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Generation of Rainfall Intensity-Duration-Frequency Relationship for Rangpur City Corporation in Bangladesh

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Abstract: *The objective of this study is to generate Rainfall IDF relationship for Rangpur City Corporation of Bangladesh. The common frequency analysis technique Gumbel distribution was used to develop IDF relationship from rainfall data of this city corporation. Yearly daily maximum rainfall data for 55 years (1955-2010) from Bangladesh Meteorological Department (BMD) was used in this study. Indian Meteorological Department (IMD) empirical reduction formula was used to estimate short duration rainfall intensity from yearly maximum rainfall data. The parameters of the IDF equation and constants for different return periods (2, 5, 10, 15, 20, 25, 30, 50, 75 and 100 years) were calculated by using nonlinear regression method. The results obtained presented that in all the cases the correlation coefficient is very high (R^2=1) representing goodness of fit of the equation to estimate IDF curves of Rangpur City Corporation. It was found that intensity of rainfall decreases with increase in rainfall duration. Further, a rainfall of any given duration will have a larger intensity if its return period is large.*

Keyword:*Rainfall Intensity, Rainfall Duration, Rainfall Frequency, Gumbel's Extreme Value Distribution Method*

I. Introduction

Due to rapid urbanization and increase in population, urban regions of Bangladesh require immediate improvement of drainage systems. Realizing the importance of this issue, the Government of Bangladesh (GOB) has emphasized on this matter; and has already taken initiative to develop or improve the drainage system of the Township/Municipal areas/City Corporations. In this regard, under Feasibility Study and Master Plan Review (FSMP) project, Rangpur City Corporation has been identified for drainage improvement studies. At present the Rangpur City is rapidly urbanizing. Due to this rapid urbanization, the drainage problem could be a big issue in the future. For improving drainage system of Rangpur City Corporation hydrological analysis was necessary for hydraulic design of the drainage system.

The rainfall Intensity Duration-Frequency (IDF) relationship in one of the most important tools in water resource engineering to assess the risk and vulnerability of water resource structure as well as for planning, design and operation. The establishment of such relationship was done as early as 1932[1, 2]. The Rainfall intensity-duration-frequency (IDF) curves are graphical exemplifications of the amount of water that falls within a given period of time in catchment areas [1]. It is a mathematical relationship between the rainfall intensity I, the duration t, and the return period T [4, 3]. In the present study a rainfall Intensity Duration-Frequency (IDF) curve has been developed for the Rangpur City Corporation.

II. Study Area

Rangpur is one of the newly established City Corporations of the country. It is the second largest city of the northern region of the country. Apart from the status of a city corporation it is the administrative headquarters of Rangpur divisionand an important regional centre for education, medicine and commerce. The total area of Rangpur City corporation is about 204 sq km. It is situated on the bank of the river Ghagot- a moribund tributary of the river Teesta. The Rangpur City Corporation is located 335km north-west of the capital city Dhaka. The man-made canal Shyamasundari passes over the city starting from Ghagot river and falls into Khoksha-Ghagot river. At present this man-made canal is the main drainage system of the city area. Figure 1 show the location Rangpur City Corporation.

