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# Location of Fraction-Saturated Areas in Watershed Using Empirically Calculated Topographical Index

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**Abstract:** In engineering practice, simple methods are important for predicting runoff from watersheds particularly for flood forecasting and water balance calculations. In the present study, it is illustrated that the often used soil conservation services runoff curve–number (SCS-CN) approach in its most elementary form can be derived from assuming that only saturated areas contribute to direct runoff. With this approach the initial abstraction or the amount of water required before runoff starts is equal to air-filled pore space per unit area for most shallow soils in the watershed. Air-filled pore space throughout the year is calculated with aid of the simple water balance employing Throntwaite-Mather procedure. As per this procedure two user-friendly computer programmes ASH.FOR and DSW.FOR are developed and coded in FORTRAN language to determine daily water storage (S) and effective rainfall / initiation of runoff ($P_e$).The water storage and fraction saturated area for untreated $wm_1$ and treated $wm_2$ micro - watersheds of Mansadevi-watershed falling within Shivalik region of India is compared. Geographic Information System (GIS Arc-Info) software is used for digitizing the contour maps of untreated $wm_1$ and treated $wm_2$ micro-watersheds. Topographical index (λ) is incorporated into modified (SCS-CN) method to find critical (λ) values to locate fraction-saturated areas graphically as per (Lyon *et. al* 2004). Further, a concept of translating graphically calculated (λ) values into empirically calculated (λ) value is proposed in the present study for convenient practical application. Comparison of empirical solution with graphical solution confirms convenient application of locating fraction-saturated areas. The results show good agreement of predicted as well as estimated runoff values with the observe runoff values for modified (SCS-CN) method over traditional (SCS-CN) method. Finally, the study confirms that incorporating topographical index, into modified (SCS-CN) method also called variable source area (CN-VSA) method (Steenhuise *et.al* 1995) is simple enough to locate fraction-saturated areas within a watershed.

**Keywords:** VSA, Water balance, critical (λ) values, shallow soils, Shivalik region of India.

## Introduction

Hydrology plays a fundamental role in addressing a range of issues related to environmental and ecological management and societal development. Central to these issues is rainfall-runoff modeling which, in particular, is used in water resources assessment, flood and drought mitigation, and water resources planning and management. In general, rainfall runoff modeling is basic to design of wide variety of hydraulic structures, environmental impact assessment, evaluation of the impact of climate change, irrigation scheduling, flood forecasting, augmentation of runoff records, pollution abatement, watershed management etc. A comprehensive literature

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search discloses the existence of several thousand models and the number of unpublished models, which exceeds the published ones. Despite their comprehensive structure, many of these models have not yet become standard tools in hydrologic practice in developing countries, such as India, Pakistan, Nepal, and other countries of Asia as well as African countries. The reason is two fold. First, most basins in these countries are ungauged and there is little hydrologic data available. Second, the models like soil water assessment tool (SWAT) and soil moisture distribution routing (Frankenberger *et.al* 1999) are containing too many parameters which are difficult to estimate in practice and which vary from basin to basin. Although some of these models have been applied to ungauged basins, the fact is that they are not easy for practical applications. Thus, what are needed in developing countries are simple models particularly for hilly areas, which can provide reasonable simulations and need little data. The Soil Conservation Service (Now the Natural Resources Conservation Service) Curve Number (SCS-CN) method (SCS, 1956) is one of the most popular methods for computing the volume of surface runoff for a given rainfall event from small agricultural, forest, and urban watersheds. The modified (SCS-CN) method also called curve number-variable source area (CN-VSA) method (Steenhuise *et.al*. 1995) seems to satisfy the criteria of variable source area (VSA) for hilly basins. The method is simple, easy to understand and useful for ungauged watersheds. The primary reason for its wide applicability and acceptability lies in the fact that it accounts for most runoff producing watershed characteristics such as soil type, land use, treatment, surface condition, and antecedent moisture condition. Of late, even landscape factor or topographical index has been incorporated as per (Lyon *et.al* 2004). The original model (SCS-CN) justified by Victor Mockus that it produces rainfall–runoff curves of a type found on natural watersheds (Rallison, 1980). Subsequently, hydrologists have shown that the basis of the method can be described in ways that are nominally consistent with both the infiltration-excess concept (Hjelmfelt, 1980) and saturation-excess or VSA hydrology (Steenhuise *et.al*.1995). Mishra and Singh (2003) provided a comprehensive review of the (SCS-CN) method and extended this concept to several areas in India. The rain fed areas of the Shivaliks have no possibility of providing irrigation through conventional methods and large amount of runoff not only goes waste from such lands, but also creates problems of soil erosion and land degradation. The management of water resources in its various forms is key to environmental, economical and social sustainability in the Shivalik region. This study focuses on the analysis of the hydrological response of the two micro-watersheds untreated $wm_1$ and treated $wm_2$, falling within Mansadevi-watershed of Shivalik region of India. The region has sub-humid, tropical monsoon season under protected forest land-use. First, an analysis of annual and seasonal rainfall, runoff, pan evaporation and potential evapotranspiration (PET) is carried out by means of a daily soil water balance as per the procedure laid by Throntwaite and Mather (1955, 57). In this study, simple computer model has been developed in Fortran language. Second, runoff components based on daily initial abstraction ($I_a$) are determined. Other related indices like event based soil water storage (S) are calculated as per (Steenhuise *et.al* 1995) and compared to determine variation in daily soil water storage in untreated $wm_1$ and treated $wm_2$ micro-watersheds for a study period of 11 years. Observed runoff flow at the outfalls of two micro-watersheds at event-scale for 11 years is used. In the present study, graphical solution of topographical index is converted into empirical solution. This confirms, convenient practical application of empirical solution for locating fraction-saturated areas. Finally, predicted runoff is compared to that of estimated and observed runoff by modified (SCS-CN) method with that of traditional (SCS-CN) method for different initial abstraction conditions. It is found that modified (SCS–CN) method, also called (CN-VSA) method in its elementary form fitted data well.

