STORM WATER MANAGEMENT USING REMOTE SENSING AND GIS- A CASE STUDY OF SURAT CITY

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Abstract— Surat city is facing Storm water drainage problem due to increasing population and developmental activities. In the present study the existing layout of drainage system has been evaluated and planning and design of modified drainage system in part of the city area (Variyali bhagol) has been done. For this various thematic maps have been generated and collated with the rainfall data in GIS environment for suggesting modification of present drainage system to prevent water logging in the study area .IDF is a tool for planning, design and operation of water Resources projects such as storm water drainage system. With the help of this tool (IDF) relationship of rainfall has been established at central zone of Surat city from daily/24 hour's rainfall data using Gumbel distribution method. These relationships are useful in the design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures. Rational Method has been used for the calculation of storm water runoff. Diameter of the drainage system has been proposed using manning's formula. The propose modified drainage system using GIS technology will help in proper draining out of storm water from the study area.

Index Terms: IDF, GIS, and DEM, Flow lines in GIS, Storm Water Drainage System, and Design

I. INTRODUCTION

A violent disturbance of atmosphere with strong wind and usually rain, thunder or snow is called storm. Storm water is a term used to describe water that originates during heavy precipitation events. It may also be used to apply to water that originates with snowmelt or runoff water from overwatering that enters the storm water system. Storm water that does not soak into the ground becomes surface runoff, which either flows directly into surface waterways or is channeled into storm sewers, which eventually discharge to surface waters such as river. A storm drainage system is a network of structures, channels and underground pipes that carry storm water (rain water) to ponds, lakes, streams and rivers.

Adequate storm water drainage is very essential in the modern infrastructure of the city since it effects the roadway serviceability and usable life. If storm water logging at the some critical low lying areas occurs Hydroplaning becomes an important safety concern. Storm water drainage design for the peak rainy days involves providing facility that collect, transport and remove storm water from the low lying critical areas of Surat city. The design must also consider the storm water reaching in the lower critical level areas through natural stream flow on manmade ditches. In Surat city some critical location flooding occurs during monsoon season. It is that interval of time in which river Tapi flows under high flood condition also. According to location there are some types of flood occurs in city like arroyos flooding, river flooding and urban flooding.

Mainly the urban area is paved with roads etc. and the discharge of heavy rain cannot absorbed into the ground due to drainage constraints leads to flooding of streets, underpasses, low lying areas & storm drains when flood gates of river Tapi are closed. Critical locational storm water backflow from drains results serious traffic at intersection of the road and affects daily life of local public of this particular area

Surat city is facing Storm water drainage problem due to increasing population and developmental activities. In the present study the existing layout of drainage system has been evaluated and planning and design of modified drainage system in part of the city area (Variyali bhagol) has been done. For this various thematic maps have been generated and collated with the rainfall data in GIS environment for suggesting modification of present drainage system to prevent water logging in the study area

Factors affecting the quantity of storm water:

The surface run-off resulting after precipitation contributes the storm water. The factors affecting the quantity of storm water flow are as below:

1) Area of the catchment
2) Slope and shape of the catchment area
3) Porosity of the soil
4) Obstruction in the flow of water as trees, fields, gardens, etc.
5) Initial state of catchment area with respect to wetness.
6) Intensity and duration of rainfall
7) Atmospheric temperature and humidity
8) Number and size of ditches present in the area

Objective of the Study

- To assess existing storm water drainage system of central zone of Surat city.
- To design modified storm water drainage system of study area considering present and future need.

II. STUDY AREA

Surat City (21.1702°N and longitude 72.8311°E) is situated on the southern part of Gujarat which is a second largest city of the state. Surat city is second largest city of Gujarat in terms of Area and Population .Area of Surat city is 326.515 sq.km and population 44,66,826 (Census 2011).This city is divided in seven main zone such as central zone, East zone , west zone, north zone, south zone, south east zone, southwest zone. Central zone of Surat divided into 12 main wards having 19513 meters of storm water drainage network. The study area Variyali bhagol is located at North West of the central zone of city (Fig. 1). Tapi River is flowing through the city. Arabian Sea forms western boundary of Surat. The average annual rainfall of the city has been 1143 mm.

