Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 06

December2016,P.P.2457-2465

Calibration & Validation of SWMM Model for Urban Watershed

NAGRAJ S PATIL, VINAYKUMAR S PATIL AND VIJAYKUMAR H

Department of Water and Land Management, Visvesvaraya Technological University, Belagavi, Karnataka, India

Email: *nagrajspatil@yahoo.com, nspatil@vtu.ac.in*

Abstract: The use of hydrological models to simulate rainfall-runoff events is an important tool for the evaluation of a watershed for different land uses, the SWMM being one of the most widely used models to represent these processes in urban areas, one of selected area is VTU campus, Belgaum. This work applied the SWMM in six small sub catchment basins in VTU campus, Belgaum aiming to evaluate the impact of the model parameters on the watershed responses. Observed pluviometric and fluviometric data were used in the model calibration, a process made by a manual trial and error method and the simulated and the observed runoff in the outlets were compared. In the calibration, the average determination coefficients from 0.87 to 0.99 were obtained, as were runoff peak errors from 0% to 31% and runoff volume errors from 0.3% to 71.1%. The calibrated parameters were distinct for high and low rainfall intensities in the same basin. The sensitivity of the parameters was shown to be variable according to the physical basin characteristics.

Keywords: *Urban runoff, Hydrological modelling, Sensitivity Analysis, SWMM Model*

1. Introduction

Urbanization creates infrastructure problems and large modifications in the environment. One of these changes refers to the increase in runoff, causing or exacerbating the urban disasters generated by the floods. Thus, the evaluation of responses from small urban watersheds is of great interest for the urbanization impact estimation, risk analysis and all projects involving these environments. Among the hydrologic models to simulate urban areas, the Storm Water Management Model, SWMM stands out. It was developed by U.S. EPA (Environmental Protection Agency) from 1969 to 1971 and has undergone several upgrades. The present study was carried out to evaluate the use of the SWMM model on small Sub catchments in VTU campus Belgaum. The focus was on the events calibration and on the understanding of the parameters involved in the simulation through a sensitivity analysis of them, based on observed field data from flow and rainfall monitoring.

1.1 Literature Review

Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. However, no comprehensive guidance is available to facilitate model evaluation in terms of the accuracy of simulated data compared to measured flow and constituent values. Thus, the objectives of this research were to: (1) determine recommended model evaluation techniques (statistical and graphical), (2) review reported ranges of values and corresponding performance ratings for the recommended statistics, and (3) establish guidelines for model evaluation based on the review results and project-specific considerations; all of these objectives focus on simulation of stream flow and transport of sediment and nutrients. These objectives were achieved with a thorough review of relevant literature on model application and recommended model evaluation methods. Based on this analysis, we recommend that three quantitative statistics, Nash-Sutcliffe efficiency (NSE), and ratio of the root mean square error to the standard deviation of measured data (RSR), in addition to the graphical techniques, be used in model evaluation. The following model evaluation performance ratings were established for each recommended statistic. In general, model simulation can be judged as satisfactory if NSE > 0.50 and RSR < 0.70, constituent-specific performance ratings were determined based on uncertainty of measured data. Additional considerations related to model evaluation guidelines are also discussed. These considerations include: Single-event simulation, quality and quantity of measured data, model calibration procedure, evaluation time step, and project scope and magnitude. A case study illustrating the application of the model evaluation guidelines is also provided. Moriasi et al. [1]. Keith [2], studied using six discrete event based urban rainfall-runoff quantity models, used by Federal agencies and these models were calibrated on twenty-three events recorded by the U.S. Geological Survey (USGS) on three urban basins during 1974-1975 in Oklahoma City. The models were the Rational Method, used by the Department of Housing and Urban Development (HUD); TR-20, used by the U.S. Soil Conservation Service (SCS); HEC-1, used by the U.S. Corps of Engineers (COE); Urban Flood Hydrograph Synthesis Model (G824), used by the USGS; SWMM, developed for the U.S. Environmental Protection Agency (EPA); and MINICAT, under consideration for use by the National Weather Service, River Forecast Center (RFC) . The models were calibrated for peak discharge on the recorded floods, and all except the Rational Method were calibrated for runoff volume. Kyung-sook et al. [4] used information contained within a GIS database together with optimization techniques to infer spatially variable control parameters for utilization with a catchment modeling system such as the Storm-Water Management Model (SWMM). The first of these alternatives can be described as a "trial and error" method whereby the values of the control parameters were modified in a systematic manner to achieve correlation between the monitored parameters and the predicted parameters describing the catchment response. To compare the proposed calibration process with a more traditional calibration process, the evaluation criteria used were the relative error in peak flow and runoff depth and the hydrograph root mean square error. Resulting from this approach, it was found that high accuracy control parameter estimation was obtained. From the comparison of the new and traditional calibration approaches, it was found that hydro informatics systems can be used effectively to evaluate catchment modeling system control parameters and to improve the accuracy and efficiency of the catchment modeling system calibration process.

