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Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment

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Abstract. This study aims to compute the runoff depth using Soil Conservation Service-Curve Number (SCS-CN) method using Remote Sensing and Geographic Information System (GIS). The SCS-CN is a quantitative description of land use / land cover / soil complex characteristics of a watershed. This model is a widely used hydrological model for estimating runoff using runoff and curve number (CN). The CN is an index that represents the watershed runoff potential. In the present study SCS-CN method is used for estimating the runoff depth in the Sheonath river upper sub-basin of Chhattisgarh State of India. The present study reveals that the remote sensing and GIS based SCS-CN can be effectively used to estimate the runoff from the river basins of similar geo-hydrological characteristics.

Keywords: Curve Number, GIS, Hydrologic Soil Group, Antecedent Moisture Condition.

1. Introduction

[1] Rainfall-runoff relationship is very complex, influenced by various storm and drainage characteristics. There are several approaches to estimate the runoff. [2] The Soil Conservation Service-Curve Number (SCS-CN) method developed by National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA) in 1969, is simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. In the present study SCS-CN method is used for estimating the runoff depth in the Sheonath river upper sub-basin of Chhattisgarh State. Base map, soil map, land use / land cover map and other associated map of the study area have been prepared using Indian Remote Sensing LISS-III data and Survey of India (SOI) topographic sheets. The objective of this study is to assess the quantity of surface runoff from the study area using GIS based The SCS-CN model is then applied to estimate the daily runoff from the sub-basin.

2. Study Area

A portion of Upper Sheonath sub-basin was considered for this study. The study area extends between latitudes 20°21'00" N and 20°37'30" N, and longitudes 80°54'00" E and 81°18'00" E. Apart from rainfall, tanks and dug wells are the source of water resources. The study area comprises of Balod (area= 549.41 sq.km.), Kanker (area= 88.01 sq.km.) and Rajnandgaon (area= 88.68 sq.km.) districts of Chhattisgarh State. There are about 23 rain gauge stations controlled by CG WRD. Raingauge station at Doundi was considered for this study. The study area comprises of three sub-basins portions namely upper Tandula (area= 39.88 sq.km.), Kharkhara (area= 106.87 sq.km.) and Tandula1 (area= 579.44 sq.km.). The study area map is shown in Fig. 1. Some of the data needed for the study were available from various sources and some of them were procured. The following paragraph gives brief information on the data sources.

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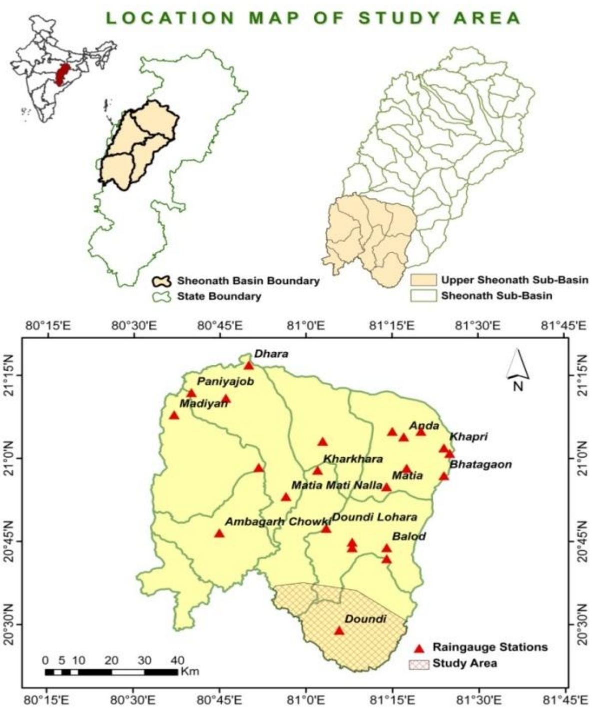

