Design of Storm Water Drains by Rational Method – an Approach to Storm Water Management for Environmental Protection

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***Abstract* - A scientific drainage system to catch the storm water is a long term ambition of the society, especially in cities. Increasing development activities have called badly for the necessity of discharging runoff safely in to environment. It is often being happened that over densification and modification of undeveloped land is also resulting increased flow with increased pollution. Irrespective of the city, most of our city's face will be fractured, if a heavy storm with high run off is hit, due to improper drainage facilities. Most of our existing storm water drains are in dilapidated stages and not working properly, losing self cleansing, no proper maintenance, and incorrect design without any scientific base, the bottlenecks go so on. A proper storm water design means a proper knowledge of a collection of data like understanding the precipitation data clearly, know the infiltration indices, concentration time, intensity of rainfall, runoff details etc. It appears most of the time that many of the data may not be correct and thus the design of the storm water drains with these so called data will be a catastrophe. The present study is the work done for the drainage design in Palayam area of Calicut City in Kerala, India where the excess runoff is really a threat to the environment due to dense population.**

Keyword- Storm water, Rational Method, Rainfall intensity, infiltration.

I. INTRODUCTION

The practice of storm water management has evolved significantly over the last twenty years and it is focused primarily on flood and erosion control. Flash floods being a natural phenomenon, total elimination or control of floods is neither practically possible nor economically viable. Hence, flood management aims at providing a reasonable degree of protection against flood damage at economic costs and preserves the environment. Structural measures include storage reservoirs, flood embankments, drainage channels, anti-erosion works, channel improvement works, detention basins and non-structural measures include flood forecasting, flood plain zoning, flood proofing, disaster preparedness etc.[1]. A good and efficient storm water management is badly required at the moment all over the universe especially in developing countries like India. The idea of efficient storm water management is based on the requirement to protect the health of the public, welfare and safety of the public, conservation of water, need to strive for sustainable environment etc. Basic considerations in a storm water catch basin design are functional requirements, technical requirements, and social and economic considerations [2]. Urban drainage includes two types of fluids viz. wastewater and storm water [3], waste water is that after the use for life support, process from industry this needs to be collected and transported without causing any hazardous issues but on the other hand storm water is the runoff which caused due to precipitation. Both storm water as well as waste water needs to be considered for the drainage system planning and design.

A. Surface Runoff and its Characteristics

Surface runoff is water, from rain, snowmelt, or other sources, that flows over the land surface, and is a major component of the water cycle. When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides, or fertilizers that become discharge or overland flow. Urbanization increases the surface runoff, by creating more impervious surfaces such as pavement and buildings do not allow percolation of the water down through the soil to the aquifer. Increased runoff reduces groundwater recharge, thus lowering the water table and making droughts worse who depend on water wells. The peak rate, volume, and timing of runoff are important characteristics in the planning and design of storm water management practice. Runoff rate and volume generally increase after urbanization and this development alters the characteristics of runoff. If the downstream channel capacity is exceeded, flood will occur over the floodplain, another related problem is channel erosion which depends on runoff rate and its duration. Thus, urbanization not only increases runoff rate and volume but also their frequency and frequency of runoff rate has a direct impact on erosion and sediment transport of river channel. Runoff from non-urban areas carries eroded sediments, nutrients from natural and/or agricultural sources, bacteria from animal droppings, and pesticides and herbicides from agricultural practices. After urbanization, runoff carries solids particles from automobile wear and tear, dust and dirt, and winter sand, nutrients from residential fertilizers, metals such zinc, copper, and lead, hydrocarbons leaching from asphalt pavement materials, spilled oils and chemicals, and bacteria from domestic animals. This change of runoff quality causes a general degradation of water quality in the receiving waters.

B. Sewers and Overflows

Storm sewers (also storm drains) are large pipes or open channels that transport storm water runoff from streets to natural bodies of water, to avoid street flooding. A storm drain, is designed to drain excess rain and ground water from paved streets, parking lots, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems. They are fed by street gutters on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns which experience regular storms. Many storm drainage systems are designed to drain the storm water, untreated, into rivers or streams. A combined sewer is a type of sewer system that collects sanitary sewage and storm water runoff in a single system. Combined sewers can cause serious water pollution problems due to combined sewer overflows, which are caused by large variations in flow between dry and wet weather. This type of sewer design is no longer used in building new communities, but many older cities continue to operate combined sewers. In these systems a sudden large rainfall that exceeds sewage treatment capacity will be allowed to overflow directly from the storm drains into receiving waters via structures called combined sewer overflows. Combined sewer overflow is the discharge of wastewater and storm water from a combined sewer system directly into a river, stream, lake, or ocean. Overflow frequency and duration varies both from system to system, and from outfall to outfall, within a single combined sewer system. During heavy rainfall when the storm water exceeds the sanitary flow, the combined sewer overflow is diluted. Each storm is different in the quantity and type of pollutants it contributes. As cities become more densely populated, the per-household volumes of wastewater exceed the infiltration capacity of local soils and require greater drainage capacity and the introduction of sewer systems. Several methods are available at the moment for managing this problem and one such method is the storm water drain design.

