93	28.75	33.80
60	21.75	24.75	29.50
75	18.64	22.73	25.00
90	16.94	20.56	24.56
105	14.56	18.46	20.00
120	13.60	17.27	20.00
150	12.39	15.00	19.50
180	10.17	14.00	15.00
240	9.48	11.50	15.00
300	8.30	9.38	10.00
360	7.50	9.00	9.90

FREQUENCY ANALYSIS CONSIDERING MAXIMUM DAILY RAINFALL DATA

The rainfall data for Imphal consists of the daily rainfall values from 1986 to 2009. The data is processed in order to obtain the yearly peak daily rainfall[4]. The resulting extreme value series is shown in Table-4.

Table-4. Extreme value Series data

S. No.	Year	Maximum daily precipitation during year in 'mm'
1	1986	80.7
2	1987	73.6
3	1988	72.0
4	1989	158.6
5	1990	55.8
6	1991	99.2
7	1992	58.4
8	1993	79.8
9	1994	69.4
10	1995	90.6
11	1996	68.8
12	1997	79.6
13	1998	73.3
14	1999	61.7
15	2000	54.4
16	2001	67.8
17	2002	106.3
18	2003	137.6
19	2004	105.9
20	2005	104.4
21	2006	41.0
22	2007	66.5
23	2008	50.0
24	2009	36.0

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Generation of shorter duration rainfall data

The extreme value series presented in table (1) is used to generate shorter duration series (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, hour series) by employing the IMD formula given as:

$$P_t = P_{24} (t / 24)^{1/3} \quad (1)$$

Where

P_t = Rainfall of t hours duration in mm
P_{24} = Daily Rainfall value in mm
t = Shorter duration in hours (1, 2, 3…)

Equation (1) is used to generate the extreme value series of duration 1 to 12 hours in steps of 1 hour. The resulting series are presented in Table-5.

Table-5. Derived shorter duration rainfalls from Maxm daily rainfall value using IMD 1/3rd rule

Year	P1hr	P2hr	P3hr	P4hr	P5hr	P6hr	P7hr	P8hr	P9hr	P10hr	P11hr	P12hr
1986	28.28	35.54	40.63	44.68	48.09	51.07	53.74	56.16	58.39	60.45	62.38	64.20
1987	25.79	32.42	37.06	40.75	43.86	46.58	49.01	51.22	53.25	55.13	56.89	58.55
1988	25.23	31.71	36.25	39.86	42.91	45.57	47.95	50.11	52.09	53.93	55.66	57.28
1989	55.57	69.85	79.85	87.80	94.51	100.37	105.61	110.37	114.74	118.80	122.60	126.17
1990	19.55	24.58	28.09	30.89	33.25	35.31	37.16	38.83	40.37	41.80	43.13	44.39
1991	34.76	43.69	49.94	54.92	59.12	62.78	66.06	69.03	71.77	74.31	76.68	78.92
1992	20.46	25.72	29.40	32.33	34.80	36.96	38.89	40.64	42.25	43.75	45.14	46.46
1993	27.96	35.15	40.18	44.18	47.55	50.50	53.14	55.53	57.73	59.78	61.69	63.48
1994	24.32	30.57	34.94	38.42	41.36	43.92	46.21	48.30	50.21	51.99	53.65	55.21
1995	31.74	39.90	45.62	50.16	53.99	57.34	60.33	63.05	65.55	67.87	70.04	72.08
1996	24.11	30.30	34.64	38.09	41.00	43.54	45.81	47.88	49.78	51.54	53.18	54.73
1997	27.89	35.06	40.08	44.07	47.44	50.38	53.01	55.39	57.59	59.63	61.53	63.32
1998	25.68	32.28	36.90	40.58	43.68	46.39	48.81	51.01	53.03	54.91	56.66	58.31
1999	21.62	27.17	31.06	34.16	36.77	39.05	41.09	42.94	44.64	46.22	47.70	49.08
2000	19.06	23.96	27.39	30.12	32.42	34.43	36.23	37.86	39.36	40.75	42.05	43.28
2001	23.76	29.86	34.14	37.54	40.40	42.91	45.15	47.18	49.05	50.79	52.41	53.94
2002	37.24	46.82	53.52	58.85	63.35	67.27	70.79	73.97	76.91	79.63	82.17	84.57
2003	48.21	60.60	69.28	76.18	82.00	87.08	91.63	95.76	99.55	103.07	106.37	109.47
2004	37.10	46.64	53.32	58.63	63.11	67.02	70.52	73.70	76.62	79.33	81.86	84.25
2005	36.58	45.98	52.56	57.80	62.21	66.07	69.52	72.65	75.53	78.20	80.70	83.05
2006	14.37	18.06	20.64	22.70	24.43	25.95	27.30	28.53	29.66	30.71	31.69	32.62
2007	23.30	29.29	33.48	36.82	39.63	42.09	44.28	46.28	48.11	49.81	51.41	52.90
2008	17.52	22.02	25.17	27.68	29.80	31.64	33.30	34.80	36.17	37.45	38.65	39.78
2009	12.61	15.86	18.13	19.93	21.45	22.78	23.97	25.05	26.05	26.97	27.83	28.64

