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Rainfall-runoff estimation by SCS-CN method: A case study

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Abstract
When the precipitation rate is greater than infiltration capacity, it results in the surface runoff. The aim of this study was to estimate the runoff depth in a catchment area using Soil Conservation Service Curve Number (SCS-CN) method. This method has been extensively applied in hydrological studies due to its simplicity, computational efficiency, and reasonable accuracy in predicting runoff volumes. The total area of study is about 10 km^2. The SCS-CN method involves the estimation of curve numbers, which represent the soil-water infiltration and runoff potential for different land use and soil conditions. Various factors influencing curve number determination, such as antecedent moisture conditions, land use, soil type, and hydrological region. Estimation of direct rainfall-runoff is always efficient but is not possible for most of the location in desired time. The effect of land use/land cover changes on runoff from watersheds. Rainfall and runoff are important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system.

Keywords: Rainfall-runoff, curve number, land use and hydrological structure

Introduction
Rainfall-runoff estimation plays a crucial role in hydrological studies and water resources management, providing valuable insights into the behavior of watersheds and their response to precipitation events (Among the various methods utilized for rainfall-runoff estimation, the Soil Conservation Service Curve Number (SCS-CN) method has gained widespread recognition and adoption due to its simplicity, efficiency, and applicability across diverse geographical settings (Ankit and Tiwari., 2014) [1].
The SCS-CN method operates on the principle of dividing a watershed into hierologically homogeneous units, where each unit is assigned a Curve Number (CN) representing the land cover, soil type, and land use characteristics. The CN is a dimensionless parameter ranging from 0 to 100, with lower values indicating lower runoff potential and higher values indicating higher runoff potential. By integrating precipitation data with CN values and antecedent moisture conditions, the SCS-CN method facilitates the estimation of direct surface runoff, providing valuable insights into watershed response to rainfall events.

Materials and Methods
Study area
Manchalapur tank system which spreads adjacent to the Manchalapur village proper is located at about 10km away from Raichur city of the Karanatak state of India. The area investigated spreads around 981 ha included its catchment, command and water spreads area. Manchalapur is situated in the North-Eastern dry zone (Zone-2) of Karnataka located at 16° 14’N latitude and 77° 19’E longitude and at an elevation of 380 m above mean sea level. Average rainfall of the area is 875.3 mm. The monthly mean maximum and minimum temperatures of the area were recorded in May and January as 44.34 °C and 10.39 °C respectively. The mean relative humidity varies between 25.92 percent in April and 67.85 percent in the month of August. Plate 1 shows the satellite image of Manchalapur tank system.

Plate 1: Satellite image of the Manchalpur tank as obtained from Google earth

Manchalapur tank system

Soil

The Manchalapur tank system, even though varied with different soil texture across the tank system, the total area could mainly be classified into vertisols (85 percent) and sandy loam soils (15 percent).

Land use pattern

The Manchalpaur tank system mainly consist of agriculture land including command area which consistute about 80 percent of total catchment area, waste land, social forest, rock out crop and water spread area as shown in Table 1.

Table 1: Distribution of area under different land use in Manchalapur tank system

Sl. No	Land use/ land cover	Catchment area (ha)
1	Agriculture land	786
2	Waste land	100
3	Social forest land	25
4	Rock out crop	35
5	Water spread area	35
	Total	981

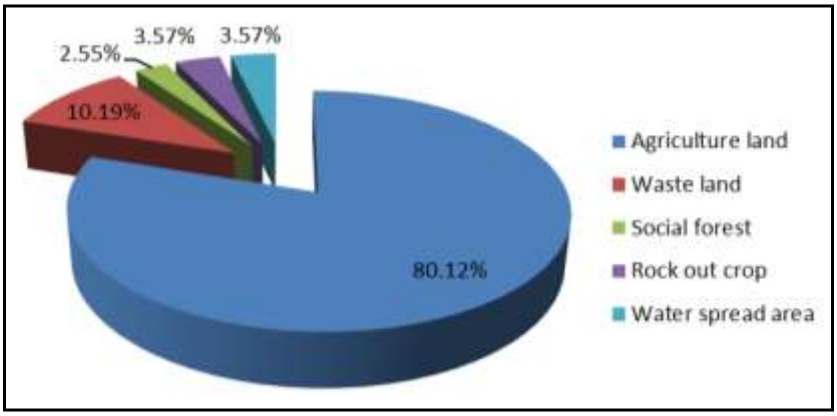

Fig 2: Land use pattern (in percentage) of the Manchalapur tank system and command area

