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Estimation of runoff for Red hills watershed using SCS method and GIS

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Abstract

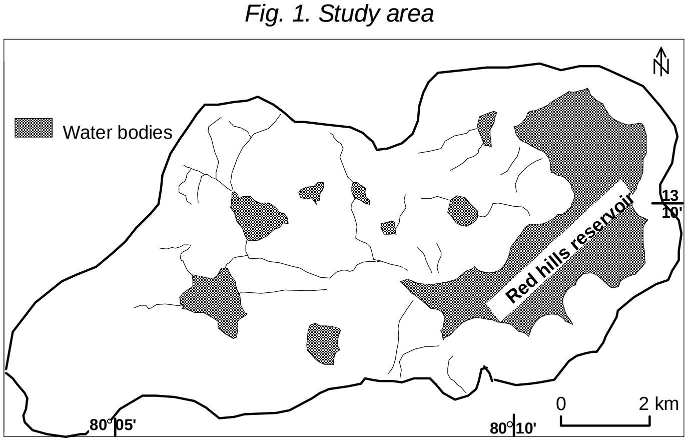
Soil Conservation Service (SCS) model was used for the estimation of runoff from an agricultural watershed namely the Red hills watershed, which is about 83.59 km^2 and part of Korattaliyar river basin catchment, situated in Thiruvallur district of Tamil Nadu state in India. The results show that a good correlation exists between rainfall and runoff and a minimum of about 66 mm rainfall per month is required to generate runoff in the area.

Keywords: Runoff, Red hills, Soil Conservation Service, watershed

Introduction

A watershed is the area covering all the land that contributes runoff water to a common point. It is a natural physiographic or ecological unit composed of interrelated parts and functions. In India, the availability of accurate information on runoff is scarce. However, in view of the quickening watershed management programme for conservation and development of natural resource and its management, the runoff information assumes great relevance. A good runoff model includes spatially variable parameters such as rainfall, soil types and land use /land cover etc. (Kumar, 1997). Quantification of runoff is critical importance where the basic reservoirs support drinking water needs of the populaces, as in the case of Red hills lake, which is an important source of water supply to Chennai city, India. In this study the Soil Conservation Service Curve Number (SCS CN method) (SCS, 1972) also known as hydrologic soil group method, was used. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and gives adequate results (Chatterjee *et al*., 2001; Ashish *et al*., 2003; Gupta & Panigrahy, 2008; Ratika Pradan *et al*., 2010). Generally, the model is well suited for small watersheds of less than 250 km^2 and requires details of soil characteristics, land use and vegetation (Sharma *et al*., 2001). Also advances in computational power and the growing availability of spatial data from remote sensing techniques have made it possible to use hydrological models like SCS curve number in spatial domain with GIS (Moglen, 2000; Geetha *et al*., 2008, Ramakrishnan *et al*., 2009).The model has been found to perform well without much calibration. In the present study, the runoff from SCS (Soil Conservation Services) Curve Number, model modified for Indian conditions has been used by using conventional database and GIS for Red hills watershed.

Fig. 1. Study area



Study area

The study area namely the Red hills, watershed (Fig. 1), situated near Chennai, India is located between 80° 03′ 45″ E to 80° 11′ 40″ E longitude and 13° 06′ 05″ N to 13° 12′ 25″ N latitude with an elevation ranging from 0 to 42 m above MSL (Mean Sea Level) and extends over an area of 83.59 km^2.The watershed receives an annual average rainfall of 152.42 mm and more than 80% of the rainfall is received during the NE monsoon (October-December).The minimum and maximum temperature varies in the range of 22°C to 39°C. The Red hill reservoir fed by watershed has a maximum capacity of 94.45 mcm.

Methodology

The hydrological soil group and soil maps of the watershed (Fig. 2, 3, 4 & 5) were used to demarcate landuse class and soil combinations in the study area, from which different curve number (CN) values were assigned and the weighted value of CN for the whole watershed was worked out. The CN value for Antecedent Moisture Condition (AMC II) can be converted into CN values for AMC I and AMC III. Substituting the value of curve number in equation 1, the retention capacity S was calculated. The direct runoff of the watershed was calculated using equation 2.

$$S = \frac{25400}{CN} - 254 \qquad (1)$$

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

Where,

Q = Runoff depth (mm) S = Maximum recharge capacity of watershed after 5 days antecedent rainfall

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Fig. 2. Hydrological soil group of the study area