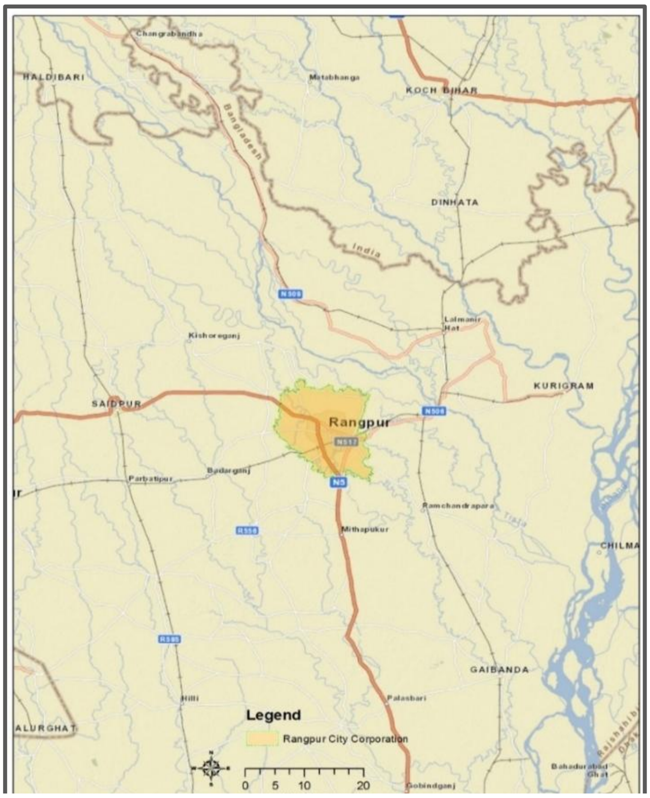

Figure 1: Location of Study Area (Rangpur City Corporation)

III. Data Collection and Methodology

For this study 24 hr daily rainfall data from year 1955 to 2010 was collected from Bangladesh Meteorological Department (BMD) for Rangpur City Corporation. From the daily data maximum yearly rainfall data was used in the analysis. The observed maximum daily rainfall in each year is shown in Figure 2.

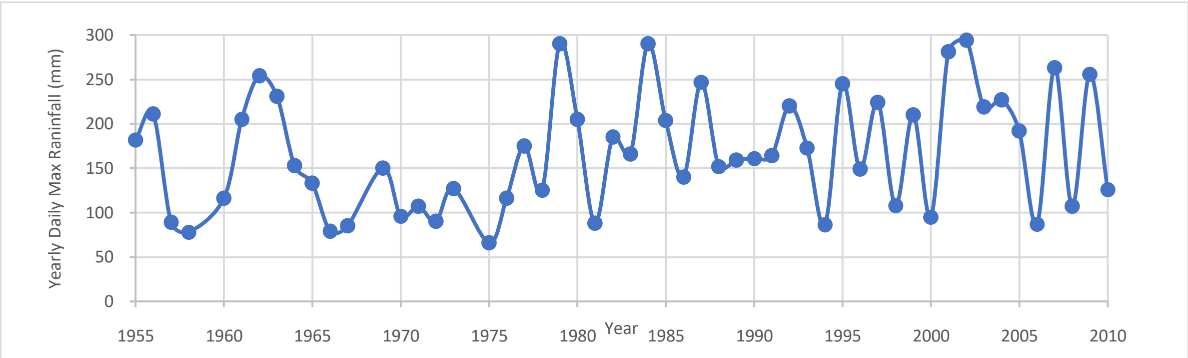

Figure 2: Maximum daily rainfall in each year

III.1 Estimation of Short Duration Rainfall

Indian Meteorological Department (IMD) use an empirical reduction equation (1) for estimation of various duration like 5min, 10min, 15min, 20min, rainfall values from annual maximum values. This equation was found to be given the best estimation of short duration rainfall [5]. In this study this empirical equation (1) was used to estimate short duration rainfall of Rangpur City Corporation. Calculated precipitation are given in Table 1.

$P_t = P_{24}\,(t/24)$ ^1/3……………………………………………………….(1)

Where, P_t is the required rainfall depth in mm at t-hr duration, P_{24} is the maximum daily rainfall in mm.

Table 1: Precipitation calculated by equation (1)