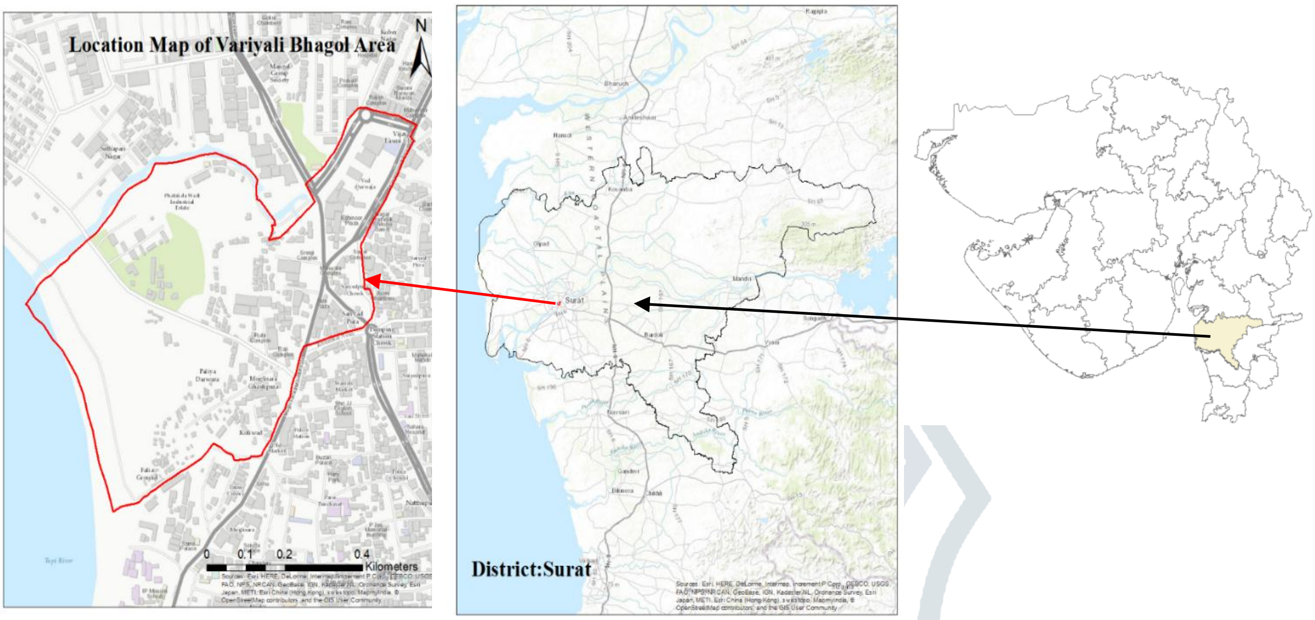

Figure.1: Location Map of Study Area

III. METHODOLOGY

- Collection of meteorological data from State Water Data Centre (SWDC) and administrative maps from Surat Municipal Corporation (SMC).
- Generation of thematic maps (Fig.2, Fig.3and Fig.4)
- Superimpose of various thematic maps such as Surface Map, Contour Map, Surface flow direction map, drainage map, slope map
- Analysis of Rainfall Data
- IDF curve derive from daily rainfall data for calculating peak discharge by Rational Method
- Analysis of spatial and non-spatial data
- Creation of sub-catchments
- Estimation of Peak discharge using rational method.
- Creation of modified Storm water drainage system
- Calculation of diameter of pipe by manning's formula.

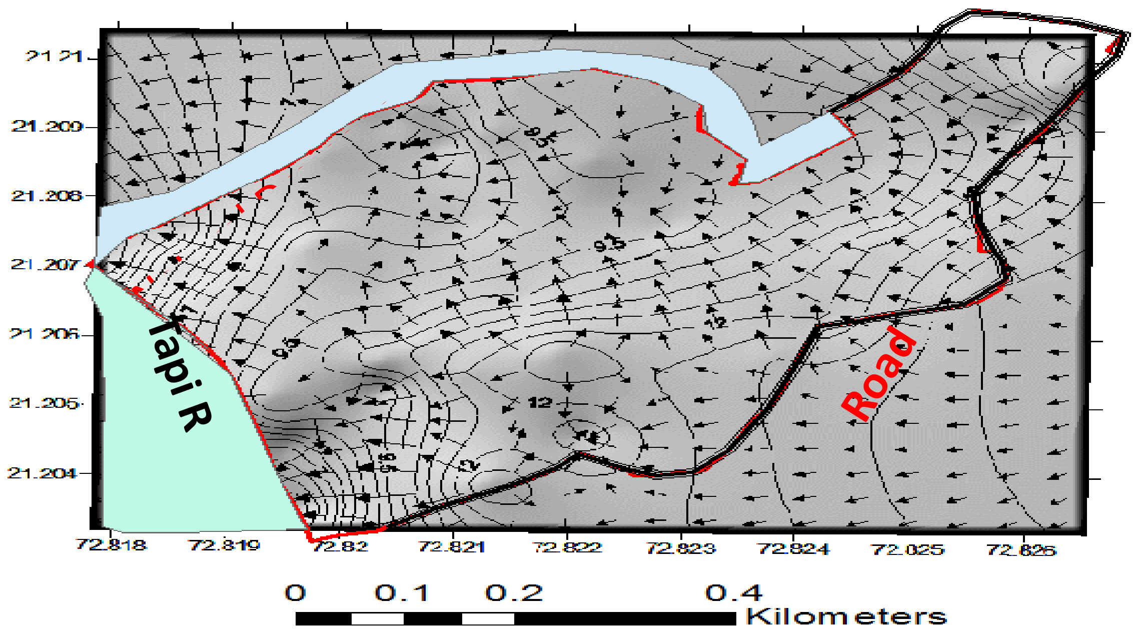

Figure.2: Study Area Map Showing natural drainage and road superimposed on surface map

