Development of rainfall Intensity-Duration-Frequency (IDF) relations for the Kalu Ganga catchment,

Abstract

The rainfall Intensity-Duration-Frequency (IDF) curves are commonly used in planning and designing of water resource development projects in un-gauged catchments. The IDF curves represent the statistical relationship between the rainfall intensity, storm duration and the return period relevant to the extreme rainfalls experienced in a particular region or a river basin. The development of such curves is a tedious task which requires continuous rainfall records for a fairly long period such as 50 years. In Sri Lanka, there are a large number of rainfall stations maintained by different organizations but recording rain gauges are not so common.

Department of Meteorology maintains recording gauges, covering the entire country, and pluviographs are available for a fairly long period. However, producing IDF curves is beyond their scope. Irrigation Department has technical knowhow and competency, but sufficient data is not available.

Regional IDF curves were initially developed by the Irrigation Department in 1970s based on the short period of data available at the time. Those curves are still being used for the designs of small-medium irrigation works carried out by many organizations.

Updating regional IDF curves is a long felt requirement but so far has not been taken fruitful actions for implementation due to problems such as insufficiency of data and other resources.

Some engineers, worked at the Hydrology Division of Irrigation Department, had initiated the work but later abandoned due to constraints mentioned above. However, the use of previous IDF curves in the present designs was questionable since the climate pattern has changed drastically during the past years.

This paper presents the procedure of developing IDF curves for a particular station using the pluviographs collected at Ratnapura meteorological station in the Kalu Ganga basin. The length of observation is over 50 years from 1955. The source of data is the Department of Meteorology, Sri Lanka.

This is an initial step to upgrade the regional IDF curves for the entire country. However its success depends on the availability and accessibility of data. Even the outcome of this study can be used for the planning of water resources projects in the upper catchment of Kalu Ganga with confidence.

1. Introduction

1.1 River Basin Information

The Kalu Ganga has a catchment area of 2839 km^2, entirely situated in the Wet Zone of the Island. The river originates from the central hills at an elevation of 2,135 m and flows to the sea at Kalutara. The length of the river is about 130 km.

The river drains the area which experiences extremely high rainfalls of the country at the upstream of Ratnapura. The average annual rainfall of the area is around 4000 mm. The heaviest rainfalls are experienced during the months of May to June causing floods in the lower basin.

The Kalu Ganga, being the largest river in the amount of water conveyed to the sea, discharges over 7200 MCM annually (Arumugam). Irrigation developments in the basin are limited to minor, medium Anicut

Schemes. Kalu Ganga water has not been used for any economic purpose on a large scale so far. During the flood, Ratnapura town is affected inundating a considerable number of houses and commercial buildings. The flooding is more frequent in the lower reaches where the gradient of the river is flatter.

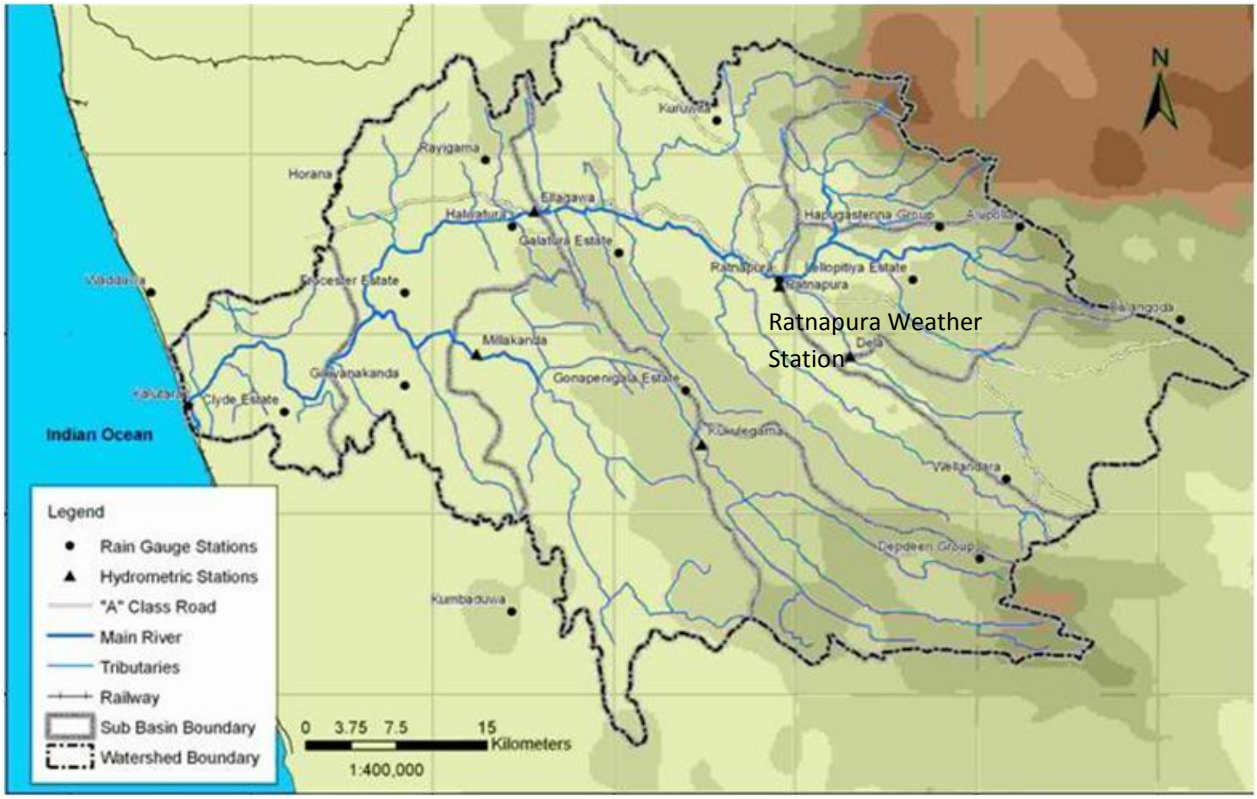

Figure1.The Kalu Ganga - River Basin Map

Heavy rainfall and the shape of the catchment (short and broad) equally contribute to the heavy floods in the Kalu Ganga basin (see River Basin map). The land is well developed and tea is grown in the lands above 610 m from MSL. Rubber and coconut are grown below that and the rice cultivation is practiced in the valleys of lower region. Ratnapura district is considered as a major gem producing area of the country.

2. Availability of Data

Ratnapura (121241 mE, 157313 mE) is a Principle Weather Station maintained by the Department of Meteorology. Pluviographs were available for over 50 Years from 1955 at the Department, even though some of those relevant to year 1980, 1986 and 1993 were missing. According to the records of annual extreme rainfalls, these years could be considered as average years and the missing data do not make any significant influence for the final results.

Further, it was possible to obtain daily rainfall data from 1950 to 2010. These data was used to compute annual extremes of daily rainfalls and also for the frequency analysis of longer durations such as 48 hour and 72 hour.

3. Methodology

3.1 Rainfalls correspond to partial durations

By examining all the pluviographs relevant to each year, the graphs relevant to high intensity rainfalls were selected. In most of the cases, the annual extreme daily rainfall represented the highest intensities relevant to partial durations as well (example year 2003). In several years, highest intensities for partial durations had occurred in the other occasion's different form the annual extreme (example, year 1959). Scanned copy of the pluviograph relevant to 17th May 2003 is shown in Fig. II.

