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Analysis of Rainfall Data and Design of Storm Water Drainage System in an Urban Area

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ABSTRACT

Rainfall data available from 1969 to 1983 are with duration of 5,10,15,30,45,60,75,90 minute. And analysis rainfall data is carried for year 1969 to 1983 and one year flood frequency is calculated. Latest rainfall data of 2001 to 2010 are available with duration of 60 minute and other minute's data are found by correlating with past data and one year flood frequency of latest data of 2001 to 2010 is calculated. Rational method is used for estimating runoff from catchment. Different curves of rainfall intensity vs duration, runoff coefficient vs duration, 10Ci vs duration are derived for city of Surat. And design of drain is carried with help of Manning's chart in study area.

KEYWORDS: Rainfall, Runoff , Storm water

Introduction

The design of the storm water drainage system is based on the estimation of quantity of runoff. Various methods are available for estimation of quantity of runoff.

1. Rational Method
2. Rainfall-Runoff Correlation Studies
3. Empirical Formula Method
4. Hydrograph Method
5. In our research work Rational Method is used it is also sug gested in CPHEEO Manual published by central government.

The design of storm sewers involves a decision as to the degree of protection to be provided against property damage, nuisance and inconvenience from surcharged sewers . It is not economically feasible to construct sewers of sufficient size to take the runoff from the extreme storms likely to occur at infrequent intervals i.e. storm sewers are not designed for the peak flow of rare occurrence. Thus, the quantity of storm water for which sewer capacity should be provided is a balance among the first cost and capitalized damage to private property, the hazard to health, and the curtailed convenience to the public .These factors, therefore , should be given consideration as well as technical hydraulic factors.

Study Area

Althan Bhimrad area of Surat City is selected as study area for which rainfall analysis of Surat City is carried out by collecting data from year 1969 to 1983 and 2001 to 2010 and Design of Drains for Althan Bhimrad area is calculated. In Althan Bhimrad area of Surat City no storm water drainage facility is existing , the storm water is disposed by natural drains and this area get frequently flooded during monsoon and thereby causes inconvenience to residents. Althan Bhimrad Area T.P 43 lies in South West Zone in SMC.

The area of South-West Drainage zone is about 2608 hectares and is covered by following drainage boundaries

North : River Tapi
East : South Drainage Zone
South : River Mindhola
West : Arabian Sea

Design Principles

The prime governing factor for design of storm water drainage system for an urban area is storm-runoff. Storm runoff is that portion of precipitation which drains over the ground surface. Estimation of such runoff reaching the storm sewers, therefore, is dependent on intensity and duration of precipitation, characteristics of tributary area, and time required for such flow to reach the sewer.

1).Estimate Of Storm Run-Off

Rational method is used for estimating runoff from catchment. This method is discussed in detail in following paragraphs Runoff-rainfall intensity Relationship: The entire precipitation over the drainage district does not reach the sewer. The characteristics of the drainage district such as imperviousness, topography including depressions and water pockets, shape of drainage basin and duration of the precipitation which will reach the sewer. This fraction known as coefficient of runoff needs to be determined for each drainage district. The runoff reaching the sewer is given by the expression: Q = 10 C i A

where Q is the runoff in m3/hr;C is the coefficient of runoff;i is the intensity of rainfall in mm/hr;A is the area of drainage district in hectare.

2).Storm frequency

Manuals on sewerage and sewage treatment has suggested following frequency of flooding in different areas (Table 1).Our study area is Central and comparatively low priced area so our flood frequency will be once in year.

TABLE – 1 Frequency of flooding in different areas

(a)	Residential areas	
	(I(i) peripheral area	twice a year
	(ii) Central and comparatively high low priced area	once a year
(b)	Commercial and high priced areas	once in 2 years

3). Intensity of Precipitation

Intensity of the rainfall decreases with the duration. Analysis of past records over a period of years of the observed data on intensity duration of rainfall in the area is necessary to arrive at a fair estimate of intensity duration for given frequencies. The longer the record available more dependable is the forecast.

The relationship may be expressed by suitable mathematical formula given in CHPEEO

The following equation is commonly used

$i = a/t^n$ Where i = intensity of rainfall (mm/hr), t = duration of storm (minutes) and a, b and n are constant.The available data on i and t are plotted are called rainfall intensity duration curve. The values of intensity, (i) can then be determined for any given time of concentration, (t_c).

