Estimation of Storm Runoff Quantity Using Rational Method and SWMM

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Abstract—In the recent years cities of India have witnessed huge losses due to flooding. These have increased the focus on urban flood management and flood risk assessment. While the new cities are being developed in accordance to flood risk management, the older cities have started facing the acute problem of floods and water logged streets every time the intensity of rainfall is higher. While assessing this situation it was found that Mumbai, faces this problem very severely and every year during monsoon most parts of this city gets waterlogged. Water logging has become a problem for government as well as residents of this city. City of Mumbai has storm water drainage system which was designed about hundred years ago. This aging system is being repaired and restructured for current demands but the problem still persists. Also the drainage system has been so designed that if there is a high tide the outlet of these drains are closed. This leads to waterlogging and flooding situation most of the time. Hence to avoid this situation water needs to be detained at a place where it won’t cause any damage to public life and during this detention water can be utilized for different purposes and the amount of water that goes into the sea as waste can be reduced. Estimation of runoff can done using empirical formulae like Rational Method, Dicken’s Method, Khosla’s Method etc. and also modern softwares like Storm Water Management Model (SWMM), HEC-HMS can be used. As per literature survey it was found that SWMM is widely used for runoff estimation and drainage modelling. Using SWMM we get peak runoff, total runoff, runoff coefficient, and return period for a particular precipitation event.

Keywords: Runoff, Urban drainage, SWMM

I.  INTRODUCTION

With the urbanisation of cities, need arises for different types of convenience systems which will protect it against any natural calamity that might result in huge economic losses and loss of life. With all the other things being taken care of, storm water management has been one neglected part of protective cover. Urban storm water management has gained importance only since the last two decades.

With the increase of runoff quantity in urban areas need arises for this water to be properly routed to a destination where it might be treated for reuse of just disposed off which is done in the case of most of the cities of the world. This routing is done with the help of drains, ditches, culverts which intercept the water from the impervious surfaces and carry it to their destination. These drains can work effectively only if they are designed to handle the estimated runoff water. If not designed using the correct tools these might fail, which in turn will cause huge loss of human life and economy. For cities like Mumbai which receive an annual rainfall of about 2000mm it becomes an important part of disaster management.

II. LITERATURE SURVEY

Tom Powers presented the paper on using rational method for estimating runoff quantity, at IASFM on March 2011. He successfully demonstrated that rational method can be used to calculate runoff volume for small catchment areas and then to design the drains to carry this water.

Needhidasan.S et. al (2013) in their paper Design of Storm Water Drains by Rational Method – an Approach to Storm Water Management for Environmental Protection, used Rational Method for calculating runoff for Palayam area of Calicut City in Kerala, India. They also designed the drains for that area using the runoff calculated by the rational method. This paper also discusses some other methods used to calculate runoff like the SCS runoff method and the modified rational method. This paper also demonstrates use of hydrograph for peak discharge calculation.

The paper published by Blanksby J et al, titled Modelling and mapping of urban storm water flooding – Using simple approaches in a process of Triage, have discussed modern soft computing techniques used for urban storm water modelling and river modelling. The techniques that have been developed after the 7th decade of the 20th century have been discussed in detail with due importance given to how these methods can be used by the government bodies to design urban storm water drains. The paper discusses LIDAR and GIS based modelling in detail with due consideration given to other techniques which are supporting it.

Prof. Shashikant D. Chawathe (2013) in his publication titled manual on rainfall analysis for storm water drainage systems have presented different mathematical calculations based on Intensity-Duration-Frequency
relationships for different cities like Mumbai, Chennai, Ahmedabad etc. This manual also explains the Rational method its limitations, design storms and rainfall measurement using Automatic Raingauge. He also recommends revising the 2 in 1 year return period recommended by the BRIMSTOWAD for design of Mumbai’s storm water drains.

