

# Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India

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**Abstract** Rainfall and runoff are significant constitute the sources of water for recharge of ground water in the watershed. Rainfall is a major the primary source of recharge into the ground water. Other, substantial sources of recharge include seepage from tanks, canals, streams and functional irrigation. Evaluation of water availability by understanding of rainfall and runoff is essential. Hydro-meteorological and hydrological data are an important role in the assessment of source water accessibility for planning and design of artificial recharge structures. The surface water resources are available in the watershed from runoff from rivers, streams and in surface water bodies. The total area of study is about 179.4 km<sup>2</sup>, of which fall in the Vaniyar sub basin but pappiredipatti is one of the main catchment of area of the basin so considered for runoff model assessment in a watershed is a precondition for the design of artificial recharge structures, reservoir and soil erosion control. Surface water resource planning and management is an important and critical issue in the hard rock regions. Runoff in a watershed affected by geomorphological factors, particularly, land use change affects the runoff volume and the runoff rate significantly. In the Present case study assumed to estimate the surface runoff from a catchment but one of the Curve Number methods is mostly used. The SCS–CN method is useful for calculating volume of runoff from the land surface meets in the river or streams. The proposed construction of artificial recharge structures can be thought of in the given study area. This output is

useful for the watershed development and planning of water resources effectively.

**Keywords** Runoff · Curve number · Soil conservation service · Remote sensing · Watershed

## Introduction

A watershed is that contributes runoff water to a common point. It is a natural physiographic of interrelated parts and functions. There are many methods offered for rainfall runoff modeling. Soil Conservation Services and Curve Number (SCS–CN) technique is one of the primordial and simplest method for rainfall runoff modeling. Several models based on SCS–CN are being referred by different researchers worldwide used such as original SCS–CN, Mishra-Singh (MS) model (2002), Michel model (2005), and Sahu model (2007), commonly on the basis of the SCS–CN concepts, with some modifications are used. SCS–CN method based on remote sensing and GIS data as inputs and median of ordering data for all the three antecedent moisture conditions (AMC I, AMC II and AMC III) is used. Watershed management for conservation and development of natural resources has required the runoff information. Spatial data have made it possible to accurately predict the runoff has led to important increases in its use in hydrological applications. The curve number method (SCS–CN, 1972) is an adaptable and widely used for runoff estimation. This method is important properties of the watershed, specifically soil permeability, land use and antecedent soil water conditions which take into consideration (Bansode et al. 2014). Earlier studies carried out by several researchers such as Kadam et al. (2012), USDA (1986), Mishra et al. (2004), Saravanan and Manjula (2015),

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Vinithra and Yeshodha (2016) and Bhura et al. (2015), In the present case study, the runoff estimation from SCS-CN model modified for India conditions has been used by using conventional database and GIS in the Pappiredipatti watershed.

### Description of the study area

The Pappiredipatti watershed is a part of the Vaniyar sub basin in the Ponnaiyar river located in the center part of Tamil Nadu. The Vaniyar River flows in Dharmapuri district and joins in the river Ponnaiyar through a structural fault. The river originates from the shervaroy hill on the south side of the river. The streams form dendritic to sub dendritic drainage pattern in the study region (Fig. 1) and feeds several small reservoirs and percolation tanks.

