



Rainfall-Runoff Analysis using Runoff Coefficient and SCS-CN Methods under GIS Approach

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Authors' contributions

This work was carried out in collaboration between both authors. 'Both authors read and approved the final manuscript.'

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ABSTRACT

Estimation of runoff in a watershed is very important to manage the water resources efficiently. In this regard, surface runoff quantification is an essential study. The main objective of this study is to quantify the surface runoff of the catchment area of a well located in AEC & RI, TNAU, Kumulur, Trichy District of Tamil Nadu State, India. An attempt also made to analyze the surface runoff by SCS-CN event and annual basis as well as by modified runoff-coefficient method. This study identified the variation of runoff volume within different approaches of SCS-CN method and runoff coefficient method. By using GPS and GIS techniques catchment area of a well and slope direction was delineated. With the help of GIS tools and remote sensing technology with ground truth verifications, the land use/ land cover and soil maps were delineated for the study area. Sandy loam and sandy clay loam type of soils are predominating and HSG 'C' was identified for the study area. The highest CN value is 92 and the maximum runoff coefficient value is 0.95 for the Built-up land, the lowest CN value is 71 and the lowest runoff coefficient is 0.11 for the area covered with trees. Three AMC conditions were considered while estimating runoff volume by SCS-CN event approach. Among 15 years of rainfall data from 2004 to 2018, the highest runoff 38452.36 m³ was generated in the year 2005 and the lowest runoff 8718.29 m³ was generated in 2018 by SCS-CN event basis method. From this study between two concepts of SCS-CN and runoff coefficient models, the SCS-CN model with an event basis approach is yielding productive results. For

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quantifying surface runoff and for planning water conservation structures event basis calculations are more effective.

Keywords: Curve number; groundwater; land use; rainfall; remote sensing; runoff-coefficient; slope; watershed.

1. INTRODUCTION

A watershed is that contributes runoff water to a common point. There are many methods offered for rainfall-runoff modeling. The Soil Conservation Service and Curve Number (SCS-CN) technique is one of the primogenital and simplest method for rainfall-runoff modeling. Several models based on SCS-CN are being referred by different researchers worldwide used such as the original SCS-CN, Mishra-Singh (MS) model (2002), Michel model (2005), and Sahu model (2007), on the SCS-CN concepts, with some modifications are used. Earlier studies carried out by several researchers such as Mishra et al. [1], Kadam et al. [2], Bhura et al. [3], Saravanan and Manjula [4], Vinithra and Yeshodha [5] and Satheeshkumar et al. [6].

The rational method is also widely used to calculate the peak stormwater runoff rate for a variety of storm water management applications [7]. The runoff coefficient will vary due to different types of physiographic features like vegetation interception, soil infiltration, slope, geomorphological structure, etc.

In this study, rational method modified as runoff coefficient method and used to calculate runoff volume with average rainfall intensity by converting cumulative rainfall depth into average rainfall intensity [8]; I.D.F Procedure, CIVE 322 Basic Hydrology Text Book, Dept. of Civil and Environmental Engg., Colorado State University). The SCS-CN with event and annual approaches as well as runoff coefficient models were adopted and analyzed for the précised surface runoff estimation for the study area.

2. MATERIALS AND METHODS

2.1 Study Area

The study area, a micro watershed of Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Kumulur, located in Lalgudi Taluk of Tichy District in Tamil Nadu State, India lies in between 10°55'56"-10°55'47" North latitudes and between 78°49'43"-78°49'38"

East longitudes. The catchment area is about 44,832.3 m² covered with built-up land, agriculture land, plantation crops, current fallow, wasteland, forestry (cultivable trees) and one open well. The study area is having third-order stream passing from near the open well.

