Applied Ecology and Environmental Sciences, 2020, Vol. 8, No. 6, 340-350
Available online at http://pubs.sciepub.com/aees/8/6/3
Published by Science and Education Publishing
DOI:10.12691/aees-8-6-3

Estimation of Surface Runoff in an Ungauged Basin Using SCS-CN Method, A Case Study of Manair River Basin in Telangana, India

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Received July 16, 2020; Revised August 18, 2020; Accepted August 27, 2020

Abstract The present research work was carried out for estimation of surface runoff in an ungauged basin by SCS-CN curve method. Satellite Images, digital elevation model data, hydrological Soil Data and precipitation data combined with Geo spatial technologies was used for land use/land cover classification, drainage extraction, basin delineation and for the surface runoff estimation of the study area. The study area Manair basin is located under 4 districts Karimnagar, Kamareddy, Medak and Rajanna-Siricilla districts of Telangana State, Southern India. Maniar River is one of the major tributary to the Godavari River. The Manair Basin is further divided into three sub basins in which three dams named Upper Maniar dam, Mid Manair dam and Lower Manair dam are there across the Manair river basin. In the present study the surface runoff estimation is computed for the entire Manair basin. The total drainage area of basin is 6668.212 sq. km and morphometric analysis shows sub-dendritric and dendritic pattern. The Maniar basin is in Elongated shape which indicates heavier flow for the long duration. The runoff estimation by SCS-CN curve method is determined by integrating land Use/land cover classification with antecedent moisture condition and hydrological soil groups. The study area receives the good rainfall but most of it is lost by surface runoff due to overland flow and Clay soil texture present in the study area. It was perceived from the results that overall increase in runoff is directly proportional to precipitation in the study area. The daily precipitation data from 11 weather stations which are present in the study area have been collected during the years 2010 - 2018 and were used to estimate the daily runoff from the basin. Daily and annual runoff has been calculated from the monthly rainfall data for the years of 2010 to 2018 in the basin.

Keywords: *Remote Sensing and GIS SCS-CN, Rainfall-Runoff, Land use/ Land cover, Basin*

Cite This Article: Abdul Moid Mohammed, Vijaya Lakshmi Thatiparthi, Kesava Rao Pyla, and Abhilash Maryada, "Estimation of Surface Runoff in an Ungauged Basin Using SCS-CN Method, A Case Study of Manair River Basin in Telangana, India." *Applied Ecology and Environmental Sciences*, vol. 8, no. 6 (2020): 340-350. doi: 10.12691/aees-8-6-3.

1. Introduction

The surface Runoff is one of the vital hydrologic variables used for effective water resources management and planning. Estimating surface runoff is a very complex process as it is nonlinear, time-varying and spatially distributed.it is estimated by determining the gradient, soil type, permeability and land use.

Surface runoff is a larger for areas with low infiltration (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land) with respect to the precipitation.

The importance of estimating surface runoff is not only to know the hydrological processes of the area but also to determine flooding areas during storms and also to build flood control channel where ever there is possibility of flash flood.

There are many methods for rainfall runoff Modelling like Soil water Analysis tool(SWAT), MIKE 11, HEC-RAS etc., among that SCS-CN curve is the simplest method for estimating runoff in a basin after rainfall event. It has been developed by Soil Conservation Service (SCS-1985), United States Department of Agriculture (USDA). The surface runoff estimation by SCS-CN curve method is determined by integrating land Use/land cover classification with antecedent moisture condition and hydrological soil groups. The SCS-CN method is adaptable in any study area and used for runoff estimation in ungauged basins. In the present case study, the SCS-CN method has been modified according to the Indian conditions with the help of remote sensing data and GIS techniques.