4). Time of Concentration

It is the time required for the rain water to flow over the ground

surface from the extreme point of the drainage basin and reach the point under consideration. Time of concentration (t c) is equal to inlet time (t i) plus time of flow in sewer (t f). The inlet time is dependent on the distance of the farthest point in the drainage basin to the inlet manhole, the shape, characteristics and topography of the basin.The time of inlet can be obtained from the formula as suggested by IRC which is given below:

$$t_i = (0.87 \frac{L^3}{H})^{0.385}$$

Where t i - time of entry in hours ; L - Length of critical point of catchment area to starting of the section in Kms ;H - fall in level from critical point to starting of section in meter

And time of flow can be obtained from the single relation as given below:

$$t_f = \frac{L}{V \cdot 60}$$

Where L - length of drain proceeding the section under consideration in meters;V - velocity in meter per sec.

5). Coefficient of Runoff

The longer the storm duration, larger may be the percentage of rainfall runoff. The proportion of pervious and imperious areas probably affects the runoff as much as any other factor. In designing storm sewers, a practical procedure includes a reasonable estimate of the probable future percentage of impervious area. Different factor used for computation of runoff coefficient is discussed in following paragraphs.

(A) Imperviousness: Estimates of the relative proportion of pervious and impervious area can be made by considering the present development of a number of typical areas in the more completely developed sections of the city for which sewers are to be designed and comparing these with the anticipated future development of the districts to be sewered. Manual on sewerage and sewage treatment has recommended the values of percent imperviousness for different areas as given in Table-2 below:

TABLE -2 Guidelines for imperviousness factors of drainage area

No.	Type of Area	Percentage of imperviousness
1	Commercial and industrial area	70 to 90
2	Residential area	
	(a) High density	60 to 75
	(b) Low density	35 to 60
3	Parks and other undeveloped area	10 to 20

The weighted average imperviousness of drainage basin for the flow concentrating at a point may be estimated as:

I= $\frac{A_1 I_1 + A_2 I_2 + \ldots}{A_1 + A_2 + \ldots}$

I = Weighted average imperviousness of the total drainage basin; A1, A2, …An = Drainage area tributary to the section of drain under consideration; I1, I2, …… In = Imperviousness of the respective areas.

(B) Computation of run off-coefficient:The weighted average runoff coefficient for rectangular areas of length four times the width as well as for sector shaped areas with varying percentage of impervious surface for different time of concentration are calculated from Horner Table given CPHEEO. Although these are applicable to particular shapes of area, they also apply in general way to areas which are usually encountered in practice.

Design Considerations

1). Self Cleansing Velocity: It is necessary to maintain a minimum velocity or "self cleansing velocity" in sewer to ensure that suspended solids do not deposit and cause nuisance. Manual on sewage treatment has recommended 0.8 mps at design peak flow.

2).Velocity at Minimum Flow: To avoid steeper gradient which will require deeper excavations it is a practice to design storm drains for self cleansing velocity at peak flow as calculated from rational method. This is done on the assumption that although silting might occur at minimum flow, the silt would be flushed out during the peak flows.

3). Erosion and Maximum velocity: Erosion of sewers is caused by sand and other gritty material in the sewer and also by excessive velocity, velocity in a sewer is recommended not to exceed 3.0 mps as recommended by manual on sewerage and sewage treatment 19.

5).Hydraulic Formulae: Usually sewers are considered as open channels in the selection of hydraulic formulae. The Kutter and Manning's formula have been widely used in designing slope and diameter of sewer line to carry the design flow at a stated velocity for open channel flow condition. The Manning formula has increased use in recent years because of its simplified form and relative ease of use and more commonly used. Hence Manning's Chart is used for designing.

6).Depth of flow: Storm sewers are generally designed to run full. But from considerations of ventilation in waste water flow the sewers should not be designed to run full.

Analysis of Rainfall Data

The flooding of the Althan Bhimrad area is quite common during the monsoon. This part of area gets flooded even when there is rainfall for one hour. This area is yet not considered for design of storm water drainage by Surat Municipal Corporation, this area falls in TP Scheme 43. Therefore, Althan bhimrad area of the Surat has been selected for design of storm water drainage system. Data collection analysis are presented here.

Analysis of maximum rainfall intensity for 5,10,15,30,45,60,75 and 90 minute duration for the period of 1969 to 1983 for the city of Surat are calculated.

Analysis of maximum rainfall intensity for 60 minute duration for the period of 2001 to 2010 for the city of Surat are done and new rainfall pattern is obtained by correlating old data because only hourly data are available nowadays .