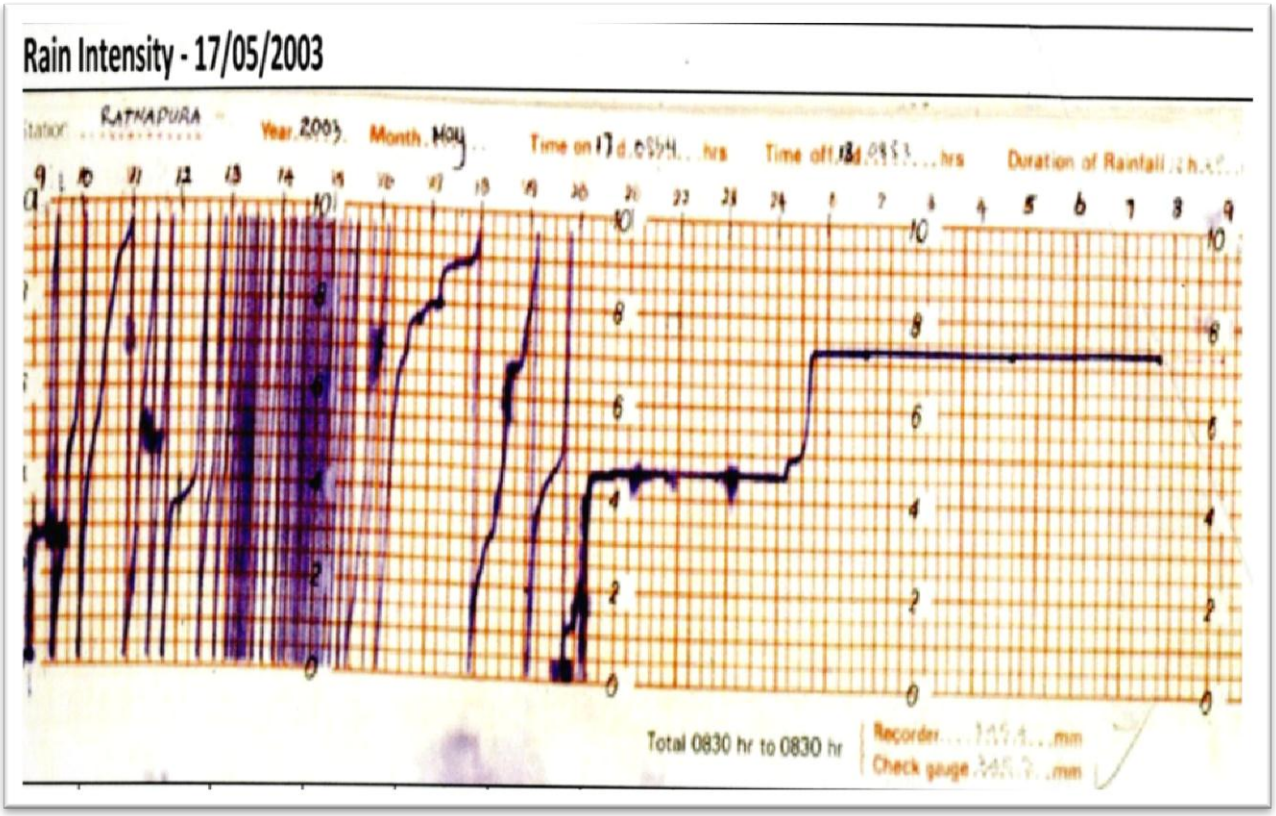

Figure II- Pluviograph Relevant to Extreme Rainfall on 17th May 2003 at Ratnapura (TAHAL)

Then the selected pluviographs for each year were referred carefully to find the accumulated rainfall depths for time periods, beginning from 8.00am and increasing step by step up to 8.00 am in the following day. Accumulated values of rainfalls relevant to 17th May 2003 are depicted in the third column of the TableIand the summary of such values related to all pluviographs are given in **Annex I.** Then those values were converted to accumulated rainfalls for the consecutive time periods of 1,2,3,4,5,6,8,10,12,18 and 24hr as shown in Table I.

Time in hr	Accumulated RF	Duration (hr)										
		1	2	3	4	5	6	8	10	12	18	24
8	0.0											
9	2.5	2.5										
10	20.0	17.5	20.0									
11	30.0	10.0	27.5	30.0								
12	53.5	23.5	33.5	51.0	53.5							
13	74.0	20.5	44.0	54.0	71.5	74.0						
14	150.0	76.0	96.5	120.0	130.0	147.5	150.0					
15	260.0	**110.0**	**186.0**	206.5	230.0	240.0	257.5					
16	307.0	47.0	157.0	**233.0**	**253.5**	**277.0**	287.0	307.0				
17	318.0	11.0	58.0	168.0	244.0	264.5	**288.0**	**315.5**				
18	330.0	12.0	23.0	70.0	180.0	256.0	276.5	310.0	**330.0**			
19	331.0	1.0	13.0	24.0	71.0	181.0	257.0	301.0	328.5			
20	339.0	8.0	9.0	21.0	32.0	79.0	189.0	285.5	319.0	**339.0**		
21	340.0	1.0	9.0	10.0	22.0	33.0	80.0	266.0	310.0	337.5		
22	344.5	4.5	5.5	13.5	14.5	26.5	37.5	194.5	291.0	324.5		
23	344.5	0.0	4.5	5.5	13.5	14.5	26.5	84.5	270.5	314.5		
24	344.5	0.0	0.0	4.5	5.5	13.5	14.5	37.5	194.5	291.0		
1	347.0	2.5	2.5	2.5	7.0	8.0	16.0	29.0	87.0	273.0		
2	347.0	0.0	2.5	2.5	2.5	7.0	8.0	17.0	40.0	197.0	**347.0**	
3	347.0	0.0	0.0	2.5	2.5	2.5	7.0	16.0	29.0	87.0	344.5	
4	347.0	0.0	0.0	0.0	2.5	2.5	2.5	8.0	17.0	40.0	327.0	
5	347.0	0.0	0.0	0.0	0.0	2.5	2.5	7.0	16.0	29.0	317.0	
6	347.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	8.0	17.0	293.5	
7	347.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	7.0	16.0	273.0	
8	347.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	8.0	197.0	**347.0**
Max RF depth within the period		110.0	186.0	233.0	253.5	277.0	288.0	315.5	330.0	339.0	347.0	347.0

Table I. Maximum rainfall depths, with respect to specified time periods, during the extreme rainfall on 17th May 2003.

Then the maximum rainfalls during each time period were computed. Similarly all selected extreme rainfalls were analyzed to find maximum rainfalls relevant to partial durations. Several rainfalls had to be analyzed to determine the highest rainfalls relevant to partial durations in some years (eg. Year 1959, 1963 etc) as shown in Table II.

Date	Duration (hr)										
	1	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**18**	**24**
8/6/1959	20.5	28.0	48.0	52.0	59.5	64.5	71.0	72.5	76.0	**99.5**	**102.0**
17/06/1959	**29.0**	**44.5**	**51.0**	**64.5**	**71.5**	**74.5**	**76.0**	**76.0**	**80.5**	81.5	86.0
1959	**29.0**	**44.5**	**51.0**	**64.5**	**71.5**	**74.5**	**76.0**	**76.0**	**80.5**	**99.5**	**102.0**
4/7/1963	**52.0**	**56.5**	61.0	65.5	67.8	70.0	73.7	81.5	108.0	124.8	124.8
18/09/1963	32.0	53.0	**67.7**	**72.7**	**86.2**	**100.0**	**101.1**	**120.0**	**137.7**	**139.0**	**139.0**
Maximum	**52.0**	**56.5**	**67.7**	**72.7**	**86.2**	**100.0**	**101.1**	**120.0**	**137.7**	**139.0**	**139.0**

Table II. Annual Maximum rainfalls with respect to partial durations in 1959 and 1963

Maximum rainfall depths relevant to partial durations for all years from 1955 to 2004 are given in **Annex** II.

3.2 Maximum Rainfall Depths correspond to longer durations

The highest rainfalls correspond to longer durations (48 hr and 72 hr) were computed using daily rainfall records available for 61years from 1950.