C. *Environmental Impacts of Urbanization.*

The influence of humans on the physical and biological systems of the Earth's surface is not a recent manifestation of modern societies; instead, it is ubiquitous throughout our human history. As human populations have grown, so has their footprint, such that between 30 and 50 percent of the Earth's surface has now been transformed [4]. Urbanization is the changing of land use from forest or agricultural uses to suburban and urban areas and this conversion is proceeding in India at an unprecedented pace, and the majority of the country's population now moving towards cities and towns for betterment. The creation of impervious surfaces that accompanies urbanization profoundly affects how water moves both above and below ground during and following storm events, the quality of that storm water, and the ultimate condition of nearby rivers, lakes, and estuaries. Urbanization causes extensive changes to the land surface beyond its immediate borders, particularly in ostensibly rural regions, through alterations by agriculture and forestry that support the urban population [5]. Within the immediate boundaries of cities and suburbs, the changes to natural conditions and processes wrought by urbanization are among the most radical of any human activity. Megacities throughout the developing world are experiencing tremendous environmental stress. The magnitude of population growth is an important variable affecting urban environmental problem because it directly affects the spatial concentration of people, industry, commerce, vehicles, energy consumption, water use, waste generation, and other environmental stresses [6]. The environmental impact of city size is generally considered negative. The larger the city, it is assumed, the great the per capita environmental costs or damages.

D. Impacts of the Runoff

Worldwide, urban runoff problems can be divided into the following categories which is given in the table.1

TABLE I
Causes and Impacts of Urban runoff problems

S.No	Urban Runoff Problems	Causes	Impacts
01.	Increased flooding	High runoff peak rates due to increased imperviousness	Loss of life and property; economic hardship; non-tangible damages such as anxiety.
02.	Reduced base flow	Reduced groundwater recharge due to increased imperviousness	Recharge is reduced; soil moisture is depleted; decreased exfiltration to rivers; reduced summer low flow in rivers.
03.	Impaired water quality	Polluted runoff from urban areas	Reduced aquatic communities
04.	Channel instability	Change in flow-duration characteristics and sediment loads.	Change in channel form by erosion and deposition.
05.	Impaired habitat	Changes in flows, water quality, and channel form	Reduced terrestrial and aquatic species.

E. *Drainage System Principles and Runoff Estimation*

A storm drainage system is a system receiving, conveying, and controlling storm water runoff in response to precipitation and snowmelt. Such systems include: ditches, culverts, swales, subsurface interceptor drains, roadways, curb and gutters, catch basins, manholes, pipes, attenuation ponds and service lateral lines [11]. It is designed to convey runoff from frequent storms (e.g., up to 2 or 5 year storms). The main purpose of this system is to minimize storm water ponding at intersections and pedestrian crossings which may cause inconvenience to both pedestrians and motorists so it is also called the convenience system. The major drainage system comprises the natural streams and valleys and man-made streets, channels and ponds. It is designed to accommodate runoff from less frequent storms (e.g., 100 year or the Regional storms). The main purpose is to essentially eliminate the risk of loss of life and property damage due to flooding. There have been many methodologies developed earlier to estimate the total runoff volume, the peak rate runoff and the run off hydrograph from land surfaces under a variety of conditions like runoff curve number method, small storm hydrology method, infiltration model methods etc. for earlier stages and Rational method, SCS method, modified Rational method in present stages. The methodology followed here is based on Rational method, which is adopted widely, however laborious effort are required to ensure that the few input data required for rational method is accurate.

1) Rational Method: Rational method was first used in 1889 developed by Emil Kuichling. The rational method is the oldest method still probably the most widely used method for design of storm drains. The idea behind the rational method is that if a rainfall of intensity ‘i’ begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration ‘t_c’, when the entire watershed is contributing to flow at the outlet. The product of rainfall intensity ‘i’ and watershed area ‘A’ is the inflow rate of the system, iA, and the ratio of this rate to the rate of peak discharge Q (which occurs at time $t_{c)}$ is termed the runoff coefficient C. The following figure.1 is the hydrograph for rational method. This is expressed in the rational formula

$$Q = 0.0028\ C\ i\ A \qquad \text{----------- (1)}$$

In Urban areas, the drainage area usually consists of sub areas or sub-catchments of different surface characteristics. As a result a composite analysis is required that must account for the various surface characteristics. ‘A’ denotes the area of the sub catchments and ‘C’ denotes the runoff coefficients of each sub catchment. The peak runoff is then computed by summing the Q of individual sub catchments. The assumptions associated with the rational method are:

1. The computed peak rate of runoff at the outlet point is a function of the average rainfall rate during the time of concentration, i.e., the peak discharge does not result from a more intense storm of a shorter duration, during which only a portion of the watershed is contributing to runoff at the outlet.
2. The time of concentration employed is the time for runoff to become established and flow from the most remote part of the drainage area to the inflow point of the sewer being designed.
3. Rainfall intensity is constant throughout the storm duration.