In the study SWMM was modified and adapted for the upper Ballona Creek Watershed, Imperviousness was obtained from land use data and the spatial distribution of precipitation was developed using the GIS and isohyetal map. The calibrated model was able to predict the observed outputs with reasonable accuracy, the sensitivity analysis was performed by changing each parameter while keeping all others constant and observing the changes in model output. The percent changes in runoff volume were most sensitive to changes in imperviousness and storage. Changes in all other parameter were small by comparison and sometimes insignificant. The complex method of box was used to calibrate the model for ten storms using several strategies and weighting functions. Janet B et al. [3]. Cambez et al. [5], has used the recent version 5 of SWMM for Microsoft windows satisfactory results were obtained from the hydraulic model calibration and verification process, but some limitations where found in the SWMM catchment hydrological description .The hydrological reduction coefficients where calculated based on the volumetric hydrological losses and where assumed constant for each calibration sub-catchment. Obtained values for the coefficients were: .70 for catchments B2-A and B2-B, 0.60 for catchment B1 and 0.30 for the pseudo-separate catchment B1-I, However, this methodology carries this disadvantage of not preserving the measured impervious areas or the hydrological reduction coefficients on the model.

1.2 Field Investigations

A variety of field investigations were performed. Every individual impervious surface was checked to estimate its hydraulic properties, including connectivity. The pavement material of every sub-catchment was observed. The Pavement material and physical connectivity of every sidewalk and driveway were also investigated carefully. The fluviometric and pluviometric data used in the simulations were obtained from monitoring stations inside the studied sub-catchments. Some rainfall events were selected and classified in groups, according to the total runoff generated, being used as inputs for the model. Vinay et al. [6]

1.2.1 Characterization of the study areas

The application of SWMM model was conducted in six small Sub catchments in VTU campus Belagavi (figure 1.), whose physical characteristics are presented in table 1. The region has a characteristic climate classified as humid subtropical.

Table 1: *Physical characteristics of the analysed Sub Catchments*

Physical parameters	Basin					
	Sub-catchment 1	Sub-catchment 2	Sub-catchment 3	Sub-catchment 4	Sub-catchment 5	Sub-catchment 6
Area(m^2)	97478.91	99717.53	99225.02	17798.41	110847.41	67943.08
Maximum elevation(m)	756	755.29	750.41	745.60	757.24	750.26
Minimum elevatio(m)	745	750.41	745.60	744.96	750.26	747.33
Avg. slope of the basin(m/m)	0.03	0.02	0.02	0.02	0.03	0.02
Impervious area(%)	40-50	40-50	40-50	10-20	40-50	50-60

1.3. Study Area

The study area VTU, Belgaum is shown in the fig.1. The total area of the study is about 119 acres, under Kinaye watershed. The latitude and longitude of the project are 15'46' N and 74'46' E respectively. The soil is red soil and red silt loams. The climate of the district is free from extremes, the dry season is from March to June, the monsoon season is from July to October and the winter period from November to

February. The normal rainfall in that station is 1193.8 mm; December to March is the very low rainfall months. August is the wettest month with monthly rainfall in excess of 250mm. The rainfall occurs in nearly 48 days in a year. The temperatures start rising from January to a peak of around 39°C in April, the hottest month in the district. Thereafter it declines during the monsoon period and December is coldest month and the temperatures dips down to 9°C.

The maximum rainfall value of 1hr duration, the maximum 1hr rainfall in a year is considered. For maximum values of 2hr to 24hr rainfall duration, the maximum rainfall in a year is considered. The total duration of this rainfall event was 24hr. Total daily rainfall on 09th July 2007 was 120 mm. For considering the highest rainfall value during 09-07-2007, for this 24hr duration, total rainfall depth was 120 mm. (see table.2).