### Methods and data collection

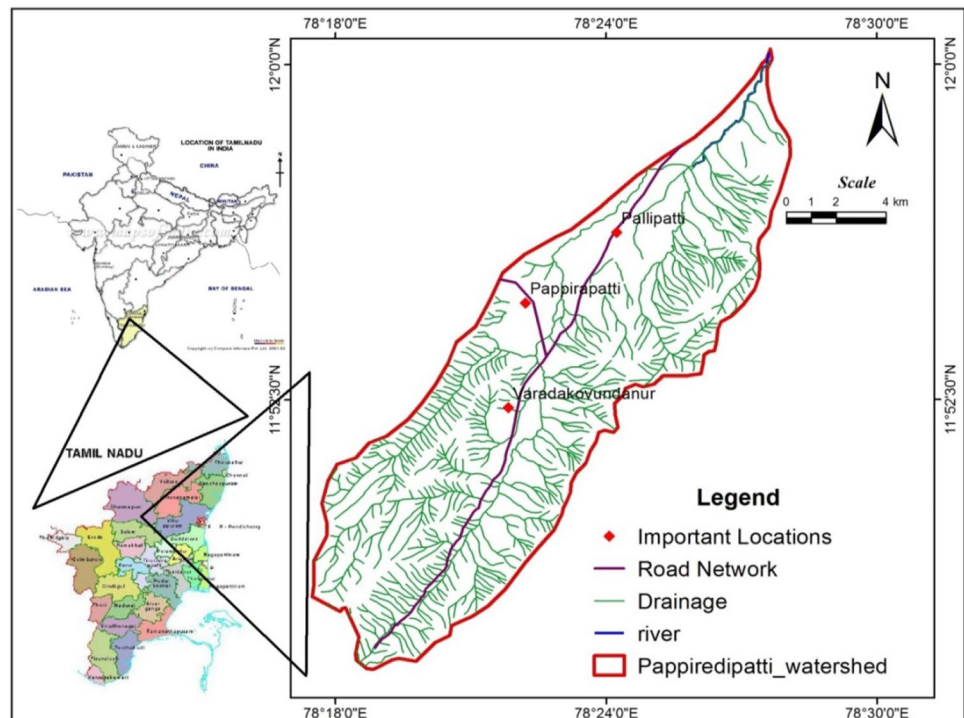
The adopted methodology of the present study is shown in this Fig. 2 which shown the flowchart for the model development of runoff. The various steps are involved in the following manner as follows. The land use and land cover map are obtained from Satellite image LISS III, toposheet were collected from Survey of India. Soil types (black soil, red soil and clay,) Texture, structure, from Survey of india, Digital Elevation model (DEM) derived from USGS Website and Rainfall Data collected 2000–2014 from PWD Dharmapuri. The various steps involved in the following

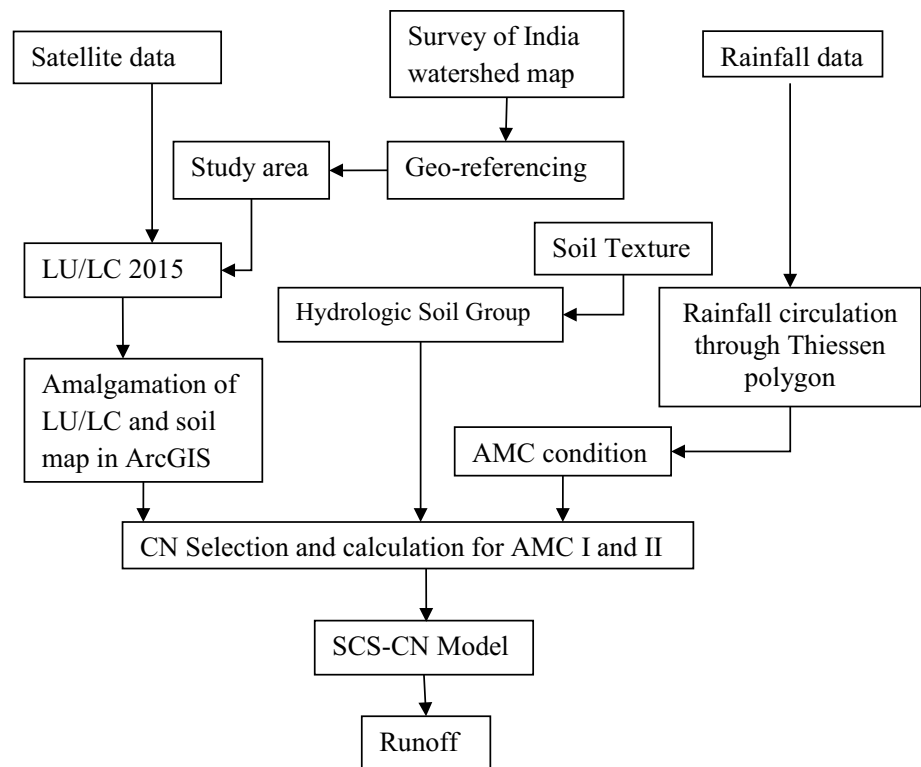
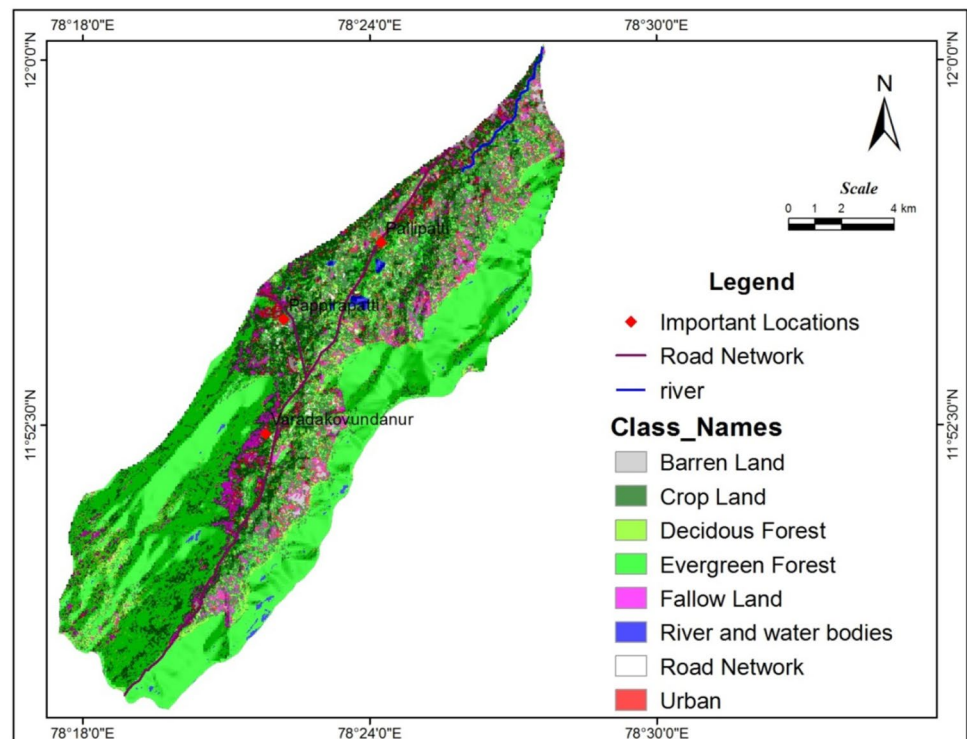
manner as defined the boundary of the watershed and catchment area, for which to find out curve number. After studying satellite image determine the land use and land cover (LU/LC) area of both type of land (Fig. 3). Determine the soil types and convert them into hydrological soil groups like A, B, C & D according to their infiltration capacity of soil. The Superimpose the land use map on the hydrologic group maps obtained each land use soil group with polygon and finally, find out the area of each polygon then assigned a curve number to each unique polygon, based on standard SCS curve number. The curve number for each drainage basin of area-weighting calculated from the land use-soil group polygons within the drainage basin boundaries (Kudoli and Oak 2015).