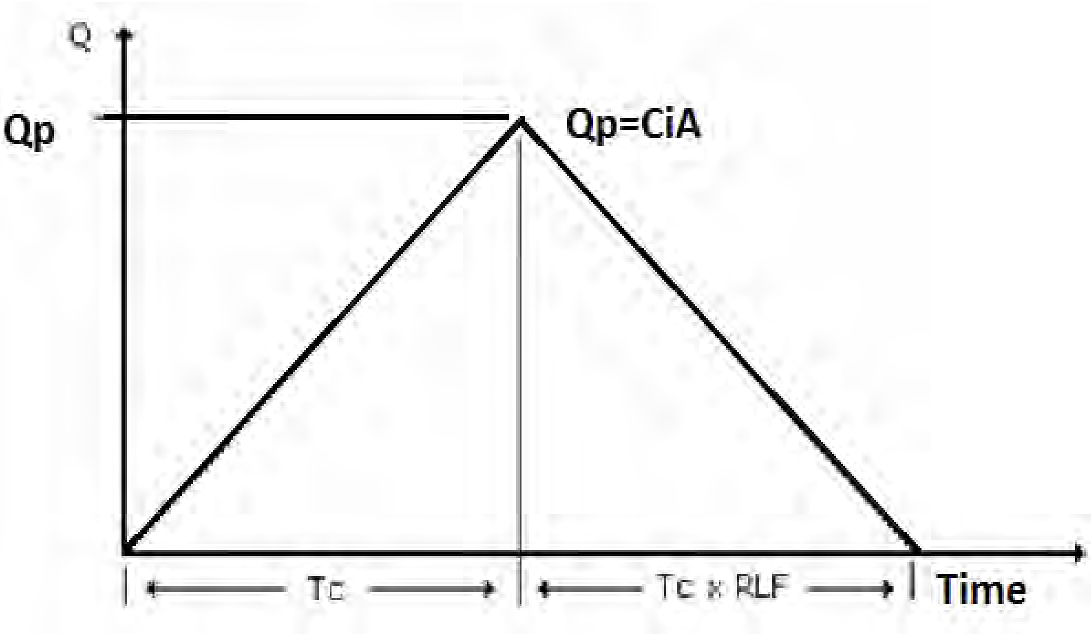

Fig-1 Hydrograph for Rational Method

From the parameters of the rational formula only the area 'A' can be precisely defined by measuring the area of the sub catchment. The intensity 'i' for the sub catchment depends on the analysis of point rainfall data, time of concentration etc. The most cumbersome process is the estimation of runoff coefficient 'C' which comprises so many characteristics on the sub catchment like land use pattern, antecedent precipitation, soil moisture, infiltration, ground slope, surface and depression storage, shape of the drainage area , over land flow velocity etc and this coefficient can vary with time also. One of the most the most serious limitations of the rational method is that it doesn't take in to consideration the real storm pattern. Thus the time variation of the rate of rainfall and the variation in area and velocity contributing the flow are therefore not accounted.

2) SCS Runoff Method: U.S Soil Conservation Service developed this method. By this method the volume and peak of the runoff can be estimated for 24-hr design storm. This method can be used for both urban and non urban small watersheds. This method requires the determination of the runoff curve number, CN for the drainage basin, which is a function of the soil and surface characteristics and land use. Soil characteristics that are associated with each group as follows:

Group A: Deep sand, deep loess and aggregated silts.

Group B: Clay loams, shallow loess, sandy loam

Group C: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.

The SCS method uses a dimensionless unit hydrograph and drainage inputs to determine flow volumes and peak discharges.

SCS runoff equation is given below

$$Q = \frac{(P - Ia)^2}{(P - Ia)+S} \quad \text{-------------------- (2)}$$

Q = Runoff,

P = Rainfall,

S = Potential maximum retention after runoff begins,

Ia = Initial abstraction,

3) Modified Rational Method: Modified rational method is an extension of the rational method for rainfalls lasting longer than the time of concentration and the hydrograph for the same is shown in the figure.2. This method was developed so that the concepts of the rational method could be used to develop hydrographs for storage design, rather than just flood peak discharges for storm sewer design. The modified rational method can be used for the preliminary design of detention storage for watersheds of up to 20 to 30 acres.

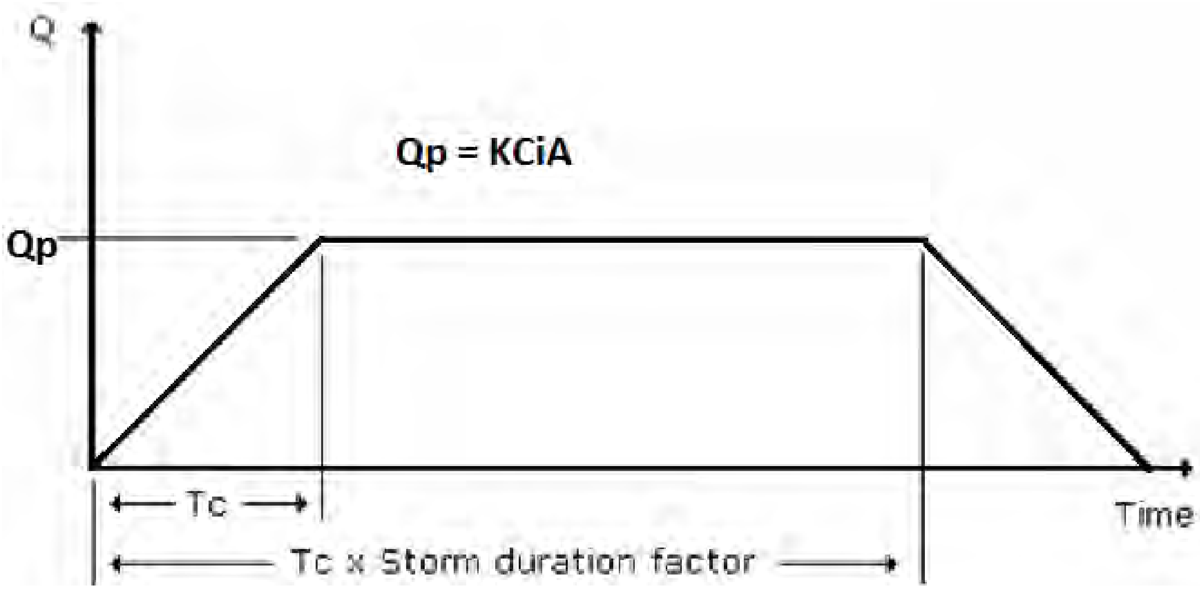

Fig-2 Hydrograph for Modified Rational Method

II. REVIEW OF LITERATURE

Various techniques and methodologies have been developed to design the storm water in the past. Usage of Rational method and the definition of parameters and its calculation have been clearly discussed in the drainage criteria manual of city of Winnipeg [7]. Design of the storm water using rational method and the comparison of the same using SCS and modified rational method were depicted clearly in the course Manuel of PDH engineers The advantages of rational methods, it short falls, methods to find out the time of concentration, guide lines for finding runoff coefficients etc were clearly discussed.

