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Paper Authors

SOUNDHARYA .R.S , NAGARAJAN. N

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RAINFALL RUNOFF ESTIMATION USING GEOMATICS AND SCS-CN TECHNIQUES IN THE MALATTAR NARI AR WATERSHED OF PENNAIYAR BASIN IN TAMIL NADU, INDIA

SOUNDHARYA .R.S [*1] , NAGARAJAN. N[2]
*1. P.G Scholar and Corresponding author, 2 .Associate Professor
Dept. of Civil Engineering, FEAT. Annamalai University, Annamalainagar, Tamilnadu, India

Abstract—Water is essential for life. Sustainable management of this scarce resource has turn out to be a challenge nowadays owing to increased demands of increasing population, developing urbanization and fast industrialization combined with rising agricultural production. The assessment of surface water resources is essential at periodic intervals. The aim of the paper is therefore to estimate and assess surface runoff in the Malattar Nari Ar watershed of Pennaiyar basin in Tamil Nadu. The SCS-CN method is useful to calculate the volume of runoff from the land surface which meets in the river or streams. Direct rainfall runoff estimation is always proficient but it is not possible for the majority of the location in preferred time. Use of geo-informatics technology is being applied to prevail over the problem in conventional technique for estimating runoff. Attention was given to derive land use classes from satellite data of 2018 as well as hydrological soil group. Soil Conservation Service – Curve Number (SCS- CN) method is used to calculate the runoff estimation with important parameters such as soil, slope, land use, rainfall, area of watershed.

Key words—Geoinformatics, Rainfall runoff, GIS, SCS- CN technique, Slope, land use, hydrological soil group

I. Introduction

Watershed is a characteristic hydrologic element administered by the territory geography from where overflow is depleted to a point. The term watershed is a common phenomenon; its size and territory relies upon the size of the base guide utilized for outline and codification. Estimation and evaluation of surface spillover is a significant pertinent issue of hydrological just as geological research. Surface spillover is a noteworthy factor influencing the turn of events and progress of floods, soil disintegration, and other hydrological dangers.

Runoff is determined mostly by the quantity of precipitation and by penetration relating to characteristics of soil type, soil moisture, antecedent rainfall, land cover type, impermeable layer and surface preservation. Travel time is mainly determined by incline, length of stream way, profundity of stream, and unpleasantness of stream surfaces. Pinnacle releases depend on the relationship of these parameters and on the absolute waste region of the watershed, the area of the turn of events, the impact of any flood control works or other characteristic or artificial stockpiling, and the time conveyance of precipitation during a tempest occasion. Mass precipitation is changed over to mass spillover by utilizing an overflow bend number (CN). Overflow is changed into a hydrograph by utilizing hypothesis of unit hydrograph and steering methods that rely upon spillover travel time through fragments of the watershed. The SCS-CN runoff curve numbering method was developed by USDA-NRCS. Many representation based on SCS–CN are used by various researchers around the world, including the original SCS–CN, Mishra-Singh model, Michel model and Sahu model, usually based on the SCS–CN concept changes are used.

Based on RS and GIS, the SCS-CN method is used as inputs for three conditions AMC I, AMC II and AMC III and to sort the data. Previous studies have been done by several researchers such as USDA (1986), Mishra et al. (2004), Nagarajan et al. (2011), Kadam et al. (2012), Saravanan and Manjula (2015), Vinithra and Yeshodha (2016). In this research, the runoff estimation from the modified SCS–CN technique for Tamilnadu environment is used using the traditional method in the Malattar Nari Ar watershed.

