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Estimation of Surface Runoff in Malattar Sub-watershed using SCS-CN Method

R. Amutha · P. Porchelvan

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Abstract Nowadays watershed management plays a vital role in water resources engineering. Watershed based on water resources management is necessary to plan and conserve the available resources. Remote Sensing (RS) and Geographic Information System (GIS) techniques can be effectively used to manage spatial and non spatial database that represent the hydrologic characteristics of the watershed use as realistically as possible. The present study area is Malattar sub-watershed (4C2B2) lies in the region Gudiyattam Block, Vellore District, Tamil Nadu. The daily rainfall data of Gudiyattam rain gauge station (1971 – 2007) was collected and used to predict the daily runoff from the watershed using Soil Conservation Service – Curve Number (SCS – CN) method (USDA, 1972) and GIS. Monthly and annual runoff have been calculated from the monthly rainfall data for the years of 1971 to 2007 in the watershed area. The average minimum and maximum rainfall for the years of 1971 to 2007 is 35.30 mm and 111.61 mm respectively and average runoff for the year of 1971 to 2007 is 31.87 mm^3 and 47.04 mm^3 respectively. The developed rainfall–runoff model is used to understand the watershed and its runoff flow characteristics.

R. Amutha (✉)[1] · P. Porchelvan[2]
[1]Vellore Institute of Technology,
Vellore – 632 014, Tamil Nadu, India
[2]SMBS, Vellore Institute of Technology,
Vellore – 632 014, Tamil Nadu, India

email : amuthanithy@gmail.com

Introduction

A watershed is the area covering all the land contributes runoff water to a common point. It is natural physiographic or ecological unit composed of interrelated parts and function. Each watershed has definite characteristics such as size, shape, slope, drainage, vegetation, geology, soil, geomorphology, climate and land use. Watershed management implies proper usage of water to land and other natural resources in a watershed for estimation of runoff which is required for planning, developing and managing the water resources and irrigation scheduling. Runoff is one of the important hydrologic variables used in the water resources applications and management planning. For gauged watershed accuracy of estimation of runoff on land surface and rivers requires much time and effort. In the present study SCS-CN technique was used to generate rainfall runoff model by incorporating spatial variation of the various physiographic characteristics of the study area such as geomorphology, geology, structures, land use/ land cover, soil and drainage pattern integrated with the help of RS data and GIS techniques.

Materials and methods

Study area

The present study was carried out in Malattar sub-watershed which is a major tributary of Palar river. Malattar river originates in the hilly regions of Venkatagrikotta in Andra Pradesh and flows Niakeneri forest of Palamanar taluk. This river confluences Palar river 5 km east of Ambur near Sathampakkam village on the left side and flows through Pernampet block of Vellore District. The main tributaries of Malattar River are, Duggammaeru, Dandapaner venka, Gittargunta venka, Batavenka, Gooddar venka, Garisala venka and Kattar river. The study area lies between east longitude from 78°39’ to 79°56’ and north latitude from 12°48’ to 12°56’ and covers an area about 163 km^2 (Fig. 1). The watershed experiences tropical monsoon climate with normal temperature, humidity and evaporation throughout the year. The monsoon season in the watershed is from June to December. The rainfall occurrence during October and November is heavy and significant amount of runoff occurs in the watershed. The rainfall station is at Modikuppam near Gudiyattam, in general, the annual rainfall is about 517.44 mm.

Methodology

In this study, Survey of India topographic sheets of 57L/9, 57L/11 and 57/13 were used to delineate the watershed boundary, drainage (Fig. 2), and contour. Remote sensing data of LANDSAT TM sensor on a scale of 1:50,000 for delineating land use/land cover map (Fig. 3), and soil map. Hydrologic soil group map (Fig. 4) was prepared according to soil characteristics and type of land use/land cover for the estimation of runoff from watershed. Daily rainfall data from Gudiyattam taluk of Modikuppam village for the year of 1971 to 2007 (36 years) data were used to calculate the runoff using SCS-CN method.

SCS curve number method

The most commonly used empirical method is the Soil Conservation Service Curve Number (SCS-CN) method to estimate the direct runoff from a watershed (USDA, 1972). The infiltration losses are combined with surface storage by the relation of

$$Q = (P\text{-}Ia)^2 / (P\text{-}Ia+S) \qquad (1)$$

where, Q is the accumulated runoff or rainfall excess in mm, P is the rainfall depth in mm, Ia is the initial abstraction in mm and includes 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,