Steven J. Burian [8] describes the necessity of proper and efficient urban drainage system. It also compares the drainage systems of past and the present, which without any doubt points to the fact that for a healthy environment especially in cities the proper design and planning of the drainage systems are inevitable.

Theodore G. Cleveland [9] described the use of Rational method and modified rational method in general for the Texas City. It also describes the applicable area of Modified rational method over rational method.

Francesco D' Asaro [10] describes in detail the Curve Number procedure, which is largely and world-wide used because of this application easiness, allows to estimate the volume of direct runoff for a given rainfall event by means of a single parameter, CN, representing of the basin infiltration storage and depending on soil types, land cover and land use.

III. STUDY AREA AND METHODOLOGY

Calicut city is situated in the West Coast of Kerala along latitude 11^{o}15'N and Longitude 75^{o}47'E roughly in the northern half of the state. The city is 435 Km to the north of Trivandrum, and 215km north of Cochin by road. The city has a linear form bounded on the west by Arabian Sea an on the east by gently rolling hills. The key plan of the study area is shown in the figure.3 explains the nature of the area. The city is fairly flat, the average altitude above MSL being 7.5m. The altitude varies from 1.2m at the coast to 15meters at the eastern portion. The quantity of rainfall in Calicut is due to the southwest monsoon, which is very active from June to October. The average number of rainy days is 160 in Calicut. Excessive falls of rain during June to August cause frequent floods in the rivers and canals submerging low lying areas. The average annual rainfall in the city is 3282mm. The monthly average rainfall values during the southwest monsoon period are shown in the following table.2. The low lying areas of the Calicut City will be flooded, when the rainfall exceeds 100mm in a day. When the daily rainfall exceeds 150mm, 20% of the residential areas and 30% of the roads and several other facilities of the city are affected. The main reason for the problem to be so acute is the poor drainage network in the city. Absence of drainage network also results in the indiscriminate discharge of wastewater in to the water bodies. There are around 10 waste water outlets to the sea and almost the same number in to the Canoly canal.

