QUANTIFICATION OF THE HYDROLOGICAL IMPACTS OF IMPERVIOUSNESS IN URBAN CATCHMENTS USING WIN TR-55

Megha Bedi[1], Amarpreet S. Arora[2], Akepati S. Reddy[3]

[1]*Civil Engineering Department, MM Engineering College, Maharishi Markarndeshwar University, Mullana, Ambala, (India)*

[2]*Environmental Science and Engineering, Marwadi Education Foundation's Group of Institutions, Rajkot, Gujarat, (India)*

[3]*School of Energy and Environment, Thapar University, Patiala, Punjab, (India)*

ABSTRACT

Stormwater has become a major issue both in urban and rural human settlements. Storm water runoff estimations have been ignored ever since. Model Town and Civil Lines sub-watersheds/catchments of the Patiala city, Punjab have been selected for the stormwater estimation. The catchment characteristics and the rainfall characteristics required in the estimations have been obtained. Water quality treatment volume – WQv, water quality capture volume, and peak runoff rates have been considered as required. The hydrological methods and models available for the quantification were reviewed, and the method appropriate for the present stormwater runoff estimations was articulated. Using the method, stormwater runoff estimations for the selected catchments has been done. Details of the catchments, the rainfall, and the runoff estimates are presented in this paper.

Keywords: Model Development, Runoff Estimation, Stormwater Management, Stormwater Quantification.

I. INTRODUCTION

Urbanization has a direct impact on the quantity and quality characteristics of the water environment owing to construction of urban infrastructures causing changes in landscape and runoff conveyance networks [5, 4]. Land use modifications associated with urbanization such as removal of vegetation, replacement of previously pervious areas with impervious surfaces and drainage channel modifications invariably result in significant changes to the flow regime of urban catchments resulting in flooding of the low lying areas during rains [2, 3, and 7].

Patiala (29°49’ and 30°47’ north latitude, 75°58’ and 76°54' east longitude), an erstwhile princely city of the Punjab state of India, doesn’t have provisions for the stormwater drainage as a result even modest rainfall events produce severe flooding in many parts of the city [1]. Before any planning or any practical steps to control the quality of urban runoff, it is necessary to first specify the quantity of the urban surface runoff generated. Water resource managers beside the maintenance of water quality are faced with the challenge of control and management of runoff quantity as well. The objective of this study was to estimate the quantity of surface runoff from different urban sub-catchments within the Patiala city, India and formulate relationships between runoff rates and catchment characteristics. These relationships are supposed to help in assessing volumes of the storm waters generated as runoff from urban sub-catchments and to develop innovative land-use-related control strategies to effectively control and utilize this potential.

II. METHODOLOGY

2.1 Selection of Sites

The present study involves two sub-watersheds Model Town and Civil Lines within Patiala (Fig. 1), which have been selected on the basis of diversity of catchment characteristics.