3.2.1 Analysis of daily Rainfalls

Daily rainfall records were available in the following format. (Table III).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	1.5	3.3	6.0	0.0	0.0	0.0	1.0
2	0.0	4.8	7.3	0.2	0.0	0.7	3.8	10.4	12.4	16.7	0.0	0.0
3	0.0	0.0	5.0	0.0	0.0	11.4	0.0	10.6	5.0	46.2	0.0	0.0
4	0.0	0.0	0.5	2.2	8.3	9.9	0.0	2.7	27.6	0.0	2.5	0.0
5	0.0	0.0	2.7	75.4	0.0	11.6	0.0	8.8	25.4	56.6	33.0	0.7
6	0.0	0.0	38.8	2.5	1.0	33.7	0.0	1.5	4.3	8.8	9.3	3.0
7	5.5	0.0	0.0	11.9	8.6	29.2	0.5	10.6	24.1	28.9	2.2	0.0
8	0.0	10.9	0.0	0.0	66.2	38.6	5.0	3.3	14.9	22.8	38.1	0.0
9	7.8	0.0	0.0	26.1	1.5	2.0	21.0	9.6	10.4	7.1	0.0	0.0
10	2.7	0.0	51.8	7.8	0.0	0.0	1.0	4.8	24.1	0.0	109.9	0.0
11	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.5	39.1	17.5	3.8	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.9	43.9	42.1	7.6	0.0
13	0.0	0.0	0.0	0.0	0.0	10.6	2.0	2.0	23.3	0.0	0.0	0.0
14	0.0	0.0	0.0	3.0	1.7	.0T	4.5	0.0	11.1	31.4	0.7	0.0
15	0.0	0.0	27.4	0.0	2.5	5.8	0.0	25.1	2.0	33.5	1.5	0.0
16	0.0	11.6	54.3	0.0	3.3	9.3	11.6	5.8	2.2	19.5	6.6	0.0
17	0.0	4.8	0.5	0.0	2.5	1.5	6.8	0.7	0.0	31.4	0.0	0.0
18	0.0	1.2	0.0	0.0	0.0	2.0	10.9	0.0	0.0	4.0	17.7	.0T
19	0.5	2.5	0.0	0.0	2.5	0.2	14.9	12.1	0.0	85.0	0.0	.0T
20	3.3	0.0	0.0	11.4	0.0	1.0	12.4	32.2	0.0	14.2	0.0	0.0
21	15.2	40.6	.0T	12.9	0.0	1.0	0.0	5.8	0.0	93.9	0.0	0.0
22	14.2	73.9	6.0	2.5	0.0	5.0	3.5	6.3	0.5	29.2	0.0	18.7
23	0.0	5.5	49.0	18.7	5.0	8.1	0.7	18.5	0.0	4.3	0.0	0.0
24	0.0	0.0	28.7	5.0	11.4	1.7	5.5	0.0	0.0	0.0	0.0	.0T
25	0.0	33.0	0.0	0.0	12.7	12.1	9.6	4.0	27.6	0.0	0.0	27.1
26	0.0	0.0	0.0	0.0	19.5	3.8	80.0	0.2	12.9	0.0	0.0	0.0
27	0.5	0.0	13.9	5.3	42.6	1.5	1.7	3.5	25.4	0.0	0.0	0.0
28	0.0	0.0	0.0	6.6	9.1	5.8	0.0	10.1	16.5	0.0	4.8	0.0
29	26.6		0.0	0.0	6.3	8.1	0.7	6.3	0.5	0.0	0.7	0.0
30	0.0		0.0	2.0	8.1	1.2	13.9	11.6	13.2	0.0	0.0	21.5
31	0.0		0.0		18.7		11.6	0.0		0.0		1.2
Maximum	26.6	73.9	54.3	75.4	66.2	38.6	80.0	41.9	43.9	93.9	109.9	27.1

Maximum Value 109.9mm

Table III. Daily rainfall record of Ratnapura Weather Station in year 1950

First, the record relevant to each year was analyzed to compute the annual maximum series of daily rainfall covering the period of all 61 years. Then the rainfalls for two and three consecutive days were analyzed using the same data and the maximum values for eachyear were selected. Two day (48 hr) and 3 day (72 hr) annual maximum rainfalls relevant to all 61 years are summarized in the table IV below.

Year	Duration (hr)		Year	Duration (hr)		Year	Duration (hr)	
	48	72		48	72		48	72
1950	123.1	193.1	**1971**	253.7	289.2	**1992**	193.0	238.0
1951	188.9	243.2	**1972**	180.5	217.8	**1993**	238.8	302.0
1952	185.6	234.1	**1973**	125.6	170.5	**1994**	168.7	260.5
1953	182.5	205.6	**1974**	175.6	260.5	**1995**	186.5	228.7
1954	119.3	165.5	**1975**	302.2	350.9	**1996**	424.0	476.2
1955	219.4	263.2	**1976**	247.0	258.1	**1997**	201.8	295.4
1956	212.2	223.3	**1977**	140.9	186.9	**1998**	147.2	178.6
1957	141.6	197.2	**1978**	341.5	419.1	**1999**	353.0	377.5
1958	151.8	241.6	**1979**	155.1	218.8	**2000**	151.3	186.2
1959	167.2	214.6	**1980**	177.8	245.1	**2001**	133.0	178.1
1960	159.4	187.8	**1981**	163.2	187.8	**2002**	146.3	170.8
1961	133.8	146.5	**1982**	375.7	416.2	**2003**	444.8	445.7
1962	197.5	224.1	**1983**	155.0	192.6	**2004**	112.8	150.1
1963	145.4	164.7	**1984**	241.5	252.2	**2005**	142.8	157.5
1964	229.3	335.7	**1985**	177.1	197.4	**2006**	196.8	250.0
1965	141.9	177.4	**1986**	157.8	219.5	**2007**	188.2	218.8
1966	196.2	283.0	**1987**	157.2	199.8	**2008**	258.3	315.9
1967	289.7	353.4	**1988**	312.5	320.5	**2009**	178.9	198.5
1968	358.4	459.4	**1989**	323.1	373.6	**2010**	187.8	281.1
1969	255.9	300.0	**1990**	161.3	184.1			
1970	182.2	198.3	**1991**	134.1	184.2			

Table IV. Annual Maximum Rainfalls with respect to 48 hr and 72 hr durations.

After finalizing the annual maximum rainfall values with respect to all durations, statistical analysis were carried out, separately for each duration, using Gumbel (EV1) distribution. Sample calculation related to 24 hr duration is presented in **Annex III**. The maximum rainfall depths were plotted against reduced vitiate, -Ln(-Ln(q)) where q is probability of non exceedance that is (1-P). It was found the data, relevant to all durations, fairly fit into the theoretical distribution (Fig.III).

4. Results

Gumble plot relevant to 24 hr duration is given in Figure III.

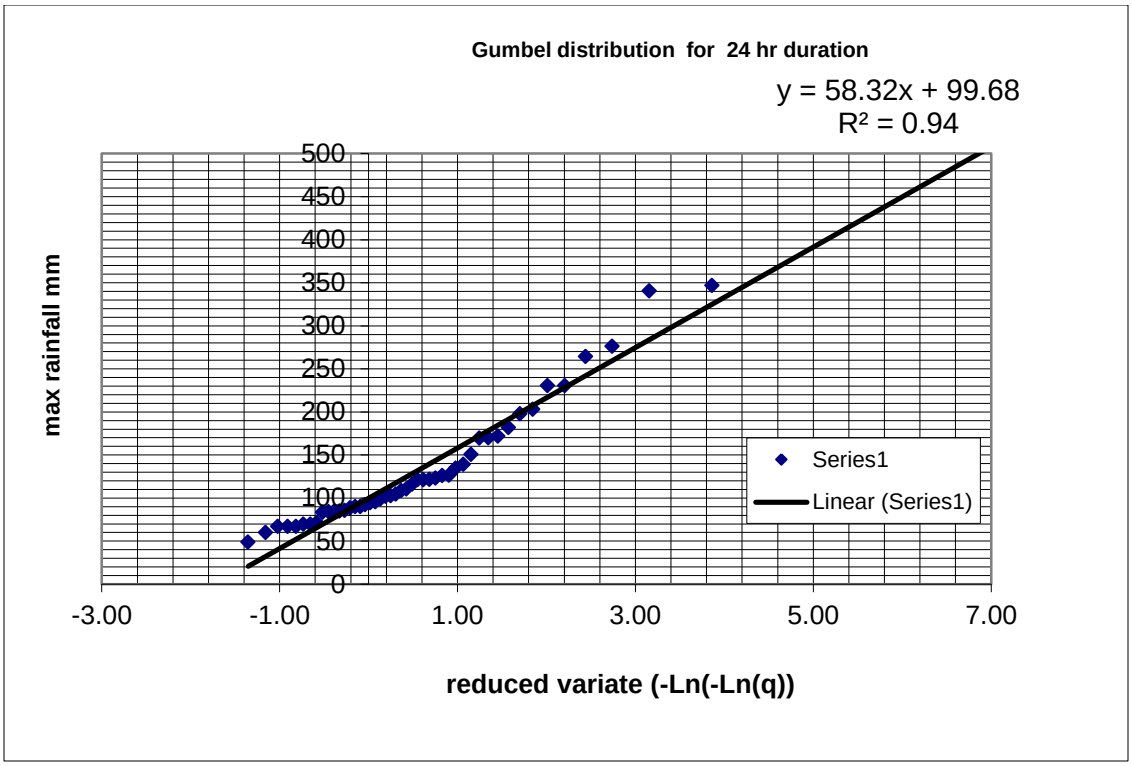

Figure III. Gumble plot relevant to 24 hr duration

Equation of trend line relevant to 24 hour duration:

$Y = 58.32X + 99.68$ Where Y = Rainfall in mm,

X = Reduced Variate = -Ln(-Ln(q))

= -Ln(-Ln(1-P))

= -Ln(-Ln(1-1/T))

Computations relevant to 24 hr duration are illustrated in Table V.