No. Yr	Year	Max Daily Rainfall (mm) in each year (P_{24})	Rainfall Precipitation $P_t = P_{24} (t/24)^{1/3}$						
			Hour						
			0.083	0.166	0.333	0.5	0.66	0.833	1
1	1955	182	27.523	34.677	43.734	50.079	54.935	59.368	63.096
2	1956	211	31.908	40.202	50.702	58.059	63.688	68.827	73.150
3	1957	89	13.459	16.957	21.386	24.489	26.864	29.031	30.855
4	1958	78	11.796	14.861	18.743	21.463	23.544	25.443	27.041
5	1960	116	17.542	22.102	27.874	31.919	35.014	37.839	40.215
6	1961	205	31.001	39.059	49.260	56.408	61.877	66.870	71.070
7	1962	254	38.411	48.395	61.035	69.891	76.667	82.854	88.057
8	1963	231	34.933	44.013	55.508	63.562	69.725	75.351	80.083
9	1964	153	23.137	29.151	36.765	42.100	46.182	49.908	53.042
10	1965	133	20.113	25.341	31.959	36.596	40.145	43.384	46.109
11	1966	79	11.947	15.052	18.983	21.738	23.845	25.769	27.388
12	1967	85	12.854	16.195	20.425	23.389	25.656	27.727	29.468
13	1969	150	22.684	28.580	36.044	41.274	45.276	48.929	52.002
14	1970	96	14.518	18.291	23.068	26.415	28.977	31.315	33.281
15	1971	107	16.181	20.387	25.712	29.442	32.297	34.903	37.095
16	1972	90	13.610	17.148	21.627	24.764	27.166	29.358	31.201
17	1973	127	19.206	24.197	30.517	34.945	38.334	41.427	44.028
18	1975	66	9.981	12.575	15.859	18.161	19.921	21.529	22.881
19	1976	116	17.542	22.102	27.874	31.919	35.014	37.839	40.215
20	1977	175	26.464	33.343	42.052	48.153	52.822	57.084	60.669
21	1978	125	18.903	23.816	30.037	34.395	37.730	40.774	43.335
22	1979	290	43.855	55.254	69.685	79.797	87.534	94.597	100.537
23	1980	205	31.001	39.059	49.260	56.408	61.877	66.870	71.070
24	1981	88	13.308	16.767	21.146	24.214	26.562	28.705	30.508
25	1982	185	27.977	35.248	44.455	50.905	55.840	60.346	64.136
26	1983	166	25.103	31.628	39.889	45.677	50.106	54.148	57.549
27	1984	290	43.855	55.254	69.685	79.797	87.534	94.597	100.537
28	1985	204	30.850	38.868	49.020	56.133	61.575	66.544	70.723
29	1986	140	21.171	26.674	33.641	38.522	42.258	45.667	48.535
30	1987	247	37.352	47.061	59.353	67.965	74.555	80.570	85.630
31	1988	152	22.986	28.961	36.525	41.824	45.880	49.582	52.695
32	1989	159	24.045	30.294	38.207	43.751	47.993	51.865	55.122
33	1990	161	24.347	30.675	38.687	44.301	48.596	52.517	55.816
34	1991	164	24.801	31.247	39.408	45.126	49.502	53.496	56.856
35	1992	220	33.269	41.917	52.865	60.535	66.405	71.763	76.270
36	1993	173	26.162	32.962	41.571	47.603	52.218	56.432	59.976
37	1994	86	13.005	16.386	20.665	23.664	25.958	28.053	29.815

Continuation of Table 1

No. Yr	Year	Max Daily Rainfall (mm) in each year (P_{24})	Rainfall Precipitation $P_t = P_{24}$ (t/24) ^1/3						
			Hour						
			0.083	0.166	0.333	0.5	0.66	0.833	1
38	1995	245	37.050	46.680	58.872	67.414	73.951	79.918	84.937
39	1996	149	22.532	28.389	35.804	40.999	44.974	48.603	51.655
40	1997	224	33.874	42.679	53.826	61.636	67.612	73.068	77.656
41	1998	108	16.332	20.577	25.952	29.717	32.599	35.229	37.442
42	1999	210	31.757	40.012	50.462	57.784	63.387	68.501	72.803
43	2000	95	14.366	18.100	22.828	26.140	28.675	30.989	32.935
44	2001	281	42.494	53.539	67.523	77.320	84.817	91.661	97.417
45	2002	294	44.460	56.016	70.647	80.897	88.741	95.901	101.924
46	2003	219	33.118	41.726	52.625	60.260	66.103	71.437	75.923
47	2004	227	34.328	43.251	54.547	62.461	68.518	74.046	78.697
48	2005	192	29.035	36.582	46.137	52.831	57.953	62.630	66.563
49	2006	87	13.157	16.576	20.906	23.939	26.260	28.379	30.161
50	2007	263	39.772	50.110	63.198	72.367	79.384	85.789	91.177
51	2008	107	16.181	20.387	25.712	29.442	32.297	34.903	37.095
52	2009	256	38.713	48.776	61.515	70.441	77.271	83.506	88.750
53	2010	126	19.054	24.007	30.277	34.670	38.032	41.101	43.682