KhabatKhosravi, Haidamirzai and ImanSaleh (2013) in their paper Assessment of Empirical Methods of Runoff Estimation by Statistical test (Case study: BanadakSadat Watershed, Yazd Province) have used empirical formulae like the Khosla Method, Indian Council of Agricultural Research (I.C.A.R) method and other methods. In all they have used 9 empirical formulae for estimation of runoff. The results were statistically compared using different methods like coupled t test, mean deviation (MD), mean deference (BIAS), percentage of relative error (RE) and Root mean square error (RMSE). The SPSS software was used to get result for coupled t test method. The results from the statistical approach were compared and the most economical runoff height was used as design runoff.

III. PROPOSED SYSTEM

A. General

The city of Mumbai covers about 603sqkm of area. Storm water drains in this city were laid during the 1920s with 0.5 as coefficient of runoff and 25mm/hr intensity of rainfall. After the floods of 1985, MCGM carried out extensive research under the name Brihanmumbai Storm Water Drain (BRIMSTOWAD) project. The report suggested that the design considerations be changed. As a result the coefficient was increased to 1 and rainfall intensity to 50mm/hr\[3\]. But this recommendation has not yet been implemented satisfactorily due many reasons, the most significant one being lack of finance. Hence, a study which might reduce this financial burden is required.

B. Study Area

The city of Mumbai has been broadly divided into the two parts i.e urban area(southern part of the city) and the suburban area(northern part of the city). Borivali is a part of suburban part of the city and has expanded to its limit in a very short period.

Since Borivali will be a huge area, a smaller fragment of this area, Gorai 1, has been considered for calculation. The total area is about 370000 sqm. This area lies at Latitude 19°13’ North and Longitude 72°52’ East. The average rainfall is of about 2000mm which is due the south-west monsoon. The climate all round the year is humid due to its proximity with the sea. Map 3.1 shows the location of Gorai 1.

C. Estimation Methods

3.3.2.1 Rational Method

For any hydraulic design it is required to calculate maximum discharge and peak value of discharge. Rational method is one of the best method to determine small watershed area runoff.

Formula

\[ Q = CiA \]

Where,

- \( Q \) = Design discharge
- \( C \) = Coefficient of Runoff
- \( i \) = Intensity of rainfall
- \( A \) = Watershed area

Coefficient of Runoff

Coefficient of runoff mainly gives characteristics of watershed area. When precipitation occurs some water get evaporate and infiltrate through soil which reduces actual surface runoff.

Limitations

One of the basic assumption of this method is that rainfall intensity must be constant for at least time of concentration. In addition to that accurate runoff coefficient determination is difficult because it depends on moisture condition of soil , vegetation growth , degree of compaction , permeability etc.

3.3.2.2 Storm Water Management Model (SWMM)

a. Governing equation

SWMM conceptualizes a subcatchment as a rectangular surface that has a uniform slope S and a width W that drains to a single outlet channel as shown in Figure 3.3. Overland flow is generated by modeling the subcatchment as a nonlinear reservoir, as sketched in Figure 3.4.
In this representation, the subcatchment experiences inflow from precipitation (rainfall and snowmelt) and losses from evaporation and infiltration. The net excess ponds atop the subcatchment surface to a depth \( d \). Ponded water above the depression storage depth \( ds \) can become runoff outflow \( q \). Depression storage accounts for initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation, and surface wetting.

From conservation of mass, the net change in depth \( d \) per unit of time \( t \) is simply the difference between inflow and outflow rates over the subcatchment:

\[
\frac{\partial d}{\partial t} = i - e - f - q \quad (3-1)
\]

where:

- \( i \) = rate of rainfall + snowmelt (ft/s)
- \( e \) = surface evaporation rate (ft/s)
- \( f \) = infiltration rate (ft/s)
- \( q \) = runoff rate (ft/s).