$$I_a = 0.3S \qquad (2)$$

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

$$S = (25400/CN) - 254 \qquad (3)$$

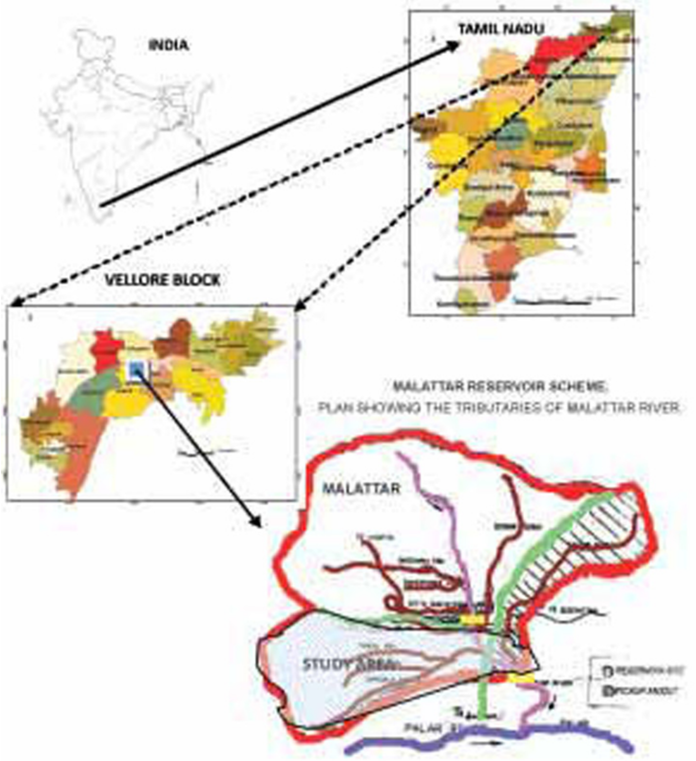

Fig. 1 Study area of the Malattar sub-watershed.

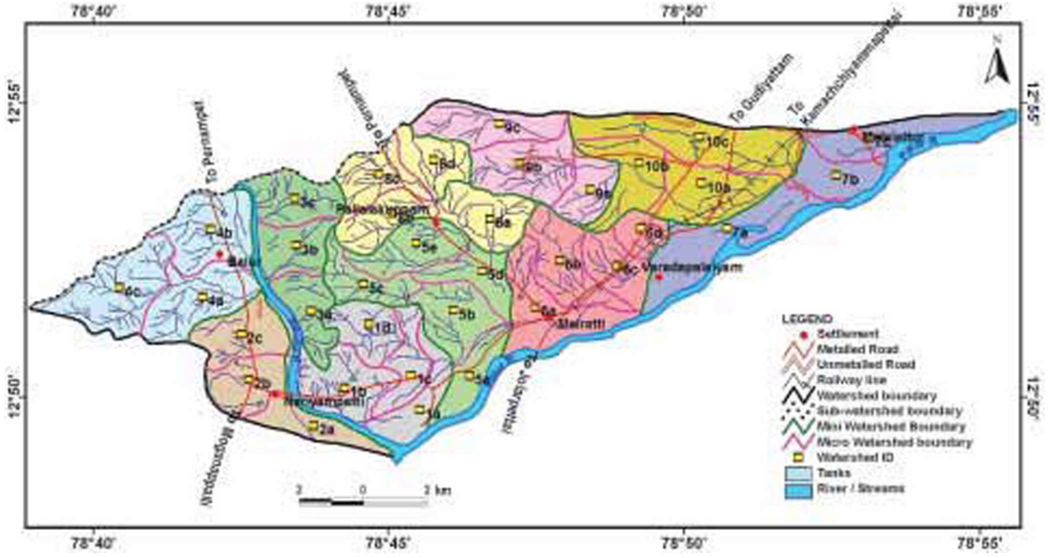

Fig. 2 Drainage pattern map of the Malattar sub-watershed with codes.

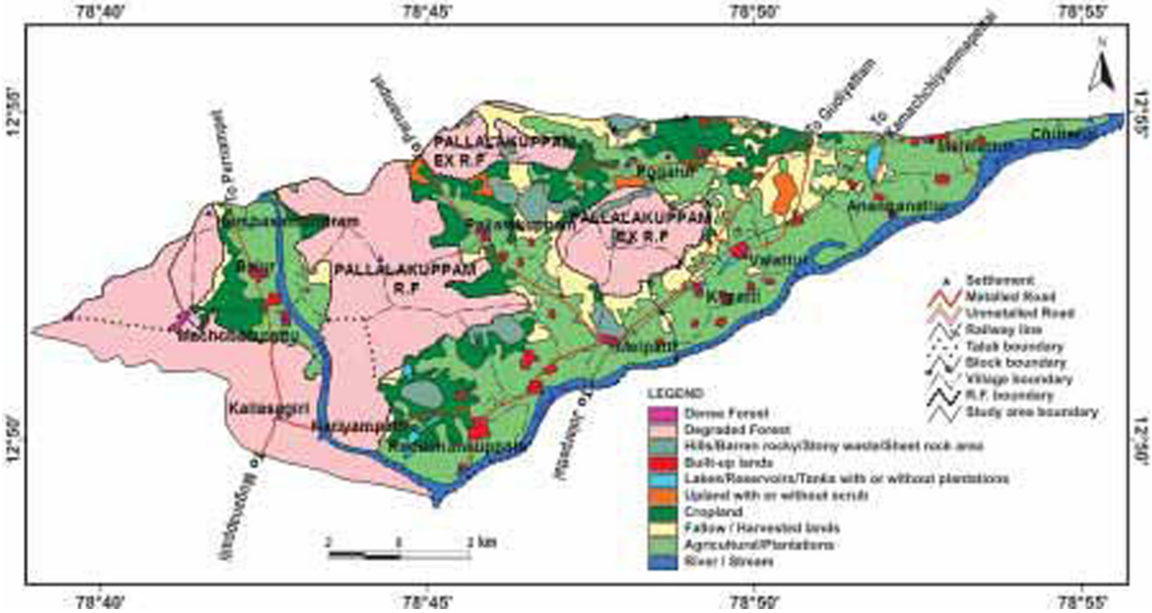

Fig. 3 Landuse/land cover map of the Malattar sub-watershed.