## Materials and Methods

### Study area

The Shivalik sediments of the western Himalaya extend from Jammu and Kashmir through Punjab, Haryana, Himachal-Pradesh and Uttar-pradesh states of India to Nepal for more than 1,500 Kilometers (Kms). The region in the north-west of India lies between 30°10' to 30°37'N latitude and 73°37' to 36 77°39'E longitude and stretches to about 530 km's lengthwise and 25 to 95 km's widthwise and cover an area of about 2.14 million hectare (Mha). The region is characterized with low hills, undulating topography, steep slopes, and erodible soils and is dissected by numerous seasonal streams. The hydrological problems of the Shivalik region are different from the plain areas, due to variation in topography, climate, land use and soil type etc. Variation in slope varies, about 40 percent of soils have steep slopes > 15%, 10 percent of soils have moderate slopes 8-15%, 17 percent of soils have gentle slopes 3-8% and 25 percent of soils have very gentle slopes 1-3%. Majority of soils are loamy like sandy loam, loam, silt loam and silt clay loam. The average soil depth for moderately deep soils range between 50-75 cm and cover major area to the extent of 64% while deep soils are >75cm and shallow soils are <50 cm and cover an area of 19 and 15 percent respectively (Sidhu *et. al* 2000). Mansa-devi watershed falling within Shivalik region has 304.5 hectares (ha). Based on parameters of land slope, soil depth, texture, extent of erosion hazards and limitations of use, the area has been classified based on land capability classification (LCC) and land use. Maximum land (88.5%) belongs to class VI and VIII and is non-arable with multidirectional steep slopes, and suffers from the erosion hazards. The arable land (11.5%) belongs to class II, III & IV is deep with sandy loam texture but suffers from the major limitation of gravels, stones and boulders in the root zone (Tiwari *et.al* 2005). The soils are deficient in organic carbon (0.32 to 0.4%) with low to medium available nitrogen (50-470 Kg / ha) and phosphorus (32-50 Kg P2O5 / ha), but high in potassium (250-270 Kg / ha) and have a Ph range 8.2-8.4 (Yadav *et.al* 2006). The land use plan of the arable and the non-arable land has been fixed. Around seventy percent areas (287.2) ha of the farm belonging to class IV, VI and VII have been put under forestry (Yadav *et.al* 2006). In view of these physiographic conditions, it is important to know the pattern of soil water storage and fraction saturated area for different years of the study as a result of rainfall events in the region. Besides, this it is equally important to locate the trend of saturated areas as a result of rainfall events within such variable slope lands. This will facilitate to identify potential water resource area and hydro logically sensitive areas (HSA) within hilly watersheds. In light of this fact, two micro-watersheds have been selected in the present study. Selected two micro watersheds are situated within the research farm of Central Soil and Water Conservation Research and Training Institute, Chandigarh. The selected micro-watersheds lie between $33^0$ 44´ to $30^0$ 46´ North latitude and $76^0$ 56´ to $76^0$ 57´ East longitudes and cover an area of 1.85 and 2.07 ha, respectively. One of them is untreated $wm_1$ and other is treated $wm_2$ with soil conservation measures. These micro-watersheds represent the case study of Shivalik region, under protected forest land-use. The micro-watersheds have a rolling topography with an elevation difference of over 150 meters between the lowest and the highest points. The climate of the study area is sub-humid tropical. Monsoon season starts from middle of June, continues through September, and contributes 90 percent of total annual rainfall. The mean annual rainfall is 1100 mm. The average annual maximum and minimum temperatures are 39.5$^0$c and 6.9$^0$c respectively.

The two micro-watersheds $wm_1$ and $wm_2$ are practically similar and adjacent, constitute an almost ideal pair for study and comparison of water storage values for untreated and treated micro-watersheds. As the soil depths are low to moderate along with higher range of slopes, the land areas converge or diverge. Therefore, saturated areas, which expand and contract seasonally, as well as during individual storms and become one of the source area of surface runoff, as such falls under the realm of variable source area (VSA) or hydrologic ally active areas (Steenhuise *et. al* 1995). After calibration of both the micro-watersheds, it is found that one micro-watershed $wm_2$ was treated with the following soil conservation measures. Construction of three earthen checks dams in the main stream. Construction of 647 staggered contour trenches of 2 m * 0.5 m * 0.25 m size. Sowing is done on the berm of the trenches with Acacia Catechu on high slopes. Eucalyptus hybrid is planted in downstream of the catchments where soil is deep. Recorded daily rainfall and evaporation data as well as event based runoff data for (11) years with effect from year 1998 to 2008 are collected. The data is compiled and used in the present study. Contour plan of two micro-watersheds is presented in Fig.1.