2.2 Experimental Tools / Techniques

Tools like GPS, total station were used to observe elevation ponits for the study area and the readings were superimposed in GIS software to delineate the exact catchment area of a well and slope map for the study area. Using Google earth map and ground truth verifications, the land use/ land cover map of the study area was generated. Soil samples were collected from the site and the texture analysis was carried out by International Pipette Method (Robinson Pipette method) [Beretta et al. (2014)] and the final soil map was delineated in GIS interface. Double Ring Infiltrometer was used to find the soil infiltration characteristics to identify the Hydrologic Soil Group of the study area as per the Table 1 [9]. 15 years of rainfall data from 2004 to 2018 collected from Meteorology Station of AEC&RI, TNAU, Kumulur. The average rainfall intensity was estimated by IDF empirical approach [8]. SCS-CN method with annual and event approaches, and runoff coefficient models were used to the calculate the surface runoff from the study area and were discussed.

2.3 SCS-CN Model

The SCS-CN (1985) method was established in 1954 by the USDA SCS [10], defined in the Soil Conservation Service (SCS) by National Engineering Handbook (NEH-4) Section of Hydrology [11].

The Soil Conservation Service Curve Number (SCS-CN) method was used to estimate the surface runoff from the study area (USDA 1964 and 1998).

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad (1)$$

Table 1. Soil Conservation Service Classification (USDA 1998)

Hydrological Soil Group (HSG)	Soil Textures	Runoff potential	Water transmission	Infiltration (mm/h)
Group A	Deep, well-drained sands and gravels	Low	High rate	>7.5
Group B	Moderately deep, well-drained with moderate	Moderate	Moderate rate	3.8-7.5
Group C	Clay loams, shallow sandy loam, soils with moderate to fine textures	Moderate	Moderate rate	1.3-3.8
Group D	Clay soils that swell significantly when wet	High	Low rate	<1.3

Where ‘Q’ is the runoff depth in mm, ‘P’ is the rainfall depth in mm, I_a is the initial abstraction in mm, ‘S’ is Potential maximum retention of the watershed in mm.

Surface storage, interception and infiltration prior to the runoff is defined as initial abstraction I_a and it is given by,

$$I_a = 0.3 \times S \quad (2) \text{ (for Indian Conditions)}$$

For Indian condition the form ‘S’ the potential maximum retention is given by,

$$S = \frac{24500}{CN} - 254 \quad (3)$$

Where CN is known as the curve number, now the equation can be re-written as

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \quad (4)$$

$$Q_v = \frac{Q \times A}{1000} \quad (5)$$

Where ‘ Q_v ’ is the runoff volume in m^3 , ‘A’ is the area of the watershed in m^2 and ‘Q’ is the runoff depth in mm.

The SCS Curve Number describes the ability of soils to allow infiltration of water concerning to their land use/ land cover (LU/LC) and antecedent soil moisture conditions (AMC) [12].

Based on the U.S soil conservation service (SCS), soils are classified into four hydrologic soil groups such as A, B, C & D concerning the rate of runoff and final infiltration as presented in Table 1. By analyzing the land use/ land cover and HSG, curve number values were obtained from Arc GIS software with digitized boundaries.

2.3.1 Antecedent moisture condition (AMC)

Antecedent Moisture Condition (AMC) is considered as the moisture available before the modeled rainfall event. For modeling purposes, AMC II in the watershed is essentially an average moisture condition, for dry condition AMC I and wet condition for AMC III. Antecedent Moisture Condition classes were categorized as I, II, III reported in Table 2.

The following equations (Equation No. 6 and 7) were used to estimate CN values for the AMC-I and AMC-III based on AMC-II (average condition) for their corresponding land use patterns [13].

$$CN (I) = \frac{4.2 CN(II)}{10-0.058CN(II)} \quad (6)$$

$$CN (III) = \frac{23 CN (II)}{10+0.13 CN (II)} \quad (7)$$

Table 2. Group of Antecedent soil moisture classes [6] (USDA 1985)

AMC group	Total 5-day antecedent rainfall (mm):	
	Dormant season	Growing season
I	Less than 13	Less than 36
II	13 to 28	36 to 53
III	More than 28	More than 53

The following Equation No. 8 was used to calculate the weighted CN value for the whole study area.

$$CN_w = \frac{CN_i A_i}{A} \quad (8)$$

Where CN_w is the weighted curve number for the whole catchment area, CN_i is the curve number from 1 to any number N , A_i is the area with curve number CN_i and A is the total area of the watershed.