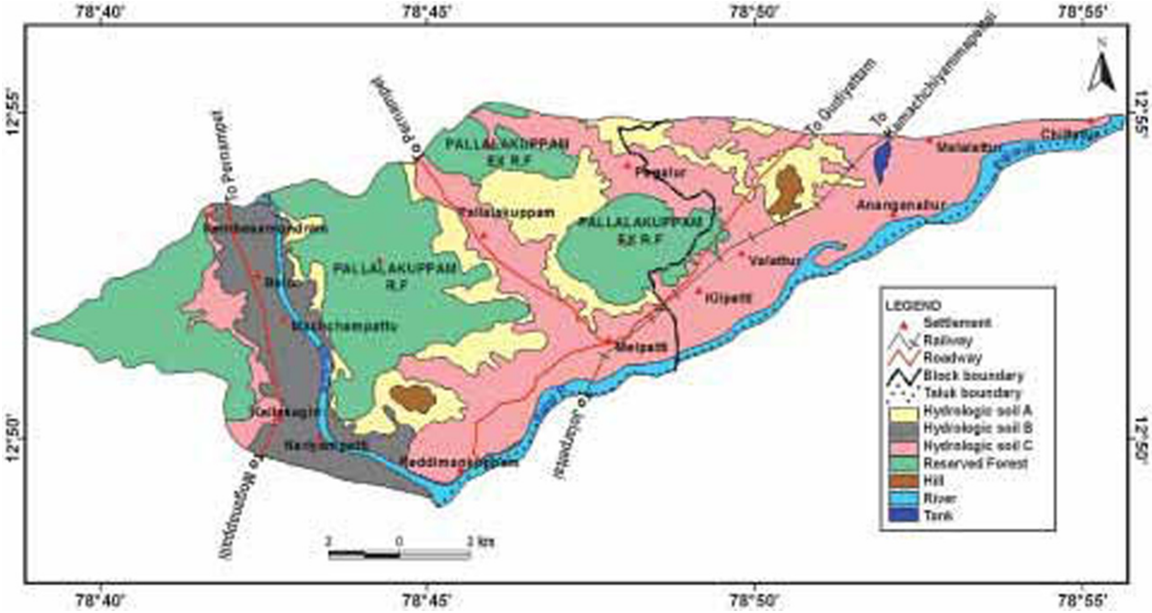

Fig. 4 Hydrologic soil group map of the Malattar sub-watershed.

where, CN is known as the curve no which can be taken from the tables, Chapter 7, SCS handbook of hydrology, section-4 (USDA, 1972).

Now the equation can be rewritten as,

$$Q= (P-0.3S)^2 / (p+0.7S) \quad (4)$$

Knowing the value of CN, the runoff from the watershed was computed from Eq.3 & 4.

The SCS curve number is a function of the ability of soils to allow infiltration of water with respect to land use/land cover and antecedent soil moisture condition (AMC). According to U.S soil conservation service soils are divided into four hydrologic soil groups such as group A, B, C & D with respect to rate of runoff potential and final infiltration rate.

HSG and Antecedent Soil Moisture Condition (AMC)

HSG is expressed as four groups, according to the soil's minimum infiltration rate, which is obtained for a bare soil after prolonged wetting (Table 1). Antecedent soil moisture condition had a significant effect on runoff considering and this aspect the soil conservation service (SCS) had developed three antecedent soil moisture conditions such as AMCI AMC II & AMC III. Prior to estimating runoff for a storm event, the curve numbers was adjusted based on the season and total 5 day antecedent precipitation. AMC is expressed as three levels, according to rainfall limits for dormant and growing seasons (Table 2). Although originally designed for use on watersheds of 1,500 ha (3,707 acres), it has been modified by some users (Jackson *et al.*, 1976; Rawls *et al*., 1981; Still and Shih, 1984, 1985, 1991) for application to larger watersheds, principally by land-cover based area-weighting of curve numbers.

Area weighted curve number

The different layers of soil, HSG and land use/land cover were overlaid one by one and the new PAT (polygon attribute table) was obtained using Arc GIS 9.1. The result obtained from this PAT was used to compute the total area weighted curve number of the study area to calculate the AMC II refer Table 3.

Estimation of rain fall - runoff

The daily rainfall database of Gudiyattam from 1971 to 2007 (for 36 years) and the area weighted curve number were inputs to the SCS formula and the results are obtained from the daily runoff values and monthly and annual runoff values are obtained. The detailed monthly rainfall and calculated values for the 36 years are given below in Table 4.

Table 1 USDA-SCS soil classification

Hydrologic soil type	Type of soil	Runoff potential	Final infiltration rate mm/hr	Remarks
Group A	Deep, well drained sands and gravels	Low	>7.5	High rate of water transmission
Group B	Moderately deep, well drained with moderately fine to coarse textures	Moderate	3.8-7.5	Moderate rate of water transmission
Group C	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderate	1.3-3.8	Moderate rate of water transmission
Group D	Clay soils that swell significantly when wet, heavy plastic and soils with a permanent high water table	High	<1.3	Moderate rate of water transmission

Table 2 Classification of Antecedent soil moisture classes (AMC)

AMC group	Soil characteristics	Total 5 day antecedent rainfall in mm	
		Dormant season	Growing season
I	Soils are dry but not to wilting point; satisfactory cultivation has taken place	Less than 13	Less than 36
II	Average condition	13-28	36-53
III	Heavy rainfalls or light rainfall and low temperatures have occurred within the last 5 days; stared soil	Over 28	Over 53