T(Return Period in yr)	P (Probability)	q = (1-P)	-Ln(-Ln(q)) (Reduced variate)	Rainfall depth (mm) for 24 hr duration
2	0.5	0.5	0.37	121
5	0.2	0.8	1.50	187
10	0.1	0.9	2.25	231
25	0.04	0.96	3.20	286
50	0.02	0.98	3.90	327
100	0.01	0.99	4.60	368
200	0.005	0.995	5.30	409

Table V. Analysis of 24 hr rainfalls for different return periods

Similarly the equations of trend lines were used to find the cumulative rainfalls relevant to each duration and different return periods of 2, 5, 10, 25, 60, 100 and 200 years.

These equations can be developed even for the higher return periods but the accuracy may become less. Summary of the results computed by the equations are given in Table VI.

Return Period T(yr)	Duration (hr)												
	1	2	3	4	5	6	8	10	12	18	24	48	72
2	45.2	66.1	77.9	84.9	90.1	95.2	101.5	106.6	111.0	118.1	121.1	193.0	237.7
5	66.8	100.1	119.1	130.6	140.2	148.0	158.8	166.9	174.5	182.5	187.2	264.8	314.3
10	81.1	122.6	146.4	160.8	173.3	182.9	196.8	206.8	216.4	225.2	230.9	312.3	365.0
25	99.2	151.0	180.9	199.0	215.1	227.1	244.7	257.3	269.5	279.1	286.2	372.4	429.1
50	112.6	172.1	206.4	227.3	246.2	259.8	280.3	294.7	308.8	319.1	327.2	416.9	476.7
100	125.9	193.1	231.8	255.4	277.0	292.3	315.6	331.8	347.9	358.8	368.0	461.1	523.9
200	139.1	213.9	257.1	283.4	307.7	324.7	350.8	368.8	386.8	398.3	408.5	505.2	570.9

Table VI. Rainfall Depths Corresponds to different Durations and Frequencies

Then the above rainfall depths were converted to intensities and were plotted against the duration as shown in the Figure IV.

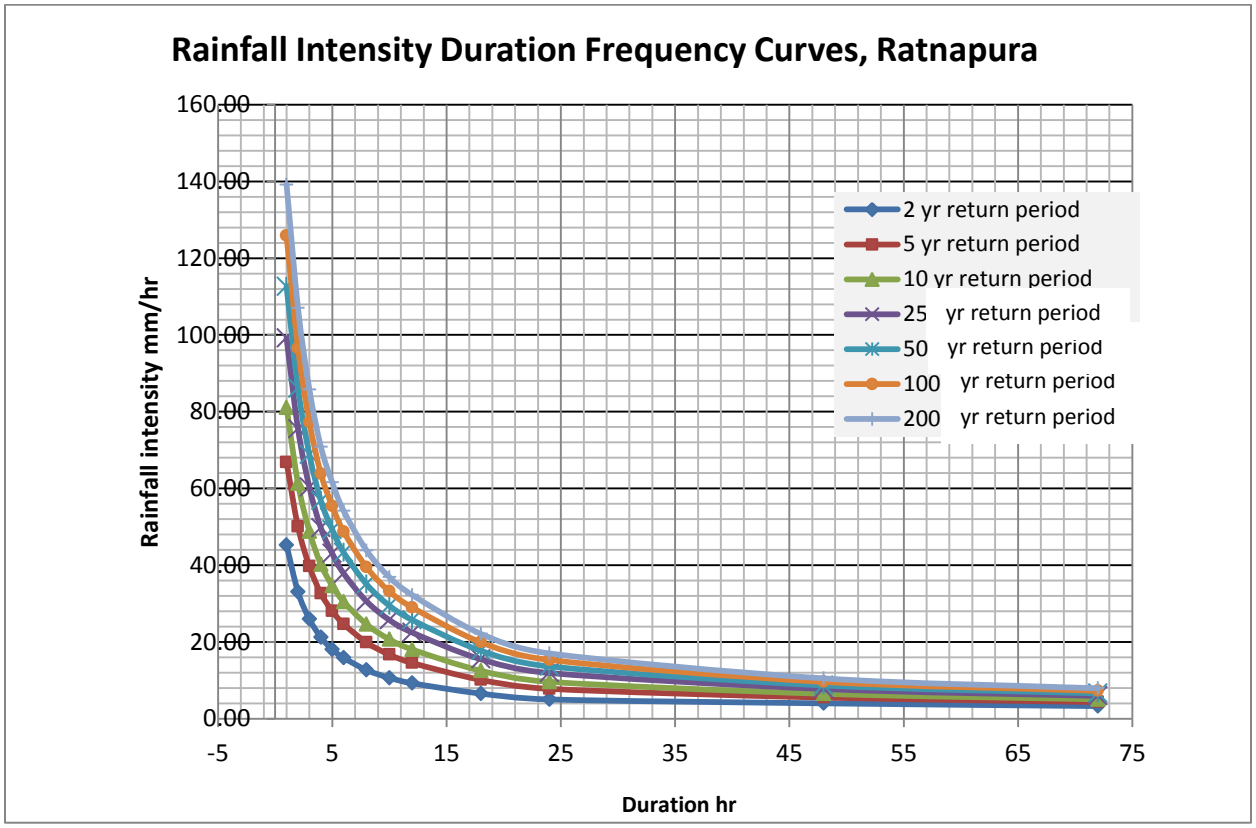

Fig. IV. Rainfall Intensity – Duration – Frequency Curves, Ratnapura Weather Station

The same graphs were plotted in the log scale for the purpose of approximating those curves to straight lines and deriving the equations of trend lines for the purpose of interpolation and extrapolation. Final results of the study are presented in Figure V.