The storage height showed to be greater in events with higher rainfall volume. The figure.2 shows the annual maximum one day rainfall from 2001 to 2014. The maximum rainfall occur in 2007 is 120 mm and minimum rainfall occur in 2001 is 48.70 mm.

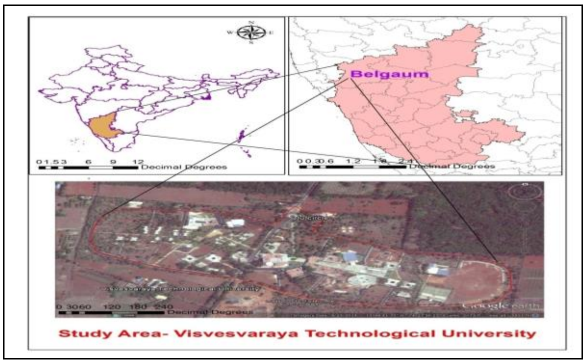


Figure 1: *Location map of study area*

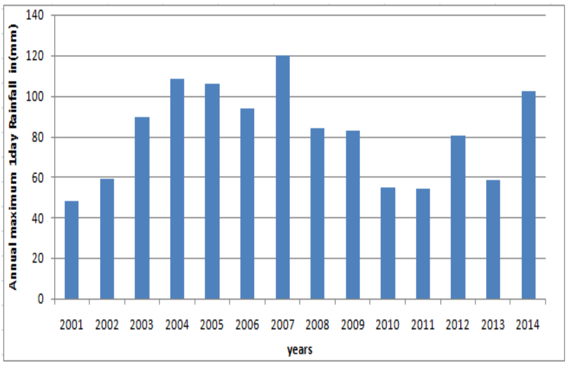


Figure 2*: Annual maximum 1 day Rainfall Distribution*

Table 2 *Rainfall Time Series*

Rainfall duration	Rainfall	Years														1day max rainfall(mm)
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
1hr max	Intensity (mm)	6.8	8.4	12.7	15.5	15.1	13.4	17.1	12	11.8	7.8	7.7	11.5	8.4	14.6	17.1
2hr max	Intensity (mm)	11.8	14.5	22.0	26.8	26.1	23.2	29.6	20.8	20.4	13.5	13.3	19.9	14.5	25.2	12.5
3hr max	Intensity (mm)	18.5	22.9	34.6	42.1	41.1	36.5	46.6	32.6	32.1	21.2	21.0	31.3	22.8	39.7	17.0
4hr max	Intensity (mm)	21.9	27.1	40.9	49.7	48.6	43.1	55.1	38.6	37.9	25.0	24.8	37.0	26.9	46.9	8.5
5hr max	Intensity (mm)	26.4	32.6	49.3	59.9	58.6	52.0	66.4	46.5	45.7	30.2	29.9	44.6	32.4	56.5	11.3
6hr max	Intensity (mm)	28.4	35.1	53.0	64.4	63.0	55.9	71.3	50.0	49.1	32.4	32.1	47.9	34.8	60.7	5.0
7hr max	Intensity (mm)	28.5	35.1	53.1	64.5	63.1	56.0	71.5	50.1	49.2	32.5	32.2	48.0	34.9	60.8	0.1
8hr max	Intensity (mm)	28.5	35.2	53.2	64.7	63.3	56.1	71.6	50.2	49.3	32.6	32.2	48.1	35.0	60.9	0.1
9hr max	Intensity (mm)	28.6	35.3	53.3	64.8	63.4	56.2	71.8	50.3	49.4	32.6	32.3	48.2	35.1	61.1	0.1
10hr max	Intensity (mm)	29.9	36.9	55.8	67.7	66.3	58.8	75.0	52.5	51.6	34.1	33.8	50.4	36.6	63.8	3.3
11hr max	Intensity (mm)	31.8	39.3	59.4	72.2	70.6	62.7	80.0	56.0	55.0	36.4	36.0	53.7	39.1	68.0	5.0
12hr max	Intensity (mm)	33.0	40.7	61.5	74.7	73.1	64.9	82.8	58.0	57.0	37.6	37.3	55.6	40.4	70.5	2.8
13hr max	Intensity (mm)	33.6	41.5	62.8	76.3	74.6	66.2	84.5	59.2	58.1	38.4	38.0	56.7	41.3	71.9	1.7
14hr max	Intensity (mm)	34.4	42.4	64.2	77.9	76.3	67.6	86.3	60.5	59.4	39.2	38.9	58.0	42.2	73.5	1.8
15hr max	Intensity (mm)	36.6	45.2	68.4	83.0	81.3	72.1	92.0	64.4	63.3	41.8	41.4	61.7	44.9	78.3	5.7
16hr max	Intensity	39.8	49.1	74.3	90.2	88.3	78.3	99.9	70.0	68.7	45.4	45.0	67.1	48.8	85.0	7.9