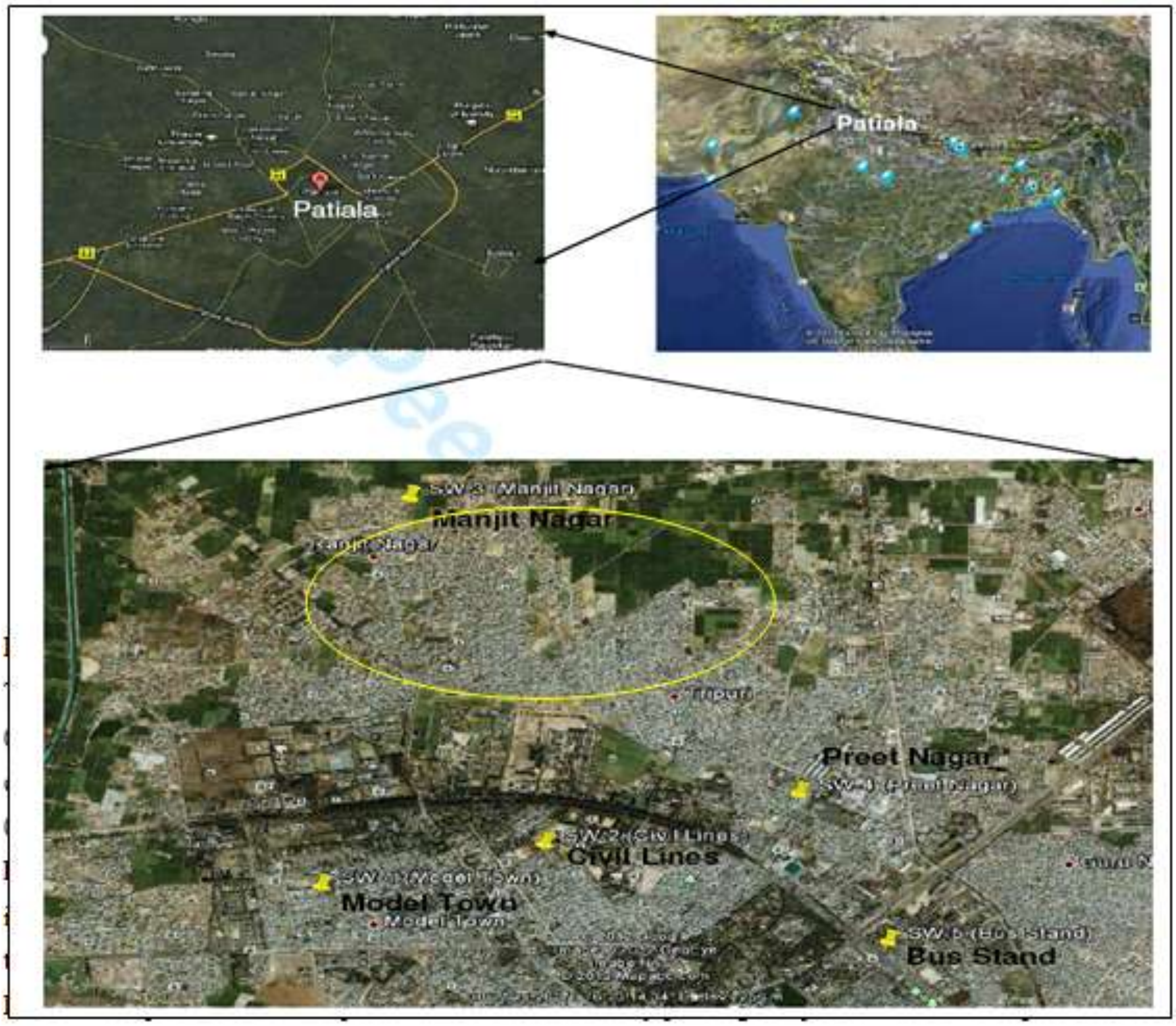


Figure 1: Map Showing the Sub-Watersheds Studied

The area of the catchments has been delineated by considering the outlet i.e. point of collection of stormwater (where the entire sub-watersheds contributes runoff generated by a storm event). For the purpose of quantification detailed study has been done on the physical characteristics of the watersheds including Land Use (impervious area including roads and roof tops), Soil Type, Grass Cover, Tree Canopy, Bare Soil. Rainfall Data has been collected for the past 5 years out of which 90 percentile values has been used for estimations. For information on the watershed characteristics, physical survey of the catchments, interviews with local people, topographical sheets, local zoning maps, maps available on net (Google maps, Encarta maps, etc.) were used. Patiala municipal council and Department of Town and Country planning, Punjab were also been depended on for the information. Data on storm/rainfall events was obtained from Indian Meteorological Department [9].

Subwatershed 1: Model Town (Commercial) This catchment within the city Patiala is a commercial area having high intensity of urbanization consequently maximum impervious cover and minimum tree canopy. It is marked by the presence of houses, workshops, theater (Tagore) and government offices. This area faces problems of open urination, MSW dumping and stormwater. The stormwater in this area collects in the pits on roads where it stagnates and is lost through percolation and evaporation. No underground sewers or tanks are created for passage of stormwater. Table 1, enlists the characteristics of the two sub-watersheds studied.