2.3.2 SCS-CN Annual Approach

In this approach only AMC-II (average condition) was considered and the average CN value (weighted CN value from Eq.7) used for calculating 'S' (potential maximum retention) in Eq. 3 for surface estimation (Eq. 1). The cumulative rainfall amount values of their corresponding years were used to estimate the surface runoff amount for that annual year [14,2,4].

2.3.3 SCS-CN Event Approach

In this approach AMC-I, AMC-II and AMC-III were considered and the average CN value (weighted CN value from Eq.7) for each condition was determined. As per Table 2, each rainy day rainfall was considered to determine suitable AMC condition for that particular day to calculate the runoff amount for that day. Each rainy day runoff amount was estimated and the summation of all those values for their corresponding year considered as that annual runoff volume [15].

2.4 Runoff Coefficient Method

Instead of the rational method to calculate peak flow discharge, the runoff coefficient method is used to calculate the runoff volume by the average rainfall intensity of a rainy day (24 h). The average rainfall intensity of rainy day from the cumulative rainfall was calculated as per the procedure "Intensity-Duration-Frequency (IDF), CIVE-322, Basic Hydrology, Hydrologic Science and Engineering, Civil and Environmental Engineering Department, Fort Collins, Colorado State University". Each rainy day runoff volume was determined by using following Formulae [8]. The annual runoff volume was computed by summing up each runoff volume of the rainy day throughout the year.

The rational model is considered as runoff coefficient method:

$$Q = \frac{CIA}{1000} \quad (9)$$

Where 'Q' is the runoff volume of a rainy day (m^3), 'C' is runoff coefficient depends on land use, soil properties and topography (unit-less), 'I' is the average rainfall intensity of a rainy day (mm) [IDF-Procedure, CIVE-322, Civil and Environmental Engineering Department, Fort Collins, Colorado State University] and 'A' is the catchment area (m^2).

3. RESULTS AND DISCUSSION

3.1 Delineation of Catchment Area of a Well

The contour map for the catchment of a well was delineated and the slope direction identified towards the southeast direction as shown in Fig. 1. With the ground truth verifications and total-station survey final well catchment was delineated as shown in Fig. 2. One open well is exiting in the low-lying part of the study area towards southeast direction.

3.2 Land use/ land cover classification

The land use and land cover map of the study area obtained as shown in Fig. 3. Fig. 3 reveals that, the study area constituting of cultivated area (42.27%) followed by plantation crop (21.52%), pasture land/current fallow (12.45%), tree cultivated area (12.09 %), waste land (7.4%), built-up land (4.01%) and water body i.e. open well (0.14%). The major area of the watershed was under crop land (cultivable land) plays an important role in producing direct surface runoff. Land use/ land cover details with respect to their areas were shown in Table 3.

3.3 Soil Classification

The soil infiltration rate and soil texture analysis were carried. Based on soil texture the study area soils were categorized into two soil groups i.e. sandy clay loam and sandy loam as shown in Fig. 4. Majority of the area covered with sandy clay loam soil (51%) followed by sandy loam soil (49%). The HSG-C (Hydrologic Soil Group) was identified for the study area based the soil properties (texture and infiltration) as per the Table 1.

