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Research Article

APPLICATION OF SCS-CN METHOD FOR ESTIMATION OF RUNOFF IN A HUMID MICROWATERSHED

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A R T I C L E I N F O

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A B S T R A C T

When precipitation rate is greater than infiltration capacity, it results in surface runoff. The aim of this study was to estimate the runoff depth in a microwatershed using Soil Conservation Service Curve Number method. The method incorporates several watershed runoff producing characteristics, viz., soil type, land cover and practice, hydrologic condition, and antecedent moisture condition. The Soil Conservation Service Curve Number values were obtained for various land use elements under different surface conditions associated with a particular antecedent moisture condition. The hydrologic soil groups were assigned after infiltration rates were obtained. For estimation of runoff, eighteen storm events were selected based on the continuity and uniformity of the rainfall over the microwatershed. The runoff estimated using Soil Conservation Service Curve Number method was highest in disturbed forest and lowest in the vegetable fields. The runoff generated in each landuse element using Soil Conservation Service Curve Number method was compared with the observed runoff generated using Web-based Hydrograph Analysis Tool software. The results showed that there was no significant difference between observed and estimated runoff depths.

INTRODUCTION

Runoff from a watershed is a function of rainfall, infiltration, and watershed characteristics. Watershed runoff is a major concern due to its impact on environmental, agricultural, and flood potential. For any watershed, runoff volume and peak flow directly depend on characteristics of watershed (Patil et. al., 2008 and Zhang et. al., 2013). The Soil Conservation Service Curve Number (SCS-CN) method is usually a good choice for the estimation of runoff. This simple method requires minimal data and gives clearly stated assumptions (Ponce and Hawkins, 1996, Tejaswini, 2011; Soulis, 2012 and Dhawale, 2013). Although many hydrologic models are available for the estimation of runoff, most physically based models are of limited use because of their large number of input parameters and complicated calibration requirements (Wu *et al*., 1993; Kothyari and Jain, 1997). SCS-CN method can be gainfully applied for small agricultural, forest, and urban watersheds. The method incorporates watershed runoff producing characteristics; soil type, land cover and practice, hydrologic condition, and antecedent moisture condition (Mishra and Singh, 2003; Mishra *et al*., 2004; Jain *et al*., 2006). The SCS-CN method is in use since 1954 and the result was first documented in National Engineering Handbook, Section-4 (NEH-4, Hydrology) in 1956. The current version of NEH-4 is NEH 630 (USDA, NRCS, 2003). In general, the method is dependent on four important catchment properties: soil type, land use, surface condition, and antecedent moisture condition (AMC). Due to its low input data requirements and its implementation within GIS, it has been incorporated in many hydrological models. The initial abstraction ratio is an important component in the calculated runoff depth, the hydrograph peak and the time distribution of runoff. The SCS-CN method has been modified for Indian conditions (Rao *et. al.,*1996; Sharma *et al.* 2001; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002). Pandey *et al*., (2004) estimated the runoff from SCS CN method modified for Indian condition using conventional data base and GIS for Dikrong river basin. Amutha *et al*., (2009) showed that estimation of runoff by SCS-CN method integrated with GIS can be effectively used in watershed management. Somashekar *et al*., (2011) estimated surface runoff of Hesaraghatta watershed using IRS ID LISS III satellite images in the form of FCC using SCS curve number method and found that the runoff estimated by SCS method provided reasonably good results. The method has been used by several workers (Mishra and Singh, 2004; Sindhu *et al*., 2013; and Al Jabari *et al*., 2009) under varying edaphic- ecological conditions. However very few studies have done a comparative analysis of SCS-CN method vis-à-vis observed runoff in humid

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watersheds. The present study examines the applicability of SCS-CN for estimation of surface runoff in humid microwatershed having a variety of land use elements.