### SCS-CN Model

The SCS-CN (1985) method has been established in 1954 by the USDA SCS (Rallison 1980), defined in the Soil Conservation Service (SCS) by National Engineering Handbook (NEH-4) Section of Hydrology (Ponce and Hawkins 1996). The Soil conversations Service-Curve Number approach is based on the water balance calculation and two fundamental hypotheses had been proposed (Jun et al. 2015). The first suggestion states about that the ratio of the real quantity of direct runoff to the maximum possible runoff is equal to the ratio of the amount of real infiltration to the quantity of the potential maximum retention. The second hypothesis states about that the amount of

**Fig. 1** Location of Study area map



**Fig. 2** Flow chart of Methodology for Rainfall-Runoff**Fig. 3** Landuse/land cover map of the pappiredipatti watershed

early abstraction is some fraction of the probable maximum retention.

The Soil Conservation Service Curve Number approach is frequently used empirical methods to estimate the direct

runoff from a watershed (USDA 1972) in the study area (Table 3). The infiltration losses are combined with surface storage by the relation of

**Table 1** Soil Conservation Service classification (USDA 1974)

Hydrologic soil (HSG)	Soil textures	Runoff potential	Water transmission	Final infiltration
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 C	Clay soils that swell significantly when wet	High	Low rate	< 1.3

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

where,  $Q$  is the gathered runoff in mm,  $P$  is the rainfall depth in mm,  $Ia$  is the initial abstraction in mm and surface storage, interception, and infiltration prior to runoff in the watershed and empirical relation was developed for the term  $Ia$  and it is given by, The empirical relationship is,

$$Ia = 0.3S \quad (2)$$

For Indian condition the form  $S$  in the potential maximum retention and it is given by,

$$S = \left( \frac{25400}{CN} \right) - 254 \quad (3)$$

where,  $CN$  is known as the curve number which can be taken from SCS handbook of Hydrology (NEH-4), section-4 (USDA 1972). Now the equation can be rewritten as,

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

Significant the value of  $CN$ , the runoff from the watershed was calculated from Eqs. 3 and 4.