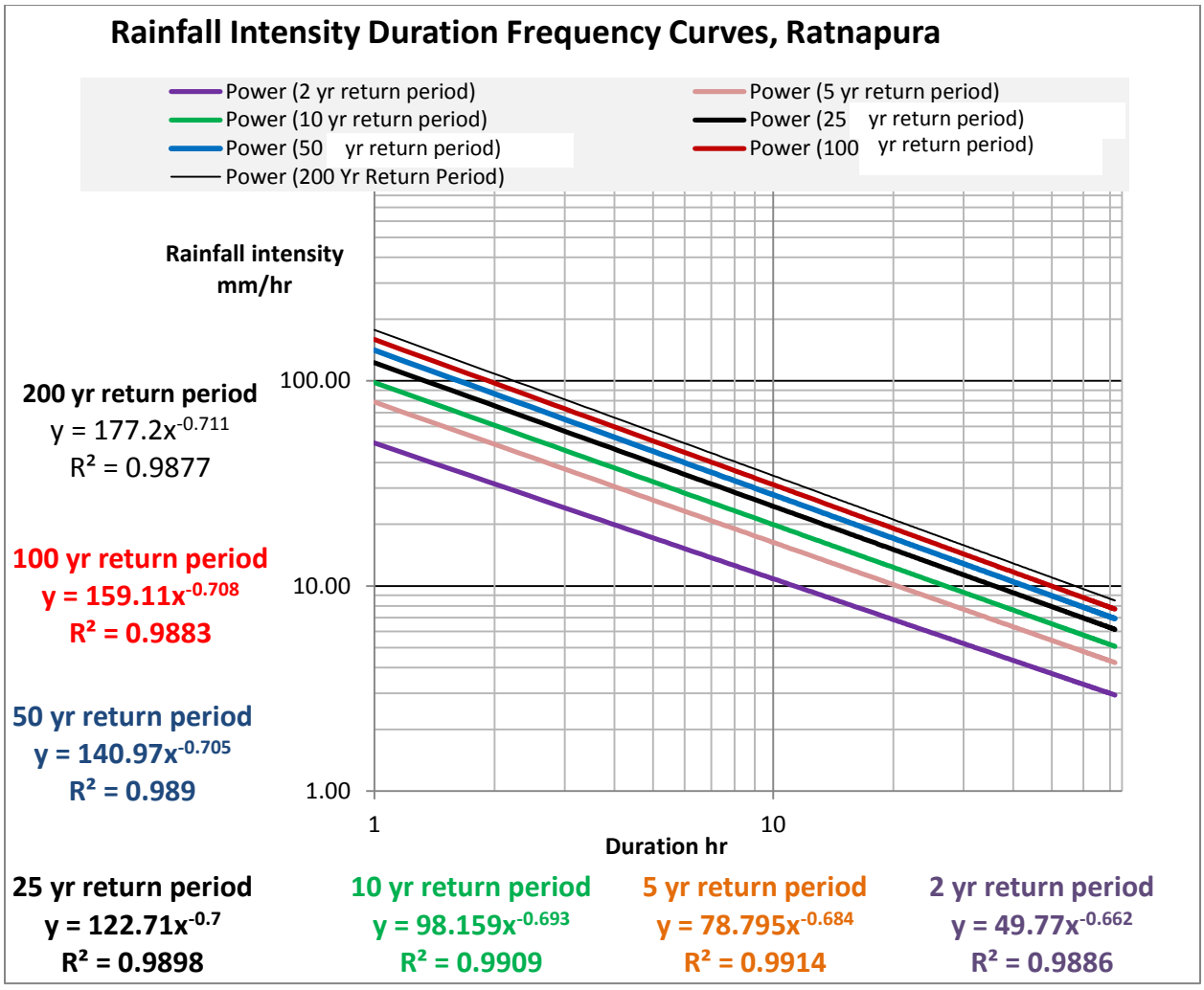

Fig. V. Final Results of the Study

5. Comparison with Previous Works

For the purpose of comparison, rainfall intensities computed using above equations are tabulated against the same parameters computed using IDF equations, previously developed by the Irrigation Department. Previous equations had been developed in 1970s with the short period of data available at the time. Period of data used for the computation had not been mentioned. Regional IDF curves had been developed for 10, 25, 50 and 100 year return periods covering entire country. Those have been published in the book 'Design of Irrigation Headworks for Small Catchments, and still being used by many organizations.

The present study is confined to Ratnapura area which is centrally located within the previously designated Hydrological Zone IV (Ponrajah, 1982). Relationships were built for seven return periods from 2 to 200 year. Rainfall intensities and depths for each return period for four different storm durations were computed and tabulated in Table VI.

Then same values were computed by the previous IDF curves and tabulated against the present computations as shown.The values computed by both methods are highlighted for the convenience of comparison.

Return Period and Duration	IDF Equation Developed by Present Study	Rainfall Intensity mm/hr with new IDF	Depth of Rainfall (with new IDF) mm	IDF Equation Developed by Previous Study	Rainfall Intensity mm/hr with previous IDF	Depth of Rainfall (with previous IDF) mm
2 year	$Y = 49.77X^{-0.662}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		15.2	91.2			
12 hr		9.61	115.27			
24hr		6.07	145.71			
48hr		3.84	184.17			
5 Year	$Y = 78.795X^{-0.684}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		23.13	138.8			
12 hr		14.4	172.79			
24hr		8.96	215.1			
48hr		5.58	267.78			
10 year	$Y = 98.159X^{-0.693}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr			$I = XD^{-Y}$ Where I : RF intensity D : Duration X, Y : two coefficients statistically computed for different return periods and Hydrological Zones. (Ponrajah - 1982)		
6 hr		28.36	170.15		26.91	161.44
12 hr		17.54	210.49		17.21	206.48
24hr		10.58	260.41		11	264.09
48hr		6.71	322.16		7.04	337.77
25 year	$Y = 122.71X^{-0.7}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		35.01	210.05		32.64	195.81
12 hr		21.55	258.6		20.63	247.51
24hr		13.27	318.38		13.04	312.85
48hr		8.17	391.97		8.24	395.47
50 year	$Y = 140.97X^{-0.705}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		39.86	239.16		36.75	220.50
12 hr		24.45	293.42		23.19	278.33
24hr		15.00	359.99		14.64	351.32
48hr		9.20	441.66		9.24	443.46
100 Year	$Y = 159.11X^{-0.708}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		44.75	268.48		40.74	244.45
12 hr		27.39	328.71		26.29	315.48
24hr		16.77	402.46		16.96	407.15
48hr		10.27	492.74		10.95	525.45
200 year	$Y = 177.2X^{-0.711}$ Where Y: rainfall intensity in mm/hr. X : Duration in hr					
6 hr		49.57	297.41			
12 hr		30.28	363.37			
24hr		18.50	443.96			
48hr		11.30	542.43			

Table VIII. Comparison of values computed by previous and newly developed IDF equations

6. Conclusions and Recommendations

Even with the new concept of climate change, the results of this study shows extremely close similarity to the IDF relations derived in 1970s by the Irrigation Department with respect to Hydrological Zone IV where Kalu Ganga basin is located. However it is too early to make the same conclusion for the other regions. When considering the Kalu Ganga basin, it is possible to use the previously developed regional IDF curves, further with utmost confidence.

Advantage of the new work is the flexibility of deriving IDF relations for different return periods and storm durations other than tabulated above. Particularly, estimating the floods of low return periods are very important in designing minor flood protection works. Secondly those can be reliably used for the high return periods up to 200 years since the data record used for the computation is sufficiently long. This is useful in the designs of spillways of minor, medium reservoirs.

Even, the extrapolation further is possible but the reliability may be reduced. If these equations to be adopted for higher return periods (e.g. 500 yr, 1000 yr etc. for using in the designs of spillways of large dams), care should be taken to apply sufficient safety factors for the designs.

Further, the precipitation data is collected at fixed time intervals from 9.00 am to 9.00 am. Such data normally under estimates the true maximum rainfall amounts for the indicated durations. Multiplying the statistical values by a suitable factor is recommended for conservative designs.

References:

1. **TAHAL Group, 2013, Feasibility Study of Ratnapura Dam & Pre Feasibility Study of Kalu Ganga Basin**
2. **Arumugam, S., 1969, Water Resources of Ceylon**
3. **Ponrajah, A.J.P., 1982, Design of Irrigation Headworks for Small Catchments**