(mm)															
17hr max Intensity (mm)	41.8	51.6	78.1	94.8	92.8	82.3	105.0	73.5	72.2	47.7	47.3	70.5	51.3	89.3	5.1
18hr max Intensity (mm)	43.8	54.1	81.7	99.2	97.1	86.2	110.0	77.0	75.7	50.0	49.5	73.8	53.7	93.5	5.0
19hr max Intensity (mm)	44.9	55.5	83.8	101.8	99.6	88.4	112.8	79.0	77.6	51.3	50.8	75.7	55.1	96.0	2.8
20hr max Intensity (mm)	45.3	55.9	84.5	102.6	100.4	89.0	113.7	79.6	78.2	51.7	51.2	76.3	55.5	96.7	0.8
21hr max Intensity (mm)	45.6	56.3	85.1	103.3	101.1	89.7	114.5	80.2	78.8	52.0	51.5	76.8	55.9	97.4	0.9
22hr max Intensity (mm)	46.5	57.5	86.9	105.5	103.2	91.6	116.9	81.9	80.4	53.1	52.6	78.4	57.0	99.4	2.4
23hr max Intensity (mm)	47.5	58.6	88.6	107.5	105.2	93.3	119.2	83.4	82.0	54.1	53.6	80.0	58.1	101.3	2.3
24hr max Intensity (mm)	47.8	59.0	89.2	108.2	106.0	94.0	120.0	84.0	82.5	54.5	54.0	80.5	58.5	102.0	0.8

1.3.1 Sensitivity analysis

For the sensitivity analysis, the events with the best results from calibration were used, intending to evaluate the main parameters involved in the peak and volume of runoff. Starting from the set of parameters that led to the best calibrations per sub-basin (sub catchment), one parameter was varied at a time in fixed percentage increments, whose results were tabulated and compared. Despite the fact that the sub-basin widths do not vary in the same watershed, the sensitivity of this parameter was also analyzed to evaluate the possible errors of the assumption that its value is approximated by the equivalent rectangle length. The following table 3 shows estimation of runoff for sub catchment 1 to 6 is shown below the runoff for maximum rainfall of 24 hr duration was computed for high peak (Year 2007) and low peak (Year 2001) was done.

Table 3: *Estimation of runoff for maximum rainfall of 24 hours duration for the Year 2007 and 2001*

SUBCATCHMENT - 1 - 2007										
Rainfall Duration (Hr)	**Flow (CMS)**	**Infiltration rate 10-5(mm)**			**Infiltration rate 25-10(mm)**			**Infiltration rate 60-40(mm)**		
		Impervious cover %			**Impervious cover %**			**Impervious cover %**		
		35	**45**	**60**	**35**	**45**	**60**	**35**	**45**	**60**
1 Hr	Runoff	0.36	0.43	0.50	0.36	0.43	0.50	0.36	0.43	0.50
2 Hr	Runoff	0.36	0.43	0.50	0.36	0.43	0.50	0.36	0.43	0.50
3 Hr	Runoff	0.44	0.55	0.72	0.40	0.51	0.68	0.40	0.51	0.68
6 Hr	Runoff	0.44	0.55	0.72	0.40	0.51	0.68	0.40	0.51	0.68
12 Hr	Runoff	0.44	0.55	0.72	0.40	0.51	0.68	0.40	0.51	0.68
24 Hr	Runoff	0.44	0.55	0.72	0.40	0.51	0.68	0.40	0.51	0.68
Estimated runoff for maximum rainfall of 24 hr duration varies from 0.36 to 0.72 CMS.										