The two most popular extreme value distributions[5] for rainfall and runoff data are:

(i) Gumbel's Extreme Value Distribution
(ii) Log Pearson Type III Distribution
(iii) I present case Gumbel's Extreme Value Distribution is used for analysis of the rainfall data.

As a first step, each of the series presented in Table-2 is arranged in descending order and ranked from 1 to 20. The plotting position is calculated using the Gringorten formula given by:

$$F_i = \frac{i - 0.44}{N + 0.12} \quad (2)$$

The reduced variate 'y' of Gumbel's distribution is given by:

$$y_i = -\ln(-\ln(F_i)) \quad (3)$$

The Location (μ) and Scale (α) parameters of the Gumbel's distribution are given by the following equations:

$$\mu = \sigma - 0.5772\alpha \tag{4}$$

Table-6. Location and Scale parameters for different duration of pptns

Duration of Pptn	Mean of Pptn	Standard Deviation *s*	α	μ
1Hr	27.61	10.0754	7.8558	23.0779
2Hr	34.71	12.6649	9.8748	29.0092
3Hr	39.68	14.4782	11.2886	33.1624
4Hr	43.63	15.9200	12.4198	36.4650
5Hr	46.96	17.1366	13.3613	39.2515
6Hr	49.88	18.1992	14.1899	41.6856
7Hr	52.48	19.1490	14.9304	43.8610
8Hr	54.84	20.0117	15.6030	45.8370
9Hr	57.02	20.8048	16.2214	47.6537
10Hr	59.03	21.5409	16.7954	49.3397
11Hr	60.92	22.2292	17.3320	50.9162
12Hr	62.69	22.8767	17.8369	52.3994

$$\alpha = \frac{\sqrt{6}}{\pi} s \tag{5}$$

Where σ is the mean value of the original series and s its standard deviation.
Following table presents the above 4 parameters for the series given in above table.

The predicted rainfall[6] using Gumbel's distribution is given by:

$$P_i = \mu - \alpha Y_i \tag{6}$$

DERIVATION OF IDF CURVES

The rainfall (P_T) corresponding to a specific return period (T) using the Gumbel's extreme value distribution is given by:

$$P_T = \sigma + k_r s \tag{7}$$

Where k_r is the frequency factor given by:

$$K_r = -\frac{\sqrt{6}}{\pi}\left(0.5882 + \ln\left(-\ln\left(1 - \frac{1}{T_r}\right)\right)\right) \tag{8}$$

In order to develop the IDF curves[7] corresponding to return periods of 1, 2, and 5 years, the frequency factors are computed using Equation (8) are -0.45026926, -0.16435536, 0.71982234, respectively.

The above values of frequency factor are used in Equation (7) in order to obtain P_T corresponding to return periods of 1, 2 and 5 years for durations of 1 to 12 Hours.

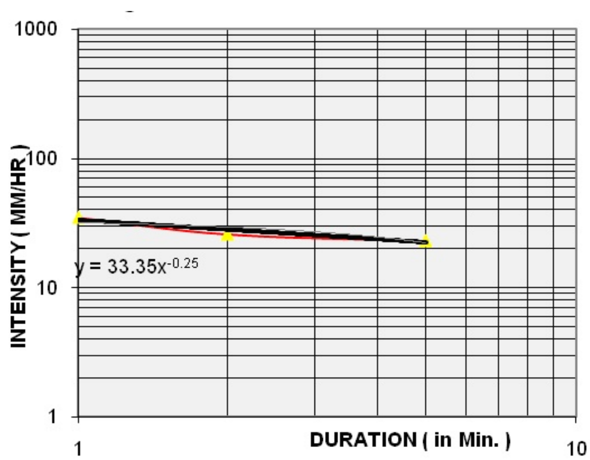

Figure-3. Values of 'a' and 'T' for storm rainfall (log log sheet).