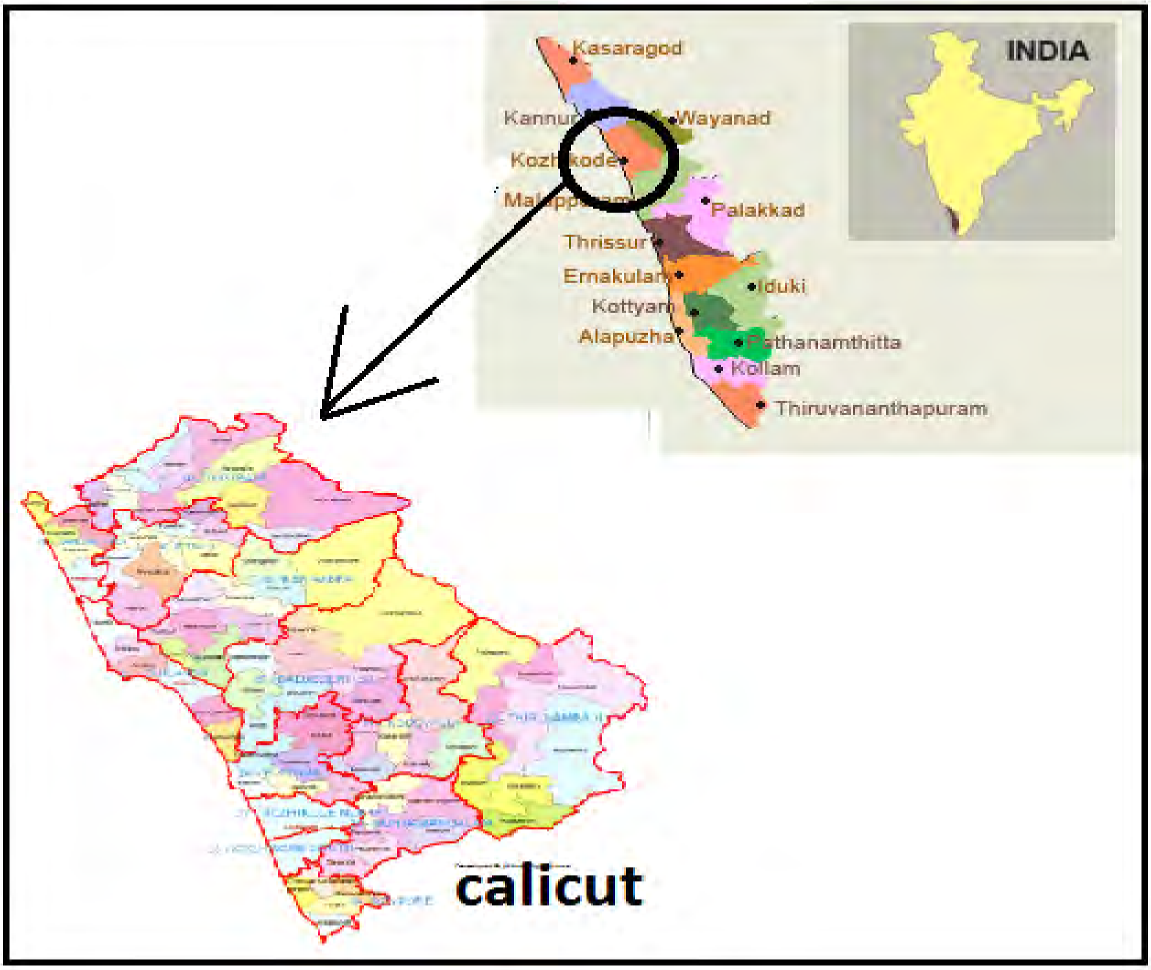

Fig: 3 Key Plan of Study Area

TABLE 2
Monthly average rainfall during Southwest monsoon

S.No	Month	Rainfall in mm
01.	June	870
02.	July	860
03.	August	405
04.	September	215

Calicut Urban area is fringed by two perennial rivers of Poonoor River in the north and Chaliar River in the south. The Kallai River that runs east to west cuts the city in to two halves in the middle and flows to Arabian Sea. The Canoly canal connecting Poonoor River to Kallai River and further down to Chaliar River provides a longitudinal drainage Channel for the urban area. Thus the urban area has got a natural network of major watercourse to which the subsidiary surface drains could be connected. Moreover the national highway 17 passing from Meenchanda to Puthiyangadi through the heart of town forms a ridge and from this ridge, rainwater finds its course to Canoly canal on the eastern side and Arabian Sea to the western side. The western portion of NH 17 can be drained to Arabian Sea and eastern portion to Canoly Canal.

A. Existing Facilities in the City for Drainage

Open surface drains, which are inadequate achieve the storm water disposal to Calicut city, and in most areas, there are no proper drainage arrangements. These run along the sides of the road and ultimately drains to natural drainage channels and finally in to Arabian Sea or Kallai River or Canoly Canal. There are about 120Kms of various types of roads and not even 50% of them have drains. Most of the houses have plastered drains by cement and they discharge sullage to the roads down below or allow it to soak in to the ground. The existing drains discharge their sullage and storm water into the nearest storm watercourse. These drains get stagnated during summer when the quantity of flow is less and then the drains get blocked due to poor maintenance. During storms, these blockages in the drains cause obstructions to the flow of storm water causing floods. Due to inadequate size and lack of proper design and maintenance, the existing drains in most of the places are not serving the purpose during flood season. This necessitates the design and construction of new storm water drains for Calicut. The following figure.4 depicts the present situation clearly and the methodology adopted is shown in the figure.5.

B. Design Criteria

The Rational method was used to design the drains in the study area. Having analyzed the available data of rainfall records (Fig. 7) the intensity of rainfall was found out to be 46mm/hr from IDF curves (Fig 8). The quantity of runoff was worked out using the formula.

$$Q = 0.0028\ C\ i\ A$$

Where Q = Run off in m^3/sec

i = Intensity of rain fall (mm/hr)

A = Area in hec

C = Coefficient of runoff.

Coefficient of Runoff: Considering the topography, slope and nature of soil in the study area the value of 'C' was assessed and found to be in between 0.7 to 0.9.

Manning's formula was used to design the drains.

$$Q = 1/N * R^{2/3} * S^{1/2}$$

Q = Runoff

N = Manning's constant

R = hydraulic mean depth

S = bed slope

Considering the type of the material for the fair condition Manning's constant was taken as 0.015. Dry weather flow was also taken in to account in the design taking 100L/head/day. Having received the population figures of previous years, projected population for next 20 yrs also was taken in to consideration to calculate dry weather flow. Self cleaning velocity was taken as 0.6m/s and the designed section was checked for velocity available. The population in the study area (37^{th} Ward of Calicut Corporation) according to statistical data is 9055 and the projected population after 20 years is 13029. Manning's Kinematic Equation was used to find out the time of concentration.

$$Tc = \frac{5.48\ (nL)^{0.8}}{P^{0.5} * S^{0.4}}$$

n= Manning's Roughness Coefficient.
L= Length of the flow path in meters
P= 2 year 24 hr rainfall depth (mm)
S= ground slope

Fig 4: The scene at Thadambattuthazham in Calicut, due to improper drainage, (Courtesy: The Hindu)