Results and discussion

The present study area constitutes different land use/ land cover of about 50% of the area is occupied by agricultural land, 60% area covers forest land, 17% area of cropland, 14% area of fallow land and remaining 21% of the area is occupied by others such as water body, hills, settlement, upland with scrub and tanks. In general, among the different land cover types the forest land plays the major role for the direct surface runoff. The hydrologic soil type plays vital role while estimating the runoff potential which represents the soil characteristics, type, and its infiltration capacity. In the study area hydrologic soil type of 'A', 'B' and 'C' were delineated with reference to soil atlas map, remote sensing data and other secondary data. The study obtained that 'C'

Table 3 Weighted curve number for Malattar sub-watershed (for AMC II)

S. No	Land use	Soil type	Area in km^2	CN	% Area	% Area * CN	Weighted Curve Number (WCN)
1	Settlement	A	0.85	77	0.558	42.941	AMC – I = 48.9 AMC – II = 69.48 AMC – III = 83.97
		B	2.36	86	1.548	133.158	
2	Wet Crop Land	A	8.54	95	5.603	532.279	
		B	20.00	95	13.122	1246.556	
		C	30.00	95	19.682	1869.833	
3	Dry Crop Land	B	8.36	55	5.485	301.666	
		C	24.01	69	15.753	1086.924	
4	Degraded Forest	B	0.08	44	0.052	2.309	
		C	40.33	60	26.460	1587.587	
5	Scrub Land	B	3.00	80	1.968	157.460	
		C	5.00	85	3.280	278.835	
		D	0.48	88	0.315	27.713	
6	Rock Out Crop	B	2.00	86	1.312	112.846	
		C	1.90	91	1.247	113.437	
		D	0.39	93	0.256	23.796	
7	Water Bodies	-	5.12	100	3.359	335.914	

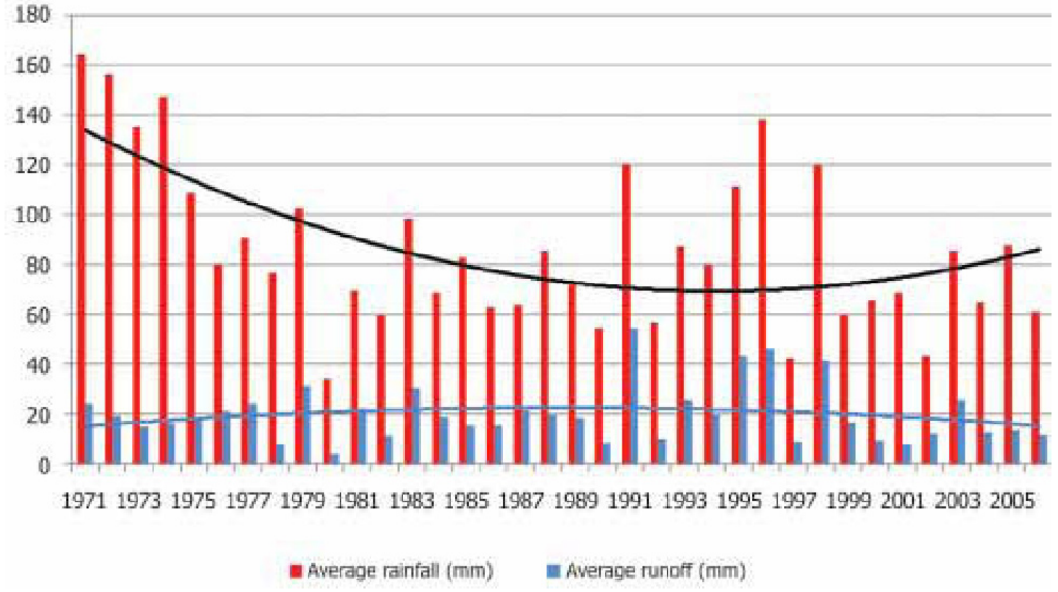

Fig. 5 Average rainfall vs average runoff.

type of HSG predominantly covered throughout the area which is mainly comprised of agricultural and crop land and then followed by 'A' and 'B' type. By intersecting the land use and hydrologic soil type the curve number was assigned according to US-SCS and derived the antecedent moisture conditions values are AMC II and AMC III. The monthly and annual runoff calculated in both mm and mm^3 and the study area is predominated by southwest monsoon. The average annual rainfall has decreased from the year of 1971 to 1989 and suddenly increased between the years of 1991 to 1997 and gradually decreases and increases from the year 1998 to 2007. The trend line for the average rainfall is in the convex form indicates that rainfall has decreased from the year 1971 to 2007 due to irregular climatic season in the recent years. The average annual runoff fairly fluctuated throughout the computed years and sudden runoff takes place in the year from 1991 to 1997. The trend line of concave shape is formed due to these years rainfall and AMC is much higher than the rest of the years. The rainfall runoff result of the trend line shows that there is no high runoff taking place comparatively and predicted trend line for the future runoff is further decreasing. This may be a reason of low rainfall and higher temperature existing in this area in recent years. It is evident that moderately less runoff in this area and further it can be controlled by afforestation in the degraded forest land since it occupies 50% of the total land area.