MATERIALS AND METHODS

SCS-CN method

The Soil Conservation Service curve number (SCS-CN) method incorporates the water balance equation involving the following terms, (i). actual moisture retention by the soil (P- I_a- Q); (ii). the potential maximum retention {S_M, where $S_M \geq$ (P- I_a- Q)}; (iii). the actual runoff taking place (Q) (iv). and the potential maximum runoff {P-Ia where (P-Ia) ≥ Q). The first equation is as follows:

$$\frac{(P-I_a-Q)}{SM} = \frac{Q}{P-I_a} \quad \text{..................1}$$

(since the ratios between the actual and potential moisture retained and the actual and potential surface runoff should be equal).

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

The second equation is as follows, which relates the initial abstraction (Ia) to the potential maximum retention (S).

$$Q = \frac{(P-0.2S_M)^2}{(P-0.2S_M)+S_M} \quad \text{.............(3)}$$

$$Q = \frac{(P-0.2SM)^2}{(P+0.8SM)} \text{ (for } P \geq 0.2 \text{ S)} \quad \text{.........(4)}$$

Q = 0 (for P≤ 0.2 S) ....(5)

The US Soil Conservation Service found that Ia = 0.2 S_M. This equation is used to define the equation for the parameter, S_M. For Indian conditions some modifications were done by Soil and Water Conservation Department, Ministry of Agriculture, New Delhi. For Indian conditions I_a = 0.3 S_M. The parameter S_M of the SCS-CN method depends on soil type, land use, hydrologic condition, and antecedent moisture condition (AMC). Analytically, parameter S is obtained from Eq. (3) (Hawkins, 1993). Thus,

$$S_M = 5[P+2Q-(4Q^2+5PQ)^{1/2}] \quad \text{.............(6)}$$

Derivation of the Curve Number

The Curve Number (CN) values are derived using the methods that have been formulated for a watershed under various conditions which can be found in the National Engineering Handbook, Section 4, Hydrology or "NEH-4" (SCS, 1972). The CN values are obtained for various land use types under different surface conditions which are associated with a particular antecedent moisture condition (Table 1). The antecedent moisture condition (AMC) is defined as the preceding moisture that is present in the soil type prior to a storm event. The AMC is synonymous with antecedent rainfall condition (ARC). The SCS, (1972), describes AMC based on 5 days antecedent rainfall before the storm under consideration during a particular dormant or growing season. Three classes of AMC have been given; I, II and III corresponding to dry season, moderate season and very wet season (Table 1). The CN value from a specific AMC will give the value for initial abstraction (S). The ARC referred to as antecedent moisture conditions (AMC) — hereafter, ARC reflects Technical Report, TR-55 terminology (USDA, 1985). The TR-55 describes the application of the SCS CN method for small urban watersheds and is most often used for stormwater practice design for developing watersheds. CN tables for site determination are listed for the average ARC (CN-II), interpreted as the median CN measured by analysis of rainfall and runoff data. A correction is applied to the CN-II for the dry ARC (CN-I) and wet ARC (CN-III) (Ponce and Hawkins, 1996).

Table 1 Seasonal precipitation limits for AMC for use in the SCS curve number method.

Antecedent Moisture Condition (AMC)	Total 5 days antecedent rainfall (mm)	
	Dry season	Growing Season
I	<12.7	< 35.6
II	12.7 – 27.9	35.6 – 53.3
III	> 27.9	> 53.3

Source: National Engineering Handbook (Mockus, 1964)

Derivation of Runoff

The CN value for AMC II is obtained from the table prescribed by TR 55, (USDA, 1985). AMC II is converted to AMC I and AMC III using mathematical equations given below (Chow, 2002):

$$CN_I = \frac{4.2*CN\ (II)}{10-(0.058*CN\ (II))} \quad \text{..........................(7)}$$

$$CN_{III} = \frac{23*CN\ (II)}{10+(0.13*CN\ (II))} \quad \text{..........................(8)}$$

where, (*II*) *CN* is the curve number for normal condition, (*I*) *CN* is the curve number for dry condition, and (*III*) *CN* is the curve number for wet condition.

$$S = \frac{25400}{CN} - 254 \quad \text{.............................(9)}$$

The CN value is substituted for S value with respect to each condition and the runoff (Q) is obtained from equation 4

The runoff (mm) for each landuse element was computed using the following formula;

$$Q = \frac{Q_i * A_i}{A}$$

………………………(10)

Hydrologic soil groups

The hydrologic soil group (HSG) as proposed by Musgrave (1955) is documented in Handbook of Agriculture (USDA 1955). Soils are classified into hydrologic soil groups (HSGs) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSGs are A, B, C and D.