Fig. 1. Location Map of Study Area

Topographic data from Survey of India (SOI) toposheets (2005-2006) of scale 1:50,000 (64 D/14, 64 D/15, 64 H/2, 64 H/3, 64 H/6 and 64 H/7 was procured and used to identify the study area). Satellite Imageries: The Indian Remote Sensing satellite with Linear Imaging Self Scanning sensors (IRS – LISS III) satellite data of scale 1:50000 were collected from Bhuvan portal of Indian Space and Research Organization (ISRO), to use land use/ land cover of the study area. Daily rainfall data (1993-2005) from Doundi raingauge station from Water Resources Department Chhattisgarh were used. The soil data from National Bureau of Soil Survey & Land Use Planning (NBSS & LUP).

3. SCS-CN Method

[3] The first concept is that the ratio of actual amount of runoff to maximum potential runoff is equal to the ratio of actual infiltration to the potential maximum retention. This proportionality concept is expressed as

$$(P - I_a - Q)/S = Q/(P - I_a) \tag{1}$$

Where: P = precipitation in millimeters ($P \geq Q$); Q = runoff in millimeters;

S = potential maximum retention in millimetres; I_a = Initial Abstraction

[3] The second concept is that the amount of initial abstraction is some fraction of the potential maximum retention and thus expressed as:

$$I_a = \lambda S \text{ (for Indian condition } I_a = 0.3S\text{)} \tag{2}$$

Where: $$S = 25400/CN - 254 \tag{3}$$

Solving equation (1) and using equation (2) we have

$$Q = (P - I_a)^2/(P - I_a + S) \tag{4}$$

[4] For Indian condition I_a = 0.3S, thus equation (4) becomes:

$$Q = (P - 0.3S)^2/(P - 0.7) \tag{5}$$

Equation (5) is the rainfall – runoff relation used in the estimation of runoff from the storm rainfall.

4. Hydrologic Soil Group (HSG)

As per [5] National Engineering Handbook (NEH) developed by USDA, soils are classified in four groups A, B, C and D based upon the infiltration and other characteristics.

***Group A*:** Soils in this group have low runoff potential and high infiltration rate when thoroughly wet. Water is transmitted freely through the soil; ***Group B*:** Soils in this group have moderately low runoff potential and moderate infiltration rate when thoroughly wet. Water transmission through the soil is moderate; ***Group C*:** Soils in this group have moderately high runoff potential and low infiltration rate, when thoroughly wet. Water transmission is somewhat restricted through the soil; ***Group C*:** Soils in this group have high runoff potential and low very low infiltration rate, when thoroughly wet. Water transmission is restricted through the soil.

5. Antecedent Moisture Condition (AMC)

AMC indicates the moisture content of soil at the beginning of the rainfall event. The AMC is an attempt to account for the variation in curve number in an area under consideration from time to time. Three levels of AMC were documented by SCS AMC I, AMC II & AMC III. The limits of these three AMC classes are based on rainfall magnitude of previous five days and season (dormant season and growing season). [1] AMC for determination of curve number is given in Table 1.

Table 1: AMC for determination of CN value

AMC	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

6. Methodology

The methodology adopted in assessing the runoff potential of the study area is explained in the following steps.

a) Preparation of Land use/Land cover information of the study area using the satellite imageries in GIS. Land use / Land cover map of the study area is shown in Fig. 2.

b) Soil information of the study area obtained is used for making appropriate hydrological soil classification A, B, C & D as shown in Fig. 3.