Conclusion

It may be inferred that estimation of runoff by SCS – CN method integrated with GIS can be used in watershed management effectively. The results of the study show that from the monthly runoff values and the seasonal runoff in the watershed can be studied for reliable accuracy along with the spatial variation of soil type and land use type. By assessing the variation in annual runoff, water irrigation can be done to the associated agricultural land and other utility purposes. After synchronizing

Table 4 Monthly runoff from Malattar sub-watershed

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1971	1	35.30	0.00	0.000
1971	2	29.10	0.00	0.000
1971	3	342.70	7.72	1.601
1971	4	84.37	0.00	0.000
1971	5	174.70	0.00	0.000
1971	6	155.80	0.00	0.000
1971	7	232.40	21.38	4.433
1971	8	241.40	38.60	8.004
1971	9	139.20	0.00	0.000
1971	10	307.40	85.80	17.794
1971	11	224.40	0.16	0.034
1971	12	0.00	0.00	0.000
1972	1	112.80	0.00	0.000
1972	2	121.02	0.00	0.000
1972	3	0.00	0.00	0.000
1972	4	185.30	0.39	0.082
1972	5	140.31	3.91	0.810
1972	6	150.40	12.76	2.647
1972	7	83.20	0.00	0.000
1972	8	100.80	0.00	0.000
1972	9	244.06	68.06	14.114
1972	10	229.40	7.98	1.654
1972	11	220.00	0.94	0.195
1972	12	286.76	24.68	5.119
1973	1	0.00	0.00	0.000
1973	2	0.00	0.00	0.000
1973	3	0.00	0.00	0.000
1973	4	68.00	7.65	1.586
1973	5	219.00	3.24	0.672
1973	6	129.60	0.00	0.000
1973	7	144.00	0.00	0.000
1973	8	155.60	0.00	0.000
1973	9	194.00	11.53	2.391
1973	10	321.80	41.52	8.611
1973	11	238.60	1.32	0.274
1973	12	149.80	9.57	1.985
1974	1	0.00	0.00	0.000
1974	2	0.00	0.00	0.000
1974	3	0.00	0.00	0.000
1974	4	46.60	0.00	0.000
1974	5	232.20	0.10	0.021
1974	6	319.60	21.10	4.375
1974	7	163.40	0.04	0.009
1974	8	374.40	7.72	1.601
1974	9	271.20	50.06	10.382
1974	10	199.20	1.08	0.224
1974	11	160.60	0.00	0.000
1974	12	0.00	0.00	0.000
1975	1	0.00	0.00	0.000
1975	2	0.00	0.00	0.000
1975	3	0.00	0.00	0.000
1975	4	0.00	0.00	0.000
1975	5	216.00	35.75	7.414
1975	6	220.60	0.77	0.159
1975	7	251.60	23.15	4.801
1975	8	190.00	12.03	2.494
1975	9	121.60	19.39	4.021
1975	10	177.00	17.91	3.714
1975	11	118.00	4.07	0.845
1975	12	6.40	0.00	0.000
1976	1	9.20	0.00	0.000
1976	2	0.00	0.00	0.000
1976	3	0.00	0.00	0.000
1976	4	35.00	0.02	0.004
1976	5	44.00	0.00	0.000
1976	6	14.20	0.00	0.000
1976	7	203.15	24.23	5.025
1976	8	194.80	1.60	0.332
1976	9	76.40	0.00	0.000
1976	10	210.20	94.16	19.528
1976	11	174.60	39.08	8.104
1976	12	2.64	0.00	0.000
1977	1	0.00	0.00	0.000
1977	2	1.60	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1977	3	0.00	0.00	0.000
1977	4	29.80	0.00	0.000
1977	5	51.00	0.00	0.000
1977	6	127.90	26.95	5.589
1977	7	64.60	0.00	0.000
1977	8	227.00	58.59	12.151
1977	9	76.40	0.00	0.000
1977	10	204.80	29.70	6.160
1977	11	305.00	47.89	9.931
1977	12	0.00	0.00	0.000
1978	1	2.40	0.00	0.000
1978	2	3.86	0.00	0.000
1978	3	0.00	0.00	0.000
1978	4	38.66	0.00	0.000
1978	5	29.80	0.00	0.000
1978	6	20.20	0.00	0.000
1978	7	101.20	5.87	1.217
1978	8	32.28	0.00	0.000
1978	9	281.50	14.64	3.036
1978	10	116.60	0.00	0.000
1978	11	113.70	4.77	0.989
1978	12	181.90	4.47	0.928
1979	1	0.00	0.00	0.000
1979	2	26.50	0.00	0.000
1979	3	5.80	0.00	0.000
1979	4	2.70	0.00	0.000
1979	5	22.50	0.00	0.000
1979	6	32.80	0.00	0.000
1979	7	148.70	24.77	5.137
1979	8	46.20	0.00	0.000
1979	9	299.30	63.62	13.193
1979	10	132.20	0.00	0.000
1979	11	499.20	144.97	30.065
1979	12	12.00	0.00	0.000
1980	1	0.00	0.00	0.000
1980	2	0.00	0.00	0.000
1980	3	0.00	0.00	0.000
1980	4	0.00	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1980	5	67.00	0.00	0.000
1980	6	43.00	0.00	0.000
1980	7	95.00	4.62	0.958
1980	8	0.00	0.00	0.000
1980	9	18.00	0.00	0.000
1980	10	37.00	0.00	0.000
1980	11	123.00	20.54	4.260
1980	12	29.20	0.00	0.000
1981	1	0.00	0.00	0.000
1981	2	30.20	0.00	0.000
1981	3	0.00	0.00	0.000
1981	4	0.00	0.00	0.000
1981	5	0.00	0.00	0.000
1981	6	0.00	0.00	0.000
1981	7	34.00	0.00	0.000
1981	8	206.20	22.43	4.652
1981	9	218.90	18.38	3.813
1981	10	319.90	146.23	30.325
1981	11	57.00	0.00	0.000
1981	12	0.00	0.00	0.000
1982	1	82.00	0.00	0.000
1982	2	17.80	0.00	0.000
1982	3	22.50	0.00	0.000
1982	4	8.00	0.00	0.000
1982	5	69.50	0.02	0.004
1982	6	143.14	43.77	9.076
1982	7	14.20	0.00	0.000
1982	8	57.30	0.00	0.000
1982	9	210.80	20.94	4.342
1982	10	69.00	14.97	3.105
1982	11	122.00	0.00	0.000
1982	12	0.00	0.00	0.000
1983	1	0.00	0.00	0.000
1983	2	0.00	0.00	0.000
1983	3	21.00	0.00	0.000
1983	4	0.00	0.00	0.000
1983	5	170.00	40.46	8.390
1983	6	95.10	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1983	7	141.50	47.19	9.786
1983	8	248.80	52.56	10.901
1983	9	258.70	38.34	7.951
1983	10	45.50	0.00	0.000
1983	11	21.00	0.00	0.000
1983	12	181.50	35.96	7.458
1984	1	0.00	0.00	0.000
1984	2	76.30	0.00	0.000
1984	3	90.10	93.00	19.287
1984	4	0.00	0.00	0.000
1984	5	33.20	0.00	0.000
1984	6	21.80	0.00	0.000
1984	7	147.10	8.31	1.723
1984	8	7.20	0.00	0.000
1984	9	171.20	37.60	7.797
1984	10	136.40	3.52	0.731
1984	11	97.80	29.98	6.217
1984	12	41.50	0.00	0.000
1985	1	0.00	0.00	0.000
1985	2	0.00	0.00	0.000
1985	3	0.00	0.00	0.000
1985	4	38.00	0.00	0.000
1985	5	27.20	0.00	0.000
1985	6	124.70	6.32	1.311
1985	7	186.40	25.04	5.193
1985	8	204.40	16.18	3.356
1985	9	134.60	0.00	0.000
1985	10	74.52	0.00	0.000