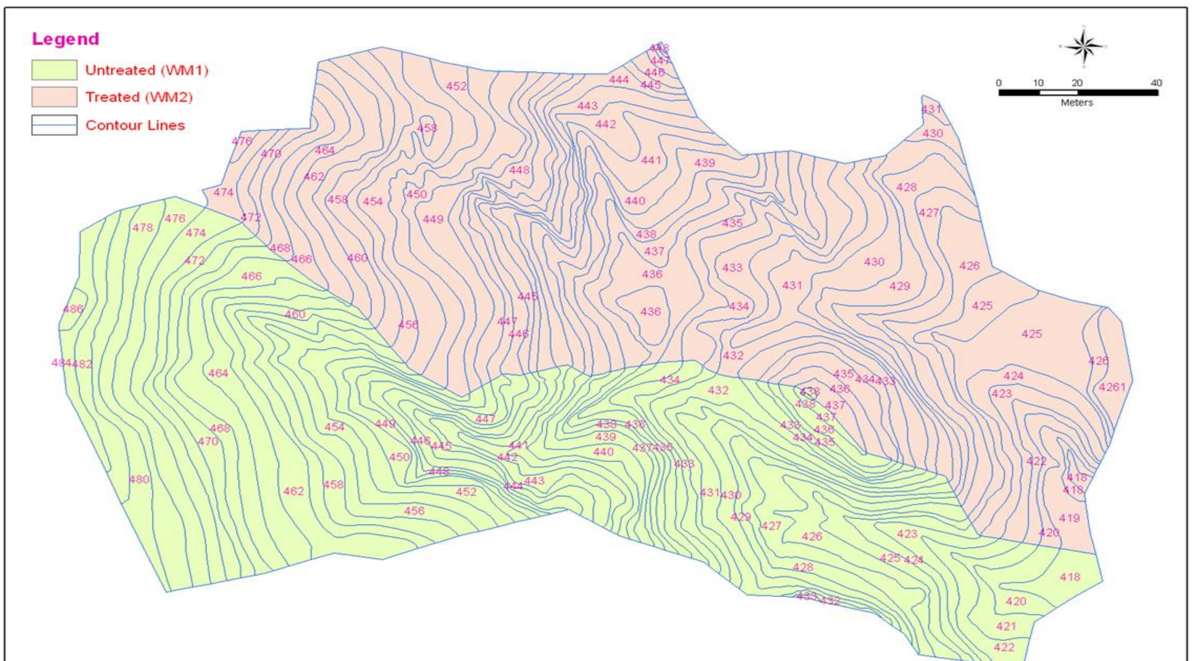


**Fig. 1** Contour Plan of Untreated (WM1) and Treated (WM2) Micro-Watersheds of Mansa Devi Watershed falling in Shivalik region

**Daily water balance**

The TM procedure Throntwaite and Mather (1955,1957) is used to determine the daily water balance given rainfall and potential evapotranspiration. A simpler technique of daily water balance model is developed in this study, in which four possible cases arose while introspection of the data pattern.

**Case-1**

When the rainfall minus potential evapotranspiration (P–PET) value at previous time step is negative and (P–PET) value at the present time step is negative value or zero value. For this case, these two values are added and storage for the present time step is obtained.

**Case-II**

When the rainfall minus potential evapotranspiration (P-PET) value for the previous time step is negative and (P–PET) value for the present time step is positive value. For this case the storage at present time step is storage at previous time step + (P-PET).

**Case-III**

When the rainfall minus potential evapotranspiration (P–PET) value for the previous time step is positive and (P–PET) value at the present time step is negative value. For this case two sub-cases are possible. When the storage at the previous time step is > available water capacity 200 mm and when the storage at the previous time step is < available water capacity 200 mm.

**Case- IV**

When the previous rainfall minus potential evapotranspiration (P–PET) values are positive and (P–PET) value at the present time step are also positive. Storage value at the present time step is obtained by adding these values. This is subjected to maximum available water capacity of 200 mm.

$$S = (P - PET)\, t - t + (P - PET)t$$

Subject to maximum available water capacity (AWC).

From this daily water balance, a dynamic initial abstraction ($I_a$) (not the usual constant value of 0.2S) is calculated. It is the deficit of maximum AWC for the shallowest soil of the selected area. In this way ($I_a$) on daily basis for 365 days of the year for (11) years of the study is calculated. It is used to determine effective rainfall / initiation of runoff ($P_e$). The calculation of ($P_e$) is further equal to rainfall (P) of any event of the year minus ($I_a$).

By using modified (CN-SCS) method (Steenhuise *et.al* 1995). The graphs are drawn for the selected area between event based observed runoff (Q) and effective rainfall ($P_e$) for (11) years from 1998-2008. The average value of water storage (S) is determined by curve fitting in the following equation of the method.

$$Q = \frac{P_e^{\,2}}{(P_{e+S})}$$ Equation (1)

Where;

Q= Observed runoff (mm)

$P_e$= Effective rainfall / Initiation of runoff (mm)

S = Water Storage (mm)

Analysis is done by curve fitting of (Q) and ($P_e$) values in the equation-- for different events of each year of the study. The least square value of (S) for each year by computer search programme is calculated. In this way the average (S) value for $wm_1$ and $wm_2$ is calculated. Coefficients of determination (R2) for each year of the study are calculated as per following equation.

$$R^2 = \frac{Ve}{V} = \frac{(Ye - \bar{Y}_0)^2}{(Y_0 - \bar{Y}_0)^2}$$ Equation (2)

Where,

$Y_e$ = Estimated value of runoff (Q) which is calculated by substituting $P_e$ value of each event of the year and S value of that particular year in equation (1).

$Y_o$ = Observed value of runoff (Q) for each event of the year during the study period.

$\ddot{Y}_0$ = Average value of observed runoff (Depending on number of events of the year).

The average value of (S) and ($R^2$) for each year of the study is presented in Table. 1. Similarly, the value of (S) based on all data points of (Q) and ($P_e$) for each year of the study is presented in Table. 2.

**Table 1: Average water storage value $S_{avg:}$ (2000-2006) for selected micro-watersheds $wm_1$ and $wm_{2.}$**

| Years | Average water storage (S) with effect from 2000-2006 (mm) | | Coefficient of determination ($R^2$) | |
|---|---|---|---|---|
| | **$wm_1$** | **$wm_2$** | **$wm_1$** | **$wm_2$** |
| 1998 | 380.0 | 470.0 | 0.7 | 0.7 |
| 1999 | 263.0 | 389.0 | 0.8 | 0.9 |
| 2000 | 470.0 | 500.0 | 0.9 | 0.9 |
| 2001 | 290.0 | 624.0 | 0.8 | 0.6 |
| 2002 | 240.0 | 440.0 | 0.8 | 0.8 |
| 2003 | 170.0 | 260.0 | 0.9 | 0.9 |
| 2004 | 424.0 | 550.0 | 0.9 | 0.9 |
| 2005 | 940.0 | 1023.0 | 0.8 | 0.8 |
| 2006 | 320.0 | 600.0 | 0.8 | 0.8 |
| 2007 | 416.0 | 500.0 | 0.7 | 0.8 |
| 2008 | 300.0 | 884.0 | 0.9 | 0.9 |
| **$S_{avg:}$** | 408.0 | 571.0 | | |