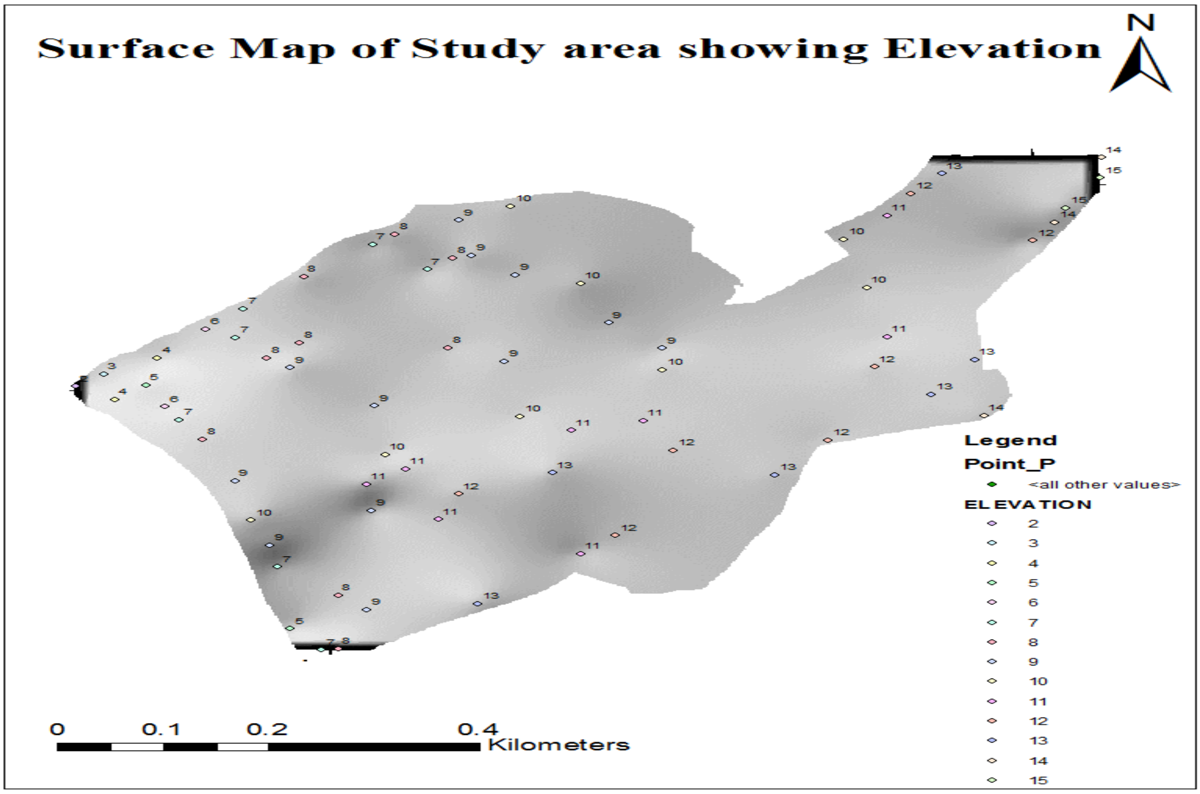

Fig.3: Surface Map of Study area showing elevation

Elevation map of Study area

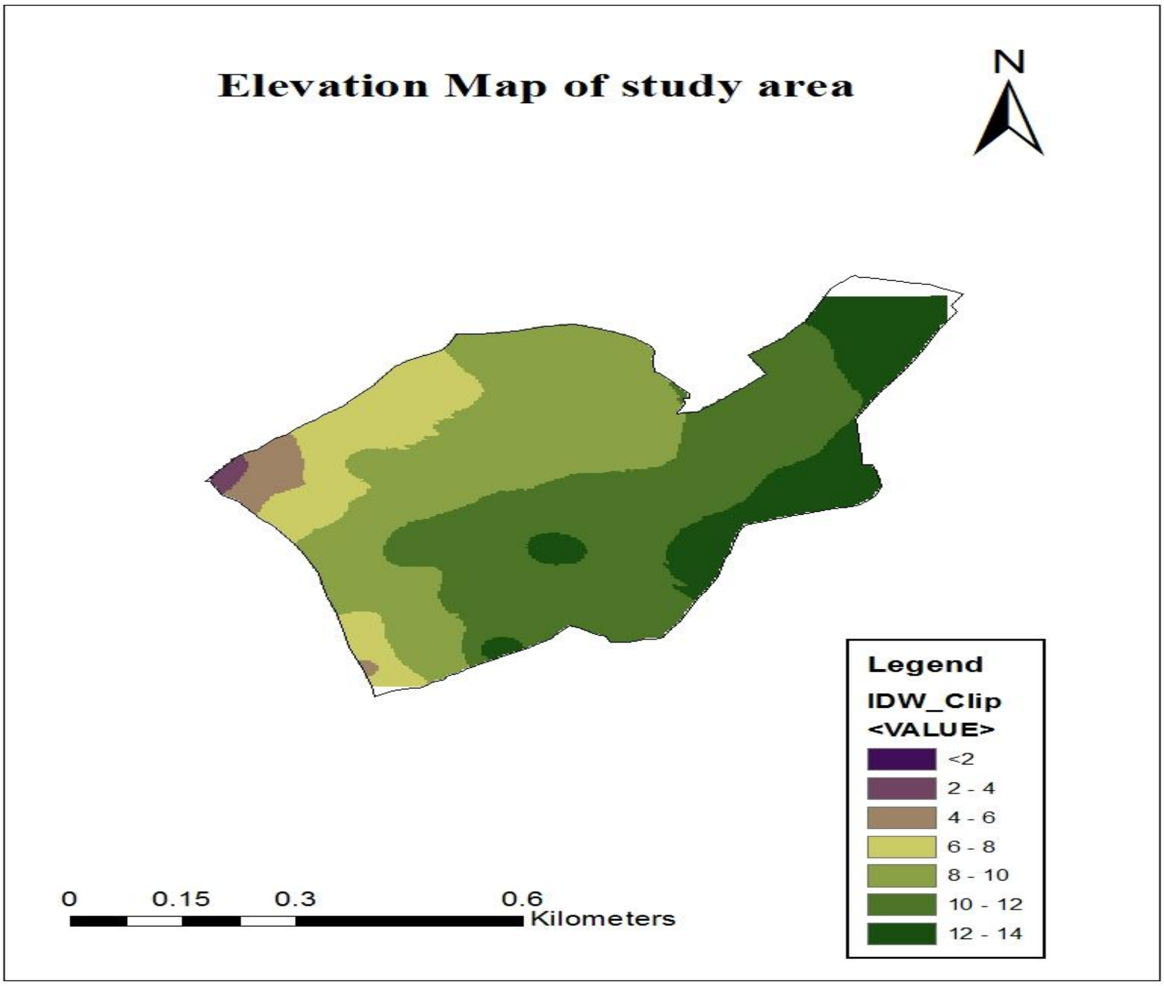

Figure 4: Elevation map of Study area

IV. DEVELOPMENT OF IDF CURVE

Data analysis using Gumbel method: Based on the hydrological data obtained from SWDC and generated using GIS tools have been analyzed for the development of IDF curve for different return period. Methodology of IDF Curve generation is given in Fig.5.