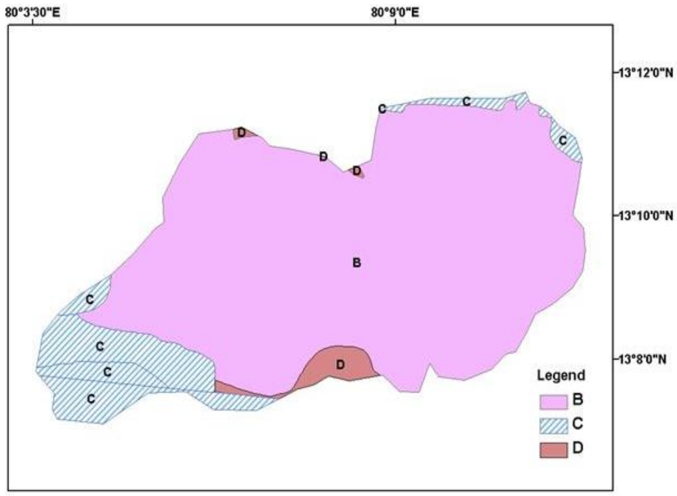


Fig. 3. Landuse and soil map of 2000 (B, C, D denotes hydrologic soil group)

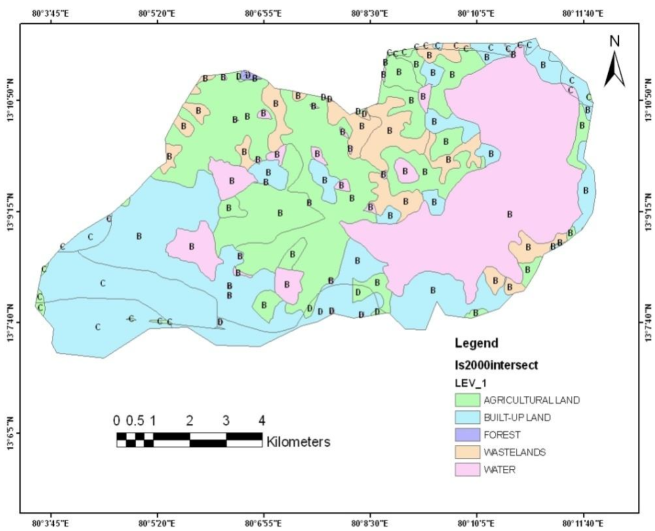


Fig. 4. Landuse and soil map of 2003 (B, C, D denotes hydrologic soil group)

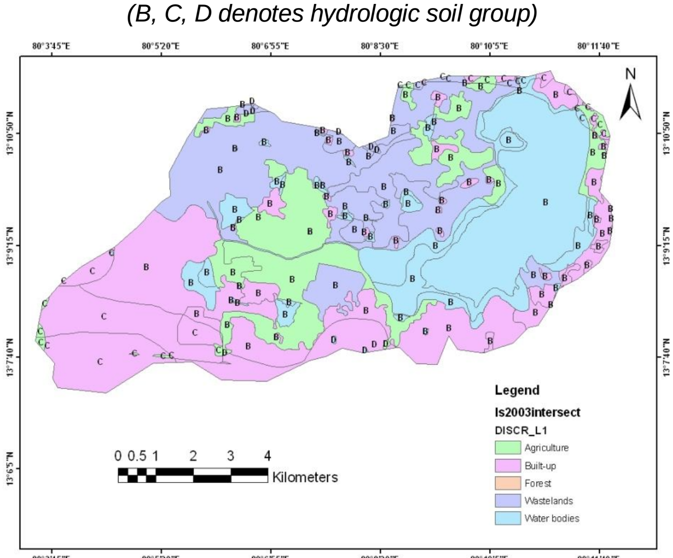


Fig. 5. Landuse and soil map of 2005 (B, C, D denotes hydrologic soil group)