III.2 Gumbel Theory of Distribution

Gumbel distribution methodology was selected for performing flood probability analysis. It is the most widely used distribution for IDF analysis owing to its suitability for modelling maxima. It is relatively simple and use extreme events (maximum values rainfall). Using Gumbel Distribution method calculates the 2, 5, 10, 15, 20, 50, 75 and 100 year return intervals for each duration period and requires several calculations. Frequency rainfall/precipitation P_T (in mm) for each duration with a specified return period T (in year) is given by the following equation:

$$P_T = P_{ave} + KS \quad \ldots\ldots (2)$$

Where K is Gumbel frequency factor given by:

$$K = -\left(\frac{6^{0.5}}{\pi}\right) * \left[0.5772 + \ln\left[\ln\left[\frac{T}{T-1}\right]\right]\right] \quad \ldots\ldots (3)$$

Where P_{ave} is the average of the maximum precipitation corresponding to a specific time duration. In utilizing Gumbel's distribution, the arithmetic average in equation (2) is used:

$$Pave = \left(\frac{1}{n}\right) \sum_{i=I}^{n} Pi \quad \ldots\ldots (4)$$

Where Pi is the individual extreme value of rainfall and n is the number of events or years of record. The standard deviation is calculated by equation (5) computed using the following relation:

$$S = \left[\frac{1}{n-1} \sum_{i=1}^{n} (Pi - Pave)^2\right]^{1/2} \quad \ldots\ldots (5)$$

Where S is the standard deviation of P data. The frequency factor (K), which is a function of the return period and sample size, when multiplied by the standard deviation gives the departure of a desired return period rainfall from the average. Then the rainfall intensity, I (mm/hr) for different return period T is calculated by equation (6). The frequency of the rainfall is usually defined by reference to the annual maximum series, which consists of the largest values observed in each year. An alternative data format for rainfall frequency studies is that based on the peak-over threshold concept, which consists of all precipitation amounts above certain thresholds selected for different durations. Due to its simpler structure, the annual-maximum-series method is more popular in practice [6].

$I = P_T/t$ ……………………………………………………………………..(6)

Where t is duration in hours.

From the raw data the maximum rainfall/precipitation (P) and the statistical variables (average and standard deviation) for each duration (5,10,20,30,40,50,60 min) were computed. Figure 3and Table 2 shows the computed intensity (I) for different return periods using Gumbel method.

Table 2: Intensity calculated using Gumbel Method

Duration **t**		Average max precipitation **Pave**	standard deviation **S**	**Return Period T**									
				2	5	10	15	20	25	30	50	75	100
hour	min			**Gumbel Frequency Factor K for each Return Period**									
				-0.16	0.72	1.31	1.64	1.87	2.04	2.19	2.59	2.91	3.14
				Rainfall Precipitation (mm/hr), using Gumbel Method, PT = Pave + KS									
0.08	5	25.34	9.84	23.72	32.43	38.19	41.44	43.71	45.47	46.89	50.87	54.01	56.23
0.17	10	31.93	12.40	29.89	40.85	48.11	52.21	55.08	57.29	59.08	64.09	68.05	70.84
0.33	20	40.27	15.64	37.70	51.53	60.68	65.85	69.46	72.25	74.51	80.83	85.82	89.35
0.50	30	46.11	17.91	43.17	59.00	69.48	75.40	79.54	82.73	85.33	92.56	98.27	102.31
0.67	40	50.58	19.65	47.35	64.72	76.22	82.71	87.25	90.75	93.60	101.53	107.80	112.23
0.83	50	54.66	21.23	51.17	69.94	82.37	89.38	94.29	98.08	101.15	109.72	116.50	121.29
1.00	60	58.09	22.57	54.39	74.34	87.55	95.00	100.22	104.23	107.50	116.62	123.81	128.90
				Intensity (mm/hr), I = PT/t									
				285.83	390.68	460.10	499.26	526.68	547.81	564.99	612.87	650.69	677.46
				180.06	246.11	289.84	314.51	331.79	345.10	355.92	386.09	409.91	426.77
				113.21	154.73	182.22	197.73	208.60	216.96	223.77	242.73	257.71	268.31
				86.33	118.00	138.97	150.80	159.08	165.46	170.65	185.12	196.54	204.62
				71.10	97.18	114.45	124.19	131.01	136.27	140.54	152.45	161.86	168.52
				61.43	83.97	98.89	107.30	113.20	117.74	121.43	131.72	139.85	145.60
				54.39	74.34	87.55	95.00	100.22	104.23	107.50	116.62	123.81	128.90