The SCS curve number is a purpose of the ability of soils to allow infiltration of water with respect to land use/land cover (LU/LC) and antecedent soil moisture condition (AMC) (Amutha and Porchelvan 2009). Based on U.S soil conservation service (SCS) soils are distributed into four hydrologic soil groups such as group A, B, C & D with respect to rate of runoff probable and final infiltration.

#### Antecedent moisture condition (AMC)

Antecedent Moisture condition (AMC) is considered when little prior rainfall and high when there has been considerable preceding rainfall to the modeled rainfall event. For modeling purposes, AMC II in watershed is essentially an average moisture condition. Runoff curve numbers from LU/LC and soil type taken for the average condition (AMC II) and Dry conditions (AMC I) or wet condition (AMC III), equivalent curve numbers ( $CN$ ) can be computed by using the following Eqs. 5 and 6. The Curve Number values recognized in the case of AMC-II (USDA 1985) (Tables 1,

**Table 2** Group of Antecedent soil moisture classes (AMC)

AMC Group	Soil characteristics	Five day antecedent rainfall in mm	
		Dormant season	Growing season
I	Wet condition	Less than 13	Less than 36
II	Average condition	13–28	36–53
III	Heavy rainfalls	Over 28	Over 53

**Table 3** Hydrological Calculations in the watershed

AMC	CN	S	P>0.3S
I	28.4	640.4	192.12
II	75.4	82.9	24.87
III	87.5	36.3	10.89

2). The following equations are used in the cases of AMC-I and AMC-III (Chow et al. 2002):

$$CN(I) = \frac{CN(II)}{2.281 - 0.0128 \, CN(II)} \quad (5)$$

$$CN(III) = \frac{CN(II)}{0.427 + 0.00573 \, CN(II)} \quad (6)$$

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 conditions.

$$CN_w = \sum CN_i * A_i / A \quad (7)$$

Where  $CN_w$  is the weighted curve number;  $CN_i$  is the curve number from 1 to any number  $N$ ;  $A_i$  is the area with curve number  $CN_i$ ; and  $A$  the total area of the watershed.

To calculate the surface runoff depth, apply the hydrological equations from 3 to 4. These equations depend on the value of rainfall ( $P$ ) and watershed storage ( $S$ ) which Calculated from the adjusted curve number. Thus, before applying Eq. (3) the value of ( $S$ ) should be determined for each antecedent moisture condition (AMC) as shown below.

There are three conditions to hydrologic condition results are summarized in the Table 3.

### Hydrologic soil group (HSG)

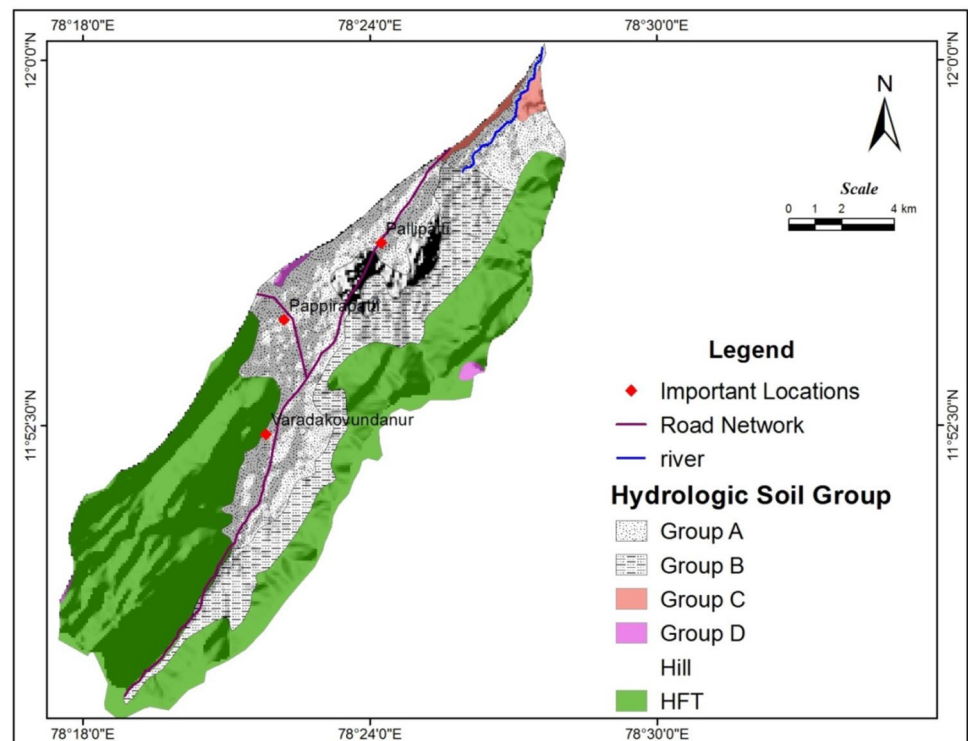
The soil texture map of the study area was traced, scanned and rectified in ArcGIS software by using the registered topographic maps. Different soil textures were digitized up to boundaries and the polygons representing many soils classes were assigned and different colors for recognition (Fig. 4). The hydrologic soil groups (HSG) divided into A, B, C, and D was carefully thought about in the classification of soils in the watershed (Table 4). The soils of group