The four groups are defined by Soil Conservation Service (SCS) soil scientists as follows:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05- 0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Study area

The study was conducted in Pahamsyiem microwatershed, Ri-Bhoi district of Meghalaya (Fig. 1).

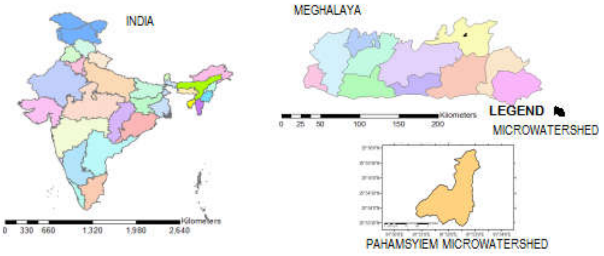

Fig.1 Location map of the study area

It lies within 25.892°-25.917° N latitudes and 91.842°-91.885° E longitudes. The microwatershed is situated on the northern slope of Meghalaya plateau. It is part of the larger system of Umran river catchment (Singh, 2007). It is an undulating hilly region and is surrounded by hills on three sides. The altitude ranges from 350-850 m a.s.l. The hills lower down to flat valley lands which are fertile and favourable for cultivation. The microwatershed is 771 ha in area. The natural vegetation of the study area can be broadly classified as subtropical evergreen forest (Champion and Seth, 1968). Pahamsyiem microwatershed has a warm sunny weather and enjoys sub-tropical climate throughout the year. The area receives moderate rain with hyperthermic rainy season. The maximum and minimum temperatures recorded during the study period were 30.8°C°C and 5.6°C respectively. The maximum relative humidity during the study year was 88.9% and minimum relative humidity was 47.1% (Fig. 2.).

The Pahamsyiem microwatershed is characterized by six landuse elements (Fig. 3.). Table 2. shows the distribution of each landuse element across the microwatershed.

Table 2 Land use elements in Pahamsyiem microwatershed

Sl. No.	Landuse element	Area (ha)	% of the area
1.	Highly disturbed forest	252.02	29.44
2.	Moderately disturbed forest	201.59	23.55
3.	Residential area	168.79	19.72
4.	Undisturbed forest	151.37	17.68
5.	Agricultural fields	43.75	5.11
6.	Broomgrass fields	38.42	4.49