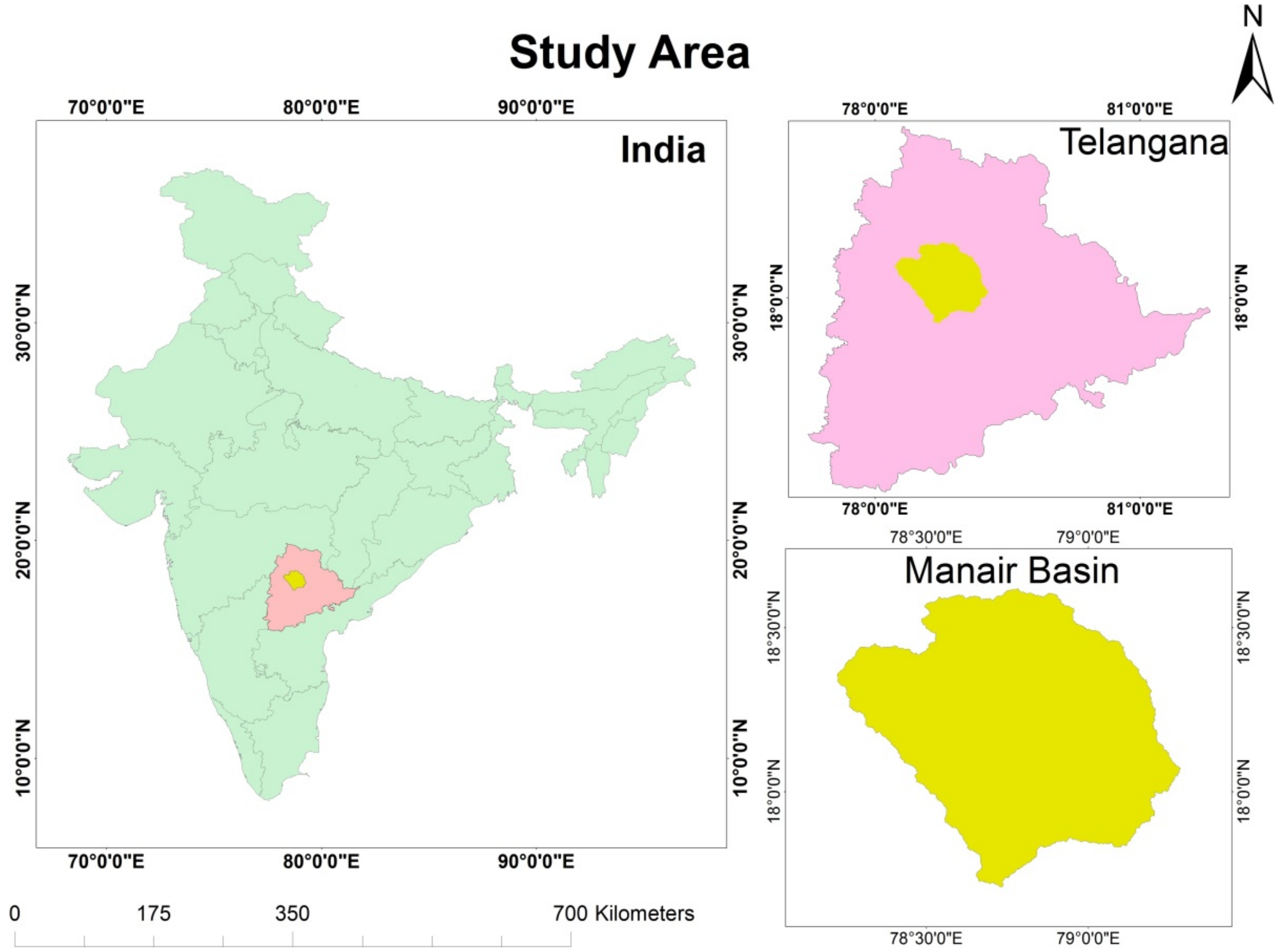

Figure 1. Location Map of Manair Basin

2. Study Area

The study area Manair basin lies between 17.70°N to 18.62°N latitude and 78.22°E to 79.28°E longitude (Figure 1). The total geographical area of the basin is 6668.212 sq. km. The streams in the study area form dendritic to sub-dendritic drainage pattern and feeds through several small reservoirs and percolation tanks. Manair River is the major tributary for the Godavari River.

Manair basin experiences southwestern monsoon rains in June-September with an annual rainfall of 600 mm. May is the hottest month with a maxi- mum temperature of 44°C and minimum temperature 27°C in the month of December. The average annual rainfall is 907 mm.

3. Materials and methods

The Following Data sets were used for the present study.

The flowchart of the adopted methodology for the present study is shown in the Figure 2.

The Sentinel satellite data of 10 m resolution and Survey of India toposheets were Geo-Referenced with reference to Ground control points and mosaics of toposheets were done in the GIS software.

Table 1. Data sets used for the present study

Si No	Data Set	Data Set Source
1	Sentinel satellite data 10 m resolution	USGS Earth Explorer portal
2	SRTM Digital Elevation Model 30m resolution	USGS Earth Explorer portal
3	Survey of India toposheets of Nos E44G3, E44G6, E44G7, E44G8, E44G10, 6 E44G11, E44G12, E44G14, E44G15, E44G16 ,E44M9, E44M10, E44M13, E44H2, E44H3, E44H4 ,E44H8 & E44N1	Open Series map from Survey of India Nakshe portal
4	Soil Map	Regional Agricultural Department, Telangana
5	Rainfall data	Weather stations installed by planning department of Government of Telangana