A indicated low runoff potential, high infiltration rate, the soils of group B indicated moderate infiltration rate, moderately well drained to well drained. The soils of group C pointed to moderately fine to moderately rough textures, moderate rate of water transmission and the soils of group D pointed to slow infiltration and possible high runoff.

### Thiessen Polygon method

Rainfall distribution by The Thiessen polygon method accepts that the estimated values taken on the observed values of the nearby station (Nalder et al. 1998). Near-est neighbor methods are intensively examined by pattern

**Fig. 4** Hydrologic soil group of the pappiredipatti watershed

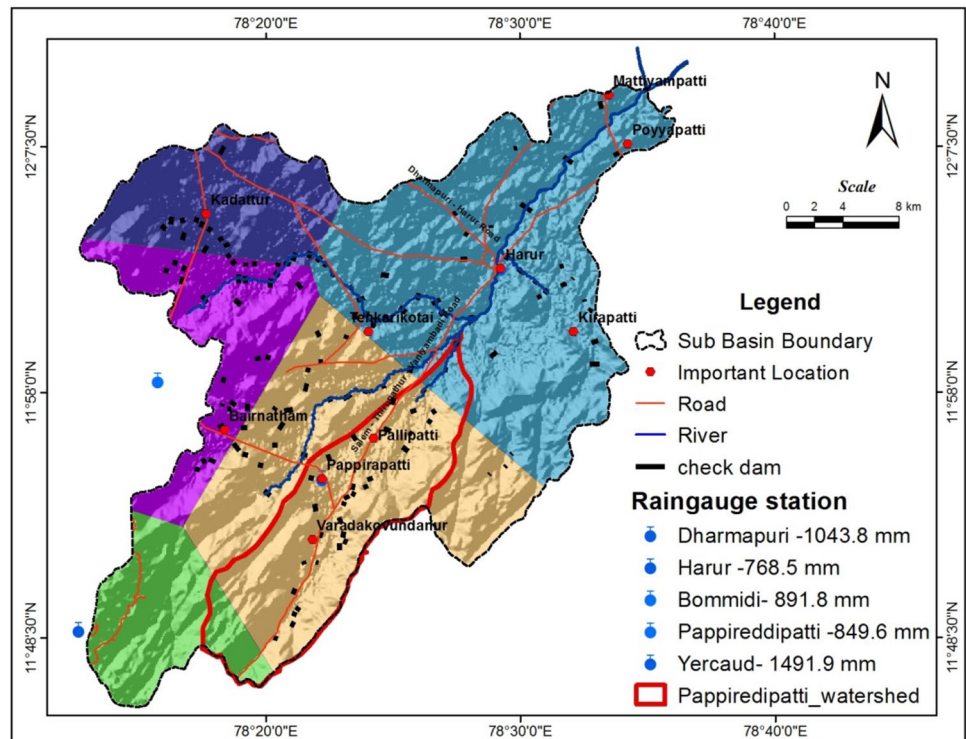


**Table 4** Weighted curve number aimed at Pappiredipatti watershed (AMC Group II)

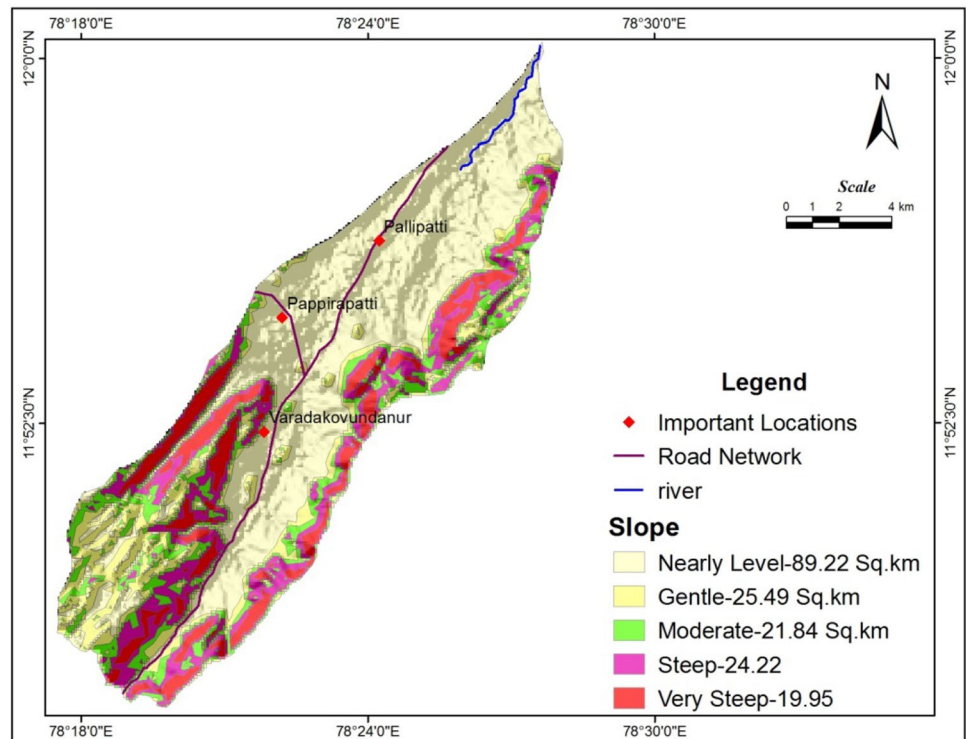
Land use Cover	Soil type (HSG)	An area in km <sup>2</sup>	CN	% Area	% Area * CN	Weighted Curve Number (WCN)
Barren land	B	8	86	4.44	381.84	AMC –I= 28.4 AMC –II= 75.4 AMC –III= 87.5
Cropland	A	30	72	16.68	1200.96	
	B	24	81	13.34	1080.54	
Forest land	B	30	68	16.68	1134.24	
	C	29.51	79	16.5	1303.5	
Fallow land	A	15	74	8.34	617.16	
	B	18	83	10	830	
Water bodies	-	1.9	100	1	100	
Road	D	0.43	91	0.23	20.93	
Built up land	A	10	59	5.55	327.45	
	B	13	74	7.22	534.28	



**Fig. 5** Spatial distribution of Rainfall pattern in this study area



**Fig. 6** Spatial distribution of Slope map



recognition procedures. Despite their inherent simplicity, nearest neighbor algorithms are considered versatile and robust. Although more sophisticated alternative techniques have been developed since their inception, nearest neighbor methods remain very popular (Ly et al.

2013). The application of rain gauge as precipitation input carries lots of uncertainties. The spatial and temporal distribution of rainfall at sub-basin scale, using GIS approaches are found to be very effective in the study area (Fig. 5).

**Table 5** Slope classes of pappiredipatti watershed (IMSD 1995)

Si.No	% Slope	Area in Km <sup>2</sup>	Implication of potential
1	Nearly level	89.22	Low surface runoff
2	Gentle	25.49	Low surface runoff
3	Moderate	21.84	Medium surface runoff
4	Steep	24.22	High surface runoff
5	Very steep	19.95	High surface runoff

Pappiredipatti watershed falls under gentle to moderate slope class (Table 5) (Low to high surface runoff) representative water holding for longer time (Pawar et al. 2008) and thus improving the chance of infiltration and recharge in this study area (Fig. 6). This is appropriate site for artificial recharge structures such as major and minor check dams and percolation tanks beside drainage.