II. Study Area

The study area Malattar-Nari Ar -Nari Ar -Nari Ar watershed is situated in the north eastern part of the Pennaiyar basin. Malattar-Nari Ar -Nari Ar watershed is bounded by T.Edayur watershed in the south west, Malattar watershed in the south, Nellikuppam watershed in the south east, Villupuram watershed in the north west, Pallichcheri watershed in the north and north east and Bay of Bengal in the East as shown in Figure 1. The study area Malattar-Nari Ar watershed lies in 11° 47' 30" N to 11° 58' 15" N latitudes and 79◦ 20' 45"E to 79◦ 48' 45"E longitudes. It is covering mostly 80 percent in Villupuram district and about 20 percent in Cuddalore district of Tamil Nadu. The watershed occupies an aerial extent of 240.46 sq.km covering most of the areas in Villupuram, Cuddalore and Thirukovilur taluks.

Malattar river is a tributary of Pennaiyar which routed from Dalavanur, Arasamangalam in Koliyanur block of Villupuram district. After running 16.32 Km towards south east, the river turned at Kangambattu to north and north eastern direction upto Pakkam at a distance of 11.12 Km. After that the river take a direction towards south east and confluence with Bay of Bengal near Pannittittu after running 16.22 Km. The Malattar river overall length is 43.70 Km. Another river called Nari Ar is the distributory of Malattar river running through Purasanur, Venkatadri Agaram, Siruvandadu and joins with Malattar near Kangambattu. The Nari Ar river length is 13.55 Km.

Cultivation is the mainly vital activity of the people for 47 percent of the inhabitants affianced in it. Paddy crop is the major yield used for cultivation in this district. Other major crops are cultivated such as Groundnuts, Sugarcane, Cereals, Millets and Pulses. Malattar and Nari rivers along with tanks and wells are the main sources of irrigation in this watershed boundary.

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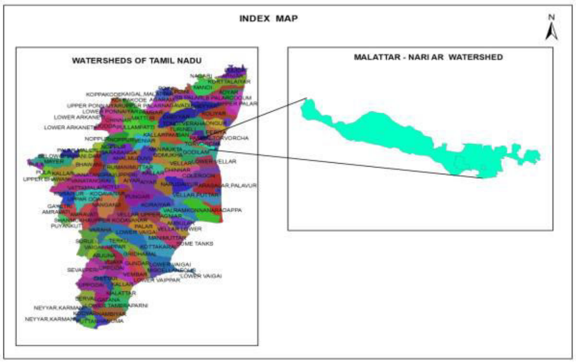

Fig. 1 Location map

III. METHODOLOGY AND DATABASE

The methodology used for this research study is presented in Figure 2 which shows the flow chart for the development of rainfall runoff model. The watershed boundary has been demarcated using the drainage patterns in the SOI topo sheets lies 58 M/5, 58 M/9 and 58 M/13 on 1:50000 scale and the elevation ridges from the Digital Elevation Model with SRTM 30 m resolution. Drainage has also been derived from the SOI topo sheets.

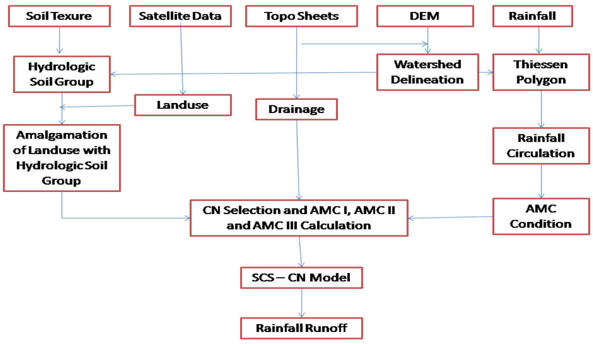

Fig. 2 Methodology

Third level classification was made to prepare land use map (Figure 3) from IRS P6 LISS III 2017. Soil texture in the region was obtained from Soil Atlas of Tamil Nadu Agricultural University, Coimbatore. Slope was derived from the SRTM DEM. Rainfall data during 1988 to 2018 have been acquired from State Ground and Surface Water Resource Data Centre of Water Resource Department. The soil textures converted into hydrological soil groups like A, C and D according to their infiltration capacity. The land use activity grouping were overlaid on the hydrologic soil groups and area for each land use class of particular soil group was find out and assigned a curve number to each distinctive polygon, based on normal SCS curve number. Curve number for drainage watershed of weighted area intended from land use/land cover and soil group polygons surrounded by the drainage basin (Kudoli and Oak 2015).