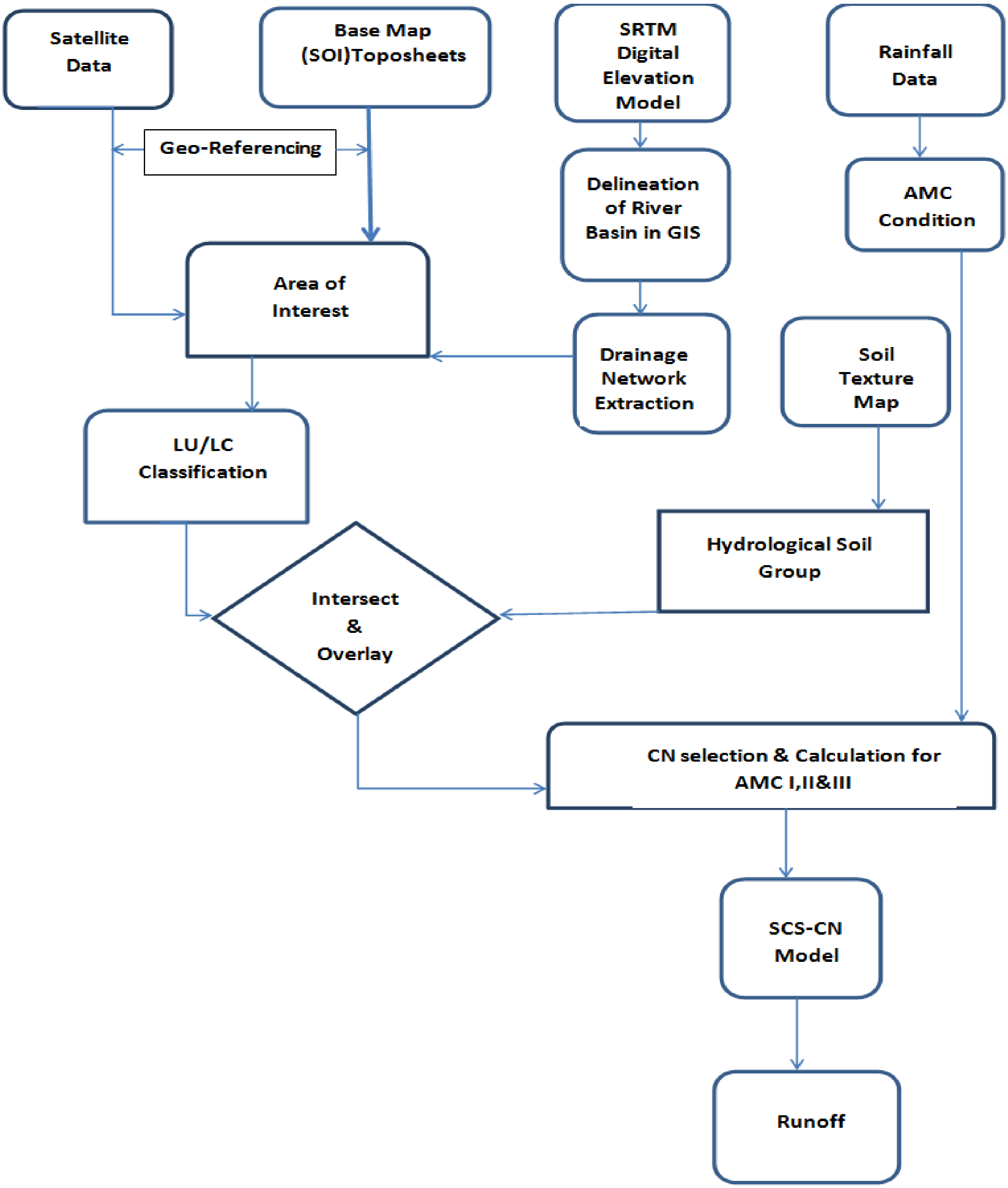

Figure 2. Flow Chart of the Methodology

Maniar river basin area and stream network was delineated and stream order was determined by using SRTM Digital Elevation Model data of 30m resolution with the help of spatial Analyst tool as shown in Figure 3 and with respect to the delineated basin the area of interest is extracted from the Satellite image and toposheets in the GIS software for generating land use and land cover map of the study area as shown in Figure 4.

Soil texture map of the area from the regional State Agricultural Department of Telangana State is used as a reference in identifying different soil texture classes. Depending upon the soil types and their infiltration abilities the hydrologic soil groups A, B, C and D were determined and then hydrologic soil map was then generated Figure 5.

The Superimpose of Land use map on hydrologic soil map have been done to obtain each land use soil group polygon and area of each polygon was found and then curve number was assigned based on the standards of SCS curve number method as shown in the Table 2.

The rainfall data was collected during the years 2010 to 2018 from the weather stations installed in the study area and by using the rainfall data the antecedent soil moisture condition of the study area was determined as shown in the Table 3.

The curve number for each drainage basin of area-weighting calculated from the land use-soil group polygons within the drainage basin boundaries