3.4 Curve Numbers and Maximum Retention Capacity (SCS-CN Method)

CN values were estimated based on hydrologic soil group and land-use patterns of the study area were presented in Table 3. The weighted

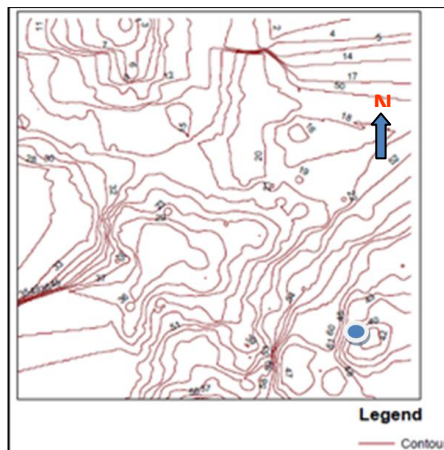


Fig. 1. Contour map of the study area

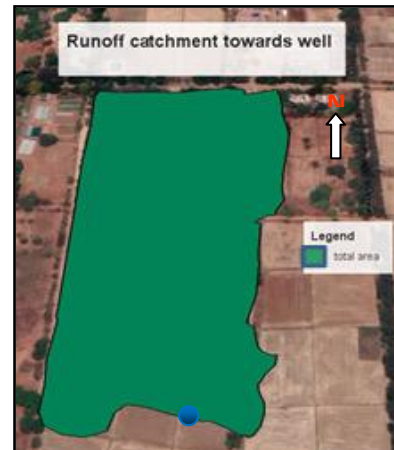


Fig. 2. Well catchment area

values of curve number for the three AMC conditions as well as maximum soil-water retention capacity for three antecedent moisture conditions were calculated as per the USDA SCS-CN method and presented in Table 4.

3.5 Estimation of Runoff Volume by SCS-CN Method

3.5.1 Estimation of runoff volume (annual basis)

From the rainfall data for 15 years (2004 to 2018), the annual runoff volume was estimated from annual rainfall depth by the SCS-CN annual basis method. The highest runoff volume generated in 2005 is 63046.09 m³ with the highest rainfall of 1476.4 mm and the lowest runoff volume amount observed in the year 2018 is 18924.7 m³ with the lowest rainfall of 524.2 mm as shown in Fig. 5.

3.5.2 Estimation of runoff volume (event basis)

In this concept, the runoff volume was calculated for each rainfall event by considering three AMC conditions with respect to their weighted CN values and 'S' values (Maximum Retention Capacity) as per the Table 4. Each rainy-day runoff amount was calculated and the annual runoff volume was computed by summing up each runoff volume of the rainy day throughout the year. From the rainfall data for 15 years (2004 to 2018), the highest runoff volume generated in 2005 is 38,452.36 m³ with the highest rainfall of 1476.4 mm and the lowest runoff volume amount observed in the year 2018 is 8718.3 m³ with the lowest rainfall of 524.2 mm

as shown in Fig. 6. This approach consumes more time for calculating longer periods of rainfall data, but it is a precise method for gauged watershed and more useful for planning of water conservation structures such as farm ponds, gully plugs, percolation ponds, check dams, and other artificial water recharge structures.

3.6 Estimation Runoff Volume by Runoff Coefficient Method

The estimated runoff coefficient values were presented in Table 5. The following Table 5 shows the highest runoff coefficient values determined for water body i.e. 1 and the next highest value for built-up land is 0.95, and the lowest value identified for the forest/ the land covered with trees is 0.12 and second lowest for plantation crops (citrus & drum stick crops) is 0.2. The highest runoff coefficient value tends to produce more surface runoff and the lowest values retain more moisture as abstraction losses hence the runoff volume was less as compare to the highest runoff coefficient values.

From this runoff coefficient method among 15 years of rainfall data (2004 to 2018), the highest runoff was obtained in the year 2005 as 38,499.81 m³ and the lowest runoff was in the year 2018 as 10,011.89 m³ as per Fig. 7.