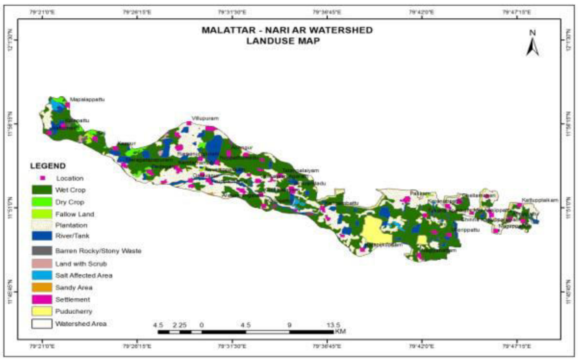

Fig. 3 Land use map

IV. SCS-CN MODEL

The SCS–CN model technique has been introduced in 1954 by the USDA SCS (Rallison, 1980), distinct in the Soil Conservation Service (SCS) by National Engineering Hand Book (NEH-4), Section of Hydrology (Ponce and Hawkins 1996). The SCS-CN technique is based on water balance calculations and two basic hypotheses (Jun et al. 2015). According to the first hypothesis, the ratio of genuine volume of direct runoff is the same to the maximum retention amount equal to the proportion of the definite infiltration volume. The second hypothesis is that the initial capture amount is the fraction of maximum retention. Soil Conservation Service - Curve Number methods are often used in empirical methods to calculate direct runoff by watershed as mentioned in Table 3 (USDA 1972). The penetration losses are combined with surface storage by the relation of

Q = (P-Ia)2/P-Ia+S (1)

where, Q is runoff volume in mm, P is the rainfall in mm, I_a is the initial abstraction in mm and surface storage, interception, and infiltration prior to runoff within the watershed and empirical equation was widen from the term I_a and it is given by,

Ia = 0.3S (2)

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

S = (25400/CN) – 254 (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 rewritten as,

$Q = (P – 0.3S)^2 / P + 0.7S$ (4)

In considerable value of CN, the runoff from the watershed was calculated from equations 3 and 4.

The SCS curve number is an objective characteristic of land use and soil capacity to permit water infiltration in relation to pre existing soil moisture condition (Amutha and Porchelvan, 2009). Based on USDA soil classification are distributed keen on four hydrologic soil groups such as A, B, C and D with respect to rate of runoff probable and final infiltration.

i. Antecedent Moisture Condition

Antecedent Moisture Condition is measured when minimal earlier precipitation and high when there was impressive going before precipitation to the rainfall model event. For the purpose of modeling, AMC II in watershed is mainly taken as normal damp condition. Runoff curve numbers from land use and type of soil taken for normal conditions (AMC II) and dry conditions (AMC I) or wet conditions (AMC III), corresponding curve numbers (CN) were calculated by using the following equation 5 and 6. The curve number values identified in the case of AMC-II (Tables 1 and 2).

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

CN (I) = CN (II) / 2.281 − 0.0128 CN (II) (5)

CN (III) = CN (II)/ 0.427 + 0.00573 CN (II) (6)

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

CNw = Σ CNi * Ai/A (7)

Where CNw is the weighted curve number; CNi is the curve number from 1 to any number N; Ai is the area with curve number CNi; and A the total area of the watershed.

