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Estimation of Runoff Potential by the Application of Curve Number Method in GIS Platform

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Abstract**: *Estimation of direct runoff is essential for planning and development of watershed. In this study estimation of the same is carried out by applying Soil Conservation Service-Curve Number (SCS-CN) model technique with Geographic Information System (GIS) approach. The SCS-Curve Number model is a hydrological model which is widely used for estimation of runoff volume generated from the rainfall event. The said model mathematically describe the rainfall – runoff relationship and uses rainfall data and Curve Number (CN) as the inputs. The Curve Number is an empirical index depends on the soil complex, land use and hydrological condition of the area. The SCS-CN method with GIS approach has been adopted for predicting the runoff volume in the catchment of upper Mahanadi, which is upstream of the confluence of Mahanadi and Pairi River. The catchment area under consideration is 8086 sq.km. The study area climate condition is tropical monsoon type which receives the normal annual rainfall of 1360 mm. The maximum precipitation about 86% of the total precipitation, observed in the monsoon period from July to Mid of September. Survey of India (SOI) topographic sheets and Indian Remote Sensing satellite image LISS-III were used to prepare thematic maps of the study area. Thematic maps and hydrological data were used to generate Curve Number map and Hydrological Soil Group map. The SCS-CN method is very useful to compute runoff volume from the land, which quatify the direct drain to the river or streams. The outcome of this study is useful for watershed planning and development effectively for the study area.***

Keywords: GIS, Remote Sensing, Curve Number, HSG, AMC .

I. INTRODUCTION

Rainfall-runoff modelling is important tool to compute runoff volume from storm rainfall data. The total runoff volume depends upon the characteristics of drainage and rainfall event [1, 7]. In hydrological cycle rainfall is one of the important components [11]. It is not possible to measure the rainfall amount accurately, as it varies from place to place, but we can measure precisely the amount of surface runoff in the form of discharge at the outlet of any hydrological unit. The runoff potential provides the knowledge of water availability in a river basin. Now a days Remote sensing and GIS technique, makes easier to perform hydrological analysis of any water resource problem at basin level. There are number of techniques for assessment of runoff volume from the given rainfall data [5, 8]. The Soil Conservation Service-Curve Number (SCS-CN) method was developed by United States Department of Agriculture (USDA), National Resources Conservation Service (NRSC), in 1969 [10], to predict direct runoff volume for the given rainstorm [7]. It is well-established conceptual model and predictable in nature [2, 8]. SCS-Curve Number method is a quantitative description of characteristics of a basin i.e. land cover and soil complex. These characteristics can be derived by applying remote sensing products to GIS. In this study,the SCS-CN method in GIS environment has been adopted for predicting the runoff volume in the catchment of upper Mahanadi, which is upstream of the confluence of Mahanadi and Pairi River. Satellite image LISS III and topographic sheets have been used to prepare Drainage map, Soil map, Land Use / Land Cover map and other thematic maps of the study area. Because of the significance of spatial analysis in hydrological modeling GIS constitutes a powerful modeling tool [5, 8]. ArcMap is being utilized for this purpose. The main aim of this research is to quantify the runoff by applying GIS based SCS Curve Number model.

II. STUDY AREA

In present study the Upper Mahanadi catchment that lies on the u/s of the Mahanadi and Pairi river confluencing at Rajim was taken as the study area. The study area geographical extent lies between 80°30’ and 86°50’ East longitudes and 19°20’ and 23°35’ North latitudes. The catchment area under consideration is 8086 sq.km. The average maximum and minimum elevation of the basin is 877 m and 426 m respectively. The average slope in hilly reach is 1 in 450 that flattens in plains by 1 in 1000. The land types are forests, cultivated and bunded lands. The soil type in hillyregion is hard sandy soil well mixed with some portion of clay.