Rainfall distribution

The surroundings of the Manchalapur tank system received relatively very low and erratic precipitation with an average annual rainfall of 713 mm. The rainfall data was obtained from the Main Agricultural Research Station (MARS) of University of Agricultural Sciences, Raichur for calculating the runoff entering the Manchalapur tank. The details of the monthly rainfall recorded from 2008 to 2018 are given in Table 2. The Runoff resulting from rainfall was estimated by using the SCS curve number method according to USDA (1972) [5].

Table 2: Mean monthly rainfall data of the study area during the period 2008 -2018

Month/Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
January	0.0	0.0	36.6	0.0	0.0	0.0	0.0	10.0	1.4	0.0	0.0
February	18.0	0.0	0.0	0.0	0.0	28.6	0.0	0.0	0.0	0.0	1.0
March	102.0	0.0	0.0	0.0	0.0	0.0	51.4	24.9	0.0	30.0	0.0
April	0.0	0.0	2.4	12.0	17.0	17.6	19.4	114.2	0.0	7.2	0.5
May	14.0	41.8	38.0	9.8	2.0	77.0	93.0	18.7	87.2	8.1	5.5
June	12.0	122.4	70.0	109.2	57.9	40.0	48.4	38.7	194.1	159.7	42.0
July	79.4	9.0	265.0	89.0	100.5	116.4	123.1	42.0	143.2	29.7	44.5
August	198.3	123.5	126.0	123.2	32.0	68.1	372.9	51.4	78.0	197.6	58.0
September	37.8	209.2	59.0	9.9	34.0	284.1	102.7	316.6	292.5	248.4	52.0
October	109.8	362.6	22.6	0.0	44.6	96.9	50.6	65.4	39.2	193.5	12.0
November	38.6	67.8	18.0	0.0	54.2	1.2	12.0	2.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0	0	1.8	2.2	8.2	0.0	0.0
Annual RF	609.9	936.3	637.6	353.1	342.2	729.9	875.3	686.1	843.8	874.2	215.5

Estimation of runoff from the catchment resulting from rainfall

Surface runoff is mainly controlled by the amount of rainfall, initial abstraction and moisture retention of the soil. The SCS curve number method is based on the water balance equation and two fundamental hypotheses which are stated as, ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration, and the amount of initial abstraction is some fraction of the potential infiltration (Athira., 2017) [2].

$$\frac{F}{S} = \frac{Q}{P\text{-}Ia} \quad (3.2)$$

$$F=(P\text{-}I_a)\text{–}Q \quad (3.3)$$

Substituting eqn. (3.3) into (3.2) and solving

$$Q=\frac{(p\text{-}I_a)}{(P\text{-}I_a)+S} \quad (3.4)$$

Where,

Q = Actual runoff (mm),

P = Rainfall (mm),

Ia = initial abstraction, which represents all the losses before the runoff begins and is given by the empirical equation;

I_a=0.2S (3.5)

Substituting eqn. (3.5) in eqn. (3.4); the eqn. (3.4) becomes

$$Q=\frac{(P\text{-}0.2S)^2}{P+0.8S}$$

S = the potential infiltration after the runoff begins given by following equation;

$$S=\frac{25400}{CN} - 254 \quad (3.6)$$

Where CN is Curve Number and estimated using antecedent moisture condition and hydrological soil group

$$CN=\frac{\Sigma\,(CN_i \times A_i)}{A} \quad (3.7)$$

Where,

CN = Weighted curve number

CN_i = Curve number from 1 to any number N.

A_i = Area with curve number CN_i (ha)

Weighted curve number for different land cover/ land use were calculated and tabulated in the table 5.

Results and Discussion

The estimated runoff quantity as a result of rainfall analyzed during the period 2008 - 2018 was tabulated in the table 4. The maximum and minimum rainfall received were 936.30 mm in 2009 and 215.50 mm in 2018 and corresponding runoff estimated were 3.11 million cum and 0.004 million cum respectively. The annual runoff depths (mm) were estimated from rainfall (mm) using SCS curve number method are illustrate in Fig. 3. The maximum runoff depth 317.94 mm observed for the rainfall of 936.30 mm during the year 2009. Table 4. shows the weighted CN and AMC employed in the estimation of runoff.