Table 1 Soil Conservation Service classification (USDA 1974)

Hydrologic Soil Group	Soil Texture	Runoff potential	Transmitivity Rate	Infiltration Rate (inches per Hour)
A	Sand	Very low	Very High	1.25
A	Sandyloam	Low	High	0.85
C	Sandyclay loam	Moderate	Moderate	0.59
D	Sandyclay	High	Low	0.31
D	Clay	High	Very low	0.13
D	Clayloam	High	Low	0.25
D	Siltyclayloam	High	Low	0.21

Table 2 Antecedent soil moisture classes (AMC)

AMC	Soil Condition	5-day Antecedent rainfall in mm	
		Dormant Season	Growing Season
I	Wet	Less than 19	Less than 31
II	Average	19 to 32	31 to 54
III	Heavy rainfall	More than 32	More than 54

To estimate the surface runoff, the hydrological equations from 3 to 4 are used. These equations depend on the value of rainfall (P) and watershed storage (S) which are intended from the adjusted curve number. Thus, before applying Eq. (3), the value of (S) should be determined for each antecedent moisture condition (AMC). There are three conditions to hydrologic condition results are in Table 3.

Table 3 Hydrological Calculations in the watershed

AMC	CN	S	P > 0.3 S
I	52.38	230.92	69.28
II	72.37	96.97	29.09
III	85.76	42.18	12.65

ii. Hydrologic Soil Group (HSG)

Soil texture (Figure 4) is categorized into hydrologic soil groups to point out the minimum rate of infiltration for obtaining bare soil subsequent to prolonged wetting. The hydrological soil group which are A, B, C, and D are one element used to determine the runoff curve numbers. The infiltration rate is the rate at which water enters the soil at the soil surface. It is restricted by surface conditions; the soil group indicates the transmission rate, the rate at which the water travels within the soil. This rate is controlled by the soil textures, the approximate numerical value ranges for infiltration rates shown in the Hydrologic Soil Group (HSG) defines have been previously published. The four groups are defined by SCS soil scientists as follows:

Low runoff efficiency and high penetration rate of Group A soil also occur when wetted well. They are mainly dark, have high sand or gravel, and have a high rate of water transmission (more than 0.30 inch/hr).

Group B soil have a moderate infiltration rate when fully wetted, and are mainly mild to moderate in depth, with moderate to well drained soils moderately and coarse to fine-grained. These soils have a water flow rate (0.15-0.30 inch/hr).

The infiltration rate is low in Group C soil when they are completely wet and consists mainly of soils with a water crust, which enhances the descending movement of water and fine textures with moderately textured soil. These soils have a low rate of water transmission (0.05-0.15 inch/hr).

Group D soil has elevated runoff efficiencies. They have very low infiltration rates when meticulously damp and consist mainly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 inch/hr).

The Soil textures (Figure 4) are divided into Hydrologic Soil Groups as A, C and D (Figure 5) carefully in the watershed (Table 4). Group A specifies low runoff potential, high infiltration rate, 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.

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Table 4 Weighted curve number (AMC Group)

Land use	Soil Type	Area in sq.km	CN	% of Area	Area x CN	Weighted Curve Number (WCN)
Wet crop	A	74.34	72	30.91	5352.48	
	C	13.58	88	5.65	1195.04	
	D	32.05	91	13.33	2916.55	
Dry Crop	A	3.06	76	1.27	232.56	
	D	1.04	90	0.43	93.60	
Fallow land	A	0.33	74	0.14	24.42	
	C	0.21	90	0.09	18.90	
	D	0.57	93	0.24	53.01	AMC I = 52.38 AMC II = 72.37 AMC III = 85.76
Plantation	A	42.64	32	17.73	1364.48	
	C	13.17	72	5.48	948.24	
	D	19.01	79	7.91	1501.79	
Land with Scrub	A	0.6	74	0.25	44.40	
	D	0.23	58	0.10	13.34	
Barren Rocky / Stony Waste	C	0.28	91	0.12	25.48	
	D	0.32	94	0.13	30.08	
Salt Affected Area	A	2.13	86	0.89	183.18	
	C	0.07	89	0.03	6.23	
Sandy Area	A	0.11	96	0.05	10.56	
Settlement	A	4.99	59	2.08	294.41	
	C	2.05	81	0.85	166.05	
	D	3.04	87	1.26	264.48	
Water Body	A	22.35	100	9.29	2235.00	
	C	1.64	100	0.68	164.00	
	D	2.66	100	1.11	266.00	