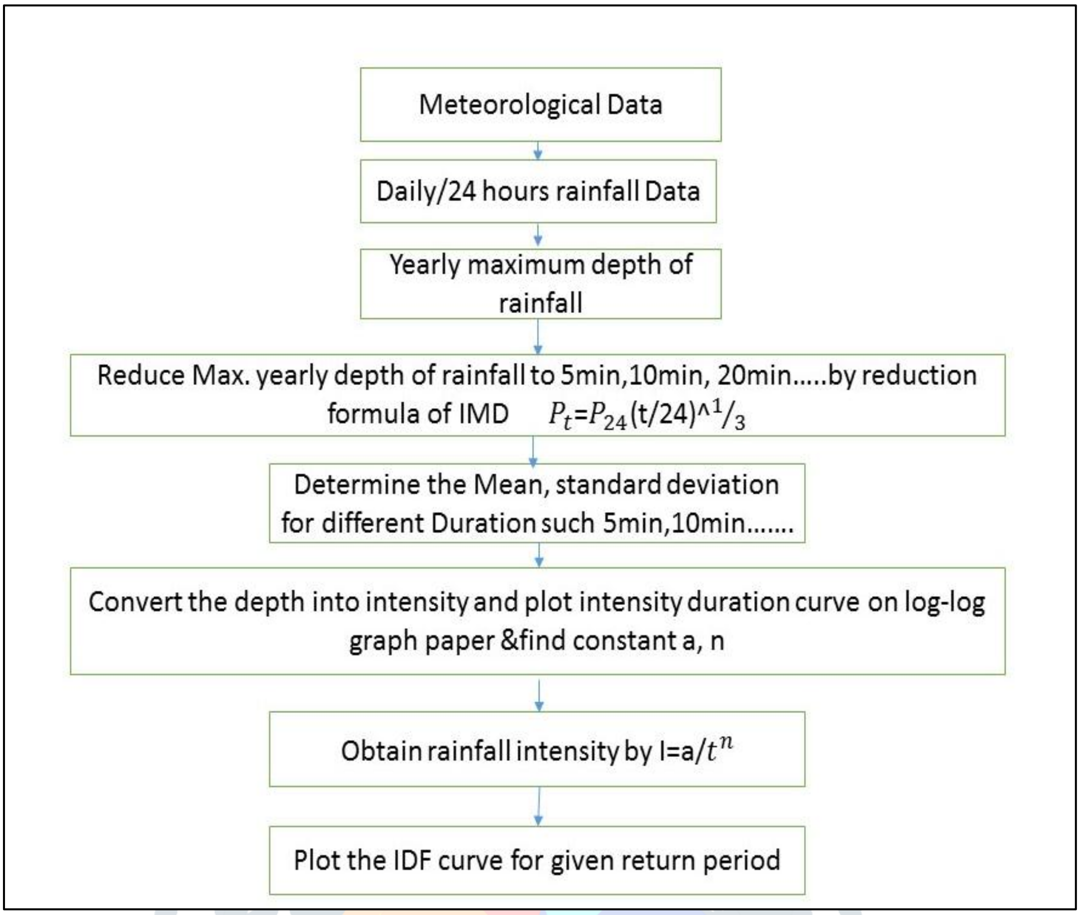

Figure 5 Methodology

Gumbel Distribution Method

Gumbel distribution methodology was selected to perform the flood probability analysis. The Gumbel theory of distribution is the most widely used distribution for IDF analysis owing to its suitability for modelling maxima. It is relatively simple and uses only extreme events (maximum values or peak rainfalls).The Gumbel method calculates the 2, 5, 10, 25, 50 and 100-Year return intervals for each duration period and requires several calculations. Frequency precipitation P_T(in mm) for each duration with a specified return period T (in year) is given by the following equation.

$$P_T = P_{ave} + KS$$

Where K is Gumbel frequency factor given by:

$$K = -\frac{\sqrt{6}}{\pi}[0.5772 + \ln\left[\ln\left[\frac{T}{T-1}\right]\right]]$$

Where Pave is the average of the maximum precipitation corresponding to a specific duration. In utilizing Gumbel's distribution, the arithmetic average in Eq. (1) is used:

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i$$

Where Pi is the individual extreme value of rainfall and n is the number of events or years of record. The standard devotion is calculated by Eq. (4) computed using the following Relation:

$$S = [\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{ave})^2]^{1/2}$$

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 (in mm/h) for return period T is obtained from:

$$I_t = \frac{P_t}{T_d}$$

Is that based on the peak-over threshold concept, which consists of all precipitation amounts Where Td is duration in hours. 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

Developing of IDF Curves from Daily/24 Hours Rainfall Data for 2 year

Daily rainfall data collected from SWDC (state water data center), Gandhinagar for 28 years

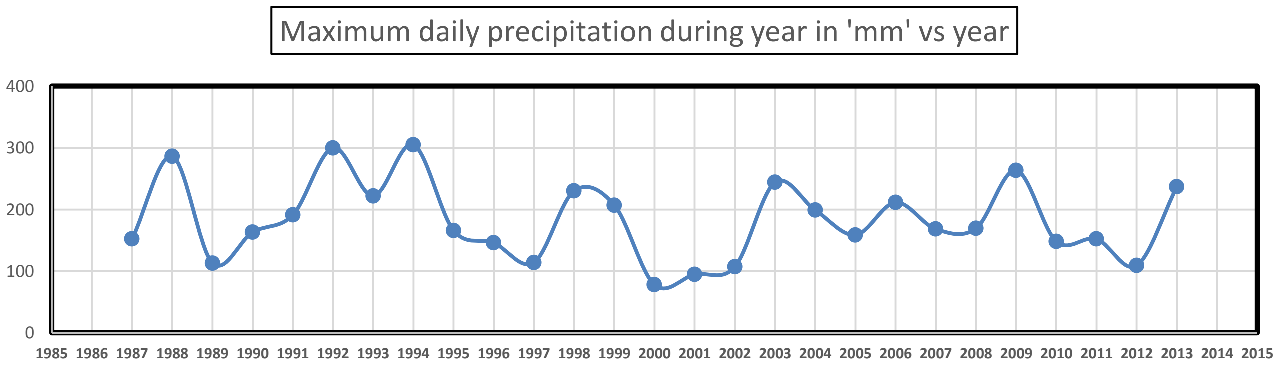

Figure III Maximum daily precipitation during year in 'mm' vs year

Reduced each of the maximum 24 hours depth series to 5min, 10min, 15min, 20min, from reduction formula by IDM given below:

$$P_{t=P_{24}}(\frac{t}{24})\ \text{^}1/3$$

P_t=Required precipitation depth for t hours in mm, P_{24}=Daily precipitation in mm, t=time duration in hours for which the rainfall depth is required