Table 3 Analysis of frequency of storm of stated intensities and duration for period of 15 year (1969 to 1983)

Duration in min	No. of storms of stated intensity in mm/hr												
	25	30	35	40	45	50	60	70	75	80	90	100	120
5							63	31	19	13	9	3	2
10						65	26	13	11	5	4	4	1
15						55	36	22	15	14	7	2	
30				45	33	28	17	8	5	5	1		
45				26	19	15	9	4	1	1			
60			25	20	14	10	5	2					
75		19	14	11	8	6	1						
90	17	15	9	7	4	3							

Table 3 and Table 5 gives the analysis of the frequency of storms of stated intensities and durations during 1969 to 1983 (15 year) and 2001 to 2010 (10 year) for which rainfall data are available for the city of Surat respectively.The storm occurring once in a year i.e. 15 times in 15 years has been found. The time intensity value for this frequency has been obtained by interpolation and given in Table 4 and Table 6

Table 4 Time intensity values for one year flood frequency for year 1969 to 1983

Duration 't' in minutes	Intensity 'i' in mm/hr
5	78.33
10	68.46
15	75.00
30	62.22

45	50.00
60	44.16
75	34.00
90	30.00

The above data are plotted on graph paper (fig.1) known as rainfall intensity duration curve for one year flood frequency is obtained.

Fig 1 Rainfall intensity duration curve for one year flood frequency for year 1969 to 1983

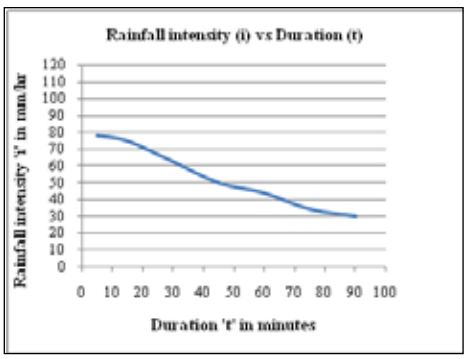


Table 5 Analysis of frequency of storm of stated intensities and 60 minute duration for period of 10 year (2001 to 2010)

Duration	No. of storms of stated intensity												
	25	30	35	40	45	50	60	70	75	80	90	100	120
60	66	44	34	26	18	15	6	3	3	2	2	1	

Table 6 Time intensity values for one year flood frequency for year 2001 to 2010

Duration 't' in minutes	Intensity 'i' in mm/hr (2001 to 2010)
5	98.69
10	86.25
15	94.50
30	78.39
45	63.00
60	55.64
75	42.84
90	37.80

Fig 2 Rainfall intensity duration curve for one year flood frequency for year 2001 to 2010

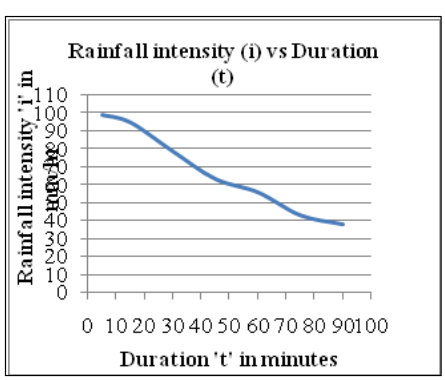
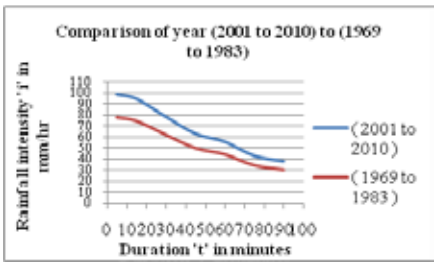


Table 7 Comparison of Time intensity values for one year flood frequency for year (2001 to 2010) to (1969 to 1983)

Duration 't' in minutes	Intensity 'i' in mm/hr (2001 to 2010)	Intensity 'i' in mm/hr (1969 to 1983)
5	98.69	78.33
10	86.25	68.46
15	94.50	75.00
30	78.39	62.22
45	63.00	50.00
60	55.64	44.16
75	42.84	34.00
90	37.80	30.00

Fig 3 Comparison of Rainfall intensity duration curve for one year flood frequency for year (2001 to 2010) to (1969 to 1983)



Computation of Constants for Equation of Rainfall Intensity Curve suggested by CPHEEO :
The constant a and n in the rainfall equation
$i = a/t^n$, where a and n are constants and t is the duration of storm has been computed. Logarithm graph is prepared considering the values of intensity (2001 to 2010).
Constants are calculated by putting values of rainfall intensity in log equation .