The relation between Intensity, Frequency and Duration is given by:

$$I = \frac{CT^m}{t^n} = \frac{a}{t^n} \tag{9}$$

I = Intensity in mm /hr
T = Frequency of occurrence in year
t = Duration of the storm in 'Hr'.

Table-7. Design Intensity for Different durations by Gumbels Extreme Value Distribution

Duration in "Hrs"	Intensity in "mm/hr"		
	1-Year Frequency	2-Year Frequency	5-Year Frequency
1	23.08	25.96	34.9
2	14.50	16.31	21.9
3	11.05	12.43	16.7
4	9.12	10.25	13.8
5	7.85	8.83	11.9
6	6.95	7.81	10.5
7	6.27	7.05	9.5
8	5.73	6.44	8.7
9	5.29	5.96	8.0
10	4.93	5.55	7.5
11	4.63	5.21	7.0
12	4.37	4.91	6.6

C, m and n are regional coefficient to be determined from the given data.

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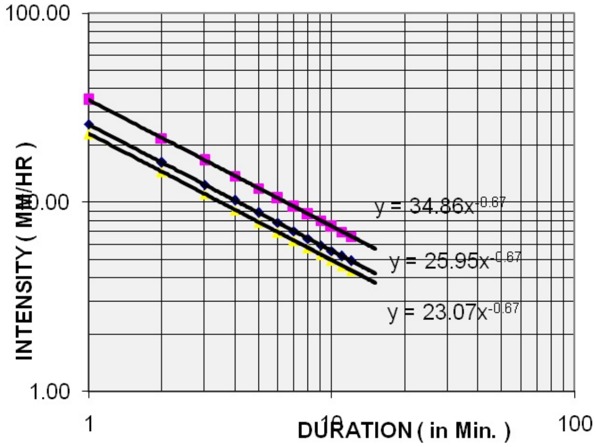

Figure-4. Intensity duration of rain storm (log log sheet).

Determination of Constants ‘a’ and ‘n’

In order to determine the constants ‘a’ and ‘n’ of Equation (9), a log-log graph is plotted as shown in Figure-2. The data for the graph is taken from table.

From the Graph, n = 0.67 and values of a = 34.86, 25.95, 23.07 for 1-year, 2-year and 5-year recurrence intervals. To obtain the values of C and m, derived values of 'a' are plotted on log-log Scale[8] against corresponding recurrence intervals.

The constants ‘c’ and ‘m’ of Equation (9) are determined by plotting the data of Return Period Vs. ‘a’. The resulting graph is shown in Figure 5.

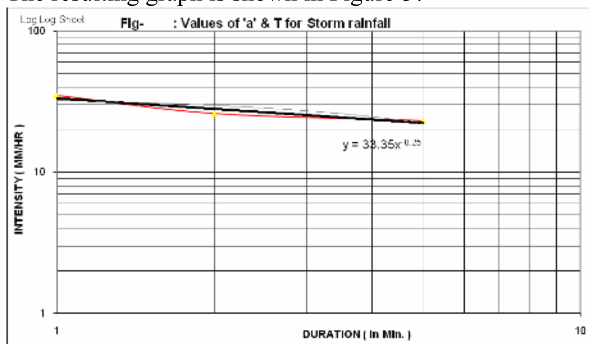

Figure-5. Determination of “a” and “n” from Graph

Values obtained are a = 33.5 and n = 0.25

The final IDF curve equation is obtained as:

$$I = \frac{33.5\ T^{0.25}}{t^{0.67}} \tag{10}$$

Equation (10) is employed to generate the Intensity-Duration-Frequency Data.