Table 1 : Hourly Maximum annual storm depth series of variyali bhagol analyzed Hourly Maximum annual storm depth series of variyali bhagol analyzed

$p_{t=}p_{24(\frac{t}{24})}$^1/3										(Pi-Pavg)^2						
sr. no	Year	daily precipitation during year in 'mm'	5min(0.083 hr)	10min(0.166hr)	20min(0.333hr)	30min(0.5 hr)	40min (0.66 hr)	50min (0.833 hr)	60min(1hr)	5min(0.083 hr)	10min(0.166hr)	20min(0.333hr)	30min(0.5 hr)	40min(0.66hr)	50min(0.833hr)	60min(1hr)
1	1985	165	25.43	31.96	40.22	45.99	50.40	54.43	57.81	4.67	7.38	11.71	15.28	18.37	21.45	24.19
2	1986	93	14.33	18.02	22.67	25.92	28.41	30.68	32.58	175.77	277.70	439.81	574.93	690.67	805.54	908.74
8	1992	300	46.23	58.11	73.12	83.62	91.64	98.96	105.11	347.54	549.19	869.29	1137.06	1365.55	1592.10	1796.22
9	1993	222	34.21	43.00	54.11	61.88	67.82	73.23	77.78	43.85	69.31	109.65	143.50	172.29	200.82	226.59
10	1994	305	47.00	59.08	74.34	85.01	93.17	100.61	106.86	376.87	595.53	942.64	1232.99	1480.77	1726.44	1947.78
11	1995	166	25.58	32.16	40.46	46.27	50.71	54.76	58.16	4.03	6.37	10.10	13.18	15.85	18.50	20.87
12	1996	145.8	22.47	28.24	35.54	40.64	44.54	48.10	51.08	26.22	41.42	65.64	85.76	103.05	120.23	135.62
13	1997	114	17.57	22.08	27.79	31.78	34.82	37.61	39.94	100.43	158.67	251.32	328.49	394.64	460.31	519.27
14	1998	230	35.44	44.55	56.06	64.11	70.26	75.87	80.59	61.70	97.51	154.29	201.89	242.42	282.58	318.83
15	1999	207	31.90	40.10	50.46	57.70	63.23	68.28	72.53	18.58	29.37	46.45	60.81	73.00	85.07	95.98
16	2000	77.8	11.99	15.07	18.96	21.69	23.77	25.66	27.26	243.37	384.51	608.93	796.06	956.28	1115.30	1258.19
17	2001	94.6	14.58	18.33	23.06	26.37	28.90	31.21	33.15	169.30	267.47	423.60	553.74	665.22	775.86	875.26
18	2002	107	16.49	20.73	26.08	29.82	32.69	35.30	37.49	123.22	194.67	308.33	403.02	484.17	564.72	637.06
19	2003	244	37.60	47.27	59.47	68.01	74.54	80.49	85.49	100.25	158.43	250.71	328.01	393.89	459.17	518.06
20	2004	199	30.67	38.55	48.51	55.47	60.79	65.64	69.72	9.47	14.97	23.67	31.00	37.21	43.35	48.92
21	2005	158.6	24.44	30.72	38.66	44.21	48.45	52.32	55.57	9.91	15.65	24.82	32.41	38.95	45.46	51.28
22	2006	211.4	32.58	40.95	51.53	58.92	64.58	69.73	74.07	24.89	39.33	62.22	81.44	97.77	113.95	128.57
23	2007	168.2	25.92	32.58	41.00	46.88	51.38	55.48	58.93	2.79	4.40	6.98	9.10	10.95	12.79	14.42
24	2008	169.2	26.08	32.78	41.24	47.16	51.69	55.81	59.28	2.29	3.62	5.75	7.50	9.02	10.54	11.88
25	2009	263.6	40.62	51.06	64.25	73.47	80.52	86.95	92.36	169.86	268.42	424.83	555.75	667.39	778.06	877.83
26	2010	148	22.81	28.67	36.07	41.25	45.21	48.82	51.86	22.87	36.12	57.24	74.78	89.86	104.84	118.26
27	2011	152	23.42	29.44	37.05	42.37	46.43	50.14	53.26	17.35	27.41	43.44	56.74	68.18	79.56	89.74
28	2012	109	16.80	21.12	26.57	30.38	33.30	35.96	38.19	116.47	184.01	291.44	380.95	457.66	533.80	602.18
29	2013	237	36.52	45.91	57.77	66.06	72.40	78.18	83.04	79.81	126.13	199.59	261.15	313.58	365.55	412.43
		Average	**27.59**	**34.68**	**43.64**	**49.90**	**54.69**	**59.06**	**62.73**	**2653.68**	**4193.03**	**6638.50**	**8681.14**	**10426.91**	**12158.56**	**13716.92**
		S								**9.74**	**12.24**	**15.40**	**17.61**	**19.30**	**20.84**	**22.13**
		k2	-0.16	-0.164	-0.16	-0.16	-0.16	-0.164	-0.164							
		pt	26	32.673	41.11	47	51.5	55.64	59.1001128							
		k5	0.72	0.719	0.719	0.72	0.72	0.719	0.719							
		PT	34.6	43.482	54.71	62.6	68.6	74.04	78.6451728							

Determined mean and standard deviation of each series of 5 min, 10 min, 15 min, 20 min …..60 min .rainfall depth for each min is calculating by Gumbel extreme event formula for given return period. Converted the depth into intensity of rainfall for 2 year return period

Table 2: Time duration and its intensity

TIME DURATION	INENSITY
	2 YEAR
5min (0.083hr)	313.1738
10min (0.166hr)	196.8258
20min (0.333hr)	123.4678
30min (0.5hr)	94.02458
40min (0.66hr)	78.06852
50min (0.833hr)	66.79774
60min (1hr)	59.10011

Plotting of the intensity duration curve on log -log graph paper to determine the value of a and n constants