The potential average ($S_{avg}$) value is calculated by taking mean of (7) year's (S) values from 2000 to 2006. Similarly, potential average ($S_{ADP}$) value between all data points of ($P_e$) and (Q) for (7) year's with effect from 2000 to 2006 for micro-watersheds $wm_1$ and $wm_2$ are calculated by computer search on the basis of least square value. The estimated values are $S_{avg}$ = 408.0, $S_{avg}$ = 571.0 and $S_{ADP}$ = 460.0, $S_{ADP}$ = 585.0 for $wm_1$ and $wm_2$ as presented in Tables 1 and 2. Two years before year 2000 and two years after year 2006 are left for prediction. Further, for different increments of ($P_e$), (Q) values and above calculated ($S_{avg}$) and ($S_{ADP}$) values, the average based water storage curves are developed for $wm_1$ and $wm_{2.}$

**Table 2: Water storage value based on all data points $S_{ADP}$ (2000-2006) as per computer search programme for selected micro-watersheds $wm_1$ and $wm_2$.**

| Years | Effective Rainfall $P_e$ (mm) | Observed Runoff Q (mm) | |
|---|---|---|---|
| | | $wm_1$ | $wm_2$ |
| 2000 | 63.5 | 8.3 | 6.9 |
| | 193.6 | 56.4 | 53.0 |
| 2001 | 107.0 | 31.0 | 14.0 |
| | 57.8 | 3.4 | 9.3 |
| | 25.0 | 4.8 | 2.7 |
| 2002 | 113.2 | 40.4 | 26.0 |
| | 72.0 | 8.6 | 4.4 |
| 2003 | 73.2 | 18.4 | 14.8 |
| | 37.5 | 4.0 | 4.4 |
| | 72.0 | 22.4 | 17.4 |
| | 80.5 | 27.3 | 19.5 |
| | 40.5 | 9.7 | 4.5 |
| 2004 | 469.0 | 246.4 | 216.0 |
| | 30.0 | 2.4 | 1.4 |
| | 26.3 | 3.3 | 2.1 |
| 2005 | 200.0 | 40.0 | 36.0 |
| | 32.2 | 6.4 | 5.7 |
| | 50.4 | 10.0 | 9.0 |
| | 25.3 | 5.0 | 4.5 |
| | 18.5 | 3.7 | 3.3 |
| | 40.0 | 8.0 | 7.2 |
| | 37.0 | 3.7 | 2.9 |
| | 78.2 | 7.8 | 6.2 |
| | 190.7 | 25.0 | 25.0 |
| 2006 | 2.2 | 4.0 | 1.2 |
| | 39.5 | 0.2 | 0.1 |
| | 118.0 | 32.1 | 19.5 |
| | 21.3 | 8.9 | 6.1 |
| $S_{ADP}$: | | 460.0 | 585.0 |

Similarly, ($P_e$) and (S) values of each year of the study are used for calculation of fraction saturated area ($A_f$) of $wm_1$ and $wm_2$ with the help of modified (SCS-CN) method (Lyon *et.al* 2004).

$$A_f = 1 - \frac{S^2}{(P_e + S)^2} \qquad \text{Equation (3)}$$

Where;

$A_f$ = Fraction saturated area (%)

$P_e$ = Effective rainfall / Initiation of runoff (mm)

S = Water storage (mm)

Similarly, against different increments of ($P_e$) values and calculated ($S_{avg}$) and ($S_{ADP}$) values, the average trend of ($A_f$) curves within $wm_1$ and $wm_2$ are determined.

**Topographical index (λ)**

Topographical index for any point in a watershed is defined as the natural log of the area of the upslope watershed per unit contour length (a), divided by the local surface topographic slope tan (β) (Western *et.al*.1999, 2002).

$$\lambda = \ln\left(\frac{a}{\tan(\beta) * D * K_s}\right) \qquad \text{Equation (4)}$$

Where;

λ = Topographical index

a = Upslope area per unit contour length

D = Depth of the soil cm

$K_s$= Saturated hydraulic conductivity mm/hr

tan (β) = Local surface topographic slope cm

The weighted average depth of soil has been taken as 60 cm (Sidhu *et. al* 2000) saturated hydraulic conductivity estimated equal to 6.82 mm / hr. As ($K_s$ = 31.39 - 0.39 CN) for CN=63 for $wm_1$ and $wm_2$, when CN ranges between (36<CN<75) as per (Kovar 1990).

Topographical index ($\lambda_1$) and ($\lambda_2$) are calculated by digitizing contour plans by using ARC-Info software. The values of ($\lambda_1$) for $wm_1$ and ($\lambda_2$) for $wm_2$ are presented in Tables.3 and 4. The curves developed between ($\lambda$) and ($A_f$) are incorporated in modified (SCS-CN) method Figs. 2-C and 2-D for location of fraction-saturated areas within study area.

**Table 3: Topographical index ($\lambda_1$) of untreated micro-watershed ($wm_1$)**

| Contour Interval (B=Boundary of micro-watershed) | Area ($m^2$) | Total Area ($m^2$) | Length of contour (m) | Up slope Area/Con Length (a) | Fraction Saturated Area ($A_f$) ($m^2$) | Height (H) (m) | Horizontal Equivalent Between Contours (L) (m) | Tanβ (H/L) | $\lambda_1 = \ln\left(\frac{a}{\tan(\beta) * D * K_S}\right)$ |
|---|---|---|---|---|---|---|---|---|---|
| B-480 | 1030.4 | 1030.4 | 117.9 | 8.7 | 1.0 | 6.0 | 10.1 | 0.5 | 5.0 |
| 480-470 | 2216.7 | 3247.1 | 116.3 | 27.9 | 0.6 | 10.0 | 19.7 | 0.5 | 6.3 |
| 470-460 | 2415.5 | 5662.6 | 133.5 | 42.4 | 0.4 | 10.0 | 21.2 | 0.4 | 6.8 |
| 460-450 | 1871.1 | 7533.7 | 113.1 | 66.6 | 0.2 | 10.0 | 16.0 | 0.6 | 7.0 |
| 450-440 | 1943.6 | 9477.3 | 75.5 | 125.5 | 0.2 | 10.0 | 39.7 | 0.2 | 8.5 |
| 440-430 | 2700.7 | 12178 | 152.9 | 79.6 | 0.2 | 10.0 | 24.1 | 0.4 | 7.5 |
| 430-B | 3048.4 | 15226.4 | 50.0 | 304.5 | 0.2 | 10.0 | 83.7 | 0.1 | 10.2 |