SUBCATCHMENT - 2 - 2007										
Rainfall Duration (Hr)	**Flow (CMS)**	**Infiltration rate 10-5(mm)**			**Infiltration rate 25-10(mm)**			**Infiltration rate 60-40(mm)**		
		Impervious cover %			**Impervious cover %**			**Impervious cover %**		
		35	**45**	**60**	**35**	**45**	**60**	**35**	**45**	**60**
1 Hr	Runoff	0.36	0.42	0.47	0.36	0.42	0.47	0.36	0.42	0.47
2 Hr	Runoff	0.36	0.42	0.51	0.36	0.42	0.51	0.36	0.42	0.51
3 Hr	Runoff	0.44	0.55	0.73	0.40	0.52	0.69	0.40	0.52	0.69
6 Hr	Runoff	0.44	0.55	0.73	0.40	0.52	0.69	0.40	0.52	0.69
12 Hr	Runoff	0.44	0.55	0.73	0.40	0.52	0.69	0.40	0.52	0.69
24 Hr	Runoff	0.44	0.55	0.73	0.40	0.52	0.69	0.40	0.52	0.69
Estimated runoff for maximum rainfall of 24 hr duration for 2007 is varies from 0.36 to 0.73 CMS.										

SUBCATCHMENT - 3 - 2007										
Rainfall Duration (Hr)	**Flow (CMS)**	**Infiltration rate 10-5(mm)**			**Infiltration rate 25-10(mm)**			**Infiltration rate 60-40(mm)**		
		Impervious cover %			**Impervious cover %**			**Impervious cover %**		
		35	**45**	**60**	**35**	**45**	**60**	**35**	**45**	**60**
1 Hr	Runoff	0.35	0.42	0.47	0.35	0.42	0.47	0.35	0.42	0.47

2 Hr	Runoff	0.35	0.42	0.51	0.35	0.42	0.51	0.35	0.42	0.51
3 Hr	Runoff	0.44	0.55	0.72	0.40	0.52	0.69	0.40	0.52	0.69
6 Hr	Runoff	0.44	0.55	0.72	0.40	0.52	0.69	0.40	0.52	0.69
12 Hr	Runoff	0.44	0.55	0.72	0.40	0.52	0.69	0.40	0.52	0.69
24 Hr	Runoff	0.44	0.55	0.72	0.40	0.52	0.69	0.40	0.52	0.69
Estimated runoff for maximum rainfall of 24 hr duration for 2007 is varies from 0.35 to 0.72 CMS.										

SUBCATCHMENT - 4 - 2007

Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.06	0.07	0.08	0.06	0.07	0.08	0.06	0.07	0.08
2 Hr	Runoff	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.07	0.09
3 Hr	Runoff	0.08	0.10	0.13	0.07	0.09	0.12	0.07	0.09	0.12
6 Hr	Runoff	0.08	0.10	0.13	0.07	0.09	0.12	0.07	0.09	0.12
12 Hr	Runoff	0.08	0.10	0.13	0.07	0.09	0.12	0.07	0.09	0.12
24 Hr	Runoff	0.08	0.10	0.13	0.07	0.09	0.12	0.07	0.09	0.12
Estimated runoff for maximum rainfall of 24 hr duration for 2007 is varies from 0.06 to 0.13 CMS.										

SUBCATCHMENT - 5 - 2007

Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.40	0.48	0.54	0.40	0.48	0.54	0.40	0.48	0.54
2 Hr	Runoff	0.40	0.48	0.57	0.40	0.48	0.57	0.40	0.48	0.57
3 Hr	Runoff	0.49	0.62	0.81	0.45	0.58	0.77	0.45	0.58	0.77
6 Hr	Runoff	0.49	0.62	0.81	0.45	0.58	0.77	0.45	0.58	0.77
12 Hr	Runoff	0.49	0.62	0.81	0.45	0.58	0.77	0.45	0.58	0.77
24 Hr	Runoff	0.49	0.62	0.81	0.45	0.58	0.77	0.45	0.58	0.77
Estimated runoff for maximum rainfall of 24 hr duration for 2007 is varies from 0.40 to 0.81 CMS.										

SUBCATCHMENT - 6 - 2007

Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.24	0.28	0.30	0.24	0.28	0.30	0.24	0.28	0.30
2 Hr	Runoff	0.24	0.28	0.35	0.24	0.28	0.35	0.24	0.28	0.35
3 Hr	Runoff	0.30	0.37	0.49	0.28	0.35	0.47	0.28	0.35	0.47
6 Hr	Runoff	0.30	0.37	0.49	0.28	0.35	0.47	0.28	0.35	0.47
12 Hr	Runoff	0.30	0.37	0.49	0.28	0.35	0.47	0.28	0.35	0.47
24 Hr	Runoff	0.30	0.37	0.49	0.28	0.35	0.47	0.28	0.35	0.47
Estimated runoff for maximum rainfall of 24 hr duration for 2007 is varies from is varies from 0.24 to 0.49 CMS										

SUBCATCHMENT - 1 - 2001

Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.10	0.10	0.11	0.10
2 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.11	0.10
3 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
6 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
12 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
24 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
Estimated runoff for maximum rainfall of 24 hr duration for 2001 is varies from 0.10 to 0.26 CMS.										