TABLE 1: Characteristics of Sub-Watersheds

LAND USE TYPE		MODEL TOWN		CIVIL LINES	
		Percent Area	Area under Land Use (m^2)	Percent Area	Area under Land Use(m^2)
IMPERVIOUS AREA		75	6376	55	17454
	Roof tops	55	3457	54	9287
	Roads (open ditches/ curbs/ storm sewers)	30	1903	25	4431
	Paved area/ drive ways/ courtyard	15	1016	21	3736
BARE SOIL (dirt/ gravel)		10	850	15	4760
GRASS COVER AND LANDSCAPING		15	1275	30	9519
	Grass cover	75	935	60	5712
	Tree canopy	25	340	40	3807

Subwatershed 2: Civil lines (Residential) This catchment within the city Patiala is a Residential area having high intensity of urbanization. It is marked by the presence of houses, school and parks. This area faces problems of open defecation, open urination, MSW dumping and stormwater. The stormwater in this area collects in an arbitrary outlet which is formed by sloping the roads toward it. Few underground sewers or tanks are created for passage of stormwater but are not well managed and often remain blocked.

2.2 Model Assessment for Quantification

For the estimation of runoff from the selected catchments two hydrological methods have been used namely Rational Method and US-SCS CN method. The Rational Method has been used to estimate peak runoff rate and US-SCS for estimation of run off volume. Curve number method developed by soil conservation services of USA, is based upon the water balance equation in a known interval of time

$$\Delta t: P = I_a + F + Q \qquad (1)$$

Where, P is total precipitation, I_a is initial abstraction, F is cumulative infiltration including I_a, Q is direct surface runoff. The equations used are:

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \qquad (2)$$

S is potential maximum retention, Q is daily runoff from catchment, P is daily rainfall.

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

Where, CN is curve. Its range $100 \geq CN \geq 0$, 100 represents condition of zero retention (impervious catchment) and 0 represents full retention. This curve number depends upon Soil type, land use/ cover and antecedent moisture condition.

The Curve Number for the catchments has been assessed with the help of hydrologic model WIN TR-55 Small Watershed Hydrology software. Both individual and weighted CN have been found out [6, 8]. The rational method is used for calculating peak discharge from a drainage area or catchment. This method doesn't yield volume of discharge and doesn't account for storage in drainage area, the available storage is assumed to be filled. It is limited to watersheds of area less than 200 acres:

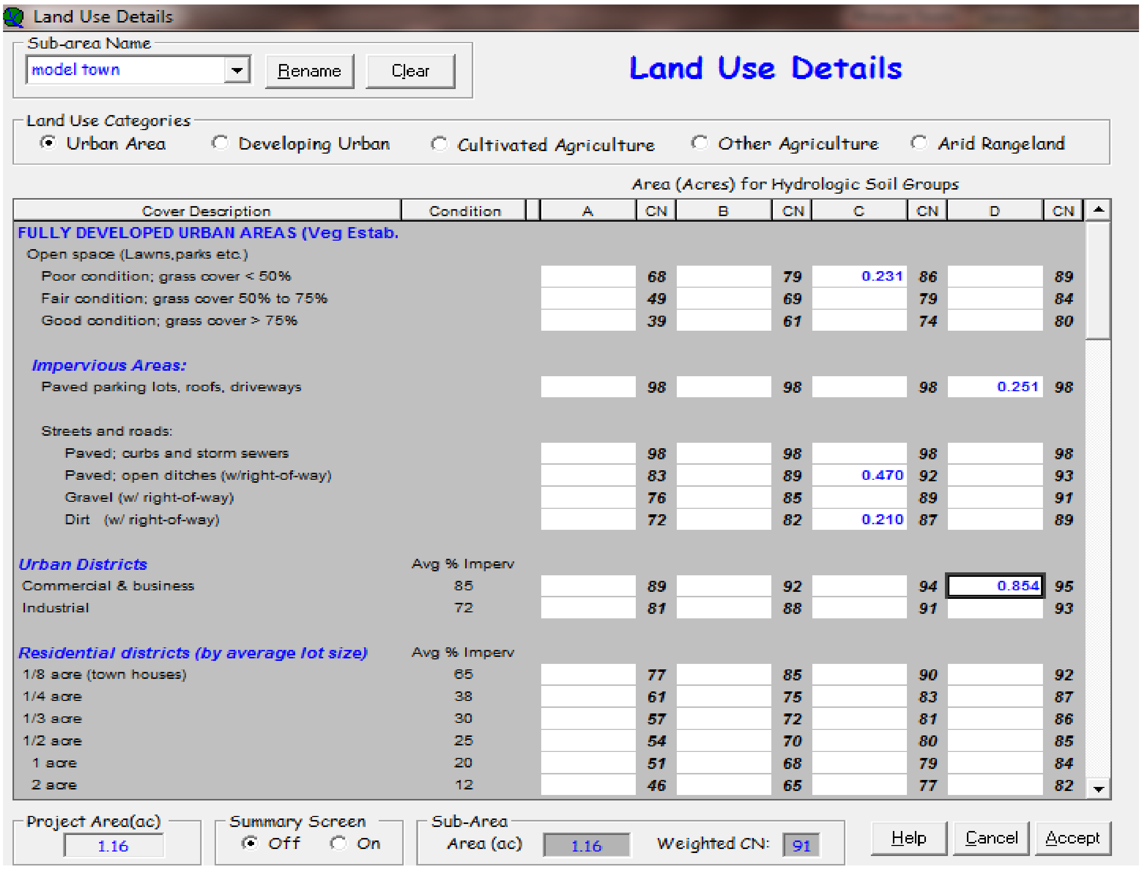
$$Q = \frac{CIA}{Z} \tag{4}$$

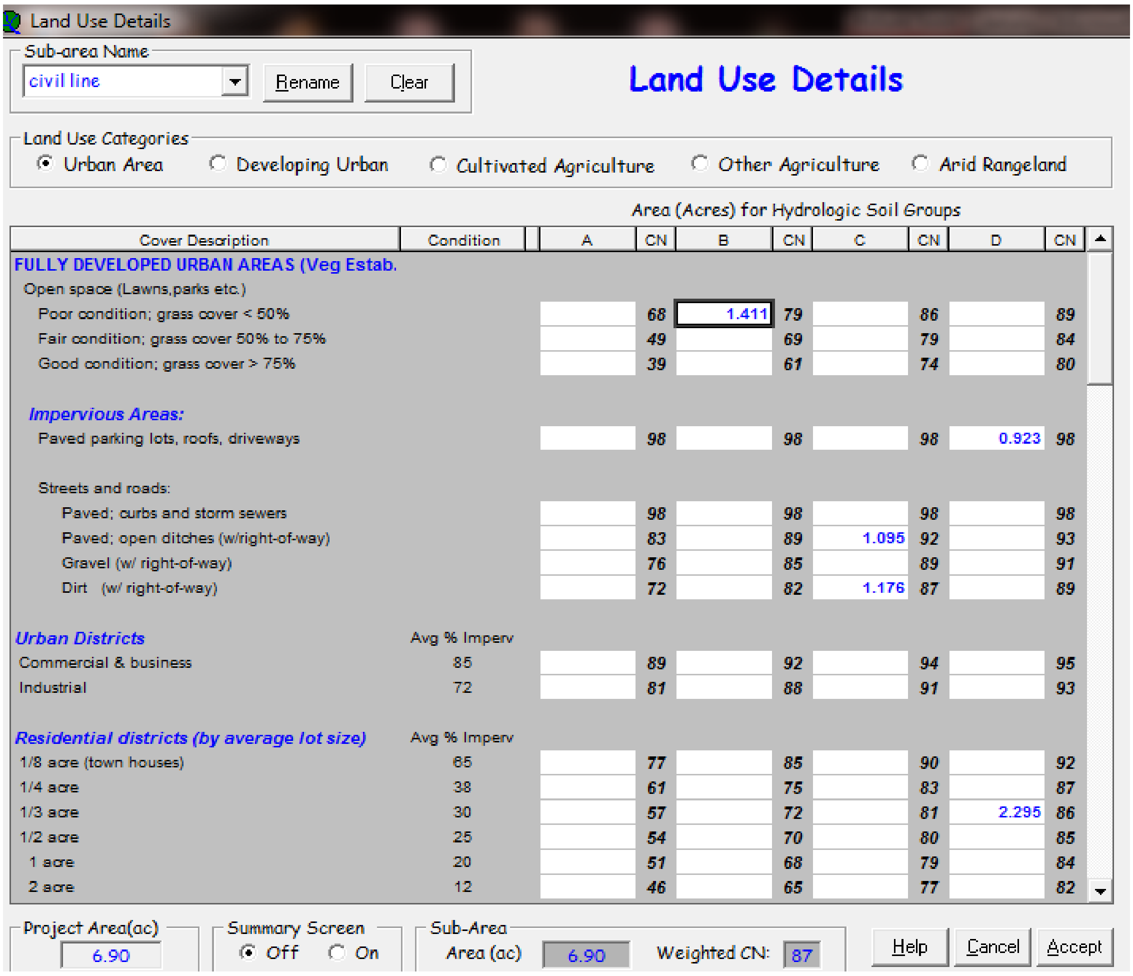
Where, C is runoff coefficient (runoff/ rainfall), Q is peak discharge from basin (m^3/h), I is intensity of rainfall (mm/h), A is area of basin (km^2), Z is a conversion factor having value 1 for I in inch/h, A in acre and Q in cubic feet per second. The calculated runoff is directly proportional to rainfall intensity which is assumed to be uniform throughout the catchment. Runoff coefficient has been calculated for both the sites with the help for literature reviewed [8]. Using these two hydrologic methods for these sites quantification analysis has been done.

III. RESULTS AND DISCUSSION

3.1 Finding Curve Number

CN for the catchments has been found out based upon the different land uses and the hydrological soil group of the areas. The win tr-55 watershed hydrology has been used to calculate individual CN for the sub-areas within the catchment and a weighted CN has been further devised and used in calculations of runoff volume from US-SCS Method.