Table 3: Weighted CN for AMC I, II & III of Manchalapur tank system

Sl. No	Land use/ land cover	Soil type	CN	Area (ha)	Area (%)	Weighted CN
1	Agriculture land	B	81	786	80.12	AMC I= 83.10 AMC II =68.18 AMC III= 91.96
2	Waste land	B	80	100	10.19	
3	Social forest	C	77	25	2.55	
4	Rock outcrop	C	77	35	3.57	
5	Water spread	-	100	35	3.57	
	Total area			981		

Table 4: Comparison of quantity of runoff received by the tank system for the past decade (2008-2018)

Year	Annual rainfall (mm)	Annual runoff depth (mm)	Annual runoff volume (Million m^3)
2008	609.9	30.53	0.299
2009	936.30	317.94	3.11
2010	637.60	14.20	0.13
2011	353.10	26.32	0.25
2012	342.20	3.57	0.03
2013	729.90	56.53	0.55
2014	875.30	208.41	2.04
2015	686.10	115.92	1.13
2016	843.80	116.89	1.14
2017	874.20	92.53	0.90
2018	215.50	0.50	0.004

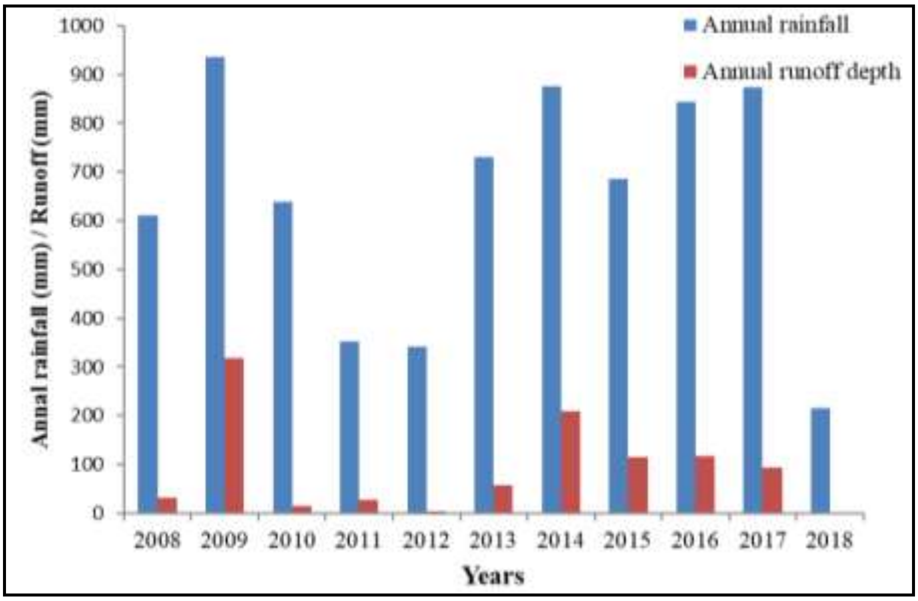

Fig 3: Annual rainfall (mm) versus annual runoff (mm) from Manchalpur tank catchment from 2008 - 2018

Conclusion

1. The analysis of rainfall data from 2008 to 2018, as detailed in Table 4, offers insights into runoff quantities over the period.
2. Maximum and minimum rainfall occurrences in 2009 and 2018, respectively, led to notable differences in estimated runoff volumes.
3. These findings underscore the significant variability in runoff generation, highlighting the impact of precipitation patterns on hydrological processes.
4. Annual runoff depths, derived using the SCS curve number method and depicted in Figure 3, show distinct variations across the study period.
5. The observed maximum runoff depth in 2009 for substantial rainfall emphasizes the importance of accurate modeling techniques in predicting runoff behavior.
6. Table 3 provides crucial data on weighted curve number (CN) and antecedent moisture condition (AMC) values used in the runoff estimation process.
7. These comprehensive findings enhance understanding of the complex relationship between rainfall characteristics and runoff generation.
8. Insights gained from this study can inform hydrological modeling and water resource management strategies for improved decision-making.

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