SUBCATCHMENT - 2 - 2001										
Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.10	0.10	0.11	0.10
2 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.11	0.10
3 Hr	Runoff	0.16	0.20	0.25	0.16	0.20	0.25	0.16	0.20	0.25
6 Hr	Runoff	0.16	0.20	0.25	0.16	0.20	0.25	0.16	0.20	0.25
12 Hr	Runoff	0.16	0.20	0.25	0.16	0.20	0.25	0.16	0.20	0.25
24 Hr	Runoff	0.16	0.20	0.25	0.16	0.20	0.25	0.16	0.20	0.25
Estimated runoff for maximum rainfall of 24 hr duration for 2001 is varies from 0.10 to 0.25 CMS.										

SUBCATCHMENT - 3 - 2001										
Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.10	0.10	0.11	0.10
2 Hr	Runoff	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.11	0.10
3 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
6 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
12 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
24 Hr	Runoff	0.16	0.20	0.26	0.16	0.20	0.26	0.16	0.20	0.26
Estimated runoff for maximum rainfall of 24 hr duration for 2001 is varies from 0.10 to 0.26 CMS										

SUBCATCHMENT - 4 - 2001										
Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2 Hr	Runoff	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
3 Hr	Runoff	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
6 Hr	Runoff	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
12 Hr	Runoff	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
24 Hr	Runoff	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
Estimated runoff for maximum rainfall of 24 hr duration for 2001 is varies from 0.02 to 0.04 CMS.										

SUBCATCHMENT - 5 - 2001										
Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.11	0.12	0.11	0.11	0.12	0.11	0.11	0.12	0.11
2 Hr	Runoff	0.11	0.12	0.11	0.11	0.12	0.12	0.11	0.12	0.11
3 Hr	Runoff	0.18	0.22	0.29	0.18	0.22	0.29	0.18	0.22	0.29
6 Hr	Runoff	0.18	0.22	0.29	0.18	0.22	0.29	0.18	0.22	0.29
12 Hr	Runoff	0.18	0.22	0.29	0.18	0.22	0.29	0.18	0.22	0.29
24 Hr	Runoff	0.18	0.22	0.29	0.18	0.22	0.29	0.18	0.22	0.29
Estimated runoff for maximum rainfall of 24 hr duration for 2001 is varies from 0.011 to 0.29 CMS.										

SUBCATCHMENT - 6 - 2001										
Rainfall Duration (Hr)	Flow (CMS)	Infiltration rate 10-5(mm)			Infiltration rate 25-10(mm)			Infiltration rate 60-40(mm)		
		Impervious cover %			Impervious cover %			Impervious cover %		
		35	45	60	35	45	60	35	45	60
1 Hr	Runoff	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07	0.06
2 Hr	Runoff	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06
3 Hr	Runoff	0.11	0.13	0.17	0.11	0.13	0.17	0.11	0.13	0.17

6 Hr	Runoff	0.11	0.13	0.17	0.11	0.13	0.17	0.11	0.13	0.17
12 Hr	Runoff	0.11	0.13	0.17	0.11	0.13	0.17	0.11	0.13	0.17
24 Hr	Runoff	0.11	0.13	0.17	0.11	0.13	0.17	0.11	0.13	0.17

Estimated runoff for maximum rainfall of 24 hr duration for 2001 (table 5.1) is varies from 0.07 to 0.17 CMS.

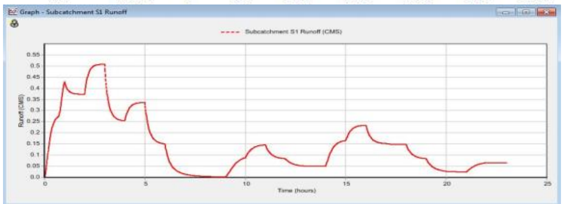
1.3.2 Effect of different rainfall on peak runoff from SWMM model

For sub-catchment 1 to 6, the variation of runoff for corresponding rainfall. For 1 hr and 2hr rainfall peak runoff is 0.57 CMS, for 3 hr rainfall peak runoff is 0.81 CMS and for 12hr and 24 hr peak runoff is 0.81 CMS. Graph for Runoff rainfall event for sub-catchment 1 to 6, is shown in figure 3.