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In plains the soil type is black soil to black cotton soil that facilitates water retention for Rabi crops. The study area climate condition is tropical monsoon type which receives the normal annual rainfall of 1360 mm. The maximum precipitation about 86% of the total precipitation, observed in the monsoon period from July to Mid of September. Rain fall is spatially homogeneous, and its intensity is close to national average.

There are five major reservoirs existing in the study area viz. Murumsilli Reservoir, Dudhawa Reservoir and Ravishankar Sagar Reservoir on Mahanadi River whereas Sikasar Reservoir was built on river Pairi which is a first major tributary of Mahanadi and Sondur Reservoir on the Sondur River.

Table 1: Location of various reservoirs in the study area

Reservoir Name (Construction Year)	Longitude	Latitude	Catchment Area(sqkm)
Ravishankar (1978)	81°34′12″ E	20°37′1″N	5044.82
Moorumsilli (1923)	81°39′26″ E	20°32′6″N	506.29
Dudhawa (1965)	81°45′16″ E	20°18′4″N	689.99
Sondhur (1987)	82°6′9″E	20°13′41″ N	390.19
Sikasar (1976)	82°19′12″ E	20°31′9″N	437.08

In the present study about 15 rain gauge stations for the study area have been considered, which are controlled by CG WRD. Catchment of upper Mahanadi basin, has been delineated in GIS from SOI toposheets and represented byFigure 1.

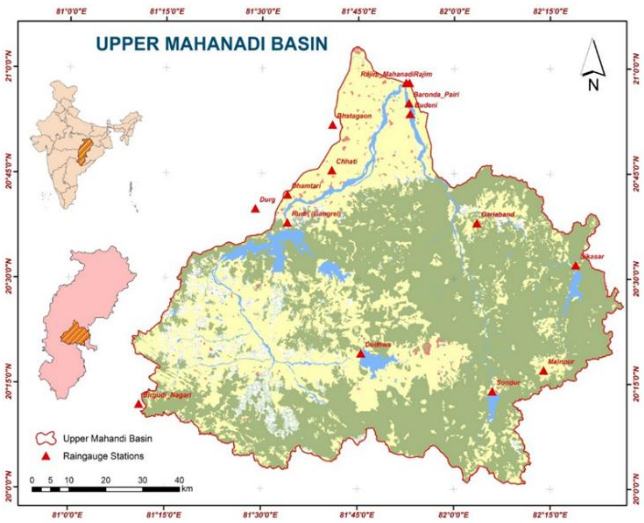

Figure 1. Study Area Map

Topographic data, toposheets (64 H/10, 64 H/13, 64 H/14, 64 H/15) of scale 1:50,000 obtained from Survey of India (SOI) were used for study area delineation. Satellite Imageries from Indian Space and Research Organization (ISRO) Bhuvan portal on scale 1:50000 were collected for LU/ LC map. The soil data has been taken from National Bureau of Soil Survey & Land Use Planning (NBSS & LUP). Daily rainfall data of required rain gage stations have been procured from Water Resources Department Chhattisgarh for the time periodfrom 2009-2017.

III. SCS-CN METHOD

The SCS-CN method computes direct runoff through an empirical formula.

$$\frac{(P-I_a-Q)}{S} = \frac{Q}{(P-I_a)} \qquad (1)$$

Where,
P represents the total rainfall (in millimeters),
Q represents the direct runoff (in millimeters), ($P \geq Q$)
S represents the potential maximum retention (in millimeters),
I_a represents the initial abstraction.

The initial abstractions, I_a, could be defined as a percentage of the potential maximum retention S.

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

The relation between potential retention **S** and the curve number CN is expressed as

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

From equation (1) and (2)

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

The equation (4) is based on the trends observed in data from study area, therefore it is an emperical equation.
Taking I_a= 0.3S *F*or Indian condition equation (4) becomes

$$Q = \frac{(P-0.3\,)^2}{(P-0.7S)} \qquad (5)$$

Equation (5) represents the rainfall – runoff relationship which is used to estimate runoff depth from the given rainfall.