Thus, CN 91 and 87 for the two catchments, show lower infiltration rates leading to higher runoff that is attributed to the high level of urbanization in these areas. Model Town having more of impervious area (75%) as compared to Civil Lines (55%), as expected has higher CN.

3.2 Finding Runoff Coefficient

The runoff coefficient (C) has been calculated based upon individual coefficients for the sub-areas within the catchment and then weighted runoff coefficient is calculated based upon the following formula:

$$C_e = \frac{\sum_i^N C_i A_i}{A} \qquad (5)$$

Where, A_i is area of sub-area i having run off coefficient C_i and N is number of sub area in the catchment.

Table 2: Runoff Coefficient for Model Town Sub-watershed

MODEL TOWN		
LAND USE	AREA (acres)	RUNOFF COEFFICIENT
Roof Tops	0.854	0.85
Paved Area (roads)/ Driveways/ Courtyards	0.721	0.65
Unpaved Area(Grass Cover/ Bare Soil)	0.441	0.25

Weighted Equivalent Runoff Coefficient = 0.647

Table 3: Runoff Coefficient for Civil Lines Sub-watershed

CIVIL LINES		
LAND USE	AREA (acres)	RUNOFF COEFFICIENT
Roof Tops	2.295	0.85
Paved Area (roads)/ Driveways/ Courtyards	2.018	0.65
Unpaved Area(Grass Cover/ Bare Soil)	2.587	0.25