From 1 hr rainfall the peak runoff occurs, after 2 hr runoff will decreases till 4 hr 30 min there will be no runoff. From 2 hr rainfall the peak runoff occurs after 2 hr and 3 hr rainfall duration, after 3 hr runoff will decreases till 5 hr 50 min after 5 hr 50 min there will be no runoff. From 3 hr rainfall the peak runoffs occurs after 2 hr, 3 hr and 4hr rainfall duration, after 4hr runoff will decreases till 6 hr after 6 hr there will be no runoff, From 6 hr rainfall the peak runoff occurs after 2 hr, 3hr, 4hr and 7 hr rainfall duration, after 7 hr runoff will decreases till 9 hr 50 min after will be no runoff. From 12 hr rainfall the peak runoff occurs after 4 hr, 5 hr 30 min, 6 hr 30 min and 10 hr rainfall duration, after 10 hr runoff will decreases till 14 hr 30 min after 14 hr 30 min there will be runoff. From 24 hr rainfall the peak runoff occurs after 5 hr, 7 hr, and 10 hr rainfall duration, after 10 hr runoff will decreases till 25 hr 30 min after 25 hr 30 min there will be no runoff. In between 15 hr 20hr in this 5 hr duration the runoff is less.

Sub catchment 1 Runoff 24 Hr rainfall event 2007

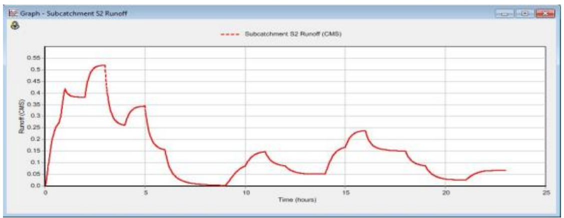
Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S1	119.2	0	1.45	65.19	49.55	11.93	0.51	0.416



The peak runoff is 0.51 CMS.

Sub catchment 2 Runoff 24 Hr rainfall event 2007

Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S2	119.2	0	1.45	65.19	49.45	12.19	0.52	0.415



The peak runoff is 0.52 CMS.

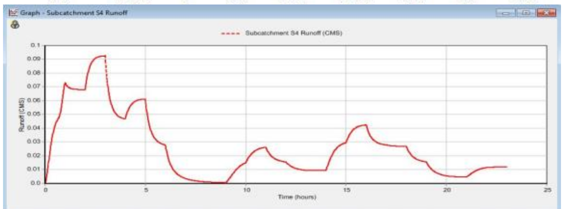
Sub catchment 3 Runoff 24 Hr rainfall event 2007

Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S3	119.2	0	1.45	65.19	49.46	12.12	0.52	0.415

Peak runoff is 0.52 CMS.

Sub catchment 4 Runoff 24 Hr rainfall event 2007

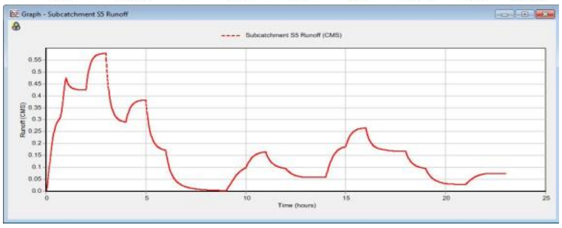
Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S4	119.2	0	1.45	65.19	49.42	2.17	0.09	0.415



Peak runoff is 0.09 CMS.

Sub catchment 5 Runoff 24 Hr rainfall event 2007

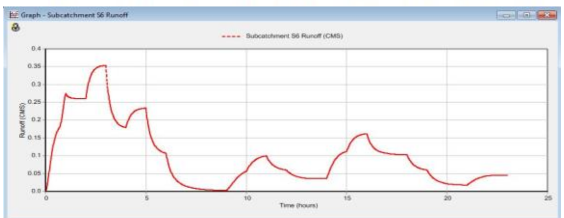
Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S5	119.2	0	1.45	65.19	49.5	13.56	0.58	0.415



Peak runoff is 0.58 CMS.

Sub catchment 6 Runoff 24 Hr rainfall event 2007

Subcatchments	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Run off CMS	Runoff coeff
S6	119.2	0	1.45	65.19	49.39	8.29	0.35	0.414



Peak runoff is 0.35 CM]S.