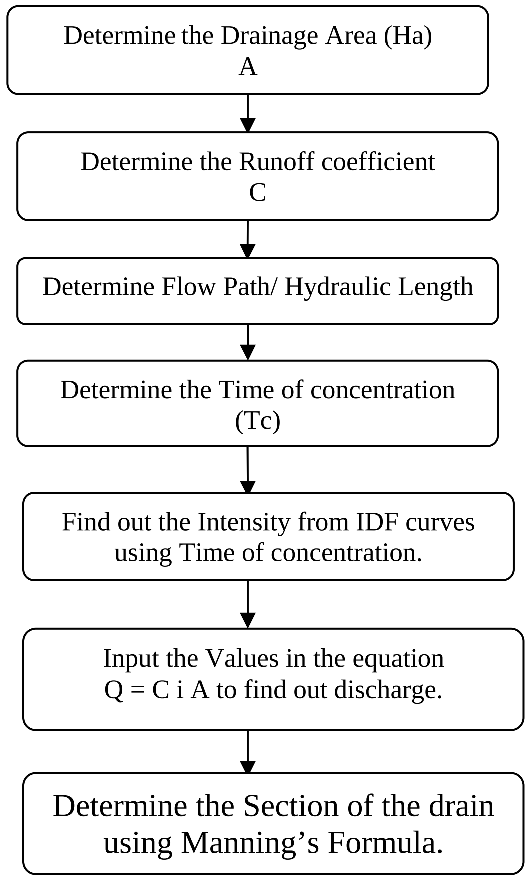

Fig: 5 Diagram Depicting Methodology

Using the above Kinematic equation the time of concentration was found out to be 12 mts. From the IDF curves of the study area for this time of concentration the intensity was traced as 46mm/hr. (refer Fig 7 below) figure. 6 below show the typical sections and Table -3 shows the part design calculation in tabular form.

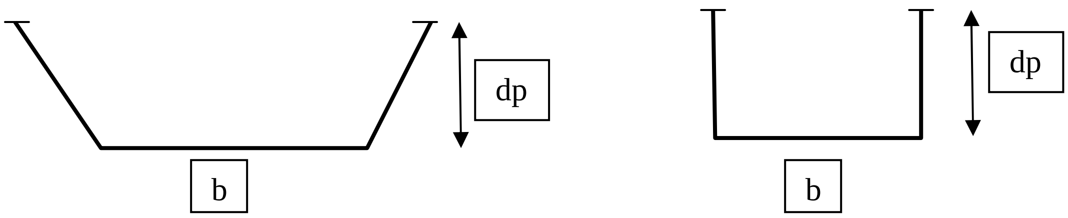

Fig 6. Typical Drain Sections.

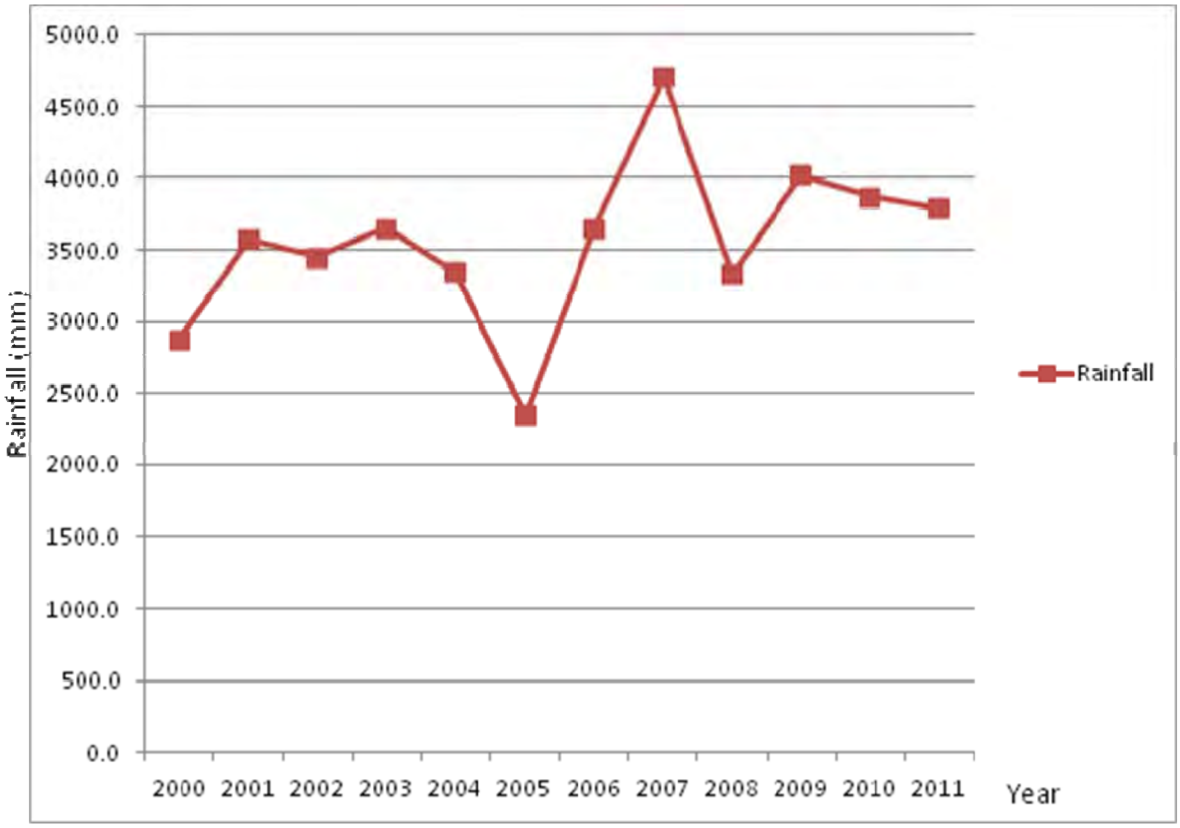

Fig: 7-Total Rainfall in Previous Years. (Courtesy, Indian Meteorological Dept.)