3.7 Comparison of Runoff Volume by SCS-CN (event, annual basis) and Runoff Coefficient methods

In most cases, the SCS-CN method was used for gauged and un-gauged watersheds to estimate runoff volume for a shorter and longer period. The large catchment area's annual runoff volume

estimating by considering the average AMC condition and average weighted CN value with SCS-CN annual basis approach. Whereas in the event basis approach, three AMC (I, II, III) conditions were considered while estimating the surface runoff. From Figures 5, 6 and 7 among three methods, the highest values of runoff volume observed in SCS-CN annual basis method followed by runoff coefficient method and

lowest values observed in SCS-CN event basis approach due to its each rainy day rainfall-runoff estimation. Among 15 years of rainfall data from 2004 to 2018, and within three (i.e. SCS-CN annual, event and runoff coefficient) calculation procedures the highest runoff volume observed in the year 2005 and the lowest runoff volume observed in the year 2018 and those were presented in Fig. 8.

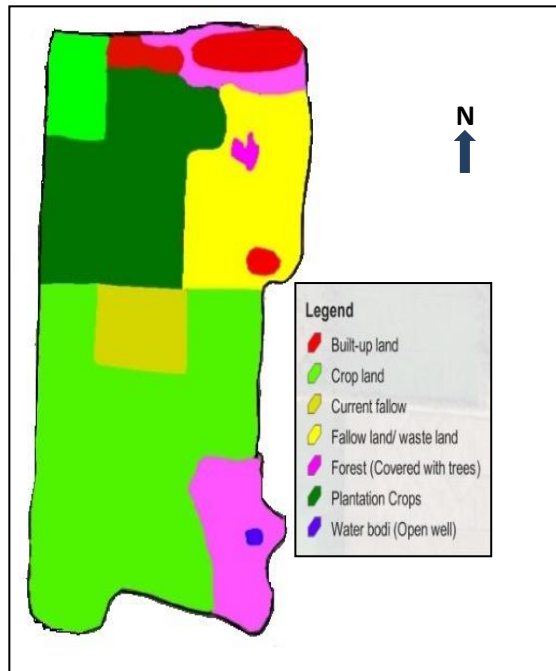


Fig. 3. Land use/land cover map of the study area

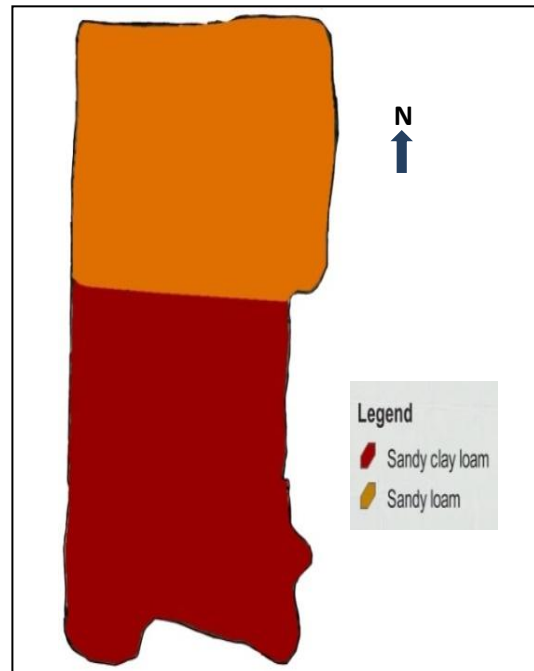


Fig. 4. Soil map of the study area

Table 3. The spatial distribution of land use and land cover and CN values for HSG-C

S. No	Land use/ land cover	Area(m ²)	Percentage (%)	Hydrologic Soil Group(C)
1	Built-Up land	1802	4.01	92
2	Plantation crop	9651	21.52	71
3	Fallow land/ Pasture	5583	12.45	79
4	Long fallow	3356	7.4	82
5	Cropland	18954	42.27	81
6	Water body	64.3	0.14	100
7	Trees/ forest	5422	12.09	70