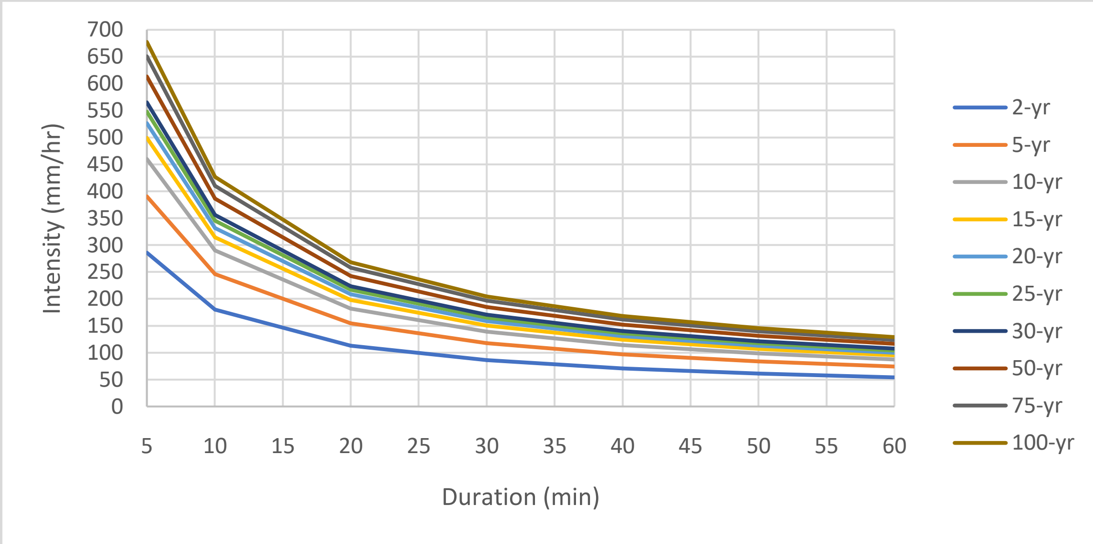

Figure 3: Computed Intensity for different Return Periods using Gumbel Method from observed rainfall

IV. Derivation of IDF equation

An equation (7)has been derived for calculating the rainfall intensity (I) for the Rangpur City Corporation for different return periods. Constants a and b for the equation (7) are given in Table 3. Figure 4 show a good agreement between intensity calculated by Gumbel (6)&by derived equation (7).

$I = \frac{a}{t^b}$ ………………………………………………………………………………….(7)

Table 3: Constants for the equation (7)

Return Period	Constants	
	a	b
2	838.01	0.668
5	1145.4	0.668
10	1348.9	0.668
15	1463.8	0.668
20	1544.2	0.668
25	1606.1	0.668
30	1656.5	0.668
50	1796.8	0.668
75	1907.7	0.668
100	1986.2	0.668