**Table 4: Topographical index ($\lambda_2$) of treated micro-watershed ($wm_2$)**

| Contour Interval (B=Boundary of micro-watershed) | Area ($m^2$) | Total Area ($m^2$) | Length of contour (m) | Up slope Area/Con Length (a) | Fraction Saturated Area ($A_f$) ($m^2$) | Height (H) (m) | Horizontal Equivalent Between Contours (L) (m) | Tan β (H/L) | $\lambda_2 = \ln\left(\frac{a}{\tan(\beta) * D * K_S}\right)$ |
|---|---|---|---|---|---|---|---|---|---|
| B-470 | 355.5 | 355.5 | 45.8 | 7.7 | 1.0 | 8.0 | 12.2 | 0.6 | 4.8 |
| 470-460 | 1364.8 | 1720.3 | 96.5 | 17.8 | 0.7 | 10.0 | 19.6 | 0.5 | 5.8 |
| 460-450 | 2289.1 | 4009.4 | 122.8 | 32.6 | 0.5 | 10.0 | 22.7 | 0.4 | 6.6 |
| 450-440 | 3528.1 | 7537.5 | 145.9 | 51.6 | 0.4 | 10.0 | 32.0 | 0.3 | 7.4 |
| 440-430 | 5151.3 | 12688.8 | 128.8 | 98.5 | 0.4 | 10.0 | 52.4 | 0.1 | 8.5 |
| 430-B | 4314.8 | 17003.6 | 175.9 | 96.6 | 0.2 | 12.0 | 39.3 | 0.3 | 8.1 |

The proceeding 2 years of data with reference to year 2000 up to year 1998 and succeeding 2 years of data with reference to year 2006 up to year 2008 are excluded for prediction. The result of $wm_1$ for year 2008 is presented for ready reference in Fig. 3. Different methods used for prediction of runoff (Q) are as follows.

1. CN-VSA method (Using average water storage (S) of the specific year)

2. Using initial abstraction as taken normally in (SCS –CN) method ($I_a$ = 0.2S).

3. Applying (SCS-CN) method, CN =63 and S=149 for $wm_1$ and $wm_2$ respectively.

4. Using potential average water storage ($S_{avg:}$) calculated for (7) years from (2000 to 2006) for $wm_1$ and $wm_2$..

5. Using potential average water storage ( $S_{adp:}$ ) simulating all data points calculated for (7) years from (2000 to 2006) for $wm_1$ and $wm_2$.

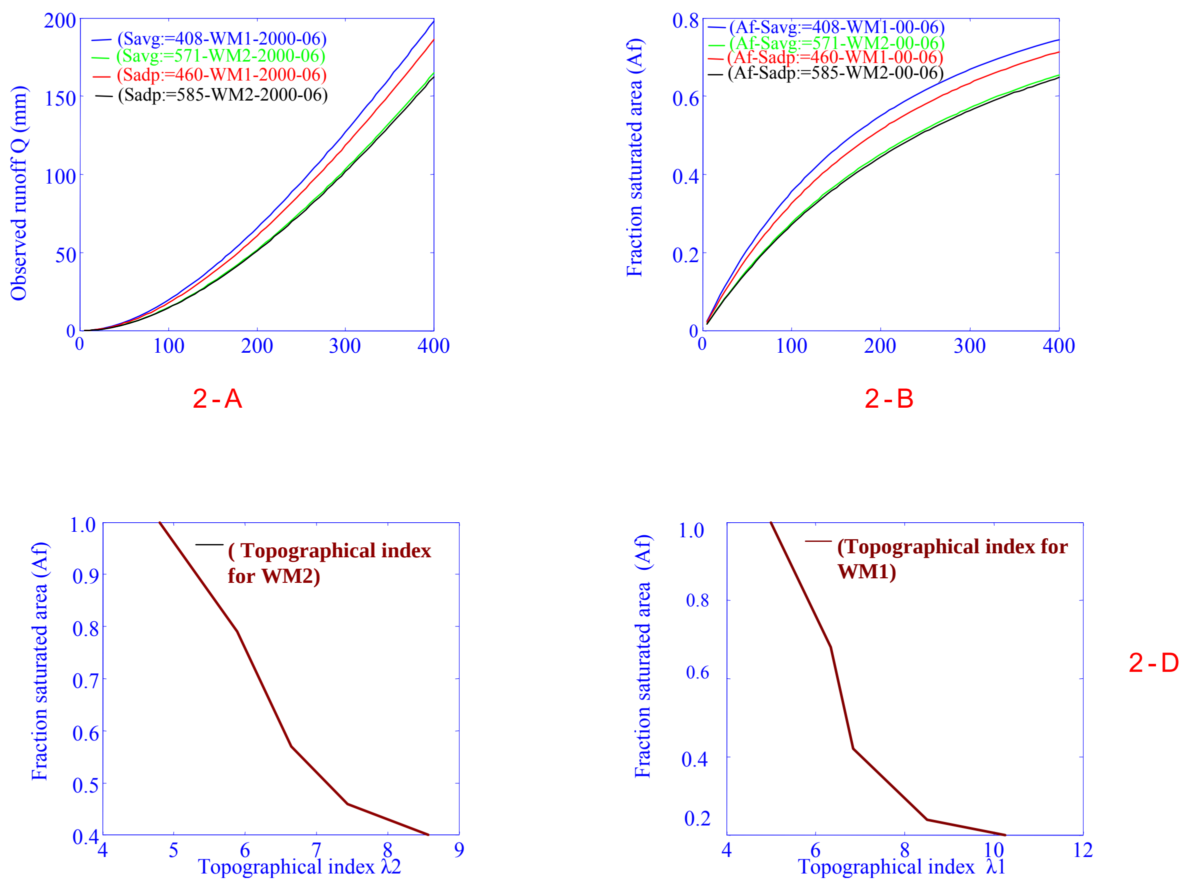


Fig.2 : Overview of runoff generation from WM1 and WM2 using modified (SCS-CN) method.