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Annex I. Page I. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	5/10/1955	6/18/1956	11/18/1957	10/27/1958	6/8/1959	6/17/1959	9/15/1959	7/17/1960	5/19/1961	5/16/1962	7/4/1963
Time											
8	1	7.5	4.25	9	8.5	5.5	10	1.6	7.5	5.3	6.5
9	1	7.5	4.25	9	8.5	5.5	10	1.6	7.5	5.3	6.5
10	1	7.5	4.25	9	8.5	21	20	1.6	7.5	5.8	9
11	2	11.5	4.25	9	10	50	20.3	1.6	18.5	10	12
12	2	11.5	4.25	9	10	56.5	20.3	1.6	28.5	24	20
13	4.5	15	4.25	9	10.5	70	26	1.6	28.5	30	47.5
14	4.5	40	4.25	9	11	77	26.5	3.5	28.5	36	47.5
15	5.5	45	30	9	16	80	32	4	39	38	47.5
16	5.5	50	57.5	9	27.5	81.5	33.5	5.5	39	46.5	50
17	39	52.5	68.5	10	27.5	81.5	35.5	6	39	47	60
18	60	55.5	70	10	48	81.5	50	6	39	47	60
19	101.5	61	70	10	55.5	81.5	56.3	6	39.3	47	61
20	110	68.5	94.5	10	75.5	81.5	70	7.6	40	47	61.3
21	116	70	100	10	79.5	86	75.8	33	40	56	63.5
22	116	70	100	10	82	86.5	76.8	36.3	45	60	68
23	116	75	100	10	83	86.8	91	70	60	67	120
24	116	84	100	10	83	86.8	98	83	73	74.5	123.7
1	116.5	92.5	100	17.5	84.5	86.8	101.7	85	74	80	129
2	116.5	94	100	30	87	86.8	102.8	101	76	90	131.3
3	116.5	94	100	109.5	88	87	102.8	104	76.5	90	131.3
4	120	94	100	113.5	88	87.5	102.8	104	77	90	131.3
5	120	98	100	113.5	95	87.5	102.8	104.2	78.5	90	131.3
6	120	107	100	113.5	106	87.5	102.8	104.2	78.5	90	131.3
7	135.5	117.5	100	113.5	109	91.5	104.1	104.2	79	90	131.3
8	135.5	133.5	100	113.5	110.5	91.5	104.3	104.2	79	90	131.3

Annex I. Page 2. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	9/18/1963	10/24/1964	12/27/1965	9/29/1966	12/20/1967	6/5/1968	5/29/1969	3/29/1970	11/16/1971	8/20/1971	6/19/1972
Time											
8	4	4.2	9.3	1	6.3	4.5	2.4	2.5	5.3	7	4
9	4	4.2	9.3	1	6.3	4.5	2.4	2.5	5.3	7	4
10	4	4.2	9.3	2	6.3	30	2.4	2.5	5.3	7.5	4
11	4	4.2	9.3	2.5	6.3	110	2.4	2.5	5.3	21	6.5
12	4	4.2	9.3	2.5	6.3	210	2.4	2.5	5.3	26.5	9
13	4	4.2	9.3	2.5	6.3	250	8.5	2.5	5.3	34	10
14	4	4.2	9.3	3.5	6.3	273	8.5	2.5	5.3	39	21
15	4	77.5	9.3	3.5	6.3	273	8.8	50	5.3	40	60
16	4	78.3	9.3	6	6.3	273	11.3	80	5.3	110	80
17	4	78.3	40	6	6.3	274	13.4	95	5.3	160	91.5
18	4.3	78.3	111	8.5	70	274	14.7	96.5	80	180	96.5
19	4.5	78.3	124.8	16	110	274.5	18.5	97	120	185.5	96.5
20	5.3	78.3	129	17.5	119.2	275.5	22	97	129.2	185.2	96.5
21	20	78.3	129.7	17.5	120	278.5	46	97	130.2	186.5	96.5
22	52	79.3	130.5	17.5	125.5	278.7	98	97	130.2	187.6	96.5
23	73	82.3	130.5	28.5	127.6	278.7	145	97	130.2	187.7	96.5
24	78	87.5	130.5	30	127.6	278.7	164	97	130.2	187.8	96.5
1	91.5	88.5	130.5	40	127.6	278.7	187.2	97	130.3	187.8	96.5
2	105.3	88.5	130.5	71.5	127.6	279	187.7	97	130.3	187.8	96.5
3	105.6	88.5	130.5	80	127.6	279	188	97	130.3	188.5	96.5
4	105.7	88.5	130.5	104	127.6	279	197	97	130.4	188.7	96.5
5	106.5	88.5	130.5	110	127.7	279	200.2	97	130.4	188.8	96.5
6	122.5	88.5	130.5	111.5	127.7	280.5	200.2	97	130.4	188.8	96.5
7	140	88.5	130.5	111.5	127.7	280.7	200.2	97	130.4	188.8	96.5
8	143	88.5	130.5	111.5	127.7	280.7	200.2	97	130.4	188.8	96.5

Annex I. Page 3. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	11/1/1972	3/28/1973	4/27/1974	5/7/1975	10/10/1975	5/22/1976	12/1/1976	11/15/1977	8/14/1978	9/26/1979	5/29/1981
Time											
8	8.5	5	1.5	2.3	0.5	2	6	9	20	2.5	5
9	8.5	5	1.5	2.3	0.5	2	6	9	20	2.5	5
10	8.5	5	1.5	4	0.5	2	6	9	40	2.5	5
11	8.5	5	1.5	4	0.5	2	6	9	60	3.5	8
12	8.5	5	1.5	10	0.5	2	6	9	90	6.5	11.5
13	8.5	5	1.5	44	10	2	6	9	91.5	7	11.5
14	8.5	5	1.5	70	20	2	6	20	140	20	11.5
15	13	5	1.5	107	30.5	2	6	70	162	41	27
16	60	5	1.5	117	31.5	18	6	73	197.5	57	28.2
17	88.5	20	1.5	122.5	33.5	48	6	73	214	57.5	30
18	90	75.5	2	123.8	39	55	10	75	218	61.5	33
19	90	77	5.5	125.5	40.5	80	70	76	218	61.5	37.5
20	90	81	5.5	130	41	90.5	74.5	76	218	61.5	43
21	92.5	84	5.5	156	41	94	75.5	76	218	61.5	49
22	94	86.5	5.5	180	41	95.8	75.5	76	218	61.5	55
23	94	88.5	5.5	197.3	41	101	75.5	76	218	67.5	57
24	94	90	5.5	200	44.5	108	75.5	76	218	69.5	61
1	94	90	5.5	202.5	46	116	75.5	76	218.5	69.5	65
2	94	90	20	205.2	46	118	75.5	76	218.5	70	68
3	94	90	80	205.3	46	160	75.5	76	236.4	77	69
4	94	90	121	205.3	46	166.5	75.5	76	238.5	86	69
5	94	90	123	205.4	64.5	167.2	75.5	76	248	93	72
6	94	90	124.3	205.5	90	170	75.5	76	252	110	72
7	94	90	124.5	205.5	100	172.5	75.5	76	281	120	72
8	94	90	124.5	205.5	103.5	174	75.5	76	284.5	129	72

Annex I. Page 4. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	8/7/1982	4/29/1982	5/17/1983	5/29/1984	10/24/1985	5/15/1987	6/2/1988	6/3/1989	3/15/1990	10/26/1990	5/29/1991
Time											
8	1.5	0.5	5.5	10	2.5	6	6	8.5	4	5.5	4
9	1.5	0.5	5.5	10	2.5	6	6	8.5	4	5.5	4
10	1.5	0.5	5.5	10	2.5	6	7.5	8.5	4	5.5	4
11	1.5	0.5	5.5	10	2.5	6	22.5	8.5	4	5.5	4
12	9	0.5	5.5	15.5	2.5	6	41.6	18	4	6.5	4
13	27.5	1	5.5	20	2.5	6	61.3	33	4	32.5	4
14	35	5	5.5	33	2.5	6	86	38	4	34	4
15	37.2	50	5.5	50	2.5	6	111.5	38	4	36	4
16	38.1	71	5.5	62	6	6	140	38	4	61.5	4
17	38.5	76	5.5	84	60	6	165.5	38	44	62.5	4
18	39	88	8.5	87	86	50	195.6	68	44	62.5	4
19	39	91	9	91	86	53	203.5	85	44	62.5	4
20	40.5	95	10	94	86	55	221.5	100	44	63	4
21	40.5	98	10	95	86	55	223.5	114	44	70	4.5
22	40.5	98	60	95	86	55	224	118	44	90	4.5
23	40.5	98	73	95	86	55	228.5	118	44	94	4.5
24	50	98	73	95	86	55	229	125	44	94	4.5
1	70	98	75	95	86	55	229.5	140	44	94	14
2	110	98	75	95.5	86	55	234	140	44	94	20
3	150	98	75	95.5	86	55	236.5	141	44	94	26
4	158	98	75	95.5	86	55	236.5	145	44	94	37
5	160	107	75	95.5	86	55	236.5	148	44	94	47
6	168	108	75	95.5	86	55	236.5	148	44	94	52
7	171	109	75	95.5	86	55	236.5	149	44	94	61
8	171	112	75	95.5	86	55	236.5	159	44	94	71