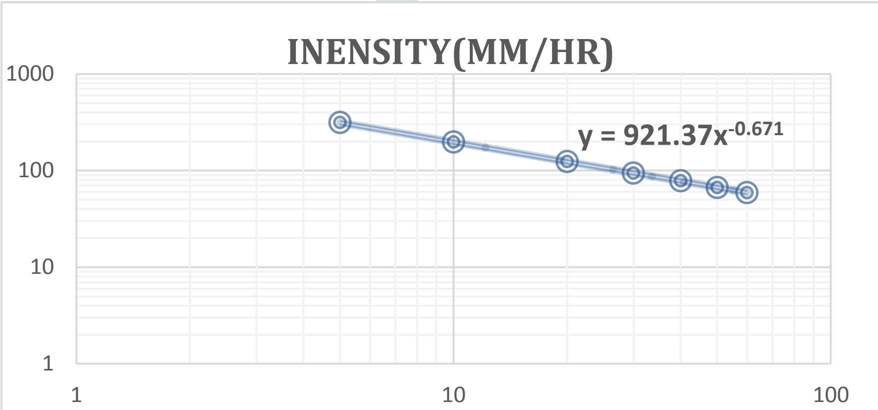

Figure 7 log-log graph of intensity vs duration for 2year

Calculated rainfall intensity by $i = a/t^n$ for 5min 10min 20min…..60min for 2 year return period

Table 3 Time duration and its design intensity

TIME DURATION (MIN)	**A**	**n**	**INTENSITY MM/HR**
5	921	0.671	312.91
10	921	0.671	196.53
20	921	0.671	123.44
30	921	0.671	94.03
40	921	0.671	77.53
50	921	0.671	66.75
60	921	0.671	59.06

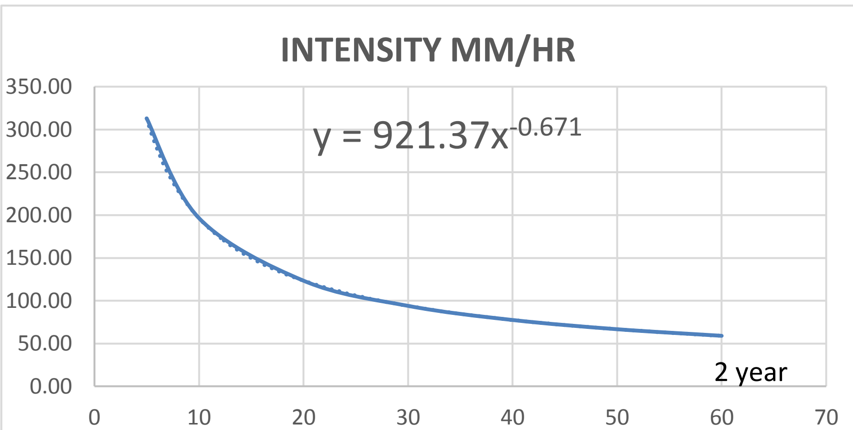

Figure 8 IDF curve for 2year

V. DESIGN STORM WATER DRAINAGE SYSTEM

Hydrological Assessment

Storm frequency:

Type of Area Frequency

(a) Residential

Peripheral : Twice in a year

Central (high value) : Once in a year

(b) Commercial: Once in 2 years

Rainfall intensity and Frequency:

The design of storm water drain is principally based on the assumptions of rainfall in a particular area. The reasonable predictions for the runoff in the future can be made from the statistical analysis of the rainfall figures taken from the past records for number of years. Such predictions, though statically sound, are still not entirely reliable.

I=a/t^n

Time Intensity Values of Storm in study Area

Estimation of storm water Runoff:

Rational Method:

Runoff-rainfall intensity relationship:

Q=10 C I A

Where Q is the runoff in mm/hr

'C is the coefficient of runoff;

I is the intensity of rainfall in mm/hr; and

'A' is the area of drainage district in hectares.

Time of concentration:

Ti = (0.885 L3 / H) 0.385

Where,

ti = Inlet time in minutes

L = Length of overland flow in kilometers from the critical point to the mouth of the drain.

H = Total fall in level from the critical point to the mouth of the drain in meters

Time of Flow in the Drain or the Conduit Flow Time (tf) - This can be obtained by dividing the length of the drain with the flow velocity in the drain.

Tf = Length of proposed drain / Flow velocity

Thus, the time concentration (tc) at a given point in the drain, can be easily obtained as,

Tc = ti + tf

Coefficient of runoff

The portion of rainfall which finds its way to the sewer is dependent on the imperviousness and The shape of tributary area apart from the duration of storm.

(A) Imperviousness

The percent imperviousness of the drainage area can be obtained from the records of a particular District. In the absence of such data, the following may serve as a guide:

Type of area	Percentage of imperviousness
Commercial and Industrial areas	70-90
Residential Area	
(i) High density	60-75
(ii) Low density	35-60
Parks & undeveloped areas	10-20

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

I=$A_1 I_1$+$A_2 I_{2\ldots\ldots}$ /A_1+A_2….

Where,

A_1 , A_2 Drainage areas tributary to the section under consideration;

I_1, $I_{2\ldots\ldots}$, Imperviousness of the respective Area sf and,

I =weighted average imperviousness of the total drainage basin

Drainage areas tributary to the section under the study area

A_1=19ha (built up area), A_2 =2ha (vegetation area), A_3=9.31(open area), A_4=8ha(road area)

I=19*0.90 +2*0.20 +9*0.20 +8.9*0.90 /40.5

I=0.62

Table 4 showing Runoff coefficient

Duration,t,minutes	10	20	30	45	60	75	90	100	120	135	150	180
Weighted average coefficients												
1) Sector concentrating in stated time												
(a)Impervious	0.5259	0.588	0.642	0.7	0.74	0.771	0.795	0.813	0.828	0.84	0.85	0.865
(b)60% impervious	0.365	0.427	0.477	0.531	0.569	0.598	0.622	0.641	0.656	0.67	0.682	0.701
(c)40% impervious	0.285	0.346	0.395	0.446	0.482	0.512	0.535	0.554	0.571	0.585	0.597	0.618
(d) pervious	0.125	0.185	0.23	0.277	0.312	0.33	0.362	0.382	0.399	0.414	0.429	0.454
2)Rectangle;(length=4*width)Sector concentrating in stated time												
(a)Impervious	0.55	0.648	0.711	0.768	0.808	0.837	0.856	0.869	0.879	0.887	0.892	0.903
(b)50 %impervious	0.35	0.442	0.499	0.551	0.59	0.618	0.639	0.657	0.671	0.683	0.694	0.713
(c)30% impervious	0.269	0.36	0.414	0.464	0.502	0.53	0.552	0.572	0.588	0.601	0.614	0.636
(d) pervious	0.149	0.236	0.287	0.334	0.371	0.398	0.422	0.445	0.463	0.479	0.495	0.522