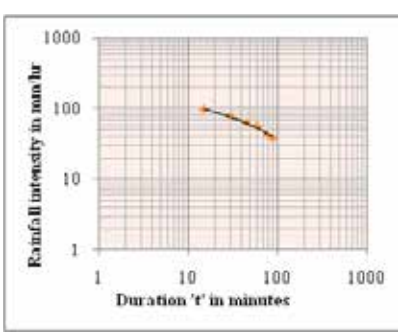
log 88 = log a – (n × log 20)…1 (t=20, i =88)
log 59 = log a – (n × log 50)….2 (t=50, i=59)
0.17 = n × 0.398

n = 0.43

Putting the value of 'n' in above equation 1

1.94 = log a – 0.43 × 1.301
log a = 2.50
a = 316

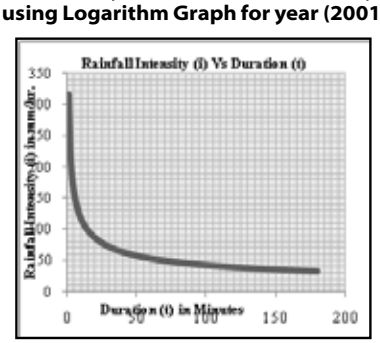
Fig 4 **Logarithm Graph of Rainfall intensity duration curve for one year flood frequency for year (2001 to 2010)**



By putting value of constants in equation we get rainfall intensity curve at any duration , and values.

$i = a/t^n$

Fig 5 Rainfall intensity duration curve for one year flood frequency using Logarithm Graph for year (2001 to 2010)

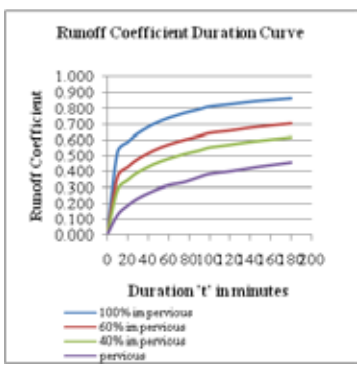


Calculation of Runoff Coefficient

Graph of runoff coefficient 'C' Vs duration time 't' is plotted as per values given in CPHEEO (Horner table) .

These curves is useful in getting rate of runoff per hectare of area for different duration of storm. The runoff coefficient increases as duration increases and runoff coefficient decreases as percent imperviousness decreases

Fig 6 Graph is obtained of Runoff Coefficient Vs Duration curve with different curves of Pervious , 40% impervious , 60% impervious , 100% impervious with help of Horner's Table.



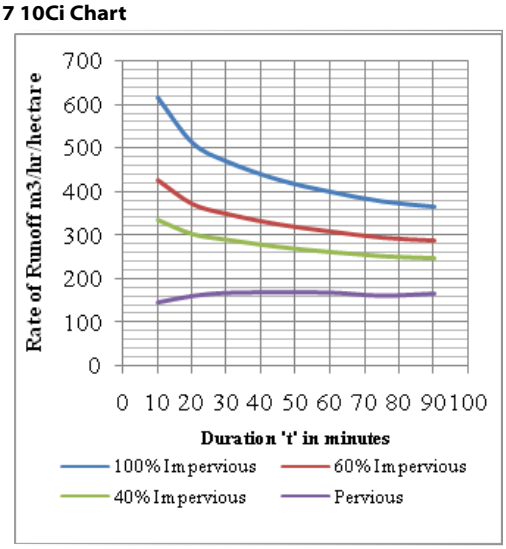
Calculation 10ci

Runoff coefficient vs. duration plotted by multiplying runoff coefficient with rainfall intensity . The values obtained by multiplying is presented in Table 8 and from this table curve is plotted. These curves is useful in getting rate of runoff per hectare of area, for different duration of storm. The runoff coefficient increases as duration increases and runoff coefficient decrease as percent imperviousness decreases.

Table 8
Values of 10 Ci (Rate of runoff in m3/hr/ha for different duration of time)

Duration time	Values of 10 Ci in m3/hr/ha			
	100% Impervious	60% Impervious	40% Impervious	Pervious
10	614.25	427.05	333.45	146.25
20	511.56	371.49	301.22	160.95
30	468.66	348.21	288.35	167.90
45	427.00	323.91	272.06	168.97
60	399.60	307.26	260.28	168.48
75	377.79	293.02	250.88	161.70
90	365.70	286.12	246.10	166.52

Fig 7 10Ci Chart



Computation of Imperviousness Factor

The percentage of impervious of the drainage basin area can be obtained from the records of a particular district or zone. However, in absence of such data, the following may serve as a guide, as per CPHEEO "Manual on Sewerage and Sewage Treatment" (2nd edition), New Delhi. These are reproduced in Table.