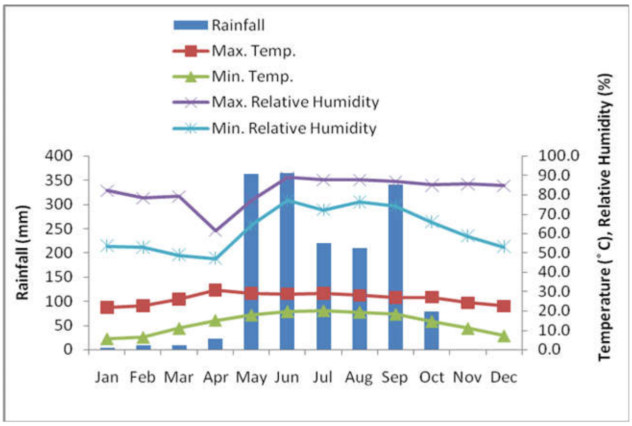

Fig. 2 Monthly rainfall, temperature and humidity in Pahamsyiem microwatershed

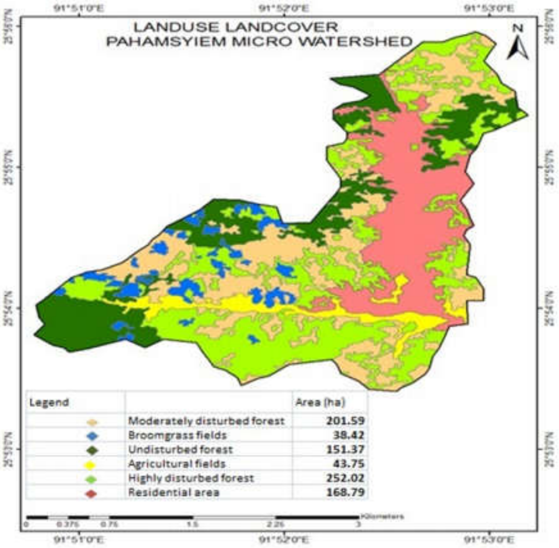

Fig. 3 Landuse landcover map of Pahamsyiem microwatershed

A detailed land cover classification was done with the use of remote sensing techniques. It showed that the dominant landuse element in the microwatershed is highly disturbed forest (29.44%) with trees scattered in various pockets. There is also road network, mainly in the lower part of the watershed, where an ever increasing settlement exists. In this study, the roads, the buildings and the bare rock were taken to be impervious areas.

Data collection

The rainfall data was collected on a daily basis at 9 am. It was measured using a non-recording raingauge that was placed in a suitable site in the study area. For estimation of runoff, a number of storm events were selected based on the continuity and uniformity of the rainfall that fell as precipitation over the entire microwatershed. The infiltration was measured in the various landuse elements using a single ring infiltrometer. The water level in the infiltrometer was noted at a constant level until it reached saturation point. This rate of water absorption by the soil type is graphically denoted by an infiltration rate curve. The rate of infiltration gives an idea of the type of soil that is innate of the study area. The soil that was collected during soil sampling seasons was brought to the laboratory and air dried. The air dried soil was analysed in the laboratory for its texture. The soil texture values were indicative of the hydrologic soil group (HSG). The streamflow was measured by a pigmy current meter at the outlet of the microwatershed. The measurements were made on a daily basis and they were used to obtain stream discharge.

The baseflow was obtained from the measurements of stream discharge by using a recursive digital filter method.

Determining runoff depth for observed data

Direct runoff volume was calculated by subtracting base flow and total runoff volume in WHAT (Web-based Hydrograph Analysis Tool) software (Engel *et al*., 2004). Runoff depth was calculated using equation as under:

$$H = \frac{(Q - bf) * t}{A}$$

Where H is the runoff depth (mm), Q is the runoff volume (m^3/s), bf is baseflow (m^3/s), t is time in seconds, A is the area of landuse element (m^2).

Statistical analysis

SPSS functions were used to perform statistical analysis of data. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check the normality of data set. The differences were considered statistically significant when $p < 0.05$. Percentage error was calculated to compare the difference between the estimated and observed runoff depth. Pair wise comparisons were done with the t-test to compare observed and estimated runoff depth data. The spearman rank correlation analysis was used to investigate the relationship between estimated (as a dependent variable) and observed (as an independent variable) runoff depths.

RESULTS AND DISCUSSION

The primary requirement to calculate surface runoff by SCS-CN method involves infiltration rates in each land use element (Table 3.).

Table 3 Infiltration rates of various land use elements

Sl. No.	Land use element	Infiltration rate (in/hr)
1	Vegetable fields	2.44
2	Paddy fields	3.93
3	Broomgrass fields	1.25
4	Undisturbed forest	4.01
5	Moderately disturbed forest	1.02
6	Highly disturbed forest	1.02

Based on the infiltration results obtained, the hydrologic soil groups (HSG) of the soils were derived and the soil type was obtained for each land use element. The values indicate that the soil in the microwatershed basically belongs to Group A.

Estimation of runoff depth (mm) in each landuse element based on the storm events is given in table 4.