Fig. 4 Soil texture

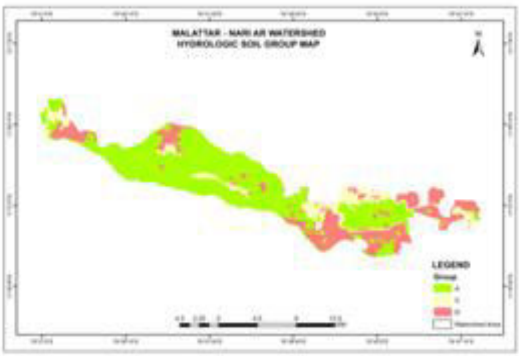

Fig. 5 Hydrologic Soil Group

iii. Thiessen Polygon Method

Rainfall distribution by Thiessen polygon method recognizes that the estimated values taken on the observed value are intensively investigated through pattern recognition systems. In spite of their inherent simplicity, adjacent neighbor an algorithm is considered versatile and robust. Although more sophisticated different methods have been developed since its inception, nearest neighbor methods remain very popular (Ly et al. 2013). The application of rain gauge as precipitation input carries many uncertainties. The spatial and temporal distribution of rainfall at watershed level using GIS approaches is established to be very efficient (Figure 6).

Fig. 6 Thiessen Polygon

iv. Slope

Slope was derived from SRTM - DEM (Figure 7) falls under gentle to moderate slope watershed (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 (Figure 8). This is appropriate site for artificial recharge structures such as check dams, vertical shafts and percolation ponds beside drainage.

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Table 5 Slope classes

Sl. No.	Slope in percentage	Area in Sq.Km	Potential implication
1	Nearly Level	84.74	Very low surface runoff
2	Gentle	71.102	Low surface runoff
3	Moderate	48.652	Moderate surface runoff
4	Steep	26.724	High surface runoff
5	Very Steep	9.242	Very high surface runoff

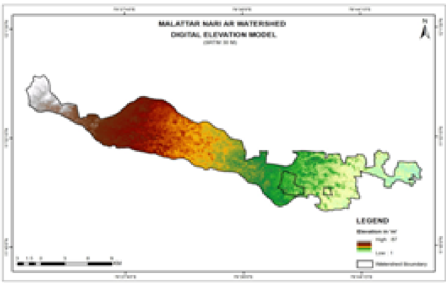

Fig. 7 DEM Model

Fig. 8 Slope map

In SCS method, as a result of the calculation, it was found that the average annual surface runoff depth for the last 31 years in Malattar Nari Ar watershed is equal to 526.64 mm and the total average volume of runoff is 175.55 m^3, which represents 45 percentage of the total average annual rainfall. The annual rainfall and runoff during 1988–2018 are shown in Table 6.

V. Results and Discussion

The calculated normal, wet and dry conditions, curve numbers are 52.38, 72.37 and 85.76 in Figure 9. The runoff varies from 26.06 to 1609.33 mm (1988–2018) as shown in Figure 10. The rainfall varies between 524.56 and 1957.80 mm in the watershed as shown in Figure 11. The average annual runoff calculated to 526.64 mm and average runoff volume for 31 years is 12.90 m^3.

Table 6 Annual average runoff depth and volume

Year	Rainfall in mm	Runoff in mm	Volume in m^3
1988	790.27	123.86	9.14
1989	978.02	186.38	14.01
1990	1393.09	286.76	25.25
1991	972.57	184.71	14.18
1992	839.66	143.47	11.84
1993	1267.90	170.92	12.08
1994	933.63	143.89	10.13
1995	1053.30	100.74	5.97
1996	1957.80	536.44	40.33
1997	1520.93	327.71	27.57
1998	1416.80	355.68	24.37
1999	1088.96	132.22	8.41
2000	1151.93	135.64	11.59
2001	827.53	27.93	1.96
2002	888.47	51.35	3.22
2003	1171.66	93.09	6.37
2004	1661.27	279.99	17.71
2005	1744.88	473.12	30.96
2006	1356.96	70.49	4.56
2007	1166.50	91.76	8.07
2008	1477.43	351.54	27.00
2009	1144.00	148.06	9.86
2010	1525.17	116.66	7.39
2011	1095.00	173.42	13.90
2012	735.23	153.12	12.71
2013	723.68	28.40	2.59
2014	1031.43	49.08	4.51
2015	1679.57	297.69	19.66
2016	524.56	8.69	0.60
2017	1226.19	115.93	8.02
2018	858.29	83.15	5.91
Average	1167.83	175.55	12.90