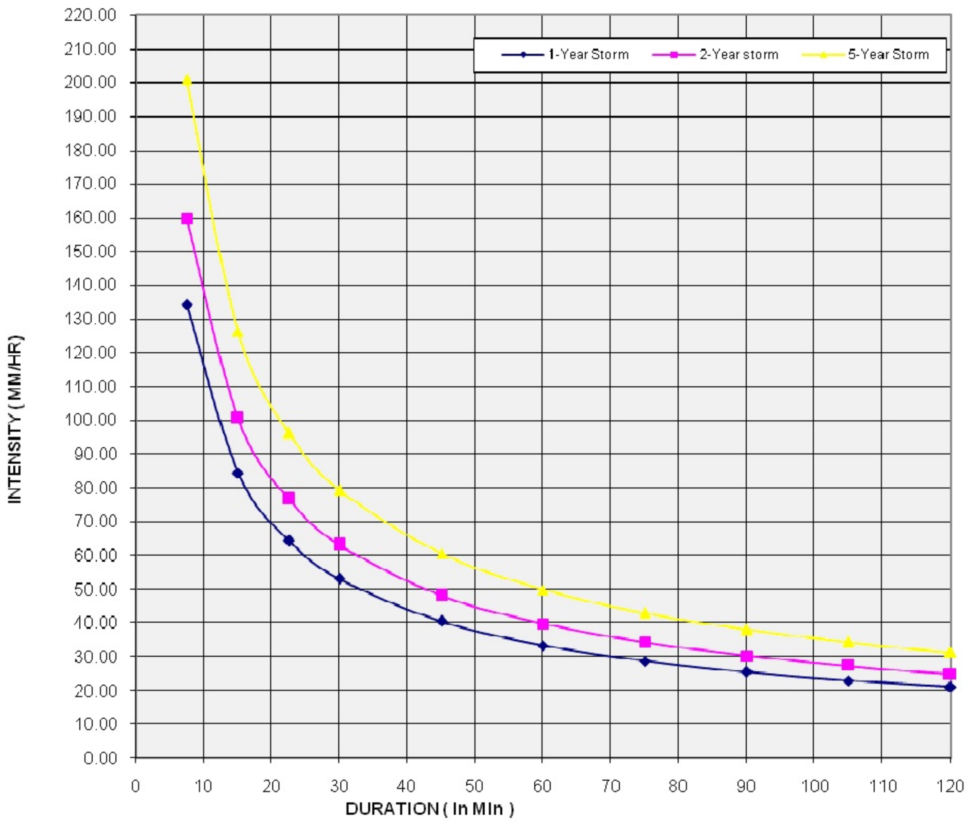

Figure-5. IDF curves for IMPHAL.

Table-8. Comparison of results of CPHEEO and Gumbel's EVD method

Duration in minutes	intensity in mm/hr CPHEEO method			intensity in mm/hr Gumbels EVD		
	1 year	2 years	5 years	1 year	2 years	5 Years
7.5	49.29	57.50	60.00	134.33	159.74	200.87
15	38.21	51.00	55.00	84.43	100.40	126.25
22.5	31.82	37.78	44.00	64.34	76.52	96.21
30	30.28	36.88	48.00	53.06	63.10	79.35
45	23.93	28.75	33.80	40.44	48.09	60.47
60	21.75	24.75	29.50	33.35	39.66	49.87
75	18.64	22.73	25.00	28.72	34.15	42.94
90	16.94	20.56	24.56	25.42	30.23	38.01
105	14.56	18.46	20.00	22.92	27.26	34.28
120	13.60	17.27	20.00	20.96	24.93	31.34
150	12.39	15.00	19.50	18.05	21.47	26.99
180	10.17	14.00	15.00	15.97	19.00	23.89
240	9.48	11.50	15.00	14.41	17.13	21.54
300	8.30	9.38	10.00	13.17	15.67	19.70
360	7.50	9.00	9.90	11.34	13.49	16.96

DISCUSSION ON RESULTS

a) Intensity of rainfall derived by two methods giving large variation in estimation of rainfall for various durations.
b) CPHEEO method gives closer results when comparative to actual intensities
c) As many cities and towns don't have automatic recording gauges it becomes difficult to estimate rainfall intensity up to 60 minutes by CPHEEO method.
d) It becomes imperative to install automatic raingauges for every town
e) In the absence of data Gumbels extreme value method can be used as it gives higher intensities for shorter durations which provide more factor of safety.
f) There is a need to evolve a realistic method which can strengthen existing methods or give realistic values in estimation of urban runoff.

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