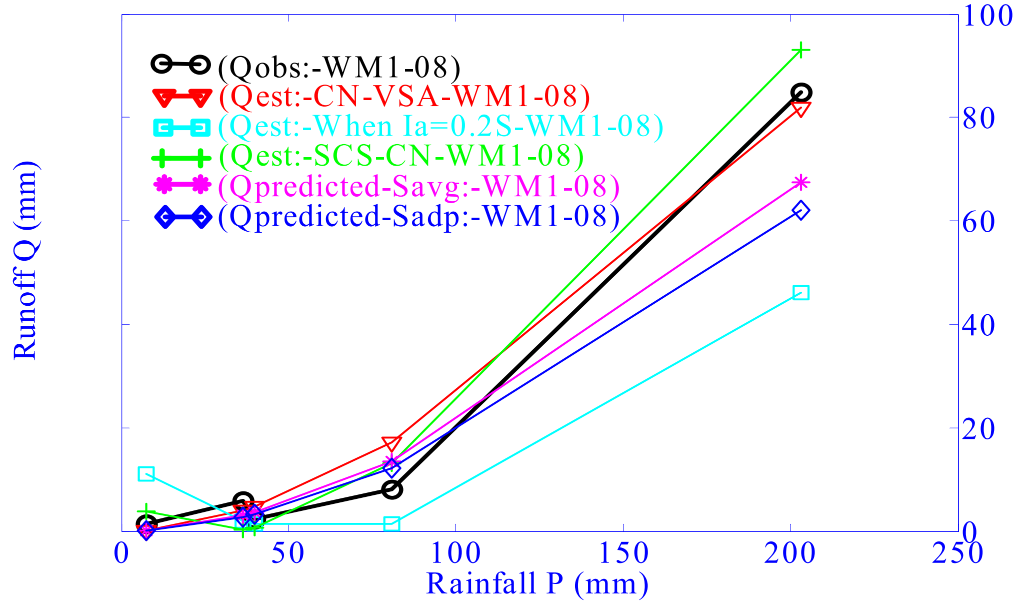


Fig. 3: Prediction of runoff from WM1 for the year 2008.

## Results and Discussion

Determining critical (λ) values above, which study areas contribute runoff in the form of saturation excess called exfiltration and below, which areas contribute runoff in the form of infiltration excess (Lyon *et.al* 2004). In lieu to this topographical index ($\lambda_1$) and ($\lambda_2$) presented in Figs. 2-C and 2-D are incorporated in Fig. 2. The **c**omparison of critical (λ) values calculated graphically and empirically for maximum observed runoff days of different years of the study within $wm_1$ and $wm_2$. are presented in Table. 5. It indicates that observed runoff (Q) for such rainfall events are marginally higher within untreated $wm_1$ in comparison to treated $wm_2$ micro-watershed. Fraction saturated area ($A_f$) is higher in $wm_1$ than $wm_2$, this is because of higher storage in $wm_2$ due to treatments. Further, micro-watershed $wm_1$ has contours ranging between (486-418) and calculated critical (λ) values during the study fall between the contours range of (470-460) (460-450) and (440-430) refer Fig. 1. This proves that as a result of maximum rainfall event during any year of the study within $wm_1$ and by virtue of its physiographic condition, almost equal area produces runoff both in the shape of infiltration excess and exfiltration excess. Similarly, in comparison to this, adjacent treated $wm_2$ has contours ranging between (476-418) and calculated critical (λ) values fall between the contour ranges of (440-430) (430- Boundary B) refer Fig. 1. This proves that as a result of maximum rainfall event during any year of the study within $wm_2$ and by virtue of its physiographic condition maximum area produces runoff in the shape of infiltration excess and lesser area produces runoff as exfiltration excess. In brief with this method, it is located that $wm_1$ has more hydrologically sensitive area in comparison to $wm_2$.

**Table 5: Comparison of critical (λ) values calculated graphically and empirically for maximum observed runoff days during study within $wm_1$ and $wm_2$.**