The rainfall runoff relationship showed in Figure 12 for Malattar Nari watershed. The rainfall- runoff is vigorously correlated with a correlation coefficient (r) value being 0.593.

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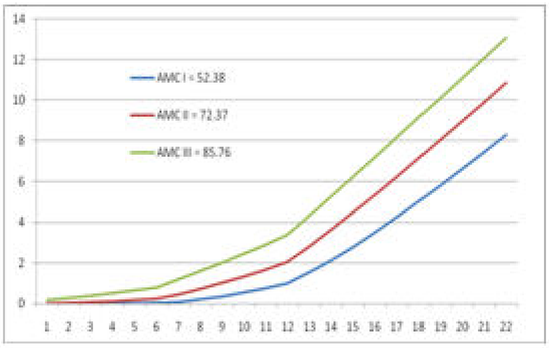

Fig. 9 Solution of runoff equation

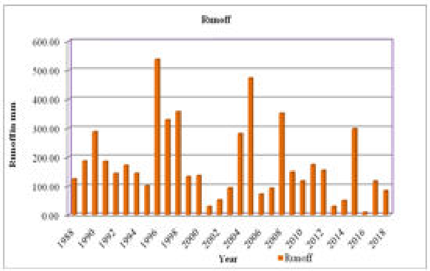

Fig. 10 Runoff variation

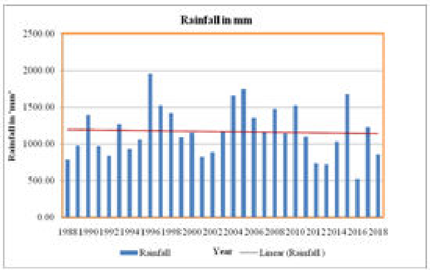

Fig. 11 Rainfall variation

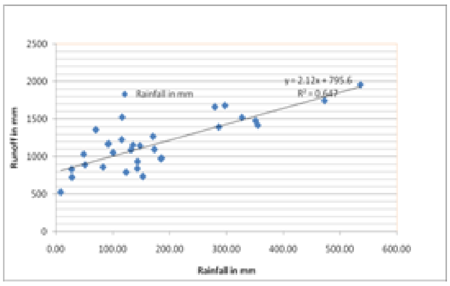

Fig. 12 Scatter plot - Rainfall and calculated runoff

VI. CONCLUSION

The SCS-CN model have been used in the present research study by utilizing DEM, land use and soil cover textures. The monthly rainfall runoff replication has found good relationship in the watershed. The amounts of runoff categorize 45 percentage of the whole annual rainfall. In this analysis, the attitude for the rainfall runoff using remote sensing and GIS, the SCS approach could be useful in other watersheds adopting for the soil conservation measures. The good soil and water conservation measures have to be designed and executed in the watersheds classified as high and moderately high for controlling runoff and soil erosion losses. In SCN-CN method, antecedent moisture condition of the soil plays a very important role because the CN number fluctuate according to the soil texture and that is considered while evaluating runoff depth. In Malattar Nari watershed, CN number is calculated as 52.38 for AMC-I, 72.37 for AMC-II and 85.76 for AMC-III (Figure 9). The SCS-CN approach is competently proven as a better method, which consumes less time and facility to handle widespread data set as well as better environmental area to identify site selection of artificial recharge structures with the help of Remote Sensing and GIS technology.

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