In the first stage of analysis, the basic characteristics of watershed were taken into account and evaluated in accordance to the SCS- CN method. In this context, the microwatershed was treated as ungauged. Eighteen storm events were selected and they were computed for each land use element. Antecedent moisture conditions were classified into the three classes. The initial abstraction (S) was greater in the AMC I and it decreased to AMC III. Initial abstraction is a function of retention which is a reflection of the microwatershed wetness. Analysis of AMC conditions for each storm event, revealed that the runoff was more for the AMC I conditions than other conditions. For storms observed under the AMC I condition, a general consistency persisted and it dominated throughout the growing season. The first storm event generated high runoff depths during dry condition and later storm events led to lower runoff depths under wet conditions. This situation is related to subsurface water storage under dry conditions. Table 4 shows the estimated and observed runoff depths in various landuse elements. The SCS- CN estimated highest runoff depth was recorded in the highly disturbed forest at 765.37 mm while it was the lowest in the vegetable field (19.17 mm). In general, the ground cover and canopy cover are important determinants of runoff. The retention in the Pahamsyiem microwatershed is attributed by its vegetational characteristics in both the agricultural and forest soils. It is noted from Table 3. that the broomgrass fields have lower runoff depth than the moderately disturbed forests. This is due to the fact that the soil erosion that occurs in the broomgrass fields contributes to land degradation. Shifting cultivation practised in these fields may lead to significant reductions in infiltration rates and saturated hydraulic conductivity (Lal and Cummings, 1979). There is absence of contour bunds or terracing in these areas. The degraded soil accelerates the runoff capacity which implies that where vegetative cover is removed, the soil surface is exposed to the impact of raindrops thereby causing a sealing of the soil surface. Less rain then infiltrates the soil and runoff increases. In case of degraded forests, the hydrological condition of forest conversion has been highlighted by Bruijnzeel (1989, 2004).

Table 4 Runoff depths estimated using SCS-CN method. The values of observed runoff are given in parentheses.

Storm date	Rainfall (mm)	5 days prior rainfall (mm)	AMC	Runoff (mm)					
				VF	PF	BF	UDF	MDF	HDF
08-04-2014	14	2	I	12.68 (1.39)	36.05 (3.25)	108.12 (1.11)	208.18 (0.28)	81.58 (0.17)	186.39 (0.17)
04-05-2014	152	14	I	31.42 (1.15)	3.3 (2.68)	21.63 (0.92)	98.82 (0.23)	7.42 (0.14)	80.29 (0.14)
19-06-2014	61	27	I	0.07 (1.38)	8.8 (3.22)	69.08 (1.10)	164.91 (0.28)	44.99 (0.17)	143.69 (0.17)
22-06-2014	81	108	III	47.18 (3.35)	65.57 (7.82)	4.21 (2.67)	0.59 (0.68)	9.36 (0.41)	0.06 (0.41)
30-06-2014	42	34	I	1.33 (3.45)	17.1 (8.05)	83.48 (2.75)	181.59 (0.70)	58.1 (0.42)	160.06 (0.42)
02-07-2014	16.1	48.2	II	0.88 (3.16)	10.07 (7.38)	36.11 (2.52)	77.2 (0.64)	25.42 (0.38)	68.33 (0.38)
06-07-2014	21.2	40.6	II	0.11 (5.06)	14.82 (11.81)	32.07 (4.04)	72.62 (1.02)	21.69 (0.62)	63.82 (0.62)
10-07-2014	25.2	38.8	II	0.02 (3.75)	18.62 (8.74)	29.11 (2.99)	69.16 (0.76)	19.02 (0.46)	60.43 (0.46)
11-07-2014	20.1	64	III	2.08 (5.26)	8.77 (12.26)	7.14 (4.19)	22.92 (1.06)	3.62 (0.64)	19.37 (0.46)
30-07-2014	17.2	23.5	I	10.65 (4.14)	33.42 (9.66)	105.09 (3.30)	205.02 (0.84)	78.62 (0.50)	183.24 (0.64)
03-08-2014	21	29.2	I	8.51 (3.30)	30.46 (7.69)	101.56 (2.63)	201.3 (0.67)	75.21 (0.40)	179.55 (0.50)
05-08-2014	29	33	I	4.91 (5.50)	24.8 (12.84)	94.39 (4.39)	193.63 (1.11)	68.35 (0.67)	171.94 (0.40)
14-08-2014	44	13	I	0.99 (3.53)	16.07 (8.23)	81.88 (2.81)	179.78 (0.71)	56.62 (0.43)	158.28 (0.40)
23-08-2014	25	2	I	6.56 (22.63)	27.53 (52.81)	97.93 (18.04)	197.44 (4.58)	71.72 (2.75)	175.72 (0.67)
21-09-2014	28	26	I	5.3 (17.52)	25.46 (40.87)	95.27 (13.96)	194.58 (3.54))	69.18 (2.13)	172.88 (0.43)
22-09-2014	203	54	III	162.99 (19.51)	84.12 (45.53)	70.53 (15.5)	27.94 (3.95)	88.81 (2.37)	174.82 (2.75)
08-10-2014	43	23	I	3.02 (12.05)	98.37 (28.12)	82.68 (9.61)	180.68 (2.44)	57.35 (1.46)	159.17 (2.13)
27-02-2015	17	0	I	39.14 (14.33)	362.43 (33.44)	105.28 (11.42)	205.21 (2.90)	78.81 (1.74)	183.44 (2.37)
Total Runoff depths (mm)				337.83 **19.17** **(130.46)**	885.75 **50.26** **(304.41)**	1225.57 **61.07** **(103.99)**	2481.56 **487.20** **(26.39)**	915.88 **239.47** **(19.82)**	2341.48 **765.37** **(15.85)**