| Date/ Year | Observed Runoff Q (mm) | | Effective Rainfall $P_e$ (mm) | | Fraction Saturated Area ($A_f$) | | Critical Topographical Index (λ) | | Contour as per figure-1 B=Boundary of micro-watershed | | Type of solution |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $wm_1$ | $wm_2$ | $wm_1$ | $wm_2$ | $wm_1$ | $wm_2$ | $wm_1$ | $wm_2$ | $wm_1$ | $wm_2$ | |
| 18-07-2000 | 56.4 | 55.0 | 193.6 | 193.6 | 0.49 | 0.48 | 6.3 | 8.0 | 470-460 | 440-430 | Graphical |
| 18-07-2000 | 56.4 | 53.0 | 109.1 | 117.5 | 0.3 | 0.3 | 6.4 | 8.2 | 470-460 | 440-430 | Empirical |
| 03-07-2001 | 31.0 | 14.0 | 107.0 | 107.0 | 0.46 | 0.27 | 7.1 | 8.0 | 450-440 | 450-440 | Graphical |
| 03-07-2001 | 31.0 | 14.0 | 73.8 | 52.4 | 0.2 | 0.1 | 7.3 | 8.0 | 450-440 | 450-440 | Empirical |
| 07-09-2002 | 40.4 | 26.0 | 113.2 | 113.2 | 0.53 | 0.36 | 6.8 | 8.0 | 460-450 | 430-B | Graphical |
| 07-09-2002 | 40.4 | 26.0 | 87.5 | 75.3 | 0.3 | 0.2 | 6.8 | 8.2 | 460-450 | 430-B | Empirical |
| 24-07-2003 | 27.3 | 19.5 | 80.5 | 80.5 | 0.53 | 0.41 | 7.7 | 8.1 | 450-440 | No effect | Graphical |
| 24-07-2003 | 27.3 | 19.5 | 68.2 | 63.5 | 0.2 | 0.1 | 7.5 | 8.1 | 450-440 | No effect | Empirical |
| 03-08-2004 | 246.4 | 216.0 | 469.0 | 469.0 | 0.77 | 0.70 | 6.4 | 7.1 | 460-450 | 450-440 | Graphical |
| 03-08-2004 | 246.4 | 216.0 | 324.0 | 314.2 | 0.6 | 0.5 | 6.5 | 6.9 | 460-450 | 450-440 | Empirical |
| 05-07-2005 | 40.0 | 36.0 | 200.0 | 200.0 | 0.32 | 0.30 | 6.2 | 7.9 | 460-450 | 440-B | Graphical |
| 05-07-2005 | 40.0 | 36.0 | 86.9 | 91.9 | 0.3 | 0.2 | 6.9 | 8.2 | 460-450 | 440-B | Empirical |
| 26-07-2006 | 32.1 | 19.5 | 118.0 | 118.0 | 0.46 | 0.30 | 7.4 | 8.2 | 450-440 | No effect | Graphical |
| 26-07-2006 | 32.1 | 19.5 | 75.4 | 63.5 | 0.2 | 0.1 | 7.2 | 8.1 | 450-440 | No effect | Empirical |

However, it is observed that interpreting critical (λ) values graphically as per (Lyon *et.al* 2004) is susceptible to human error. Therefore, transforming the graphical solutions into more convenient practical application, a concept of calculating critical (λ) values empirically for any rainfall event is worked out and applied in the present study. The graphical solution of topographical index presented in Figs. 2-C and 2-D, where the Y-axis of the graphs indicate fraction-saturated area ($A_f$) and X-axis indicate topographical index (λ). Taking third degree polynomial of two topographical index graphs in the same order of axis ($Y = A_f$) and ($X = \lambda$). Plotting graph between ($X = \lambda$ and $Y = A_f$) the resultant third degree polynomial equations for these graphs, we get is in terms of ($Y = A_f$ and $X = \lambda$) as presented in equations (5 and 6). Therefore, by knowing different values of ($X = \lambda$) we can get different values of ($Y = A_f$). The third degree polynomial equations are as follows,

$$Y = 0.024*x^3 - 0.48*x^2 + 2.9*x - 4.4 \qquad \text{Equation (5)}$$

$Y = 0.018*x^3-0.32*x^2 + 1.7*x-1.7$ Equation (6)

Where,

$Y = A_f$ and $X = \lambda$

But the point to be noted is that we have to find ($\lambda$) values instead of ($A_f$) values. This gives a clue that our problem is just reverse and by reversing the axis as presented in Figs.4 and 5. By plotting graph between ($Y= \lambda$ and $X = A_f$) in comparison to earlier ($Y= A_f$ and $X = \lambda$) we get third degree polynomial equation of the graphs in terms of ($Y = \lambda$ and $X = A_f$) as presented in equations (7 and 8). Since, the $A_f$ values are known and from these values corresponding ($\lambda$) values can be calculated. However, it is important to mention that this polynomial equation is easier to use as compared to earlier equations (5 and 6) obtained by plotting graph between ($X= \lambda$ and $Y= A_f$). This equation has three roots two imaginary and one real root, thus becomes difficult to solve as compared to simple equations (7 and 8) when the graphs are drawn between ($Y= \lambda$ and $X = A_f$).

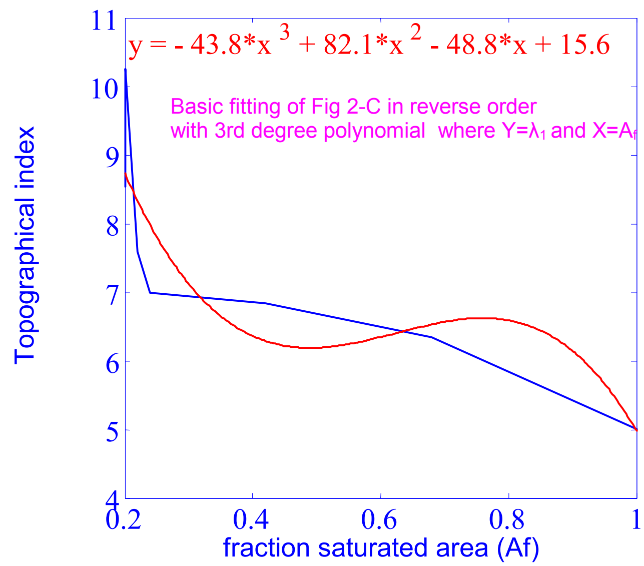


Fig. 4: Basic fitting of topographical index $\lambda_1$ when plotted between (x, y)

The empirical solution proposed for determining critical ($\lambda$) values by using polynomial equation to the graphical solution in the present study as ($\lambda_1$) for $wm_1$ and ($\lambda_2$) for $wm_2$ are as follows,

$$\lambda_1 = -43.83*x^3 + 82.09*x^2 - 48.84*x + 15.571$$ Equation (7)

Where,

$Y= \lambda$ and $X = A_f$

Similarly,

$$\lambda_2 = 15.62 * x^3 - 29.74 * x^2 + 12 * x + 6.8 \quad \text{Equation (8)}$$

By referring to equations (7) and (8) critical (λ) values are calculated empirically and presented in Table. 5. It is observed that the critical (λ) values calculated empirically can be obtained conveniently for all the rainfall events of the years of the study. Comparing critical (λ) values obtained for maximum runoff days of each year of the study calculated empirically are closer to critical (λ) values calculated graphically. This proves the fact that proposed method of locating fraction-saturated areas empirically within watersheds may be more convenient.