Table 4. Curve Number and 'S' values for Three Antecedent Moisture Conditions

S. No	Antecedent Moisture Condition	Weighted CN value for the catchment area	Max. retention capacity 'S' (mm)
1	AMC-I	62.958	149.443
2	AMC-II	77.78	72.56
3	AMC-III	89.127	30.98

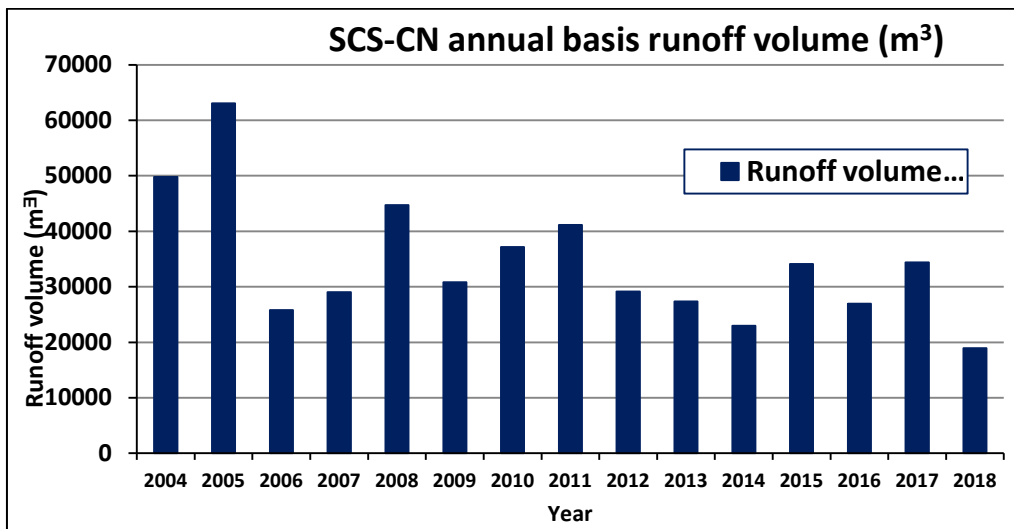


Fig. 5. Runoff volume for 2004-2018 years by SCS-CN method (Event basis)