Annex I. Page 5. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	11/13/1992	10/22/1994	4/14/1995	10/7/1995	6/9/1996	5/13/1997	7/21/1997	5/2/1998	4/20/1999	2/29/2000	6/1/2000
Time											
8	8	6	4	2	0	4	10	0.5	0.5	8	3.5
9	8	6	4	2	0	4	10	0.5	0.5	8	8
10	8.5	6	4	7.5	0	4	10	0.5	0.5	8	10.3
11	8.5	6	4	8	0	4	10	0.5	0.5	8	14.5
12	9	6	4	8.5	0.2	4	13.5	0.5	0.5	8	15
13	10	6	4	9.5	0.5	4	13.5	0.5	0.5	8	15
14	10.2	6	4	11	17.5	4	14	0.5	0.5	8	15
15	17	6	4	11	40	40	14	0.5	0.5	8	15
16	25	6	4	11	40	90	14	0.5	0.5	8	15
17	34.5	6	5.5	19	59.5	92.5	14.5	0.5	0.5	8	15
18	60	70	6	19	60	93	14.5	0.5	0.5	30	15
19	78	96	60	21	90	93	17.5	0.5	3.5	80	15
20	80	96	90	21	140	100	35.5	100.5	4.5	81	15
21	90	96	96	40	158	103.5	57.5	122	7.5	85.5	15
22	95.5	96	96.5	42.5	185	105	77.5	122	7.5	86	15.25
23	97	96	96.5	42.5	230	105	110.5	122	7.5	86	15.25
24	97.5	96	96.5	42.5	287.5	105	115	122	7.5	86	15.25
1	99.5	96	96.5	44.5	330.5	105	139	122	20	86	20
2	101	96	96.5	46.5	333	105	143.5	122	60	86	40
3	101.5	96	96.5	57	340	105	148.5	122	133	86	60
4	102	96	96.5	60	340.5	105	158.5	122	170	86	62.25
5	102.5	96	96.5	70	340.5	105	172	122	210	86	70
6	102.5	96	96.5	87.5	340.5	105	176	122	220	86	91.5
7	106.2	96	96.5	114	340.5	105	180	122	230	86	92
8	107	96	96.5	118	340.5	105	180	122	231	86	112

Annex I. Page 6. Hourly Rainfalls extracted from Pluviographs of Ratnapura Meteorological Station

Date =>	11/22/2001	10/30/2002	10/20/2002	5/17/2003	2/1/2004
Time					
8	0	6	0	0	6
9	0	6	0	2.5	6
10	0	6	0	20	6
11	0	6	10	30	6
12	0	6	19	53.5	6
13	0	6	25	74	6
14	0	6	25	150	6
15	0	66	25	260	6
16	0	66	25	307	6
17	0	66	25	318	6
18	10	66	25	330	6
19	50	66	25	331	6
20	90	66	25	339	6
21	90	66	25	340	6
22	90	66	25	344.5	6
23	90	66	25	344.5	54
24	90	66	25	344.5	54
1	90	66	32	347	54
2	90	66	40	347	54
3	90	66	48	347	54
4	90	66	48	347	54
5	90	66	60	347	54
6	90	66	60	347	54
7	90	66	60	347	54
8	90	66	60	347	54

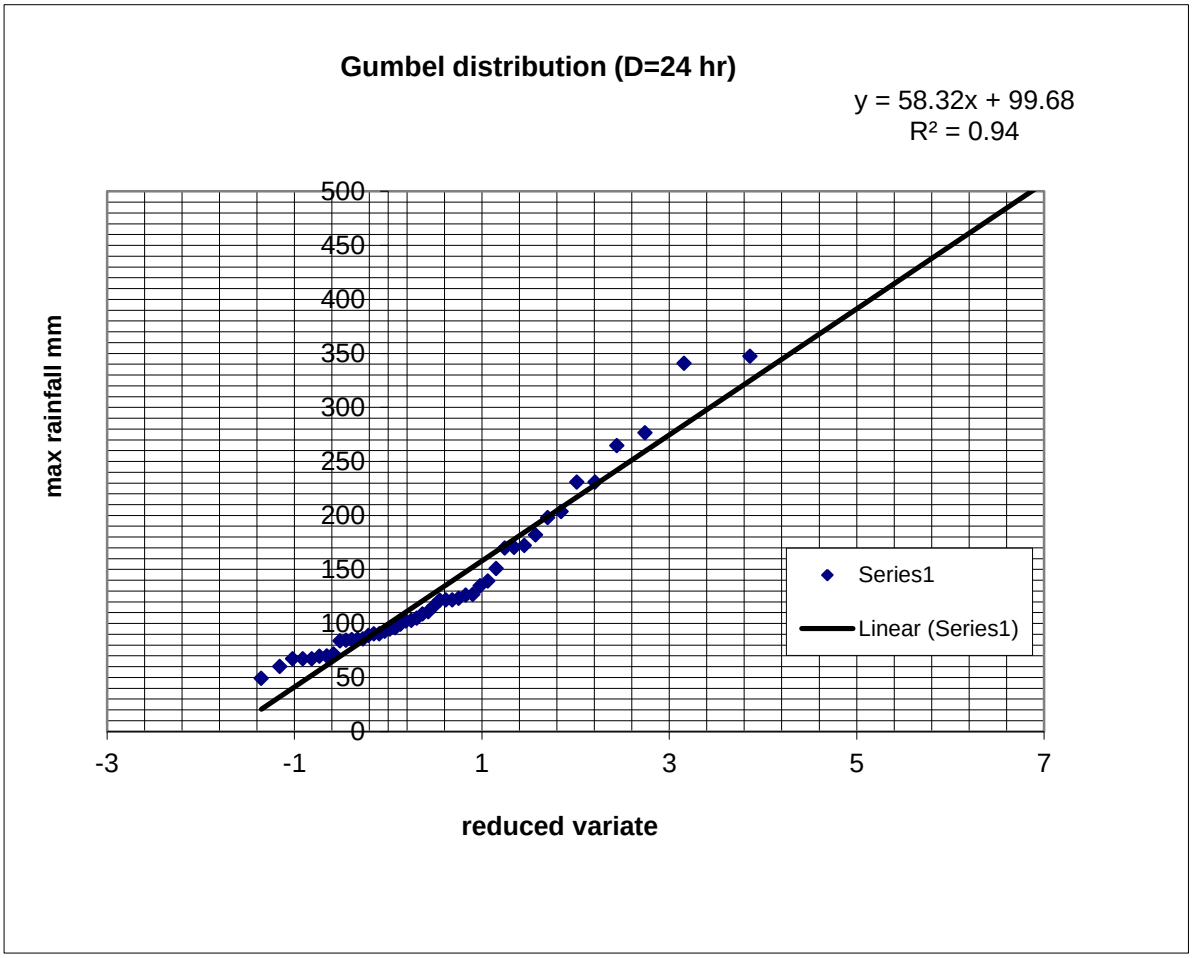
Annex II. Annual Maximum Rainfalls with respect to Partial Durations