TABLE –9 Guidelines for imperviousness factors of drainage area

No.	Type of Area	Percentage of imperviousness
1	Commercial and industrial area	70 to 90
2	Residential area	
	(a) High density	60 to 75
	(b) Low density	35 to 60
3	Parks and other undeveloped area	10 to 20

The weighted average imperviousness of the drainage basin for the flow concentrating at a point may be estimated as Built up Area and Open Area.The total drainage basin under consideration is divided into 2 parts i.e.

- Built-up area = 60% of total area; which may contain buildings, terraces, roofs, footpaths, roads etc.
- Open area = 40% of the total area; which may contain open ground, parks and gardens, lawns or any underdeveloped area.
- The imperviousness of the built-up area at the end of design period is considered as 90% i.e. impervious factor 0.9.
- Similarly, the imperviousness of the open area at the end of design period is considered as 20% i.e. impervious factor 0.2

Therefore, total weighted average imperviousness of the area will be

$$I = \frac{0.9\times60+0.2\times40}{60+40} = \frac{54+8}{100} = 0.62$$

DESIGN OF DRAINS

The Althan Bhimrad area of Surat has been considered for design storm water drainage system of T.P.Scheme 43. The design is based on the rational formula for the estimation of peak runoff. Following assumptions have been made

Imperviousness factor = 0.62
Minimum velocity in sewer = 1.0 mps

Rainfall Intensity is based on the one year storm flood frequency, as the area is central and comparatively low priced area. Quantity of storm water runoff is calculated using rational formula given in Section 4.2.1 Q = 10 CiA

Where Q is the runoff in m3 /hr , c is the coefficient of runoff, i is the intensity of rainfall in mm / hour, and A is the area of drainage district in hectares.Storm water runoff is determined in the following manner

I From rainfall records of last 15 year (1969 to 1983) and number of storm of various intensity for various time duration have been listed in Table- 3. The storm occurring once in a year i.e. 15 times in 15 years, the time intensity values for this frequency has been obtained by interpolation and are given in Table 4.

II From rainfall records of 10 year (2001 to 2010) and number of storm of various intensity for various time duration have been listed in Table- 5. By correlating old data we obtain the storm occurring once in a year i.e. 10 times in 10 years, the time intensity values for this frequency has been obtained by interpolation and are given in Table 6.

III Generalised formula adopted far intensity and duration is.

$$i = a/t^{n}$$

where i = intensity of rainfall (mm/hr),t = duration of storm (minutes) and a and n are constants. A logarithm Graph is obtained (Fig.4) from once in year rainfall intensity curve of year (2001 to

2010) and values of constant a and n for different time duration has been computed .

IV Another graph (Fig.6) of runoff coefficient 'C' vs duration time 't' is plotted as per values given in Horner Table in CPHEEO.

V From above graphs the values of c and i for the same duration time t are determined and the curves for 10 ci vs t for the various values of imperviousness are plotted (fig.7) with the help of Table-8. The value of 10 ci gives the rate of runoff in m3 /hr per hectare of the tributary area. These curves ultimately used in calculating the run-off from the tributary areas for a given time of concentration and imperviousness factor.

Results And Discussion

(i) In the rainfall intensity equation i = the values of constants a and n are computed for different rainfall intensity duration, from the rainfall data available for the city of Surat, the value of constants a and n for different rainfall intensity duration are given
a = 316
n = 0.43

(II) Using these constants a and n, the rainfall intensity for any duration may be computed.Plot between rainfall intensity and duration is generated (Fig.2) The values of rainfall intensity may be read directly for different duration of storm from this graph.

(iii) Plots between runoff coefficient and duration are given in Fig.6. The values of runoff coefficient for different duration and for 100%, 60%, 40% and 20%. Imperviousness may be directly read from these graphs.

(iv) Plots between rate of runoff and duration are given in Fig.7. The values of rate of runoff per hectare of area for different duration and for 100%, 60%, 40% and 20%. Imperviousness may be directly read from these curves.

(v) Design diameter, slope and profile of the storm water drains are calculated from Manning's Chart.

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