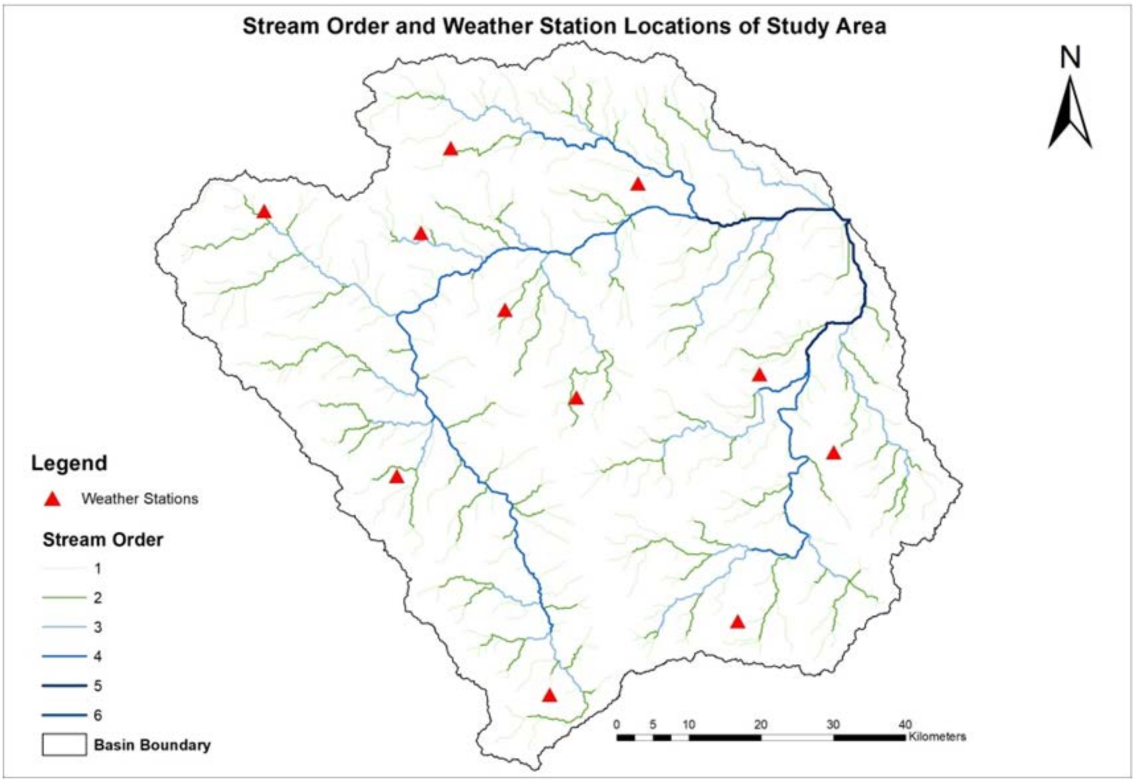

Figure 3. Map showing Stream order of basin and Weather station locations

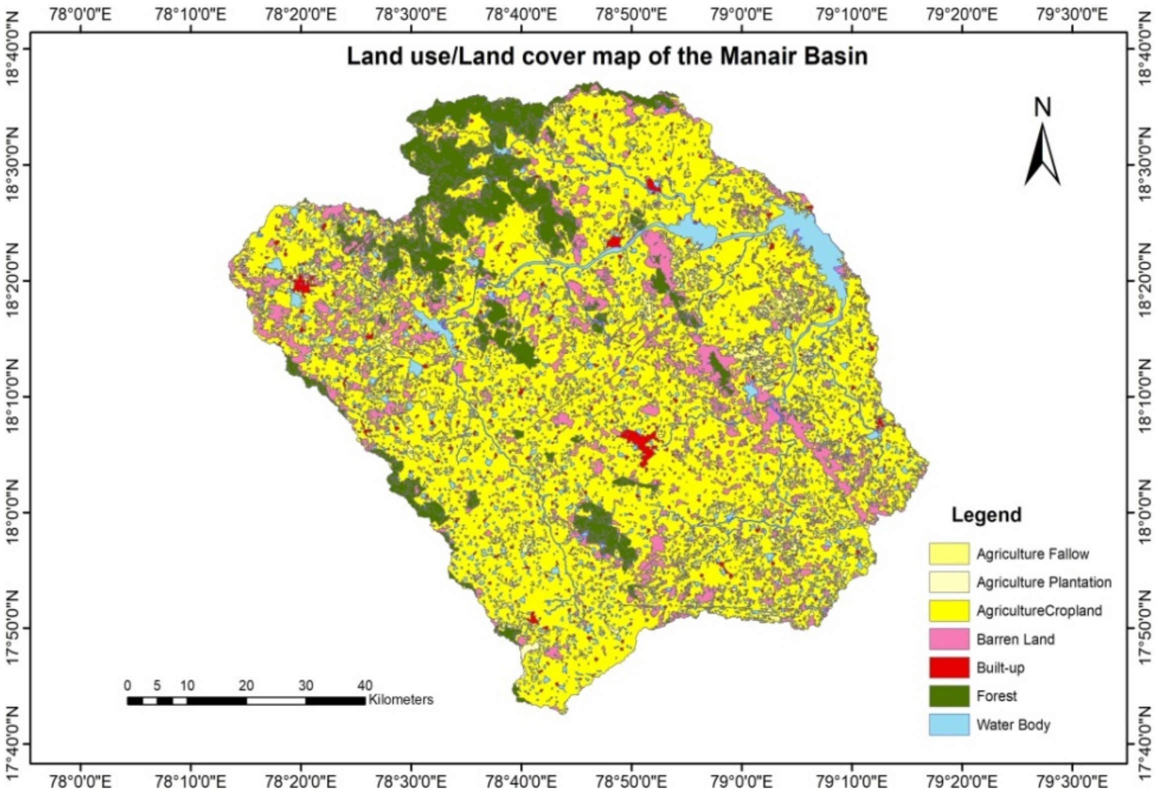

Figure 4. Land use/Land cover map of the Manair Basin

4. SCS-CN Model

The SCS-CN model was developed by the USDA SCS (1974) and it is mostly used as empirical method to estimate direct runoff of the watershed.