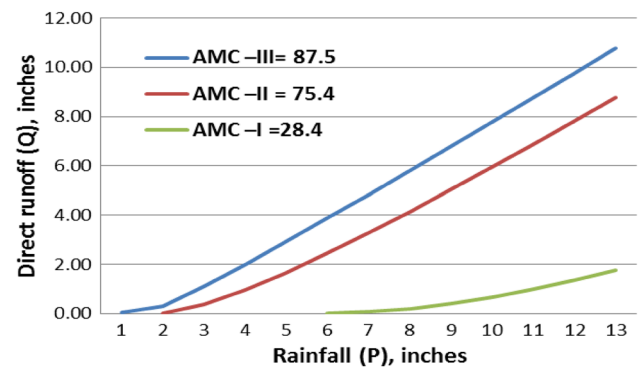
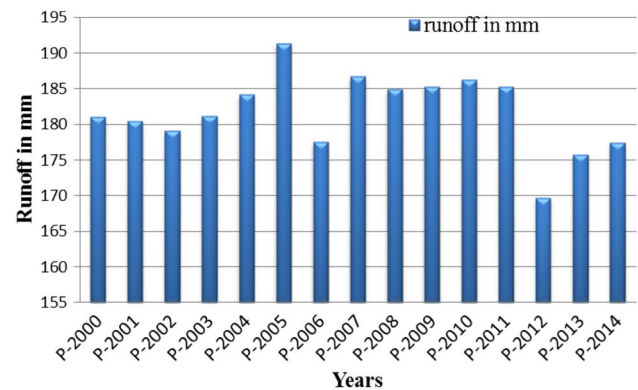
SCS method, as a result of the calculations, it was found that the average annual surface runoff depth for the last fifteen years in pappiredipatti watershed is equal to 2725.96 mm multiple by the area of the watershed ( $A = 179,840,000 \text{ m}^2$ ) gives the total average volume of runoff as (32,682,501 m<sup>3</sup>), which represents 6.6% of the total annual rainfall. The annual rainfall and runoff during 2000–2014 in the study area are shown in Table 6.

## Results and discussion

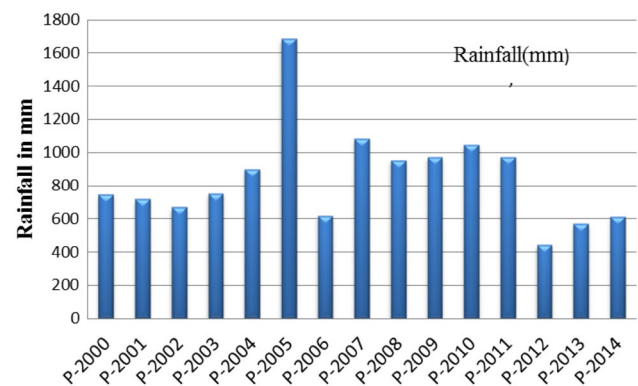
The calculated normal, wet and dry conditions, curve numbers are 85.92, 72.8 and 93.46 in Fig. 7. The runoff varies 169–191 mm (2000–2014) as shown in Fig. 8. The rainfall

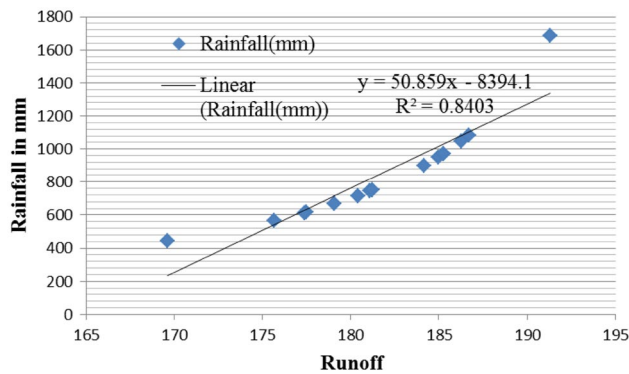
**Table 6** Annual average runoff depth and volume

Years	Rainfall In mm	Runoff In mm	Volume (m <sup>3</sup> ) =Runoff × area
2000	744.9	181.0952	32,568,156
2001	716.4	180.3947	32,442,184
2002	668.1	179.0811	32,205,949
2003	750	181.2153	32,589,755
2004	899.3	184.161	33,119,513
2005	1684.8	191.3213	34,407,216
2006	617.2	177.4919	31,920,137
2007	1082.4	186.7158	33,578,963
2008	950.7	184.9723	33,265,418
2009	971.8	185.2818	33,321,074
2010	1047.1	186.2894	33,502,288
2011	971	185.2703	33,319,006
2012	443.5	169.6139	30,503,369
2013	567.3	175.6806	31,594,391
2014	613.9	177.3805	31,900,101
Average	848.56	181.731	32,682,501

**Fig. 7** Solution of runoff equation**Fig. 8** The runoff varies in pappiredipatti watershed

varies between 410 to 1650 mm in the watershed as shown in Fig. 9. The average annual runoff calculated come to be 181.7 mm and average Runoff volume for fifteen years is 32,682,501 Mm<sup>2</sup>. The rainfall runoff relationship showed in Fig. 10 for pappiredipatti watershed. The rainfall-runoffs are vigorously correlated with a correlation coefficient (r) value being 0.84.