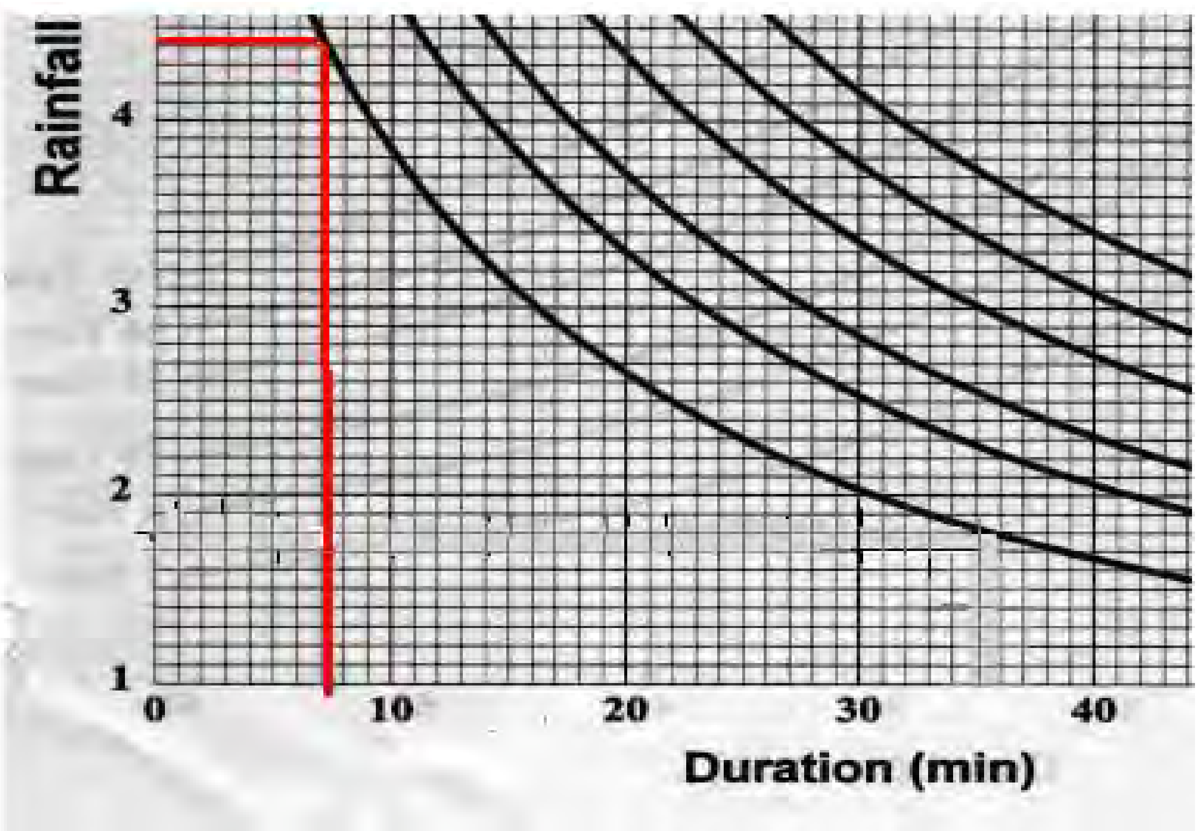

Fig: 8-IDF curve for the Study Area

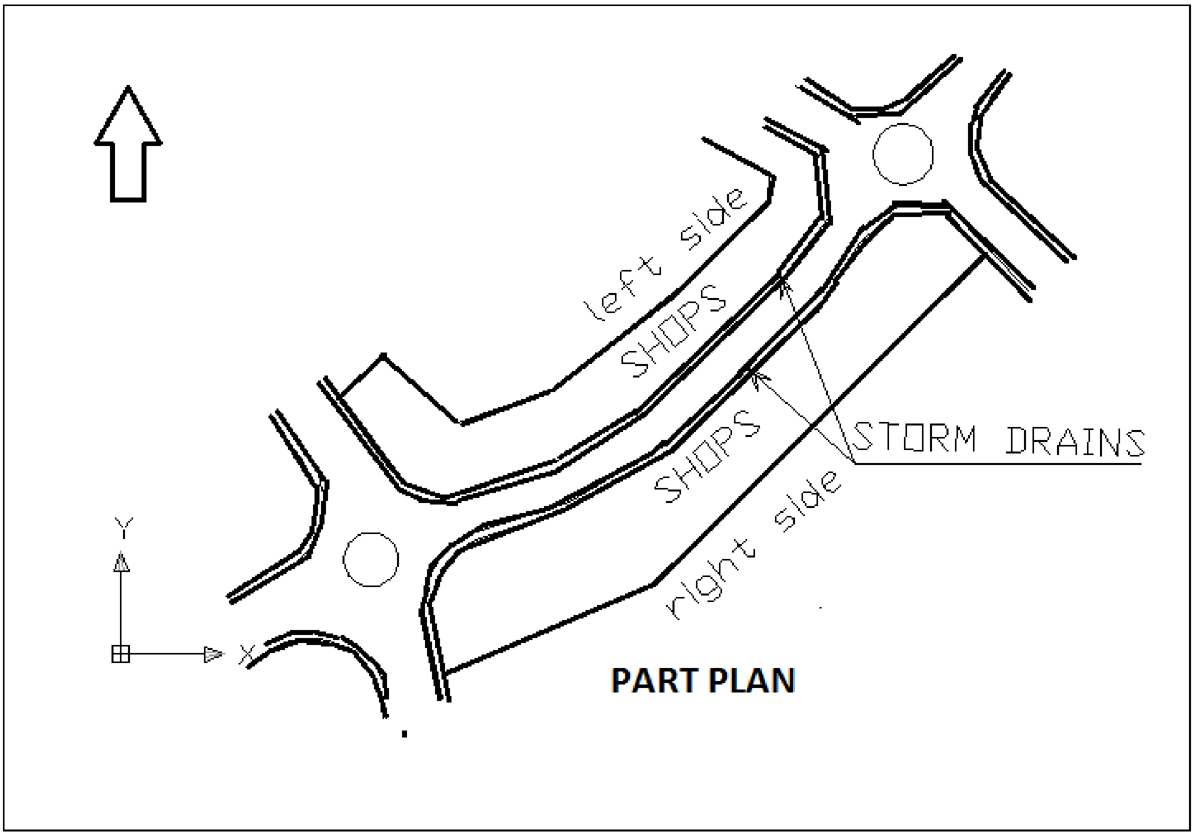

Fig. 9 Part plan of the Study area

TABLE 3
Design Details of the drain

Parameters						**Trapezoidal section** 						**Rectangular section** 			
Drain	**L (m)**	**A (ha)**	**C**	**CA**	**Cumulative Q m^3/s**	**Side slope H:V**	**d (m)**	**S**	**b (m)**	**V m/s**	**dp (m)**	**d (m)**	**b (m)**	**V m/s**	**dp (m)**
LEFT	60 B1-B2	8950	0.9	8055	0.1014	1 in 0.3	0.3	5.18×10^{-3}	0.25	1.10	0.5	0.3	0.35	1.05	0.5
	90 B2-B3	1600 14000	0.7 0.9	10480	0.24	1 in 0.3	0.4	5.18×10^{-3}	0.35	1.36	0.6	0.4	0.5	1.2	0.6
	180 B3-B4	18000	0.9	16200	0.47	1 in 0.2	0.5	5.18×10^{-3}	0.45	1.60	0.7	0.5	0.6	1.5	0.7
	180 B4-B5	18000	0.9	16200	0.68	1 in 0.3	0.6	5.18×10^{-3}	0.55	1.69	0.8	0.6	0.7	1.6	0.8
RIGHT	90 A1-A2	7350	0.9	6615	0.09	1 in 0.3	0.3	4.9×10^{-3}	0.2	1.04	0.5	0.3	0.3	1.01	0.5
	90 A2-A3	3600	0.9	3240	0.15	1 in 0.3	0.3	4.9×10^{-3}	0.35	1.12	0.5	0.3	0.4	1.11	0.5
	180 A3-A4	7200	0.9	6480	0.23	1 in 0.3	0.4	4.9×10^{-3}	0.35	1.27	0.6	0.4	0.45	1.28	0.6
	180 A4-A5	7200	0.9	6480	0.32	1 in 0.3	-.4	4.9×10^{-3}	0.45	1.41	0.6	0.4	0.6	1.34	0.6

IV. CONCLUSION

Rational method has been effectively used here to design the storm water drains of the study area (Refer part plan in Fig 9). In Rational Method the runoff coefficient comprises lot of factors of the catchment basin, land use pattern, soil cover, infiltration details etc. Diligent efforts are required to estimate these parameters in order to reach the value of runoff coefficient. In the present study utmost care has been taken to finalize the value of runoff coefficient 'C'. It was noted that the existing sections are not sufficient in most of the places to accommodate the runoff. The inundation of the study area is mainly due to the blockage of the drains in various points; therefore periodical maintenance of existing drains is essential. In those places where space constraints are acute, trapezoidal sections may be replaced with existing rectangular sections.