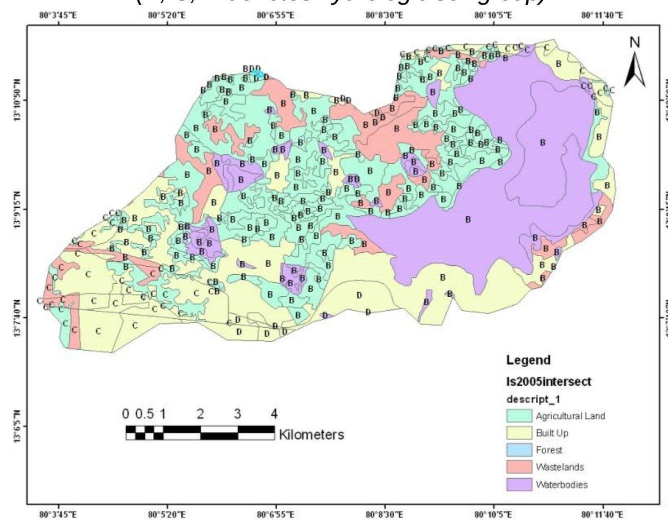


Fig .6. Runoff vs rainfall

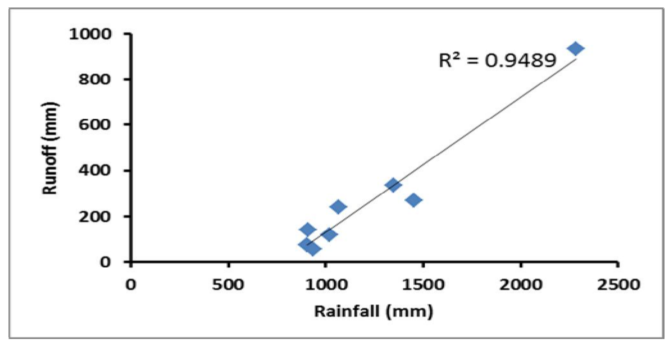


Fig. 7. Percentage of runoff versus rainfall

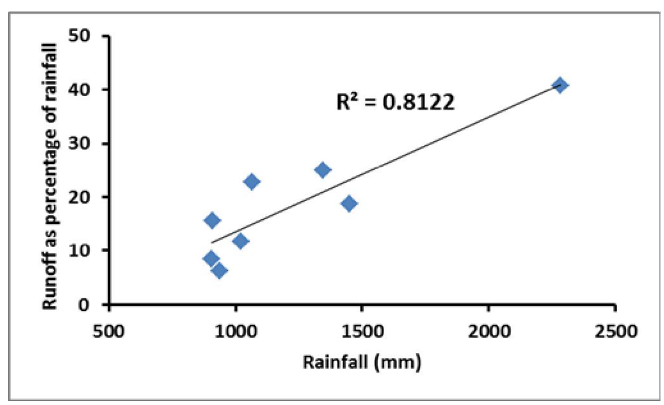
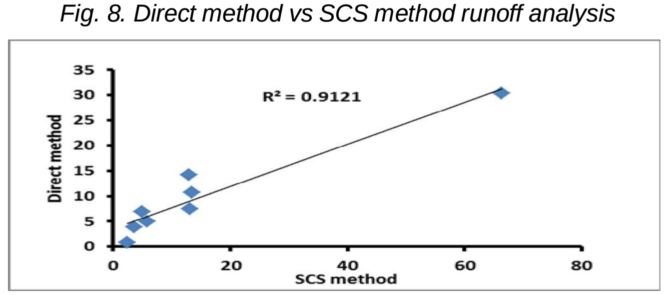


Fig. 8. Direct method vs SCS method runoff analysis



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Ia = 0.3 S (Initial abstraction of rainfall by soil and vegetation, mm)
CN = Curve number

$$CN = \frac{\sum [(N_i \times A_i)]}{A}$$

Table 1. Land use categories for the years 2000, 2003 and 2005

Year	Agricultural land(km^2)	Water bodies (km^2)	Waste land (km^2)
2000	28.75	21.18	33.66
2003	20.75	20.17	42.67
2005	23.92	23.12	36.55

Table 2. Rainfall and runoff generated in Redhills watershed (SCS method)

Year	(mm)	Jun	Jun	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	Runoff as % of rainfall
	RF*	56.9	61.8	99.4	71.0	247.0	230.6	53.0	0.0	217.5	0.0	33.3	30.1	1100.6	
1999-00	Runoff	0.0	0.0	0.7	0.0	29.6	19.8	0.0	0.0	7.9	0.0	0.0	0.0	57.9	5.3
	RF*	71.9	82.2	120.2	101.4	142.0	111.7	98.5	3.0	0.0	0.0	107.5	20.1	858.4	
2000-01	Runoff	9.5	0.0	0.0	0.0	15.4	0.0	0.1	0.0	0.0	0.0	11.2		36.2	4.2
	*RF**	42.4	194.4	47.3	172.3	385.1	193.4	203.5	52.0	0.0	0.0	0.0	38.0	1328.3	
2001-02	Runoff	0.0	12.4	0.0	0.8	93.7	5.0	23.3	0.0	0.0	0.0	0.0	0.0	135.2	10.2
	RF*	42.8	119.1	101.6	149.6	344.4	262.2	123.6	0.3	0.0	0.4	0.5	11.9	1156.6	
2002-03	Runoff	0.0	8.9	0.0	14.9	52.1	55.2	0.0	0.0	0.0	0.0	0.0	0.0	131.1	11.3
	RF*	31.5	151.2	101.9	159.1	203.3	173.0	131.2	32.9	16.0	16.0	20.0	21.1	1057.2	
2003-04	Runoff	0.0	0.0	9.7	7.6	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.4	2.3
	RF*	224.7	73.9	44.7	0.0	70.7	242.5	276.5	0.0	0.0	0.0	91.7	0.0	1024.8	
2004-05	Runoff	0.0	0.0	0.0	0.0	0.3	5.4	26.9	0.0	0.0	0.0	17.6	0.0	50.1	4.9
	RF*	58.4	100.3	98.6	229.8	616.0	489.7	488.6	0.6	0.0	24.9	56.5	19.0	2182.4	
2005-06	Runoff		2.0	0.0	13.8	258.9	142.5	245.7	0.0	0.0	0.0	0.0	0.0	662.9	30.4
	RF*	101.0	67.8	139.9	185.0	428.0	210.2	47.4	9.8	11.7	0.5	13.4	27.9	1242.9	
2006-07	Runoff	0.0	0.0	0.0	17.5	105.4	2.0	3.7	0.0	0.0	0.0	0.0	0.0	128.5	10.3