AMC, Antecedent Moisture Condition; VF, vegetable fields; PF, paddy fields; BF, broomgrass fields; UDF, undisturbed forest; MDF, moderately disturbed forest; HDF, highly disturbed forest.

Table 5 Percentage error between estimated runoff and observed runoff in various landuse elements

Landuse element	Percent error (%)
Vegetable fields	79
Paddy fields	44.96
Broomgrass fields	41.27
Undisturbed forest	1746.15
Moderately disturbed forest	1108.22
Highly disturbed forest	4728.83

Table 6 Spearman's rho correlation coefficient values between estimated (SCS-CN) and observed (WHAT) runoff depths in various landuse elements

Landuse element	Correlation coefficient (Spearman rho)	p value
Vegetable fields	0.118	0.641
Paddy fields	0.443	0.065
Broomgrass fields	0.429	0.075
Undisturbed forest	0.074	0.769
Moderately disturbed forest	0.362	0.140
Highly disturbed forest	0.249	0.319

A degraded forest discontinues sufficient infiltration and groundwater recharge via vertical percolation during the wet season, after storm events and even on dry season, inspite of gains from evapotranspiration. Chappel (2007) further states that reduced infiltrative capacity of the soils leads to decreased stormflow pathways especially on hillslopes implying a negative feedback on runoff generation. Ground cover beneath the trees, especially leaf litter, was more effective in reducing runoff than the amount of canopy cover. Canopy cover was more effective during the less intense storms but was ineffective when the rainfall intensity was high. Increase in urbanization and impervious surface in a watershed strongly impacts the stream hydrology and this linearly increases the runoff (Brabec *et al*. 2002, Hatt *et al*. 2004, Olivera and DeFee, 2007 and O'Driscoll *et al*. 2010).

There exists spatial variability in runoff behaviour across the microwatershed. The soil textural classes and infiltration rates are primary determinants of soil surface runoff. The precipitation in the form of rainfall has a direct influence in the runoff generation. The study suggests a distinct seasonal variation in runoff during the selected storm events. The runoff was most prominent during growing season (Table 1) which also corresponded well with the antecedent rainfall.

The percentage errors between the estimated and observed values obtained revealed that the differences were maximum in case of forest areas (Table 5). The runoff depths estimated using the SCS-CN method were compared with WHAT observed runoff depths using bivariate analysis (Spearman's correlation coefficient). The rho values and p values between the two methods applied to the various landuse elements in the microwatershed clearly shows that there are no significant difference between runoff estimated using SCS-CN method and the observed values ($p>0.05$) (Table 6). High positive correlation between runoff depth data generated using SCS-CN method and that of observed values have also been reported by a number of researchers (Nayak and Jaiswal, 2003; Malekian *et al.*, 2005; and Ebrahimian et.al., 2009). This study suggests that SCS-CN method is reliable and can be used for estimation of runoff in humid watersheds dotted with diverse landuses.

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