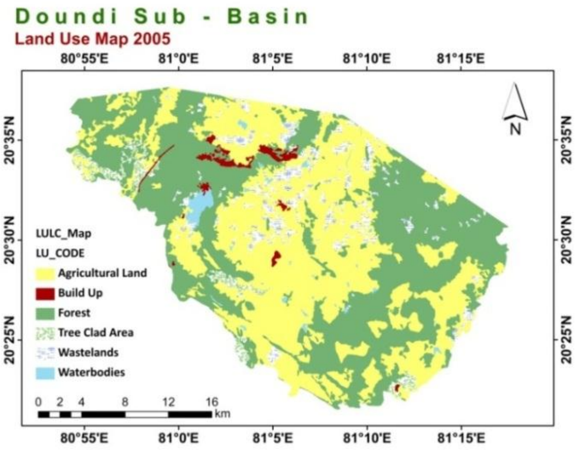

Fig. 2. Land Use map of Study Area

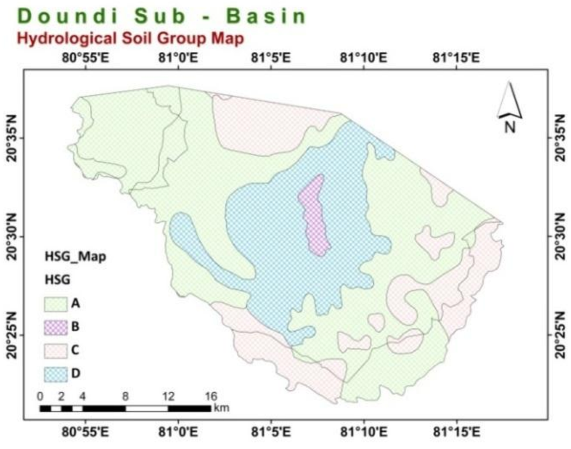

Fig. 3. Hydrologic Soil Group Map

c) Theissen polygons are established for each identified raingauge station. For each theissen cell, area weighted CN (AMC II) and also CN (AMC I) and CN (AMC III) were determined. [1] CN for AMC II is given in Table 2.

CN for AMC I is calculated as:

$$CN_I = CN_{II}/(2.281 - 0.01281 CN_{II}) \tag{6}$$

CN for AMC III is calculated as:

$$CN_{III} = CN_{II}/(0.427 + 0.00573 CN_{II}) \tag{7}$$

SCS runoff CN for hydrologic soil cover complex under AMC II condition for the study area is given in Table 2. [6] Area weighted composite curve number for various conditions of land use and hydrologic soil conditions are computed as follows:

$$CN = (CN_1 \times A_1) + (CN_2 \times A_2) + \cdots \dots \dots + (CN_n \times A_n)/A \tag{8}$$

Where A_1, A_2, A_3, …., A_n represent areas of polygon having CN values CN_1, CN_2, CN_3,…..,CN_n respectively and A is the total area. The composite curve number for different AMC conditions are as follows: AMC I = 47.17; AMC II = 61.08; AMC III = 74.34.

d) Using equation (5) with rainfall data, corresponding runoff series is derived.

Table 2: Curve Number for HSG under AMC II Conditions

Land Use	**Hydrologic Soil Group**			
	A	**B**	**C**	**D**
Agriculture Land	76	86	90	93
Buid Up	49	69	79	84
Tree cover	41	55	69	73
Forest	26	40	58	61
Wasteland	71	80	85	88
Water bodies	97	97	97	97