RF* = Rainfall

Where,
CN_i = Weighted curve number from 1to any number
A_i = Area with curve number CN_i
A = Total area of the watershed.

Results and discussion

A very large part of the Red hills watershed falls under Hydrologic Soil Group B with an area of 70.37 km^2 while Soil Group C carries an area of 10.66 km^2 and Group D 2.57 km^2. The land cover categories for the year 2000, 2003 and 2005 are given in Table 1.

Using the land use and soil maps the weighted curve number values obtained are 61.61, 67.05 and 69 for the years 2000, 2003 and 2005, respectively. Fig. 6 and 7 shows the trend of runoff versus rainfall as well as the percentage of runoff versus rainfall estimated using the equations 1 and 2. The monthly as well as annual runoff estimated using these equations are given in Table 2. The runoff as a percentage of rainfall sharply increases with significant increase in rainfall. This is reflected in a high correlation coefficient of 0.95 between runoff and rainfall. From Table 2 it is seen that a minimum of about 66 mm rainfall in a month is required to generate any runoff even in wet months. In drought years, such as 1999 and 2003, the runoff generated was seen to be very low (even the runoff as percentage of rainfall).

The direct runoff from the Red hills lake can be estimated by using the relationship:
R = Daily inflow in to Red hills reservoir - [(Discharge from Poondi - loss during conveyance to Red hills) + Discharge from Cholavaram - Conveyance loss)].

Conveyance losses can be approximately estimated from the difference between discharge from these lakes and inflow into red hills lake during non-rainy periods. From the Direct method and SCS method, shows a good correlation (Fig. 8).

Conclusion

For estimation of direct runoff from a watershed produced by a given precipitation, various models are available. This study shows that in Red hills lake catchment, a good correlation exists between rainfall and runoff and a minimum of about 66 mm rainfall in a month is required to generate runoff in the area. Using the land use and soil maps for the years 2000, 2003 and 2005; the weighted curve number values obtained are 61.61, 67.05 and 69. The runoff as a percentage of rainfall sharply increases with significant increase in rainfall. This is reflected in a high correlation coefficient of 0.95 between runoff and rainfall. The rainfall runoff comparative study between direct runoff and SCS runoff gives a high correlation (r = 0.91). In drought years, such as 1999 and 2003, the runoff generated was seen to be very low and this resulted in the feed reservoir remaining dry for most part of the respective periods. As a consequence, piped water supply was stopped for a significant period during these years in the Chennai city.

Table 3. Runoff estimated using direct method from the lake

Year	Direct method		
	RF(cm)	Runoff (cm)	Runoff as % of rainfall
1999-00	110.06	4.96	4.50
2000-01	85.84	3.86	4.50
2001-02	132.83	10.71	8.06
2002-03	115.66	7.45	6.44
2003-04	74.68	0.76	0.72
2004-05	124.45	6.93	6.76
2005-06	218.24	30.37	13.91
2006-07	121.06	14.25	11.47

Recommendations

The soil maps produced according to old American Soil Classification System (1938) must be renewed with soil maps prepared using new soil classification system that contain more correct and detailed information about soils. The CN is usually selected from available tables in either NEH-4 or various subsequent documents. This routine application of the CN methods using handbook estimates may lead to variable, inconsistent, or invalid results. Therefore, to get more precise and consistent estimation of CNs, it is necessity to develop credible methods of determining CNs from field measured data.

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