The Soil conversations Service-Curve Number method is centered on the water balance calculation.

Two fundamental hypotheses had been proposed [19]. The first suggestion states about that the ratio of the amount of direct runoff to the maximum possible runoff is equal to the ratio of the total of infiltration to the capacity of the potential maximum retention. The second hypothesis states about that the amount of early abstraction is some fraction of the probable maximum retention.

Table 2. Soil Conservation Service classification (USDA1974)

Hydrologic soil (HSG)	Type of soil	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 D	Clay soils that swell significantly when wet	High	Low rate	< 1.3

The infiltration losses are combined with surface storage by the relation of

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

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

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

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

Where CN is known as the curve number. Hence, the equation can be rewritten as,

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

After getting the significant value of CN, the Runoff of the basin was calculated from Eq.s 3 & 4.

In SCS curve number runoff is estimated by the ability of soils to allow infiltration of water with respect to land use/land cover and antecedent soil moisture condition (AMC) of the watershed. Based upon the U.S. soil conservation service, soils are divided into four soil groups namely A, B, C & D according to their rate of runoff potential and final infiltration rate of the soils as shown in Figure 5.

5. Hydrological Soil Group (HSG)

The Soil map was developed from the data of Regional Agricultural Department of Telangana . Soil texture refers to relative proportion of various soil separates in a soil material and is related to soil-water inter relationship. Clay content present in the soil is considered for determining the soil group.

The Soil textures in the study area were digitized and depending upon the soil texture and infiltration ability the soil groups (Table 2) were assigned to the soils as A, B, C and D in the as shown in Figure 4.

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

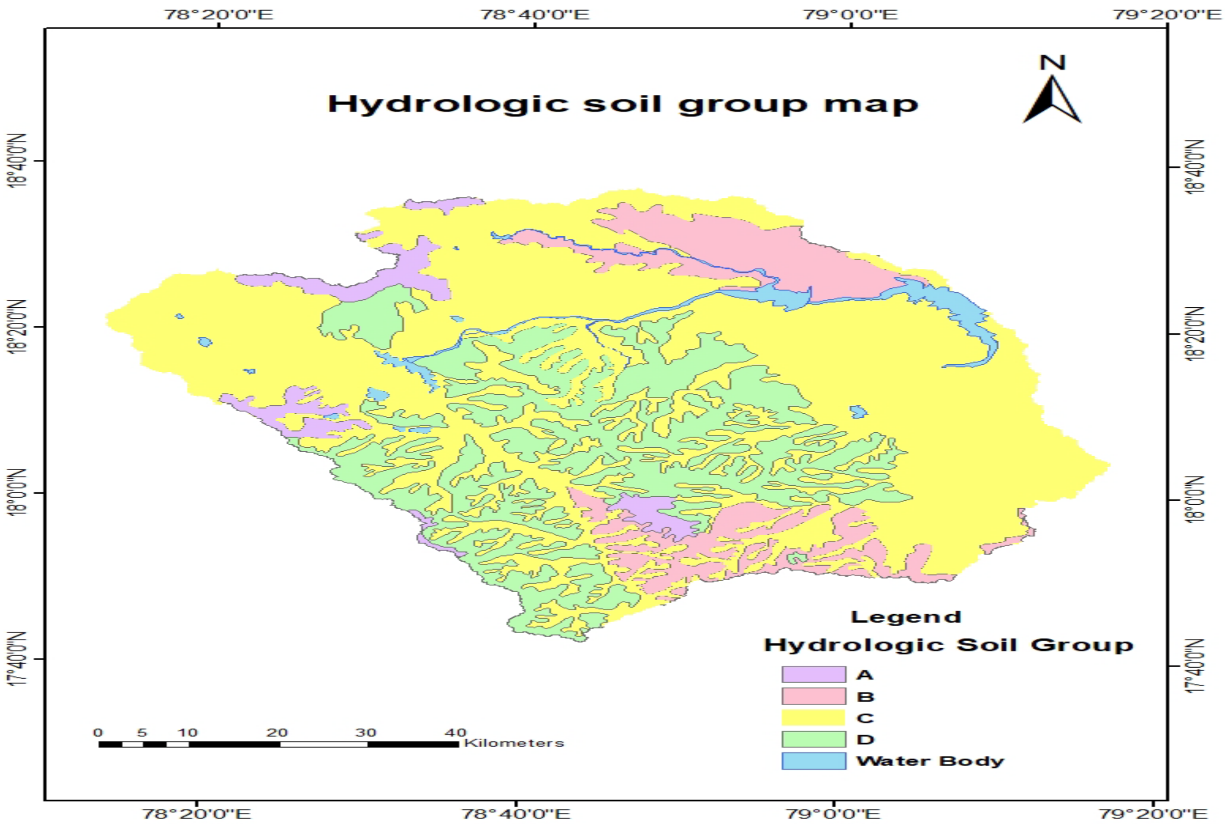

Figure 5. Hydrologic soil group map of the study area

6. Antecedent Soil Moisture Condition

The soil moisture condition in the basin before the storm event occurs is another important factor influencing the surface runoff. In the Curve Number Method, the soil moisture condition is classified into three Antecedent Moisture Condition (AMC) Classes:

AMC I: The soils in the basin are dry,

AMC II: Average condition.