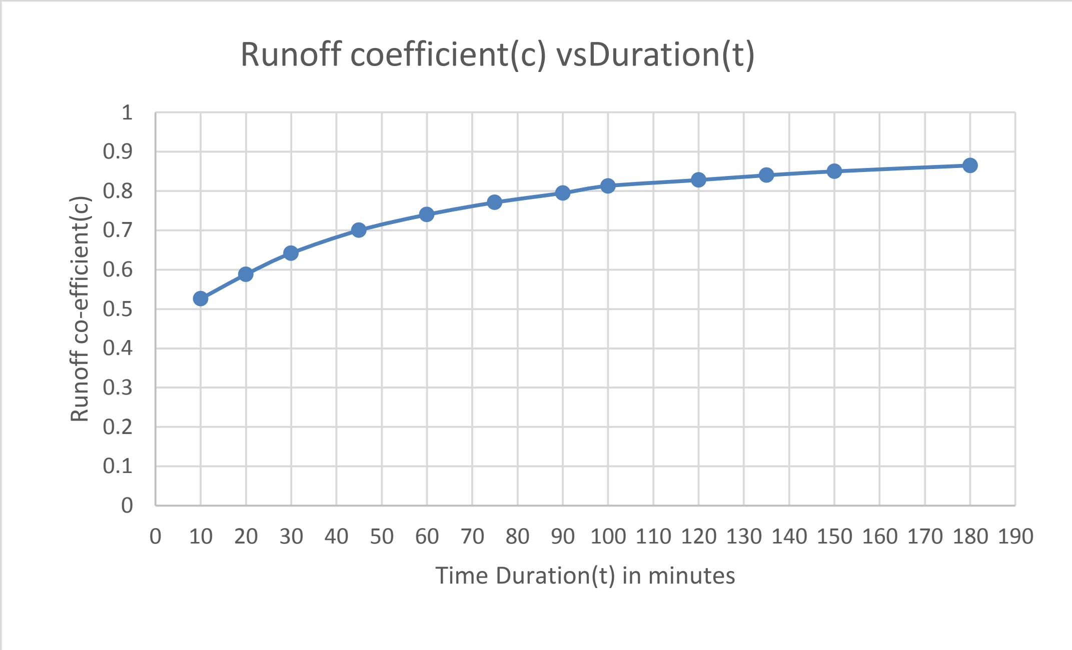

Fig.9: Runoff coefficient(c) vs Duration (t)

From the above two graphs of ‘c’ and ‘I’ for the same duration time ‘t’ are determined and the value of runoff Q in cubic m/hour of drainage basin is worked out from the equation

Q = 10 CIA

Where c= runoff coefficient

I = intensity of rainfall mm/hour, A= Area in ha

For a given time of concentration and imperviousness factor for each section of drain is designed

Design of storm drainage system

For design of storm drainage system in variyali bhagol area of Surat city, Manning’s formula is adopted, which is;

$V = 1/n \times R^{2/3} \times S^{(1/2)}$

For circular conduits

$V = 1/n \times 3.968 \times 10^{-3} \times d^{(2/3)} \times S^{(1/2)}$

And

$Q = 1/n \times 3.118 \times 10^{-3} \times d^{8/3} \times S^{(1/2)}$

Where

Q = Discharge in Littre/second

S = slope of hydraulic gradient

D = diameter of pipe in mm

R = hydraulic radius in m

V = Velocity in m/second

As pipes deteriorate with age, a roughness coefficient is considered for the design period assuming fair condition in sewer. The roughness coefficient ‘n’ is assumed to be the same for all sizes and is taken 0.013 for design.