Weighted Equivalent Runoff Coefficient = 0.566

Higher runoff rate for Model Town indicates higher runoff due to larger impervious area

3.3 Finding Peak Runoff Rate (Q)

Table 4: Peak Runoff Rate for the selected Sub-watersheds

Catchment	Runoff Coeff. ‘C’	Rainfall Intensity (mm/h)	Area (Km^2)	Q (peak runoff rate, m^3)
Model Town	0.647	174	0.008501	0.957
Civil Lines	0.566	174	0.31733	31.252

Higher peak runoff for Civil Lines is attributed to higher catchment area.

3.4 Finding Runoff Volume (V)

Table 5: Runoff Volume for the Selected Sub-Watersheds

Catchment	CN	S	P	Q (runoff rate)	Area (m^2)	Volume (m^3)
Model Town	91	25.121	29	11.71	8501	99.53
Civil Lines	87	37.954	29	7.72	31733	245.02

The volume of runoff as expected is more from Civil Lines due to larger area contributing the runoff as compared to Model Town. This huge volume of water gets generated due to vast expanses of the impervious areas and is collected on the roads resulting in floods. This water can be used as a resource and as a means for recharge of groundwater after suitable treatment.

IV. CONCLUSIONS

Two catchments were selected from Patiala city and the runoff resulting from precipitation event for the past 5 years (90 percentile value) has been estimated. Both the catchments show significant differences in characteristics as well as the resulting runoff. The hydrological methods used for estimation; Rational Method and US-SCS methods, prove useful and effective. Peak runoff of 957 L/h for Model town and 31252 L/h for Civil Lines has been reported. A higher peak runoff for Civil Lines is due to the higher catchment area contributing to the runoff. Stormwater conveyance systems and a proper management schemes can be designed based upon these values. Runoff volume of 99532 L for Model Town and 245016 L for Civil Lines per precipitation event has been reported and as expected that for Civil Lines is higher due to higher catchment area.

Stormwater managers need to take care of the volume generated for avoiding flooding of the area and also need to take care of the quality as well. The research conducted can prove to be useful towards managing the stormwater especially for underdeveloped or developing areas with improper drainage facilities.

REFERENCES

[1] Arora, A.S. and Reddy, A.S., "Multivariate analysis for assessing the quality of stormwater from different urban surfaces of the Patiala city, Punjab (India)", Urban Water Journal, 10(6), pp. 422-433, 2013.

[2] ASCE, "Aspects of hydrological effects of urbanization", Journal of the Hydraulics Division ASCE, 101, pp. 449–468, 1975.

[3] Codner, G.P., Laurenson, E.M., and Mein, R.G. , "Hydrologic effects of urbanization: a case study", Proceedings of the Hydrology and Water Resources Symposium, Institution of Engineers, Australia, pp. 201–205, 1988.

[4] Goonetilleke, A., Thomas, E., and Ginn, S., "Understanding the role of land use in urban stormwater quality management", Journal of Environmental Management, 74, pp. 31–42, 2005.

[5] Marsalek, J., Watt, W.E. and Anderson, B.C., "Trace metal levels in sediments deposited in urban stormwater management facilities", Water Science Technology, 53, pp. 175–183. 2006

[6] Mishra, S.K.; Singh, V.P., Water Science & Technology Library Vol. 42, Soil Conservation Service Curve Number (SCS-CN) Methodology.

[7] Mein, R.G. and Goyen, A.G: Urban Runoff, Civil Engineering Transactions, Institution of Engineers Australia CE30, pp. 225–238, 1988.

[8] Subramanya, K, Engineering Hydrology, Third Edition.

[9] Arora, A.S. and Reddy, A.S., "Conceptualizing a decentralized stormwater treatment system for an urbanized city with improper stormwater drainage facilities" International Journal of Environmental Science and Technology, DOI 10.1007/s13762-014-0655-3, 2014.