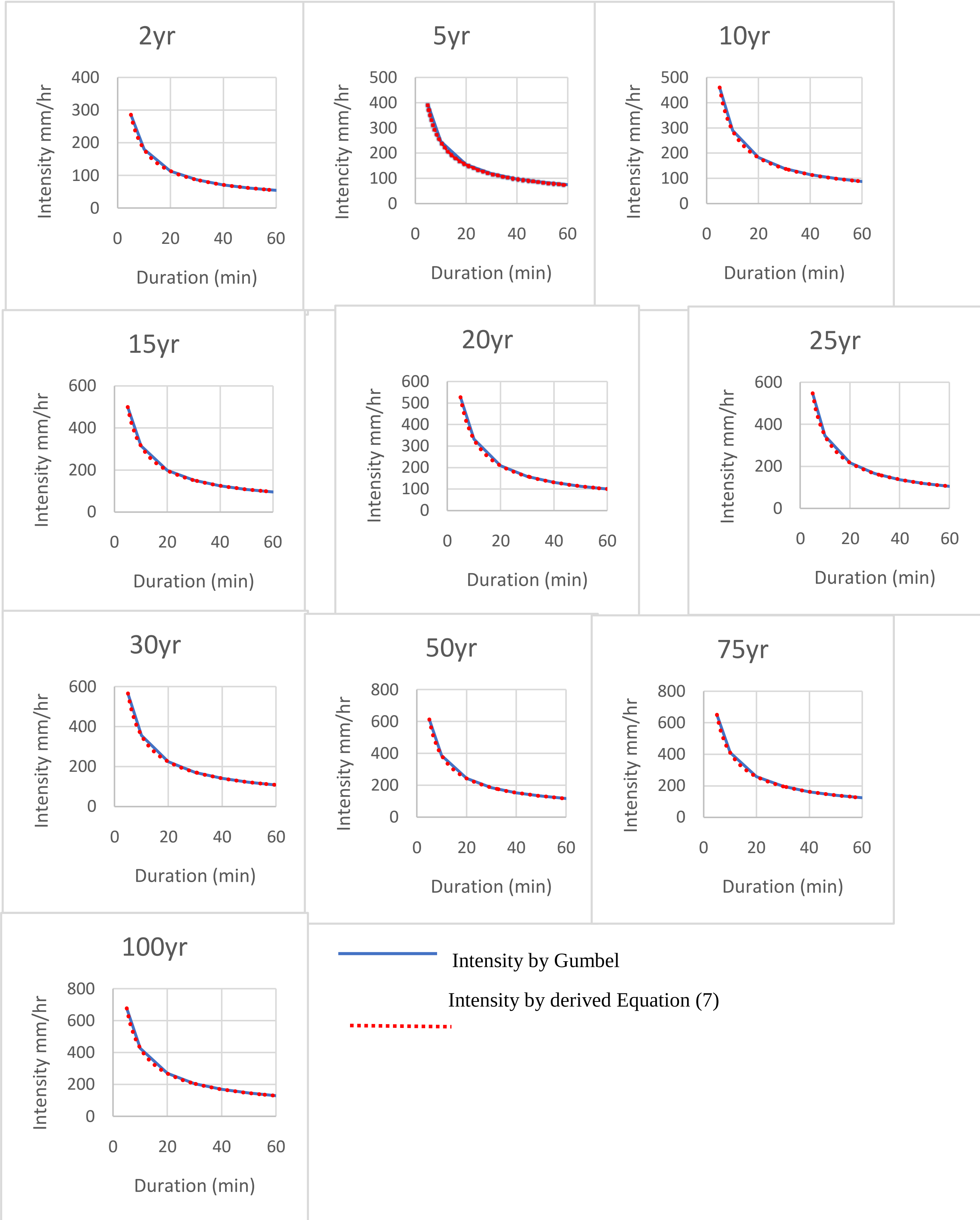

Figure 4: Agreement between intensity calculated by Gumbel & derived equation (7)

VI.Conclusion

IDF is a good tool for planning, design and operation of water resources projects such as storm water drainage system. A relationship of R-IDF has been obtained to estimate rainfall intensities for different durations and return periods ranging between 2 and 100 years. The parameters of the design rainfall intensity for a given period of recurrence interval were estimated for the Rangpur City Corporation. The results showed that in all the cases data fitted the equation with a correlation coefficient (R^2) equal to 1. This indicates the goodness of fit of the equation to estimate IDF curves in the Rangpur City Corporation for durations varying from 5 to 60 min and return periods from 2 to 100 years.These relationships are useful in the design of urban drainage works, e.g. storm drainage, culverts and other hydraulic structures

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