Table 3: Sample of Daily Rainfall Runoff Computation of Study Area

Day	**Month**	**Year**	**Daily rainfall (mm)**	**5-day cumulative rainfall**	**Season**	**AMC Condition**	**Curve number (CN)**	**Surface retention (S)**	**Daily runoff (mm)**
15	6	1993	0	8	D	AMC I	47.17	284.4778	0
16	6	1993	70	70	D	AMC III	74.34	87.67339	14.53523
17	6	1993	0	70	D	AMC III	74.34	87.67339	0
18	6	1993	0	70	D	AMC III	74.34	87.67339	0
19	6	1993	0	70	D	AMC III	74.34	87.67339	0
20	6	1993	5	75	D	AMC III	74.34	87.67339	0
21	6	1993	0	5	D	AMC I	47.17	284.4778	0
22	6	1993	7.2	12.2	D	AMC I	47.17	284.4778	0
23	6	1993	0	12.2	D	AMC I	47.17	284.4778	0
24	6	1993	0	12.2	D	AMC I	47.17	284.4778	0
25	6	1993	9.3	16.5	D	AMC II	61.08	161.8481	0
26	6	1993	0	16.5	D	AMC II	61.08	161.8481	0
27	6	1993	0	9.3	D	AMC I	47.17	284.4778	0
28	6	1993	0	9.3	D	AMC I	47.17	284.4778	0
29	6	1993	27.4	36.7	D	AMC III	74.34	87.67339	0.013581
30	6	1993	0	27.4	D	AMC II	61.08	161.8481	0
1	7	1993	28.4	55.8	D	AMC III	74.34	87.67339	0.04903
2	7	1993	0	55.8	D	AMC III	74.34	87.67339	0
3	7	1993	0	55.8	D	AMC III	74.34	87.67339	0
4	7	1993	0	28.4	D	AMC III	74.34	87.67339	0
5	7	1993	0	28.4	D	AMC III	74.34	87.67339	0
6	7	1993	0	0	D	AMC I	47.17	284.4778	0
7	7	1993	114	114	D	AMC III	74.34	87.67339	43.85514
8	7	1993	12.2	126.2	D	AMC III	74.34	87.67339	0
9	7	1993	14.4	140.6	D	AMC III	74.34	87.67339	0
10	7	1993	2.3	142.9	D	AMC III	74.34	87.67339	0
11	7	1993	0	142.9	D	AMC III	74.34	87.67339	0
12	7	1993	9	37.9	D	AMC III	74.34	87.67339	0
13	7	1993	45.3	71	D	AMC III	74.34	87.67339	3.383507
14	7	1993	13.2	69.8	D	AMC III	74.34	87.67339	0
15	7	1993	20	87.5	D	AMC III	74.34	87.67339	0

D = Dormant Season

7. Result & Discussion

In the GIS based SCS-CN model, the CN and daily rainfall values were used as inputs to compute daily runoff. For various curve numbers, the runoff estimated for different AMC conditions. The individual composite curve number was computed for all study area for AMC II condition. Using equation (5) the daily runoff depth were computed. The sample of daily rainfall runoff computation is shown in Table 3. From the daily runoff, monthly and annual values can be derived. The sample of daily and monthly runoff computation is presented in Table 3.The runoff depths are computed for each rainfall event for the years 1993-2005 is shown in Table 4 and the relationship between rainfall-runoff is shown in Fig. 4. [2] For those rainfall events whose intensity is less than 0.3S, the runoff depth is taken as zero.

Table 4: Runoff Values (1993-2005)

Year	Rainfall (mm)	Runoff (mm)
1993	932.9	87.61116345
1994	1398.1	177.7679955
1995	337.1	159.0557422
1996	1003.8	179.2897151
1997	744.4	47.56410764
1998	822.2	36.59633216
1999	737.1	59.66273246
2000	606.3	27.16940485
2001	1609	266.4422655
2002	652.5	69.06983142
2003	394.3	63.18721288
2004	1075.51	102.116767
2005	1272.3	199.1441498

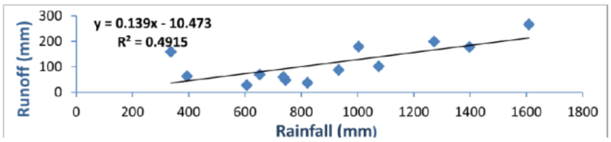

Fig. 4. Rainfall-Runoff relationship

In the present study, the process of runoff computation using SCS-CN model in GIS environment has been presented. Remote sensing and GIS with application of SCS-CN model proves to be a powerful tool for runoff estimation. [2] Thus, land use planning and watershed management can be done effectively and efficiently using SCS-CN number method with GIS.

8. Acknowledgement

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