IV. HYDROLOGIC SOIL GROUP (HSG)

Table2 represents Natural Resource Conservation Service (NRCS) Soil classification which is based on runoff potential of soil.

Table 2: Soil Classification

Soil Group	Rate of Infiltration	Rate of Water transmission	Runoff Potential of soil
Group A	high	high	low
Group B	moderate	moderate	moderately low
Group C	low	somewhat restricted	moderately high
Group D	very low	restricted	high

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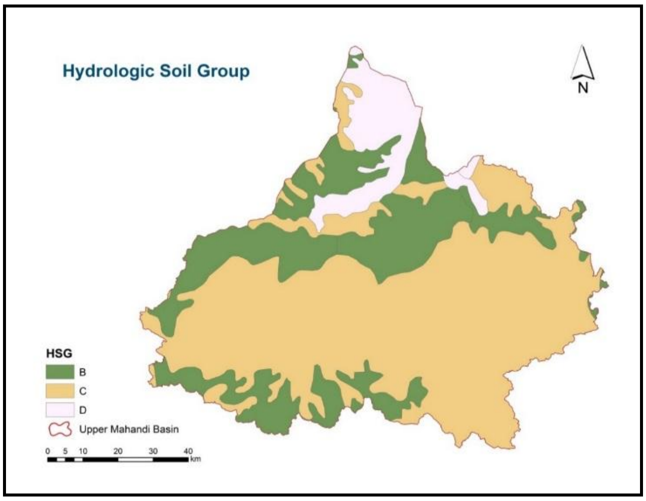

Figure 2. Study area Soil map

Figure 2 represents soil complex of the study area as per HSG classification.

V. ANTECEDENT MOISTURE CONDITION (AMC)

Antecedent Moisture Condition is wetness index of the basin at the beginning of the rainfall event [3,6]. AMC is classified in the three levels as follows:

AMC I - in this level condition of soil is dry.
AMC II - in this level condition of soil is average.
AMC III – in this level soil condition is saturated due to 5 days Antecedent Rainfall.

AMC II condition is an average condition for Runoff CN and soil type, so equivalent CN for AMC I and AMC III conditions [4], can be computed by the Equations (6) and (7)

Calculation of CN (AMC I condition):

$$\mathbf{CN_I} = \frac{\mathbf{CN_{II}}}{(\mathbf{2.281-0.01281CN_{II}})} \quad (6)$$

Calculation of CN (AMC III condition):

$$\mathbf{CN_{III}} = \frac{\mathbf{CN_{II}}}{(\mathbf{0.427+0.00573\ CN_{II}})} \quad (7)$$

Table 3: Antecedent Moisture Conditions

AMC CLASSES	Total five days Antecedent Rainfall in mm	
	Dormant Season	Growing Season
AMC I	< 13	< 36
AMC II	13 - 28	36 - 53
AMC III	> 28	> 53

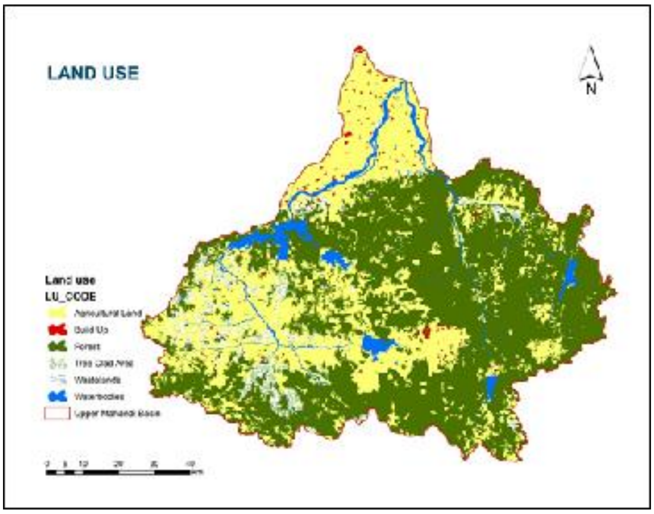

Figure 3. Study area Land Use/ Land map

VI. METHODOLOGY

The overall steps carried out to compute the runoff potential is described in the following points:

1. Study area delineation and preparation of study area map in GIS, represented by Figure 1.
2. Preparation of soil map in GIS, represented by Figure 2.
3. Preparation of LU/LC map in GIS by using the LISS III satellite data shown in Figure 3.
4. Preparation ofTheissen polygons for identified rain-gauge stations using GIS as shown in Figure 4 & Table 4.
5. Computation of weighted area curve number CN (for AMC II), CN (for AMC I) and curve number CN (for AMC III) as shown in Table 3.

$$\mathrm{CN} = \frac{[\Sigma(\mathrm{CN_i} \times \mathrm{A_i})]}{\mathrm{A}} \quad (8)$$

Where, CN represents weighted Curve Number
A_i Represents Area from 1 to n (having curve number CN_i)
CN_iRepresents Curve Number from 1 to n
'A' is the Total Area.
'n' is any number.

6. Computation of runoff for corresponding rainfall data by using Equation (5)

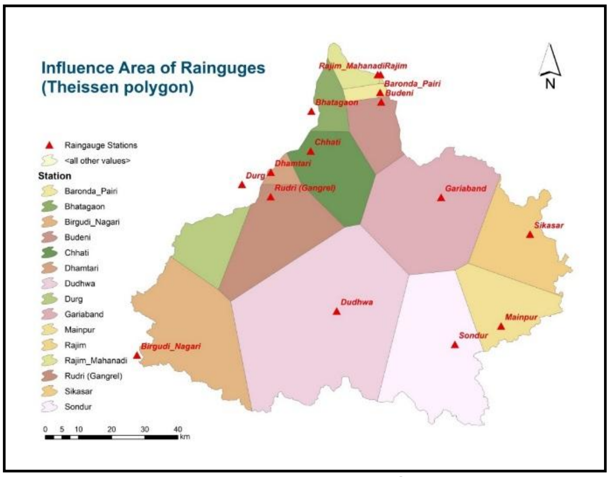

Figure 4. Theissen Polygon of study area

Table 4. Raingauge Station Area Weightage

S. No.	Raingauge Station Name	Area (sq. Km.)	Weightage
1.	Birgudi_Nagari	879.50	0.108
2.	Sondur	1034.55	0.127
3.	Gariaband	1105.65	0.135
4.	Durg	314.34	0.038
5.	Mainpur	465.45	0.057
6.	Dudhwa	2014.32	0.247
7.	Sikasar	554.41	0.068
8.	Rajim_Mahanadi	95.64	0.012
9.	Rajim	2.26	0.000
10.	Chhati	487.03	0.060
11.	Budeni	277.25	0.034
12.	Bhatagaon	155.99	0.019
13.	Baronda_Pairi	51.62	0.006
14.	Rudri (Gangrel)	667.13	0.082
15.	Dhamtari	62.10	0.008

Table- 5 shows study area SCS runoff Curve Number for HSG under AMC II condition [6]. Weighted composite CN was computed for land use type and HSG classification of the area, as shown in Figure 5.