1985	11	187.90	56.43	11.704
1985	12	17.40	0.00	0.000
1986	1	56.60	0.00	0.000
1986	2	5.00	0.00	0.000
1986	3	0.00	0.00	0.000
1986	4	9.80	0.00	0.000
1986	5	31.60	155.00	32.144
1986	6	26.80	0.00	0.000
1986	7	115.24	21.28	4.414
1986	8	48.00	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1986	9	156.10	28.66	5.944
1986	10	119.20	0.12	0.025
1986	11	174.10	42.07	8.724
1986	12	13.00	0.00	0.000
1987	1	22.00	0.00	0.000
1987	2	0.00	0.00	0.000
1987	3	24.40	0.00	0.000
1987	4	6.40	0.00	0.000
1987	5	8.20	0.00	0.000
1987	6	104.00	0.12	0.025
1987	7	44.80	0.00	0.000
1987	8	160.80	248.00	51.431
1987	9	81.60	0.00	0.000
1987	10	80.85	0.00	0.000
1987	11	103.60	0.00	0.000
1987	12	128.60	0.59	0.123
1988	1	0.00	0.00	0.000
1988	2	0.00	0.00	0.000
1988	3	1.20	0.00	0.000
1988	4	78.00	6.78	1.406
1988	5	70.80	0.00	0.000
1988	6	10.50	0.00	0.000
1988	7	204.40	33.18	6.881
1988	8	330.70	45.56	9.448
1988	9	178.10	29.23	6.063
1988	10	93.60	4.96	1.028
1988	11	31.20	0.00	0.000
1988	12	30.20	0.00	0.000
1989	1	0.00	0.00	0.000
1989	2	0.00	0.00	0.000
1989	3	18.40	0.00	0.000
1989	4	1.00	0.00	0.000
1989	5	64.60	0.00	0.000
1989	6	44.30	0.00	0.000
1989	7	380.20	107.63	22.321
1989	8	6.20	0.00	0.000
1989	9	173.00	30.41	6.307
1989	10	74.80	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1989	11	82.00	0.00	0.000
1989	12	17.80	0.00	0.000
1990	1	0.00	0.00	0.000
1990	2	4.00	0.00	0.000
1990	3	10.60	0.00	0.000
1990	4	12.20	0.00	0.000
1990	5	137.20	2.45	0.508
1990	6	27.00	0.00	0.000
1990	7	14.60	0.00	0.000
1990	8	112.60	15.12	3.136
1990	9	164.00	33.43	6.933
1990	10	50.80	0.00	0.000
1990	11	111.80	0.00	0.000
1990	12	8.40	0.00	0.000
1991	1	0.00	0.00	0.000
1991	2	0.00	0.00	0.000
1991	3	0.00	0.00	0.000
1991	4	70.72	6.79	1.408
1991	5	23.60	0.00	0.000
1991	6	252.60	43.32	8.984
1991	7	48.40	0.00	0.000
1991	8	257.60	95.06	19.714
1991	9	132.60	20.84	4.322
1991	10	476.00	343.41	71.218
1991	11	182.30	39.68	8.229
1991	12	0.00	0.00	0.000
1992	1	1.00	0.00	0.000
1992	2	0.00	0.00	0.000
1992	3	0.00	0.00	0.000
1992	4	15.60	0.00	0.000
1992	5	104.70	1.72	0.357
1992	6	34.30	0.00	0.000
1992	7	48.00	1.67	0.346
1992	8	36.00	0.00	0.000
1992	9	75.80	0.00	0.000
1992	10	158.00	34.75	7.207
1992	11	191.00	28.41	5.892
1992	12	14.50	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1993	1	0.00	0.00	0.000
1993	2	0.00	0.00	0.000
1993	3	0.00	0.00	0.000
1993	4	0.00	0.00	0.000
1993	5	26.00	0.00	0.000
1993	6	127.20	20.18	4.185
1993	7	9.00	0.00	0.000
1993	8	151.40	29.64	6.147
1993	9	244.30	48.35	10.027
1993	10	182.00	10.63	2.204
1993	11	187.00	50.20	10.411
1993	12	120.50	32.43	6.725
1994	1	0.00	0.00	0.000
1994	2	0.00	0.00	0.000
1994	3	0.00	0.00	0.000
1994	4	28.50	0.00	0.000
1994	5	74.50	0.00	0.000
1994	6	46.50	0.83	0.172
1994	7	209.00	59.06	12.248
1994	8	156.50	33.57	6.962
1994	9	115.50	7.64	1.584
1994	10	212.50	26.68	5.533
1994	11	108.50	15.64	3.243
1994	12	6.50	0.00	0.000
1995	1	23.00	0.00	0.000
1995	2	10.50	0.00	0.000
1995	3	40.00	0.00	0.000
1995	4	0.00	0.00	0.000
1995	5	450.00	250.09	51.864
1995	6	122.90	23.23	4.818
1995	7	188.90	16.27	3.374
1995	8	239.50	38.21	7.924
1995	9	124.50	41.73	8.654
1995	10	115.50	0.00	0.000
1995	11	17.50	0.00	0.000
1995	12	0.00	0.00	0.000
1996	1	0.00	0.00	0.000
1996	2	0.00	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1996	3	2.50	0.00	0.000
1996	4	72.00	0.00	0.000
1996	5	36.00	0.00	0.000
1996	6	256.00	86.17	17.870
1996	7	41.40	0.00	0.000
1996	8	277.50	91.03	18.878
1996	9	398.60	87.83	18.214
1996	10	164.50	0.00	0.000
1996	11	74.04	0.00	0.000
1996	12	334.40	102.52	21.261
1997	1	0.50	0.00	0.000
1997	2	0.00	0.00	0.000
1997	3	0.00	0.00	0.000
1997	4	51.00	0.00	0.000
1997	5	8.00	0.00	0.000
1997	6	12.00	0.00	0.000
1997	7	0.00	0.00	0.000
1997	8	11.00	0.00	0.000
1997	9	84.50	0.00	0.000
1997	10	7.30	0.00	0.000
1997	11	96.50	24.22	5.023
1997	12	174.00	40.91	8.484
1998	1	0.00	0.00	0.000
1998	2	0.00	0.00	0.000
1998	3	0.00	0.00	0.000
1998	4	27.00	0.00	0.000
1998	5	14.50	0.00	0.000
1998	6	73.00	0.54	0.112
1998	7	248.50	56.73	11.765
1998	8	137.60	3.52	0.730
1998	9	262.70	70.09	14.535
1998	10	303.00	52.34	10.854
1998	11	237.70	109.09	22.623
1998	12	132.00	29.01	6.016
1999	1	4.50	0.00	0.000
1999	2	0.00	0.00	0.000
1999	3	0.00	0.00	0.000
1999	4	14.50	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
1999	5	56.00	0.00	0.000
1999	6	42.00	0.00	0.000
1999	7	0.00	0.00	0.000
1999	8	82.00	0.00	0.000
1999	9	105.00	24.59	5.100
1999	10	210.00	90.48	18.764
1999	11	158.50	26.16	5.425
1999	12	50.50	1.17	0.243
2000	1	0.00	0.00	0.000
2000	2	97.50	0.14	0.029
2000	3	0.00	0.00	0.000
2000	4	39.50	0.00	0.000
2000	5	83.30	30.37	6.298
2000	6	77.80	0.00	0.000
2000	7	62.20	0.00	0.000
2000	8	208.80	30.91	6.410
2000	9	96.10	0.00	0.000
2000	10	55.20	0.00	0.000
2000	11	0.00	0.00	0.000
2000	12	69.00	0.23	0.048
2001	1	0.00	0.00	0.000
2001	2	0.00	0.00	0.000
2001	3	0.00	0.00	0.000
2001	4	27.20	0.00	0.000
2001	5	116.00	0.00	0.000
2001	6	13.80	0.00	0.000
2001	7	111.20	5.38	1.116
2001	8	52.40	0.00	0.000
2001	9	237.00	11.28	2.339
2001	10	194.00	26.00	5.392
2001	11	30.70	0.00	0.000
2001	12	44.80	0.00	0.000
2002	1	4.20	0.00	0.000
2002	2	0.00	0.00	0.000
2002	3	0.00	0.00	0.000
2002	4	17.40	0.00	0.000
2002	5	176.50	56.43	11.703
2002	6	129.00	28.60	5.931