Year	Duration (hr)										
	1	2	3	4	5	6	8	10	12	18	24
1955	41.5	62.5	96.0	104.5	110.5	110.5	111.5	114.0	115.0	131.0	134.5
1956	25.0	30.0	35.5	39.5	41.0	46.0	57.0	63.5	77.5	102.5	126.0
1957	27.5	53.3	64.3	65.8	65.8	90.3	95.8	95.8	95.8	95.8	95.8
1958	79.5	92.0	99.5	103.5	103.5	103.5	103.5	103.5	104.5	104.5	104.5
1959	29.0	44.5	51.0	64.5	71.5	74.5	76.0	76.0	80.5	99.5	102.0
1960	33.7	46.7	62.4	75.4	77.4	93.4	98.0	98.2	100.0	102.6	102.6
1961	15.0	28.0	33.0	34.0	36.0	36.5	38.5	44.5	47.5	69.5	71.5
1962	14.0	20.0	26.0	30.2	36.5	43.0	43.0	46.0	57.0	84.7	84.7
1963	52.0	56.5	67.7	72.7	86.2	100.0	101.1	120.0	137.7	139.0	139.0
1964	73.3	74.1	74.1	74.1	74.1	74.1	75.1	83.3	84.3	84.3	84.3
1965	71.0	101.7	115.5	119.7	120.4	121.2	121.2	121.2	121.2	121.2	121.2
1966	31.5	41.5	64.0	74.0	80.0	86.5	94.0	95.5	104.0	109.0	110.5
1967	63.7	103.7	112.9	113.7	119.2	121.3	121.3	121.3	121.4	121.4	121.4
1968	100.0	180.0	220.0	245.5	268.5	268.5	269.5	270.0	274.0	274.5	276.2
1969	52.0	99.0	123.0	142.0	165.2	168.7	175.0	182.3	186.8	197.8	197.8
1970	47.5	77.5	92.5	94.0	94.5	94.5	94.5	94.5	94.5	94.5	94.5
1971	74.7	120.0	140.0	145.5	146.5	153.5	172.5	178.5	180.1	181.5	181.8
1972	47.0	75.5	80.0	81.5	86.5	87.5	92.5	92.5	92.5	92.5	92.5
1973	55.5	70.5	72.0	76.0	79.0	81.5	85.0	85.0	85.0	85.0	85.0
1974	60.0	101.0	115.5	117.5	118.8	119.0	119.0	119.0	122.3	123.0	123.0
1975	37.0	63.0	97.0	107.0	113.0	118.5	121.5	170.0	193.3	203.0	203.2
1976	60.0	64.5	68.5	78.0	88.5	92.0	99.0	114.0	158.0	172.0	172.0
1977	50.0	61.0	64.0	64.0	66.0	67.0	67.0	67.0	67.0	67.0	67.0
1978	48.5	70.5	106.0	122.5	137.5	157.5	194.0	198.0	198.0	216.4	264.5
1979	21.0	37.0	50.0	50.5	54.5	59.0	59.5	67.5	67.5	113.0	126.5
1981	15.5	16.7	18.5	22.0	26.0	31.5	43.5	49.5	56.5	64.0	67.0
1982	45.0	80.0	100.0	109.5	117.5	119.5	130.5	130.5	132.0	159.0	169.5
1983	50.0	63.0	63.0	65.0	65.0	67.5	69.5	69.5	69.5	69.5	69.5
1984	22.0	34.0	51.0	64.0	68.5	74.0	81.0	85.0	85.0	85.5	85.5
1985	54.0	80.0	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5
1987	44.0	47.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
1988	30.1	55.6	84.1	109.6	134.3	154.0	188.1	214.0	217.5	230.5	230.5
1989	30.0	47.0	62.0	76.0	80.0	80.0	102.0	105.5	110.0	139.5	150.5
1990	40.0	40.0	40.0	55.0	56.0	57.0	58.0	83.5	88.5	88.5	88.5
1991	11.0	21.0	27.0	35.0	45.0	51.0	66.5	66.5	67.0	67.0	67.0
1992	25.5	43.5	53.0	61.0	67.8	73.0	85.3	87.3	90.8	96.8	99.0
1994	64.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1995	54.0	84.0	90.0	90.5	92.0	92.5	92.5	92.5	97.0	107.0	116.0
1996	57.5	102.5	145.5	172.5	197.5	240.5	273.0	293.0	330.0	340.5	340.5
1997	50.0	86.0	88.5	93.0	103.5	121.5	131.0	154.5	162.5	166.5	170.0
1998	100.0	121.5	121.5	121.5	121.5	121.5	121.5	121.5	121.5	121.5	121.5
1999	73.0	113.0	150.0	190.0	202.5	212.5	223.5	223.5	226.5	230.5	230.5
2000	50.0	72.0	73.0	77.5	78.0	78.0	96.8	96.8	97.0	97.0	108.5
2001	40.0	80.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
2002	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
2003	110.0	186.0	233.0	253.5	277.0	288.0	315.5	330.0	339.0	347.0	347.0
2004	50.0	63.0	65.0	65.0	66.0	66.0	66.0	66.0	66.0	66.0	69.7

Annex III. **Frequency Analysis, Ratnapura Met. Station**
Annual Maximum Rainfall, 24 hr Duration

Rank	Year	Rainfall (mm)	Rainfall in descending order	P=m/(n+1) where p-probability of exceeding, m - rank, n- number of obsevations	Return Period (T)=1/p, years	q (Probability of non-exceedence) = (1-P)	Y (Reduced Variate) = -Ln(-Ln(q))
1	1955	134.5	347.0	0.02	48	0.98	3.86
2	1956	126.0	340.5	0.04	24	0.96	3.16
3	1957	95.8	276.2	0.06	16	0.94	2.74
4	1958	104.5	264.5	0.08	12	0.92	2.44
5	1959	102.0	230.5	0.10	10	0.90	2.21
6	1960	102.6	230.5	0.13	8	0.88	2.01
7	1961	71.5	203.2	0.15	7	0.85	1.85
8	1962	84.7	197.8	0.17	6	0.83	1.70
9	1963	139.0	181.8	0.19	5	0.81	1.57
10	1964	84.3	172.0	0.21	5	0.79	1.45
11	1965	121.2	170.0	0.23	4	0.77	1.35
12	1966	110.5	169.5	0.25	4	0.75	1.25
13	1967	121.4	150.5	0.27	4	0.73	1.15
14	1968	276.2	139.0	0.29	3	0.71	1.06
15	1969	197.8	134.5	0.31	3	0.69	0.98
16	1970	94.5	126.5	0.33	3	0.67	0.90
17	1971	181.8	126.0	0.35	3	0.65	0.83
18	1972	92.5	123.0	0.38	3	0.63	0.76
19	1973	85.0	121.5	0.40	3	0.60	0.69
20	1974	123.0	121.4	0.42	2	0.58	0.62
21	1975	203.2	121.2	0.44	2	0.56	0.55
22	1976	172.0	116.0	0.46	2	0.54	0.49
23	1977	67.0	110.5	0.48	2	0.52	0.43
24	1978	264.5	108.5	0.50	2	0.50	0.37
25	1979	126.5	104.5	0.52	2	0.48	0.31
26	1981	67.0	102.6	0.54	2	0.46	0.25
27	1982	169.5	102.0	0.56	2	0.44	0.19
28	1983	69.5	99.0	0.58	2	0.42	0.13
29	1984	85.5	95.8	0.60	2	0.40	0.08
30	1985	83.5	94.5	0.63	2	0.38	0.02
31	1987	49.0	92.5	0.65	2	0.35	-0.04
32	1988	230.5	90.0	0.67	2	0.33	-0.09
33	1989	150.5	90.0	0.69	1	0.31	-0.15
34	1990	88.5	88.5	0.71	1	0.29	-0.21
35	1991	67.0	85.5	0.73	1	0.27	-0.27
36	1992	99.0	85.0	0.75	1	0.25	-0.33
37	1994	90.0	84.7	0.77	1	0.23	-0.39
38	1995	116.0	84.3	0.79	1	0.21	-0.45
39	1996	340.5	83.5	0.81	1	0.19	-0.52
40	1997	170.0	71.5	0.83	1	0.17	-0.58
41	1998	121.5	69.7	0.85	1	0.15	-0.66
42	1999	230.5	69.5	0.88	1	0.13	-0.73
43	2000	108.5	67.0	0.90	1	0.10	-0.82
44	2001	90.0	67.0	0.92	1	0.08	-0.91
45	2002	60.0	67.0	0.94	1	0.06	-1.02
46	2003	347.0	60.0	0.96	1	0.04	-1.16
47	2004	69.7	49.0	0.98	1	0.02	-1.35
Mean		131.6	mm				
Standerd dev.		70.2	mm				

Annex III. Page 2



Equations of trend line : Y = 58.32X + 99.68

T (yr)	P	q, (1-p)	y, Reduced Variate	Max. Rainfall (mm)
2	0.5	0.5	0.37	121
5	0.2	0.8	1.50	187
10	0.1	0.9	2.25	231
25	0.04	0.96	3.20	286
50	0.02	0.98	3.90	327
100	0.01	0.99	4.60	368
200	0.005	0.995	5.30	409

Storm Duration = 24 hr