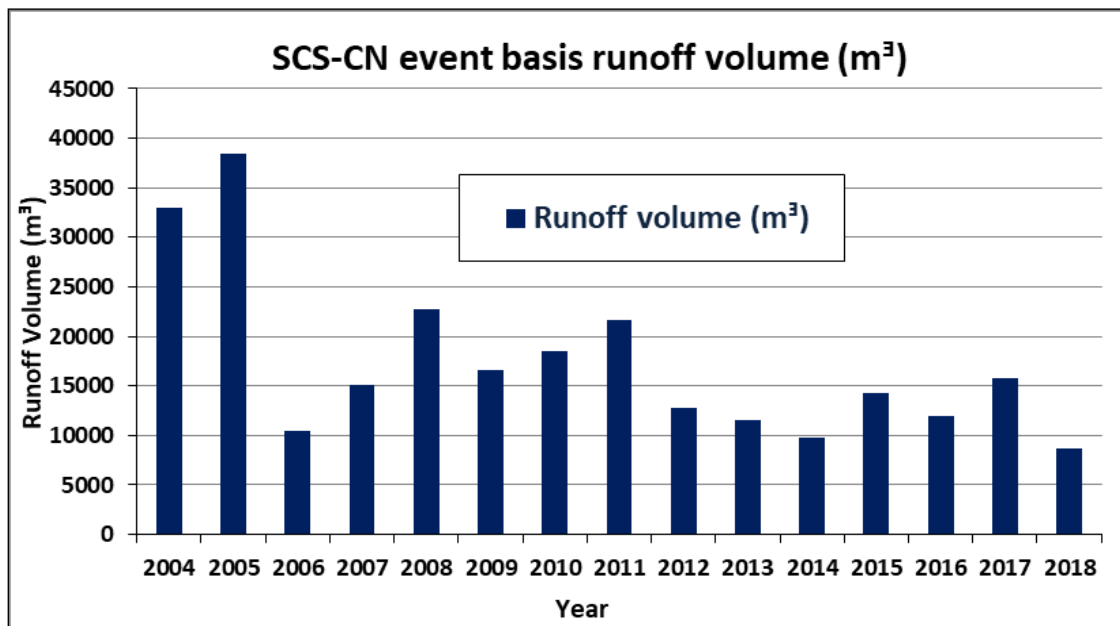


Fig. 6. Runoff volume for 2004-2018 years by SCS-CN method (Event basis)

Table 5. Spatial distribution of runoff coefficient values for different land use/ land cover pattern

S. No	Land use/ land cover	Area(m ²)	Area in percentage(%)	Topography	Runoff Coefficient(C)
1	Built-Up land	1802	4.01	Nearly level	0.95
2	Plantation crop	9651	21.52	Moderate	0.2
3	Fallow land/ Pasture	5583	12.45	Moderate	0.3
4	Waste land /Long fallow	3356	7.4	Gentle	0.68
5	Cropland	18954	42.27	Gentle	0.4
6	Water body	64	0.14	-	1
7	Tree Cultivation/ forest	5422	12.09	Gentle	0.12