***Figure 3:** Graph for Runoff rainfall event for sub-catchment-1 to 6*

1.4 Calibration

With the procedure adopted to calibrate the events, a set of parameters that led to the best fit between the observed and the simulated hydrograms was obtained for each event. Table 4 provides Calibration values of Nash-Sutcliffe efficiency (NSE), RSR and runoff peak values using SWMM model. The validation obtained comparing the calibrated values are shown in table.5.

Table 4: *Calibration values of Nash-Sutcliffe efficiency (NSE), RSR and runoff peak values using SWMM model*

Catchments	R^2		NSE		RSR		Runoff Peak (CMS)	
	Min	Max	Min	Max	Min	Max	Min	Max
S1	0.912	0.996	0.228	0.756	0.300	0.88	0.360	0.720
S2	0.918	0.993	0.275	0.765	0.293	0.85	0.370	0.740
S3	0.918	0.993	0.275	0.765	0.293	0.85	0.370	0.740
S4	0.915	0.998	0.287	0.766	0.292	0.84	0.070	0.130
S5	0.916	0.994	0.256	0.761	0.296	0.86	0.410	0.820
S6	0.910	0.990	0.299	0.761	0.291	0.84	0.240	0.500

Table 5: *The validation obtained comparing the calibrated values*

SWMM parameters for each basin						
Catchment		ni	np	Infiltration (mm)	Pervious (%)	Impervious (%)
Sub Catchment 1	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40
Sub Catchment 2	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40
Sub Catchment 3	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40
Sub Catchment 4	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40
Sub Catchment 5	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40
Sub Catchment 6	min	0.011	0.13	60	35	65
	max	0.012	0.15	5	60	40

In the calibration process, some observations could be made. Similar to the conclusions of Zaghloul [7], in simplified discretizations, the runoff peak is greater than in detailed discretizations. In the Cancela basin, this increase was 8.2% for the events of Group A and 6.1% for Group C. Reduction in time was noted in simplified discretization with an average value. It is possible to conclude that in natural river beds, as illustrated in Chow & Ben [8] [9], when the water level grows until the bankfull depth, the Manning's decreases. However, when this depth is extrapolated, the flow finds greater resistence due to the distinct composition of the boundaries, especially because of the vegetation, usually denser in these regions. This profile is also observed in the analyzed watersheds, even in the urbanized areas, where a vegetated transition zone can be found between the stream and the impervious areas.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}\right]}$$

Where, ni Manning's impervious value, np Manning's pervious value.

To check the results are validate or not the SWMM results were compared with the Rational runoff formula (i.e. Q=CxIxA, where Q= discharge, I= intensity of rainfall, A= area) and performance table is show in table 6. Results of 1 hour runoff data is showed in table 6.

Table 6: *One hr runoff by SWMM and Rational method*

Results	Flow	SWMM model runoff	Rational runoff formula
Sub catchment 1	CMS	0.32	0.36
Sub catchment 2	CMS	0.32	0.35
Sub catchment 3	CMS	0.32	0.35
Sub catchment 4	CMS	0.05	0.06
Sub catchment 5	CMS	0.36	0.40
Sub catchment 6	CMS	0.22	0.23

To check the existing drainage adequacy, peak discharge were computed by using manning roughness coefficient. Manning equation gives the value of velocity of liquid in the channel if the cross section area of channel is known discharge can be computed by multiplying the velocity into cross sectional area. Table 7 shows the performance of SWMM.

Table 7.*Performance of SWMM*

Results	Flow	SWMM model runoff	Manning's equation runoff
Sub catchment 1	CMS	0.55	0.82
Sub catchment 2	CMS	0.57	0.82
Sub catchment 3	CMS	0.56	0.82
Sub catchment 4	CMS	0.10	0.82
Sub catchment 5	CMS	0.63	0.82
Sub catchment 6	CMS	0.38	0.82

Conclusions

The results obtained using the Pearson's correlation coefficient and the SWMM model software is almost equal The result of six sub-catchments, it can be said that existing drainage system is adequate for existing conditions but As the impervious cover increases above 60% or rainfall intensity increases in future, the peak discharge may exceed the design capacity of existing channel in sub catchment 5. To control the runoff on the sub catchment 5 we can change the drainage dimension to $((0.85 + 0.60) \times 0.75)$ m, so that in future we can reduce the runoff or we can provide Green Roofs or Continuous permeable pavement or Infiltration trenches.

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