AMC III: The soils in the basin are practically saturated from antecedent rainfalls (i.e. the soil moisture content is at maximum field capacity).

The above classes were based on the 5-day antecedent rainfall (i.e. the accumulated total rainfall preceding the runoff under consideration). In SCS method, a distinction was made between the dormant and the growing season to allow for differences in transpiration as shown in Table 3.

The following equations are used in the cases of AMC-I and AMC-III [20]:

Table 3. 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

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

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

Where, CN (II) is the curve number for normal condition, CN (I) is the curve number for dry condition, CN (III) is the curve number for wet conditions.

$$CNw = \sum CNi * \frac{A_i}{A} \quad (7)$$

Where is the weighted curve number; is the curve number from 1 to any number N; is the area with curve number; and

A is the total area of the watershed.

7. Integration for Estimating Surface Runoff Potential

The soil group and land use/ Land cover layers were overlaid and intersected on one another in GIS software. For Estimation of the curve number HSG and the LULC classes namely Agricultural Crop Land, fallow, plantation, built-up forest land and barren lands were taken into consideration in order to determine the curve number values. Curve numbers are allotted for each land use-soil group combination of the classes (Table 4).

The result obtained from this intersection was used to compute total area weighted curve number of the study area to calculate the AMC II as shown in Table 5.

Table 4. Distribution of land use with corresponding CN and HSG

S.NO	Land use	Soil type	Area in Km2	CN	% Area	% Area Weighted Curve * CN	Weighted Curve Number (WCN)
1	Agricultural Crop Land	A	1.69	67	1.23	82.08	AMC - I = 71.00 AMC - II = 84.50 AMC - III= 92.85
		B	582.79	78	8.74	681.71	
		C	2561.42	85	38.41	3265.05	
		D	1061.43	89	15.92	1416.68	
2	Agricultural Fallow Land	A	14.17	76	0.21	16.15	
		B	57.62	85	0.86	73.45	
		C	334.37	90	1.32	118.93	
		D	88.12	93	5.01	466.34	
3	Agricultural Plantation	A	0.74	65	0.01	0.72	
		B	1.8	73	0.03	1.97	
		C	9.39	79	0.14	11.12	
		D	8.31	81	0.12	10.09	
4	Barren Land	A	35.717	68	0.54	36.42	
		B	63.26	80	0.95	75.89	
		C	153.9	85	2.31	196.18	
		D	447.425	88	6.71	590.46	
5	Built up	A	1.9	77	0.03	2.19	
		B	14.99	85	0.22	19.11	
		C	83.77	90	0.46	41.39	
		D	30.67	92	1.26	115.58	
6	Forest Land	A	122.05	25	1.83	45.76	
		B	11.19	55	0.17	9.23	
		C	366.87	70	1.70	119.23	
		D	113.58	77	5.50	423.64	
7	Water bodies		421.04	100	6.31	631.41	
8	Total		6668.212			8450.80	

Table 5. Hydrological Calculations in the Basin

AMC	CN	S	P>0.3S
I	71	103.74	31.12
II	84.5	46.59	13.97
III	92.85	19.55	5.86

8. Results & Discussions

The present study area basin has land use/ land cover of about 64% area is of cropland, 7% area is of fallow land, 9% extent covers forest land, and remaining 20% of the area is occupied by others such as Built-up, water body, scrub land, hills and tanks. Forests play vital role in direct runoff in the watershed.

The soil type 'C' of soil group is predominately covered over 52% of the area which mainly has agriculture land which has moderate water transmission rate. The soil type 'D' of soil group has 26% cover of the total area which indicates slow infiltration and possible high runoff. The remaining 22% of the area comes under Group 'A' and Group 'B' Soils which have low runoff potential.

The calculated weighted CN values are 84.5 (CNII), 71(CN-I), and 92.85 (CN-III) for corresponding AMC-II, AMC-I, and AMC-III, respectively. Based on the precipitation data and weighted Curve numbers daily runoff for the years 2010 to 2018 was estimated for each storm event.it can be observed that precipitation is more during the south-west monsoon (June to September).

The precipitation varies between 523.1 to 1481 mm in the basin. Runoff varies 50.32mm-472.85 mm (2000-2018).

The average annual runoff calculated come to be 893.45 mm and average Runoff volume for Nine years is 11,89,116.90 Mm^2.

It is observed that moderately less runoff due to presence of more vegetation in this area i.e. 20% of the total rainfall occurred in last 9 years in the area. Most of the precipitation during cyclonic storms results in maximum flows in the streams. The daily rainfall and runoff and annual runoff during 2010-2018 in the study area are shown in Table 6 & Table 7.