**Fig. 9** The rainfall varies in pappiredipatti watershed



**Fig. 10** Scatter plot between the rainfall and calculated runoff

## Conclusion

Soil Conservation service and Curve Number model have been utilized in the present work by land use map and soil map described in ArcGIS, as input. The monthly rainfall-runoff simulation found good in the watershed. The amount of runoff represents 6.6% of the total annual rainfall. In the present study, the methodology for the tenacity of runoff utilizing GIS and SCS approach could be applied in other vaniyar watersheds for orchestrating of sundry conservation measures. The good soil and water conservation measures need be planned and implemented in the watersheds such as classified as high followed by moderately high for controlling runoff and soil loss. In SCN Curve number method Antecedent moisture condition of the soil plays a very consequential role because the CN number varies according to the soil and that is considered while estimating runoff depth. For a given study area that is pappiredipatti watershed CN number is calculated equals to 75.4 for AMC -I, 28.4 –AMC-II and 87.5 for AMC-III (Fig. 7). In conclusion, Soil Conversations Service –Curve Number approach is efficiently proven as a better method, which consumes less time and facility to handle extensive data set as well as larger environmental area to identify site selection of artificial recharge structures.

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## References

- Amutha R, Porchelvan P (2009) Estimation of surface runoff in Malattar sub-watershed using SCS-CN method. *J Soc Remote Sens* 37(2):291–304
- Bansode A, Patil KA (2014) Estimation of runoff by using SCS curve number method and arc GIS. *Int J Sci Eng Res* 5(7):1283–1287
- Bhura CS et al (2015), Estimation of surface runoff for Ahmedabad urban area using SCS-CN method and GIS, *IJSTE. Int J Sci Technol Eng* 1(11):2349–2784
- Chow VT, Maidment DK, Mays LW (2002) *Applied Hydrology*, McGraw-Hill Book Company, New York, USA
- IMSD (1995) Technical guidelines, integrated mission for sustainable development, national remote sensing center (NRSC) Department of Space, Government of India.
- Jun LI, Changming LIU, Zhonggen WANG, Kang L, (2015), Two universal runoff yield models: SCS versus LCM. *J Geogr Sci* 25(3):311–318. doi:[10.1007/s11442-015-1170-2](https://doi.org/10.1007/s11442-015-1170-2)
- Kadam A et al (2012) Identifying potential rainwater harvesting sites of a semi-arid, Basaltic Region of Western India, using SCS-CN method. *Water Resour Manag* 26:2537–2554. doi:[10.1007/s11269-012-0031-3](https://doi.org/10.1007/s11269-012-0031-3)
- Kudoli AB, Oak RA (2015) Runoff estimation by using GIS based technique and its comparison with different methods—a case study on Sangli Micro Watershed. *Int J Emerg Res Manag Technol* 4(5):2278–9359
- Ly S, Charles C, Degré A (2013) Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modeling at watershed scale. A review. *Biotechnol Agron Soc Environ* 17(2):392–406.
- Mishra SK, Jain MK Singh VP (2004) *Evaluation of the SCS-CN-based model incorporating, antecedent moisture*. *Water Resour Manag* 18:567–589,2004. Kluwer Academic Publishers. Printed in the Netherlands
- Pawar NJ, Pawar JB, Kumar S, Supekar A (2008) Geochemical eccentricity of ground water allied to weathering of basalt from the Deccan volcanic province, India: insinuation on CO2 consumption. *Aqua Geochem* 14:41–71
- Ponce VM, Hawkins RH (1996) Runoff Curve Number: Has It Reached Maturity?. *Journal of Hydrol Eng* 1(1):11–19
- Rallison RE (1980) Origin and Evolution of the SCS Runoff Equation. *Proceeding of the Symposium on Watershed Management* 80 American Society of Civil Engineering Boise ID
- Saravanan S, Manjula R (2015) Geomorphology based semi-distributed approach for modeling rainfall-runoff modeling using GIS. *Aquat Proc* 4:908–916
- USDA (1986) *Urban hydrology for small Watersheds*, TR-55, United States Department of Agriculture, 210-VI-TR-55, 2nd edn June 1986
- USDA (1972) *Soil Conservation Service, National Engineering Handbook. Hydrology Section 4. Chapters 4-10*. Washington, D.C: USDA
- USDA-SCS (1974) *Soil survey of Travis County, Texas*. College Station, Tex.: Texas Agricultural Experiment Station, and Washington, D.C: USDA Soil Conservation Service
- Vinithra R, Yeshodha L (2016) Rainfall–runoff modelling using SCS-CN method: a case study of Krishnagiri District, Tamilnadu. *Int J Sci Res* 5(3):2319–7064