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REFERENCES

[1] Needhidasan.S et.al, *Preserving the Environment due to the flash floods in Vellar River at T.V.Puthur, Virudhachalam Taluk, Tamil Nadu – A Case Study*, International Journal of Structural and Civil Engineering Research (In Press), 2013.

[2] Dieter H. Lindner, *Surface water drainage design considerations practices*, Canadian Water Resources Journal, 12:3, 67-78, 2013.

[3] Butler and Davies, *Urban Drainage* Text Book, 2000.

[4] Vitousek*;* Harold A. Mooney; Jane Lubchenco; Jerry M. Melillo. *Science, New Series*, Vol. 277, No. 5325, pp. 494-499, 1997.

[5] Lambin, E.F., Baulies, X., Bockstael, N., Fischer, G., Krug, T.,Leemans, R., Moran, E.F., Rindfuss, R.R., Sato, Y., Skole, D.,Turner, B.L. II, Vogel, C., *Land-use and land-cover change (LUCC): Implementation strategy*, IGBP Report No. 48, IHDPReport No. 10, Stockholm, Bon, 1999.

[6] Bartone, Carl R., Janis Bernstein, and Josef Leitmann, *Managing the Environmental Challenge of Mega-Urban Regions*, Paper prepared for the International Conference on Managing the Mega-Urban Regions of ASEAN Countries: Policy Challenges and Responses. Bangkok: Asian Institute of Technology, Nov-Dec 1992.

[7] James F MacLAREN Limited, *Drainage Criteria Manual for the City of. Winnipeg*, Chapter 3 Willowdale, Ontario, 1997.

[8] Steven J. Burian, Stephan J. Nix, Robert E. Pitt and S. Rocky Durran, Journal of Urban Technology, Volume 7, Number 3, pages 33-62, 2000.

[9] Theodore G. Cleveland, et al, *Texas, metropolitan area: USGS Scientific Investigations Report, 2011*

[10] Franceso D Asaro, Giovanni Grillone, *Runoff Curve Number Method in Sicly: CN determination and Analysis of the initial Abstraction Ratio*, 2nd Joint Federal Interagency conference, Las Vegas NV, June 27-July 2010.

[11] Storm Water Design Criteria Manual for Municipal Services, Engineering and Public Works Department, Riverview, May 2011.