Table 6. Daily runoff observed for different storm events during 2010-2018 from Maniar basin

Date	Rainfall in mm	AMC	Runoff in mm
30-06-2010	134.2	I	59.26
04-07-2010	5.4	III	0.11
10-07-2010	18.2	II	1.42
19-07-2010	41.4	I	3.43
22-07-2010	16.2	II	0.89
23-07-2010	27.4	III	12.82
25-07-2010	17.2	II	1.14
28-07-2010	11.2	II	0.07
04-08-2010	24.4	I	0.12
05-08-2010	25.2	I	0.18
11-08-2010	51.4	I	6.99
14-08-2010	20.2	III	7.40
20-08-2010	37.2	I	2.25
23-08-2010	51.2	II	19.83
28-08-2010	14.3	III	3.60
29-08-2010	31.2	I	0.96
02-09-2010	21.4	II	2.49
03-09-2010	46.6	II	16.57
05-09-2010	8.4	III	0.84
06-09-2010	29.4	I	14.42
25-09-2010	56.2	I	9.03
02-10-2010	35.2	I	1.77
20-10-2010	28.2	I	0.50
21-10-2010	23.4	II	3.27
22-10-2010	11.3	III	2.03
23-10-2010	21.3	III	8.18
11-07-2011	24.4	I	0.12
12-07-2011	31.2	I	6.99
14-07-2011	5.2	I	0.08
18-07-2011	30.4	III	0.82
19-07-2011	30.4	III	0.82
20-07-2011	40.2	III	23.58
29-07-2011	43.2	III	3.99
01-08-2011	10.2	I	0.02
02-08-2011	15.2	I	4.13
25-08-2011	45.2	I	4.66
29-08-2011	24.3	I	3.65

Date	Rainfall in mm	AMC	Runoff in mm
01-09-2011	29.4	II	0.67
21-09-2011	30.2	I	0.79
12-05-2012	22.2	I	0.02
01-07-2012	66.2	I	13.85
16-07-2012	82.2	I	22.86
17-07-2012	9.2	III	1.13
20-07-2012	8.2	III	0.77
24-07-2012	44.2	I	4.32
26-07-2012	30.2	III	15.07
27-07-2012	11.3	III	2.03
28-07-2012	19.2	III	6.71
29-07-2012	35.0	III	19.08
31-07-2012	4.2	III	0.00
01-08-2012	10.0	III	1.45
13-08-2012	56.2	I	9.03
15-08-2012	12.0	III	2.37
18-08-2012	9.0	III	1.05
26-08-2012	48.2	I	5.74
29-08-2012	14.4	III	3.66
30-08-2012	15.3	III	4.19
12-09-2012	35.6	I	1.86
20-09-2012	27.4	I	0.40
05-11-2012	22.3	I	0.02
06-11-2012	30.4	I	0.82
22-02-2013	60.2	I	10.87
11-04-2013	33.2	I	1.33
16-06-2013	22.2	I	0.02
24-06-2013	28.8	I	0.58
25-06-2013	24.2	II	3.60
14-07-2013	38.2	I	2.51
25-07-2013	12.2	II	0.17
26-07-2013	17.4	II	1.19
27-07-2013	12.4	III	2.57
28-07-2013	61.2	III	42.71
30-07-2013	190.4	III	168.79
31-07-2013	30.5	III	15.32
02-08-2013	18.2	III	6.03
03-08-2013	38.2	III	21.83
11-08-2013	34.8	I	1.68
12-08-2013	28.4	I	0.53
13-08-2013	12.8	III	2.78
30-08-2013	25.2	I	0.18
20-09-2013	25.2	I	0.18
01-10-2013	28.4	I	0.53
02-10-2013	28.2	II	5.45
03-10-2013	15.2	III	4.13
15-10-2013	98.4	I	33.24
16-10-2013	40.6	III	23.93
19-10-2013	16.6	III	4.99
05-11-2013	36.2	I	2.00
06-11-2013	38.2	II	11.05
07-11-2013	10.6	III	1.70
08-11-2013	13.2	III	2.99
05-03-2014	30.2	I	0.79
08-03-2014	11.2	II	0.07
09-03-2014	15.2	II	0.66
14-03-2014	30.2	I	0.79
15-07-2014	23.2	I	0.06
03-08-2014	33.2	I	1.33
04-08-2014	10.2	II	0.02