Note that the fluxes \( i, e, f, \) and \( q \) are expressed as flow rates per unit area (cfs/ft² = ft/s) Assuming that flow across the subcatchment’s surface behaves as if it were uniform flow within a rectangular channel of width \( W \) (ft), height \( d \), and slope \( S \), the Manning equation can be used to express the runoff’s volumetric flow rate \( Q \) (cfs) as:

\[
Q = (1.49/n) * W * S^{1/2} * (d - ds) \quad (3-2)
\]

Here \( n \) is a surface roughness coefficient, \( S \) the apparent or average slope of the subcatchment (ft/ft), \( A_x \) the area across the subcatchment’s width through which the runoff flows (ft²), and \( R_x \) is the hydraulic radius associated with this area (ft). Referring to Figures 3-1 and 3-2, \( A_x \) is a rectangular area with width \( W \) and height \( dds \). Because \( W \) will always be much larger than \( d \) it follows that \( A_x = (d - ds) \) and \( R_x = d - ds \). Substituting these expressions into Equation 3-2 gives

\[
Q = (1.49/n) * W * S^{1/2} * (d - ds)^{5/3} \quad (3-3)
\]

To obtain a runoff flow rate per unit of surface area, \( q \), Equation 3-3 is divided by the surface area of the subcatchment, \( A \) (which should not be confused with the cross-section area \( A_x \) through which the runoff passes):

\[
q = (1.49/n) * W * S^{1/2} / A * n \quad (d - ds)^{5/3} \quad (3-4)
\]

Substituting this equation into the original mass balance relation 3-1 results in:

\[
\frac{\partial d}{\partial t} = i - e - f - \alpha (d - d_s) \quad (3-5)
\]

Where \( \alpha \) is defined as:

\[
\alpha = 1.49 * W * S^{1/2} / A * n \quad (3-6)
\]

**IV. RESULTS**

On basis of collected data we had completed calculation of year 2010 for BorivaliGorai 1 region. Some output results of software is given below:

**Table 1 Event Summary**

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>Total precipitation mm</th>
<th>Total Runoff mm</th>
<th>Total Infiltration</th>
<th>Total runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUB1</td>
<td>3432.0</td>
<td>00.00</td>
<td>504.24</td>
<td>2927.8</td>
</tr>
</tbody>
</table>

**Table 2 Event Statistics**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Start date</th>
<th>Monthly duration (hours)</th>
<th>Monthly mean mm/hour</th>
<th>Exceedance frequency (percent)</th>
<th>Return period months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>07/01/2010</td>
<td>696.0</td>
<td>1.797</td>
<td>14.29</td>
<td>13.00</td>
</tr>
<tr>
<td>2</td>
<td>08/01/2010</td>
<td>648</td>
<td>1.589</td>
<td>28.57</td>
<td>6.50</td>
</tr>
<tr>
<td>3</td>
<td>06/02/2010</td>
<td>456</td>
<td>1.568</td>
<td>42.86</td>
<td>4.33</td>
</tr>
<tr>
<td>4</td>
<td>09/01/2010</td>
<td>432</td>
<td>0.767</td>
<td>57.14</td>
<td>3.25</td>
</tr>
<tr>
<td>5</td>
<td>10/05/2010</td>
<td>144</td>
<td>0.417</td>
<td>71.43</td>
<td>2.60</td>
</tr>
<tr>
<td>6</td>
<td>11/05/2010</td>
<td>120</td>
<td>0.380</td>
<td>85.71</td>
<td>2.17</td>
</tr>
</tbody>
</table>

**V. CONCLUSION**

With the help of SWMM after entering the required data like the area of catchment, rainfall data (time series), infiltration characteristics etc and running the simulation, we get results such as total precipitation, total runoff, total infiltration, peak runoff, runoff coefficient. We can compare the results obtained through Rational Method and SWMM software can be used to decide the design flow for design of drains.

Results can be obtained in tabular as well as in graphical format using SWMM software. The sample results have been shown in the figures below. To view a graph on screen select the graphs from the results menu in the main tool bar and select the desired parameters of which the plot is required. The graphs of runoff vs. elapsed time.
time, precipitation vs. elapsed time have been shown in the figures 3 and 4.

Figure 3 Hydrograph

Figure 4 Precipitation vs Time

Analysis of the precipitation characteristics of the study area gives a good idea about the intensity of rainfall, runoff which can be useful in determining the design parameters of the drains. SWMM provides us with the peak runoff and the average runoff and also the return period for all the precipitation events that have taken place during the time period that was entered for analysis. Hence it becomes easier to decide the design runoff and design return period for the precipitation event.

REFERENCES