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
2002	7	7.60	0.00	0.000
2002	8	59.30	0.09	0.019
2002	9	128.80	5.19	1.076
2002	10	0.00	0.00	0.000
2002	11	0.00	0.00	0.000
2002	12	0.00	0.00	0.000
2003	1	0.00	0.00	0.000
2003	2	0.00	0.00	0.000
2003	3	0.00	0.00	0.000
2003	4	0.00	0.00	0.000
2003	5	53.40	0.00	0.000
2003	6	157.60	29.53	6.124
2003	7	299.40	57.74	11.974
2003	8	133.50	3.58	0.742
2003	9	150.20	51.72	10.726
2003	10	195.40	59.38	12.314
2003	11	33.00	0.00	0.000
2003	12	3.00	0.00	0.000
2004	1	3.40	0.00	0.000
2004	2	0.00	0.00	0.000
2004	3	0.00	0.00	0.000
2004	4	15.80	0.00	0.000
2004	5	232.80	82.03	17.012
2004	6	8.80	0.00	0.000
2004	7	123.20	4.10	0.850
2004	8	47.00	0.00	0.000
2004	9	154.00	2.40	0.498
2004	10	103.20	0.38	0.079
2004	11	89.80	8.42	1.746
2004	12	0.00	0.00	0.000
2005	1	0.00	0.00	0.000
2005	2	0.00	0.00	0.000
2005	3	20.00	0.00	0.000