Further, by referring to prediction of runoff (Q) graph for $wm_1$ for the year 2008 as presented in FIG. 3. It is indicated that predicted runoff ($Q_{predicted}$) and estimated runoff ($Q_{est}$) by modified (SCN- CN) method are closer to observe runoff ($Q_{obs;}$) followed by estimated runoff ($Q_{est:}$) by normal (SCS-CN) method and lastly when initial abstraction is calculated as ($I_a$=0.2S). The trend is repeated in all the graphs for the years (1998 and 1999) as well as for the years (2007 and 2008).

## Conclusion

As the discharge / runoff data is scanty within ungauged watersheds of India in particular and other countries in general. Therefore in absence of physically recorded data, the daily water storage and runoff data obtained by computer aided daily water balance may be good alternative to determine average water storage (S) on yearly basis as presented in Tables. 1 and 2.

Using potential water storage ($S_{avg:}$) values of micro-watersheds in modified (SCS-CN) method. Conveniently, watershed characteristics can be developed as presented in Fig. 2-A. Further, knowing peak values of runoff ($P_e$) data can be transformed into peak discharge values to assist in designing soil and water conservation structures.
The effect of bioengineering measures like construction of earthen check-dams, construction of contour trenches of size 2 m x 0.5 m x 0.25 m. Sowing of Acacia Catechu on berms of trenches on high slopes has proved to have long lasting effect on water storage performance of treated $wm_2$ over untreated $wm_1$ micro-watersheds as presented in Table. 5.

The modified (SCS-CN) method adopted in this study for variable source area very conveniently gives the event based details of fraction-saturated areas ($A_f$) as presented in Fig. 2-B and ($A_f$) values of different events can be calculated as presented in Table. 5.

The importance of the finding is enhanced by incorporating topographic index (λ) of $wm_1$ and $wm_2$ is presented in Table. 3 and 4 and Figs. 2-C and 2-D in modified (SCS-CN) method also called variable source area (CN-VSA) method as presented in Fig. 2. This help in calculating critical (λ) values to locate fraction saturated areas and type of runoff as presented in Table.5.This is of vital importance during watershed investigation cum planning phase.

Transforming the graphical solutions into more convenient practical application, a concept of calculating critical (λ) values empirically for any rainfall event is worked out and applied in the present study as presented in equations 5 to 8. This may overcome chances of error in calculating critical (λ) values graphically and data can be obtained more conveniently.

Prediction of runoff (Q) graph for $wm_1$ for the year 2008 is presented in FIG. 3. It is indicated that predicted runoff ($Q_{predicted}$) and estimated runoff ($Q_{est}$) by modified (SCN- CN) method are closer to observe runoff ($Q_{obs;}$) followed by estimated runoff ($Q_{est:}$) by normal (SCS-CN) method and lastly when initial abstraction is calculated as ($I_a$=0.2S). The trend is repeated in all the graphs for the years (1998 and 1999) as well as for the years (2007 and 2008).

The modified (SCS-CN) method also called (CN-VSA) method has been successfully applied to Shivalik micro-watershed and may be applied in similar watersheds to generate the data.

**References:**


Frankenberger, T. R., Brooks, E. S., Walter. M. T., Walter, M, F., Steenhuis, T. S. (1999) A GIS-based variable source area model, Hydrological Process, 13, 804-22.

Hjelmfetl, A. T. (1980) Curve number procedure as infiltration method, Journal of Hydrology, 100, 1107-111.

Kovar, P. (1990) Application of adapted curve number model on the Sputka basin Hydrology of Mountainous Areas (Proceedings of the Strbské Pleso Workshop, Czechoslovakia, IAHS Publ. no. 190.

Lyon, S. W., Todd, M. W., Pierre, G.M. and Steenhuis, T. S. (2004) Using a topographic index to distribute variable source area runoff predicted with the SCS curve-number HYDROLOGICAL PROCESSES 18,2757-2771.

Mishra, S.K., and V.P. Singh, 2003. Soil Conservation Service Curve Number (SCS-CN) Methodology 'Kluwer' Academic Publishers, Dordrecht, The Netherlands, ISBN 1-4020-1132-6.

Rallison, R. K. (1980) Origin and evolution of the SCS runoff equation. In Proceedings of Symposium on Watershed Management, 21-23 July Boise, ID, American Society of Civil Engineers, New York, NY, 912-924.

Sidhu, G. S., Walia, C. S., Sachdev, C. B. (2000) Soil resource of N-W Shiwaliks for perspective land use planning, In: Mittal, S. P., Aggarwal, R. K., Samra, J. S. (Eds) fifty years of research on sustainable resource management in Shivaliks, CSWR&TI Chandigarh-India.

Soil Conservation Services (SCS),1956. Supplement A, Section 4, Chapter 10, and Hydrology, National engineering handbook, USDA, Washington, DC.

Steenhuis, T. S., Winchell. M., Rossing. J., Zollweg, J. A., and Walter, M. F. (1995). SCS Runoff Equation Revisited for Variable-Source Runoff Areas, Journal of Irrigation and Drainage Engineering, Volume 121, No. 3, 234-238.

Thornthwaite, C. W., Mather, J. W. (1957) Instructions and tables for computing potential evapotranspiration and the water balance, Publications in Climatology 10: 181-311.

Tiwari, A. K., Bhatt, V. K., Agnihotri, Y. and Aggrawal, R. K. (2006) Application of SCS curve number model for estimation of runoff in forest micro-watersheds of Shiwaik region, Journal soil water conservation India, 5(2); 64-68.

Western, A. W., Grayson, R. B., Bloschl, G., Willgoose, G. R., McMahon, T. A. (1999) Observed spatial organization of soil moisture and its relation to terrain indices, Water Resources Research 35: 797–810.

Yadav, R. P., Aggarwal, R. K., Bhattacharya, P., and Bansal, R. C. (2005) infiltration characteristics of different aspects and topographical locations of hilly watershed in Shivalik-lower Himalayan region in India, Indian J. Soil Cons, 33(1): 42-48.