Date	Rainfall in mm	AMC	Runoff in mm
05-08-2014	70.2	III	51.19
08-08-2014	14.2	III	3.55
09-08-2014	4.4	III	0.01
29-08-2014	22.2	I	0.02
04-09-2014	25.2	I	0.18
05-09-2014	21.2	I	0.00
06-09-2014	44.2	II	14.93
07-09-2014	24.2	III	10.33
08-09-2014	22.2	III	8.84
06-01-2015	28.4	I	0.53
13-03-2015	25.2	I	0.18
18-03-2015	17.4	II	1.19
28-03-2015	22.2	I	0.02
15-05-2015	102.0	I	35.69
20-05-2015	10.4	III	1.62
26-05-2015	12.6	II	0.22
27-05-2015	22.2	II	2.79
28-05-2015	8.4	III	0.84
08-06-2015	25.2	I	0.18
18-07-2015	24.2	I	0.11
19-07-2015	61.8	I	11.64
20-07-2015	16.2	III	4.74
27-07-2015	44.4	I	4.39
14-08-2015	70.2	I	15.96
17-08-2015	4.2	III	0.00
24-08-2015	78.2	I	20.48
03-02-2016	72.2	I	17.06
10-04-2016	26.4	I	0.29
12-04-2016	52.6	II	20.84
30-05-2016	22.6	I	0.03
31-05-2016	63.6	I	12.5
01-06-2016	4.2	III	3 0.00
03-06-2016	9.2	III	1.13
04-06-2016	38.2	III	21.83
08-06-2016	14.2	II	0.46
12-06-2016	23.4	II	3.27
15-06-2016	23.4	III	9.73
16-06-2016	26.0	III	11.71
17-06-2016	18.2	III	6.03
18-06-2016	31.2	III	15.89
21-06-2016	10.4	III	1.62
27-06-2016	88.2	I	26.58
30-06-2016	17.4	III	5.51
01-07-2016	21.4	III	8.26
02-07-2016	4.4	III	0.01
03-07-2016	10.2	II	0.02
04-07-2016	10.6	III	1.70
07-07-2016	28.2	I	0.50
09-07-2016	30.4	II	6.57
10-07-2016	14.8	III	3.89
12-07-2016	4.6	III	0.02
04-08-2016	50.4	I	6.59
05-08-2016	23.4	II	3.27
07-08-2016	68.4	III	49.48
17-08-2016	45.4	I	4.73
18-08-2016	20.2	II	2.06
19-08-2016	21.2	III	8.11
20-08-2016	5.2	III	0.08
21-08-2016	15.2	III	4.13
22-08-2016	15.6	III	4.37

Date	Rainfall in mm	AMC	Runoff in mm
23-08-2016	16.2	III	4.74
25-08-2016	11.2	II	0.07
28-08-2016	56.8	I	9.30
29-08-2016	80.2	III	60.72
30-08-2016	81.0	III	61.49
31-08-2016	75.6	III	56.32
01-09-2016	7.2	III	0.47
03-09-2016	20.0	III	7.26
14-09-2016	60.2	I	10.87
15-09-2016	12.2	III	2.47
08-06-2017	100.4	I	34.59
10-06-2017	20.2	III	7.40
12-06-2017	11.4	III	2.07
13-06-2017	62.2	III	43.64
14-06-2017	22.2	III	8.84
14-07-2017	23.4	I	0.07
19-07-2017	11.2	III	1.98
14-08-2017	71.5	I	16.67
19-08-2017	8.35	III	0.82
20-08-2017	38.8	I	2.68
22-08-2017	19	II	1.67
14-09-2017	21.23	I	0.00
30-09-2017	47.9	I	5.63
06-10-2017	44.13	I	4.30
06-07-2018	29.7	I	0.71
08-07-2018	16	II	0.84
09-07-2018	12.4	III	2.57
10-07-2018	4.8	III	0.04
14-07-2018	22.3	I	0.02
20-07-2018	36.5	I	2.08
21-07-2018	15.4	II	0.70
12-08-2018	80.7	I	21.96
16-08-2018	33.9	III	18.15
17-08-2018	9.8	III	1.36
21-08-2018	40.8	III	24.11
23-08-2018	4.1	III	0.00
24-08-2018	4	III	0.00
22-09-2018	55.2	I	8.59

Table 7. Annual runoff depth and volume

Years	Rainfall In mm	Runoff In mm	Volume=Runoff*Area(m^2)
2010	1095.4	179.55	11,97,277.46
2011	523.1	50.32	3,35,544.42
2012	885.8	116.42	7,76,313.24
2013	1299.4	380.99	25,40,487.41
2014	625.4	92.76	6,18,543.34
2015	792.8	100.57	6,70,622.08
2016	1481	472.85	31,53,064.04
2017	722.5	130.36	8,69,268.11
2018	615.72	81.121	5,40,932.02

9. Conclusions

In the present study, a SCS-CN method is used to estimate surface runoff potential in an ungauged basin. Land use map and soil map of the study area as input in GIS software. The daily rainfall-runoff simulation was found in the basin. The amount of runoff represents 20% of the total annual rainfall. In SCN Curve number method Antecedent moisture condition of the soil plays a very important role as the Curve number varies according to the soil moisture and that is considered while estimating the runoff depth. Conversations Service Curve Number method is capably recognized as a good technique, which consumes less time for extensive data sets as well as bigger environmental area to recognize site selection of artificial recharge structures. The water and soil preservation actions need to be planned and applied in order to construct appropriate groundwater structures, namely percolation tanks, check dams and contour bunds after comprehensive studies of groundwater Prospective zones

Conflict of Interest

The author declares that they have no conflict of interest.

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