Table 5: Runoff Curve Number for HSG under AMC II Conditions

Land Use Type	HSG			
	Group A	Group B	Group C	Group D
Built up	49	69	79	84
Agricultural Land	76	86	90	93
Forest	26	40	58	61
Tree cover	41	55	69	73
Waterbodies	97	97	97	97
Wasteland	71	80	85	88

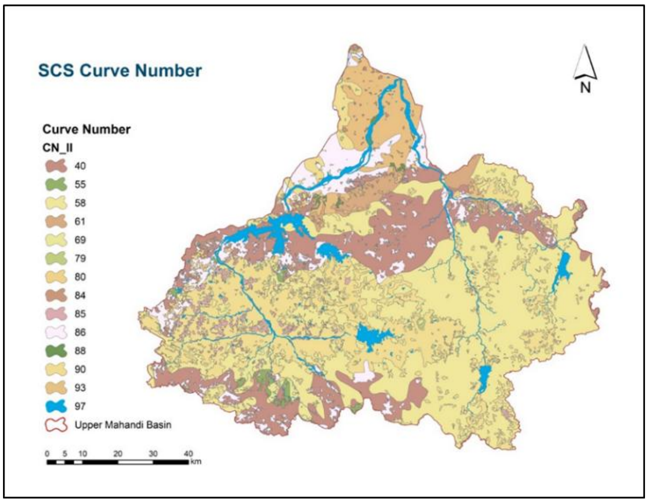

Figure 5. Curve Number map

VII. RESULT

In computation of daily runoff, daily rainfall data and the Curve Number have been utilized as input data in the SCS-CN model with GIS approach. Estimation of runoff have been done for various Curve Numbers and Antecedent Moisture Conditions. For the whole study area, the composite curve number (for AMC II condition) was computed. The daily runoff depth was computed using equation (5) [9, 10]. Daily runoff values have been used to derived Monthly and annual runoff values. The runoff predicted for rainfall events for the period of year 2009-2017 is shown in Table 6. rainfall-runoff relationship was established and is presented in Figure 6. For rainfall intensity having values less than 0.3S, value of runoff depth was considered as zero.

Table 6: Value of Runoff obtained from SCS-CN model

S. No.	Year	Rainfall (in mm)	Runoff (in mm)
1	2009	910.50	179.92
2	2010	1462.02	192.31
3	2011	1016.03	104.07
4	2012	1102.18	112.01
5	2013	1240.56	135.09
6	2014	1323.47	348.24
7	2015	842.63	91.35
8	2016	1122.72	70.59
9	2017	810.97	57.89

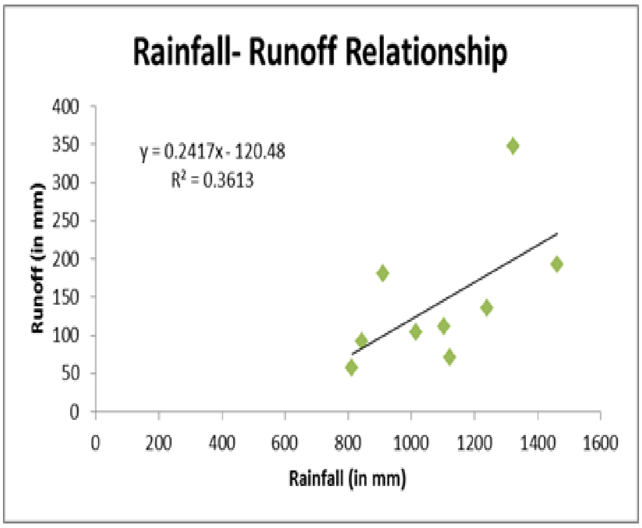

Figure 6. Rainfall- Runoff relationship

VIII. CONCLUSION

In this study, SCS Curve Number method in Geographical Information System environment was applied to predict runoff depth for the given rainfall data. The relationship was established between daily rainfall and estimated runoff (Year 2009-2017) for catchment of upper Mahanadi. HSG maps were developed for the study area from the soil maps, soil classification and soil characteristics of the study area. The SCS-Curve Number method with GIS approach proves to be a prevailing means to estimate the runoff volume. SCS-Curve Number method proves to be simple, reliable and effective model for computing the runoff. In the present study the runoff is simulated. The model can be applied for not only water availability study but also for studying the urban drainage, flood forecasting, future urbanization impact and many others.

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