Year	Month	Rainfall in mm	Runoff in mm	Runoff in mm^3
2005	4	41.20	0.00	0.000
2005	5	109.00	0.41	0.085
2005	6	52.20	0.00	0.000
2005	7	136.10	39.50	8.192
2005	8	92.60	10.16	2.107
2005	9	94.20	0.00	0.000
2005	10	289.60	34.06	7.063
2005	11	145.90	3.24	0.672
2005	12	72.20	0.00	0.000
2006	1	0.00	0.00	0.000
2006	2	0.00	0.00	0.000
2006	3	21.40	0.00	0.000
2006	4	60.20	8.76	1.817
2006	5	53.86	0.00	0.000
2006	6	93.20	0.00	0.000
2006	7	27.80	0.00	0.000
2006	8	45.40	0.00	0.000
2006	9	205.40	51.53	10.686
2006	10	101.20	0.91	0.189
2006	11	128.20	23.17	4.805
2006	12	0.00	0.00	0.000
2007	1	0.00	0.00	0.000
2007	2	0.00	0.00	0.000
2007	3	0.00	0.00	0.000
2007	4	31.20	0.00	0.000
2007	5	40.60	0.00	0.000
2007	6	61.60	0.00	0.000
2007	7	203.00	41.94	8.698
2007	8	134.00	2.13	0.442
2007	9	22.00	0.00	0.000
2007	10	200.00	71.15	14.755
2007	11	0.00	0.00	0.000
2007	12	200.00	111.61	23.146

the available flow in the watershed a real world model can be arrived in the efficient water management of the watershed.

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Table 5 Average annual rainfall and runoff of Malattar sub-watershed

Year	Rainfall (mm)	Average rainfall (mm)	Runoff (mm)	Average runoff (mm)	Runoff
1971	1966.77	163.90	153.67	12.81	31.87
1972	1874.05	156.17	118.72	9.89	24.62
1973	1620.4	135.03	74.83	6.24	15.52
1974	1767.2	147.27	80.1	6.68	16.61
1975	1301.2	108.43	113.07	9.42	23.45
1976	964.19	80.35	159.1	13.26	32.99
1977	1088.1	90.68	163.13	13.59	33.83
1978	922.1	76.84	29.75	2.48	6.17
1979	1227.9	102.33	233.36	19.45	48.4
1980	412.2	34.35	25.16	2.1	5.22
1981	866.2	72.16	187.05	15.59	38.79
1982	816.24	68.01	214.51	17.88	44.99
1983	1183.1	98.59	214.51	17.88	44.99
1984	822.6	68.55	172.41	14.37	35.75
1985	995.12	82.93	103.98	8.67	21.56
1986	755.44	62.95	247.13	20.59	51.25
1987	765.25	63.77	248.71	20.73	51.58
1988	1028.7	85.73	119.71	9.98	24.83
1989	862.3	71.86	138.04	11.5	28.63
1990	653.2	54.43	51	4.25	10.58
1991	1443.82	120.32	549.1	45.76	113.87
1992	678.9	56.58	66.55	5.55	13.8
1993	1047.4	87.28	191.43	15.95	39.7
1994	958.3	79.86	143.42	11.95	29.74
1995	1332.8	111.07	369.53	30.79	76.63
1996	1656.94	138.08	367.55	30.63	76.22
1997	444.8	37.06	65.13	5.43	13.51
1998	1436	119.67	321.32	26.78	66.64
1999	723	60.25	142.4	11.87	29.53
2000	789.4	65.78	61.65	5.14	12.79
2001	827.1	68.93	42.66	3.56	8.85
2002	522.8	43.57	90.31	7.53	18.73
2003	1025.5	85.46	201.95	16.83	41.88
2004	778	64.83	97.33	8.11	20.18
2005	1053	87.75	87.37	7.28	18.12
2006	736.66	61.39	84.37	7.03	17.5
2007	892.4	74.36	226.83	18.9	47.041

References

CGWB (1998) Detailed guidelines for implementing the Ground Water estimation methodology-1997' Central Ground Water Board, Ministry of Water Resources, Government of India

Chow Ven Te, David R Maidment and Larry W Mays (1998) Applied Hydrology, McGraw-Hill Company, New York

Hand Book of Hydrology (1972) Soil and Water Conservation Department, Ministry of Agriculture, New Delhi

IRS Report (1998) 'Identification of ground water recharge areas in Salem and Villupuram using RS&GIS, District Reports, Department of Rural development,' Govt of Tamilnadu and TWARD, Institute of Remote Sensing, Anna University

Linsley RK (1982) 'Rainfall-runoff models an overview', rainfall runoff relationship, VP Singh, ed. Water Resources publications, Littleton, Colo., pp 3–22