Layout of storm water Drainage Network and Analysis

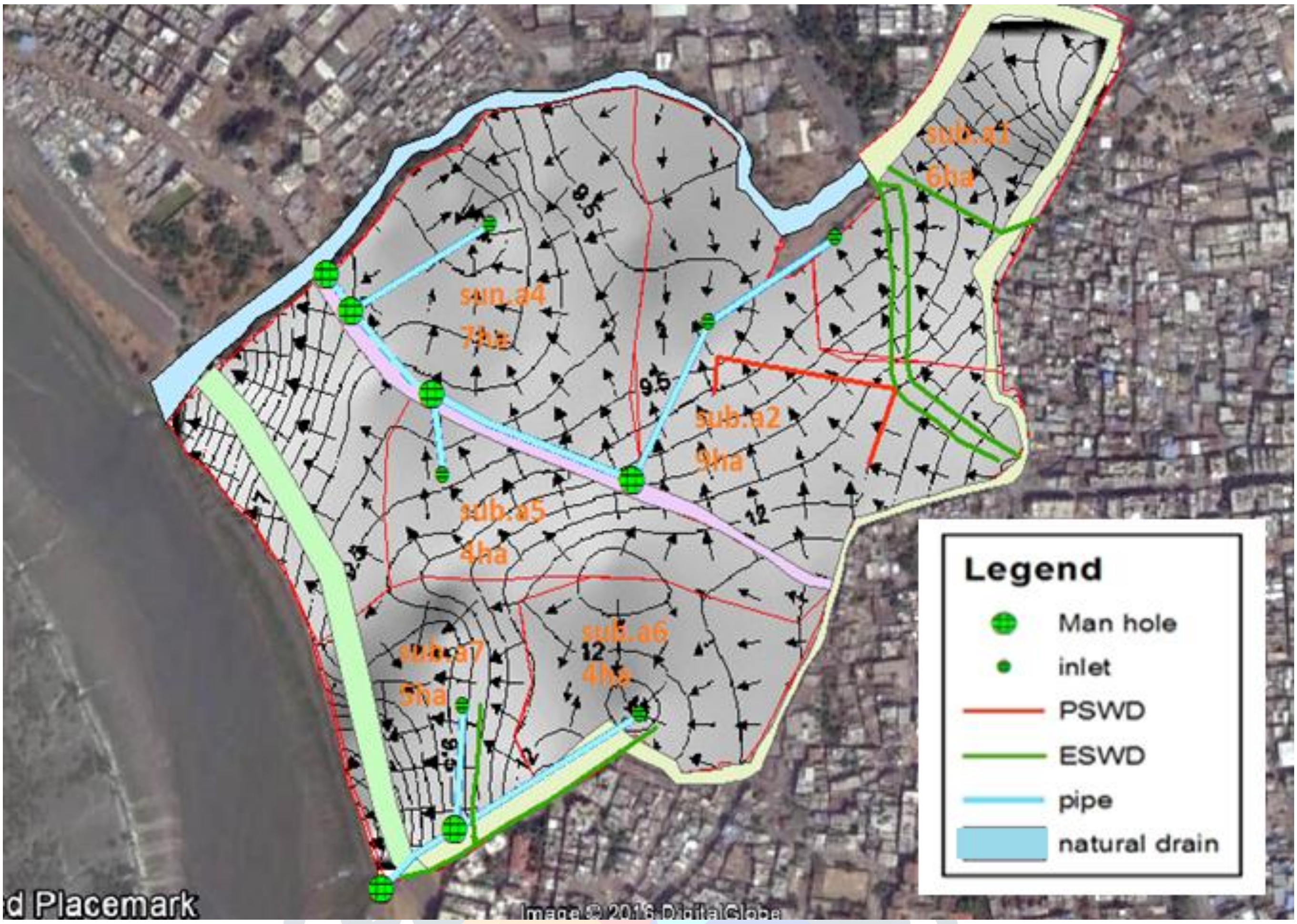

Figure 10. Existing (ESWD), proposed (PSWD) and modified (PIPE) storm water drainage network

Analysis

Table 5. : Details of the location of drains, tributary area, time of concentration, Intensity of rainfall, runoff coefficient,

	Location of drain			Tributary Area 'a'(Ha)			Time of concentration(min)			I (mm/hr)	c
line	Node from	Node to	L of pipe(m)	Imp. facter	tributary area	Effective A	ti	tf	tc=ti+tf		
		sub1		0.62	6	3.72	30	0	30	94.03	0.642
1	sub1	sub2	114	0.62	9	5.58	30	0.82	30.82	93.8	0.65
2	sub2	Manhol1	177.64	0.62	15	9.3	30	1	31	92	0.66
		sub5		0.62	4	2.48	30	0	30	94.03	0.642
	1	2	256	0.62	19	11.78	30	0.81	30.81	93.9	0.649
		sub4		0.62	7	4.34	30	0	30	94	0.642
	2	3	135	0.62	26	16.12	30	1.52	31.52	91.5	0.67
		sub6		0.62	4	2.48	30	0	30	94.03	0.642
		sub7		0.62	5	3.1	30	0	30	94.03	0.642
	sub6	MH1	260	0.62	9	5.58	30	0.3	30.3	94	0.642

Table 6. : Details of Run off and design of storm water drainage

	Location of drain		Runoff(cubic m/hr)10ciA		Design					
line	Node from	Node to	cubic m/hr	cubic m/s	Q(lit/s)	Slope(1/300)		n	Diameter (mm)	Velocity (m/s)
		sub1	2245.66	0.62	623.80	1 in 300	0.003333	0.013	735.02	1.47
1	sub1	sub2	3402.13	0.95	945.04	1 in 300	0.003333	0.013	1038.24	1.85

2	sub2	Manhol1	5646.96	1.57	1568.60	1 in 300	0.003333	0.013	1176.92	2.01
		sub5	1497.11	0.42	415.86	1 in 300	0.003333	0.013	631.39	1.33
	1	2	7178.86	1.99	1994.13	1 in 300	0.003333	0.013	1255.99	2.10
		sub4	2619.10	0.73	727.53	1 in 300	0.003333	0.013	778.61	1.52
	2	3	9882.37	2.75	2745.10	1 in 300	0.003333	0.013	1377.21	2.23
		sub6	1497.11	0.42	415.86	1 in 300	0.003333	0.013	631.39	1.33
		sub7	1871.39	0.52	519.83	1 in 300	0.003333	0.013	686.59	1.40
	sub6	MH1	3367.42	0.94	935.39	1 in 300	0.003333	0.013	855.56	1.62

VI. CONCLUSIONS

Surat city is facing Storm water drainage problem due to increasing population and developmental activities. In the present study the existing layout of drainage system has been evaluated and planning and design of modified drainage system in part of the city area (Variyali Bhagol) has been done. The study area is bounded by natural drainage on the western north site and on the western site by main Tapi River and on the southern site and northern site by roads. In the design these futures have been considered in conjunction with elevation of the area and existing drainage system for designing modified storm water drainage system.

IDF is a tool for planning, design and operation of water Resources projects such as storm water drainage system. With the help of this tool (IDF) relationship of rainfall has been established at central zone of Surat city from daily/24 hour's rainfall data using Gumbel distribution method. These relationships are useful in the design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures

Rational Method has been used for the calculation of storm water runoff. Section wise run off (Lit/Sec.) in the study area is 623.80 (section one), 945.04(section two) 727.53(section four), 415.86(section five), 415.86(section six), 519.83(section seven). Total runoff of the study area has been calculated based on the topography and rainfall data. Total length and Diameter of the drain has been proposed using manning's formula. The proposed modified drainage system using GIS technology will help in proper draining out of storm water from the study area. This study can be applied for the designing of the storm water system of other cities.

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