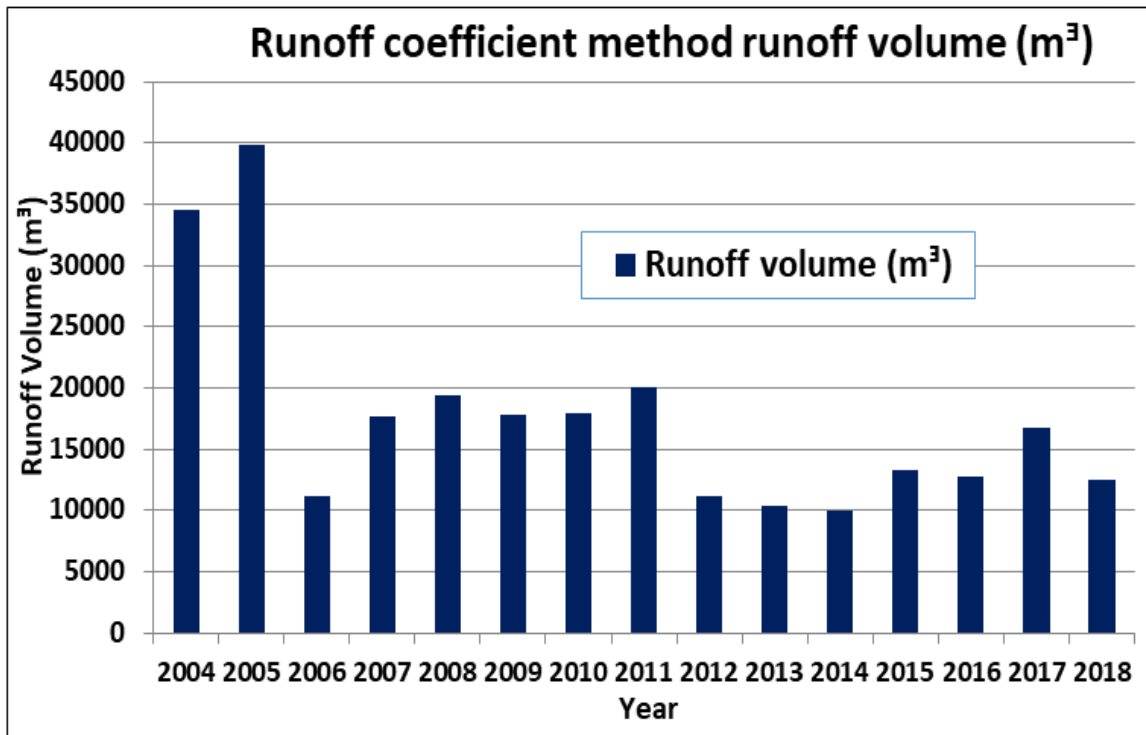


Fig. 7. Runoff volume for 2004-2018 years from runoff coefficient method

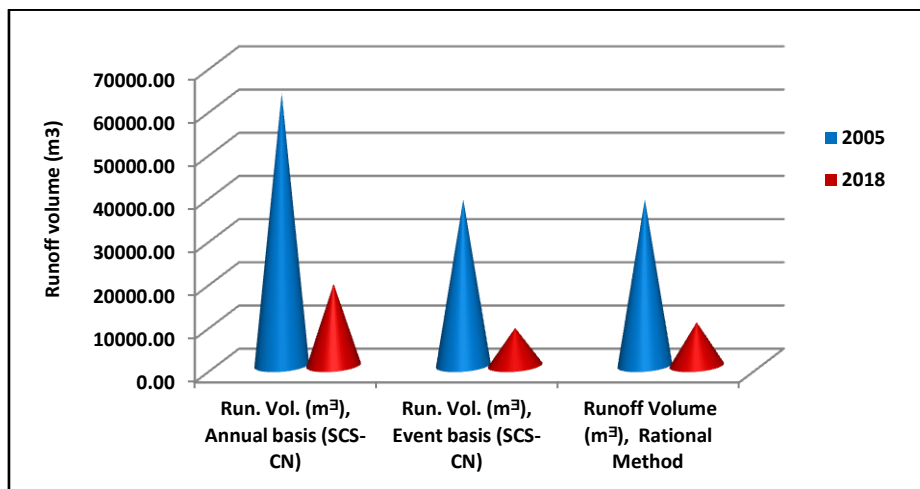


Fig. 8. Comparisons of three different approaches of runoff calculations for 2005 and 2018 years (SCS-CN and runoff coefficient methods)

Fig. 8. shows that, a significant difference was found in runoff volume within the SCS-CN model of the event and annual basis. The maximum runoff volume observed in the year 2005 is 63046.09 m³ in annual basis whereas 38452.36 m³ for event basis. The lowest runoff volume is 18924.87 m³ in the annual method, and 8718.30 m³ in the event approach. Whereas, there is no differences between SCS-CN event approach and runoff coefficient method. Among three

methods, the lowest values were observed in event basis calculation because it calculates each rainy day runoff volume and considered three AMC conditions according to their previous rainfall (considered dry-spells) and subtracted the initial abstraction losses in each rainfall event as per Eqn. [2]. [13,6] [Mishra et. al. (2005)]. Whereas in annual approach the abstraction losses are neglected from the total annual rainfall as a whole i.e. only once in a year [2,3,4].

Therefore, the event basis calculations are considered as accurate and precise technique as compare to the annual basis concept of the SCS-CN method. Hence, the SCS-CN event basis approach is more productive as compared to SCS-CN annual basis calculations and runoff coefficient method.

4. CONCLUSION

From this study, a catchment area of a well 44,823 m² was delineated in the AEC & RI, Kumulur, TNAU. The land use/ land cover map, soil map and slope map of the study area were delineated in GIS interface with ground truth verifications. Three methods i.e. SCS-CN event and annual approaches and modified runoff coefficient models were analyzed by comparing with each other also with realistic data. From all the comparisons, the analysis revealed that, SCS-CN event basis approach giving productive results for precise surface runoff estimation however, it consumes more time. From the results among 15 years of rainfall data (2004-2018), significant amount of surface runoff (maximum 38452.36 m³ in the year 2005 and minimum 8718.30 m³ in the year 2018) contributing from the study area towards the Southeast direction where a open well is located within this catchment. Hence, a suitable water harvesting structure (farm pond) proposed to collect surface runoff to improve the groundwater resources for the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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