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Runoff Estimation for Darewadi Watershed using RS and GIS

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***Abstract*: An accurate understanding of the hydrological behavior of a watershed is important for effective management. Runoff is the most basic and important data needed when planning water control strategies/ practices, such as, waterways, storage facilities or erosion control structures. The most popular method used for runoff estimation is SCS runoff curve number method. In the present study Darewadi watershed was taken as case study for highlighting the role of GIS and RS in estimation of runoff from the watershed by SCS curve number method using OVERLAY techniques. 20 years daily rainfall data was acquired from Indian Metrological Department (IMD), Pune. The study reveals that the SCS-CN model can be used to estimate surface runoff depth when adequate hydrological information is not available.**

***Index Terms*: SCS CN, Runoff estimation, AMC, GIS, RS.**

I. INTRODUCTION

Remote sensing Techniques are more reliable, up-to-date, and faster than conventional techniques. It plays a vital role in acquisition of data in the different aspects of landuse and soil cover, which are essential parameters in the field of watershed runoff estimation. GIS is capable of handling spatial and aspatial data when compared to conventional information system. It also identifies the spatial relationships between map features. The use of GIS technology as a spatial data management and an analysis tool provides an effective mechanism for hydrologic/ hydraulic studies.

Thus the remote sensing along with GIS application aid to collect, analyze and interpret the data rapidly is very much helpful for watershed planning. For un-gauged watersheds accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. This information is essential in dealing with watershed development and management problems. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. In this study SCS CN modified for Indian condition has been used for generation of runoff of the watershed [8].

The Soil Conservation Services (SCS) runoff model is useful for evolving the runoff potential for every feature utilizing different antecedent moisture condition (AMC) to obtain runoff potential layer and for computing the peak runoff rate. The peak runoff rate can be utilized to calibrate the conventional rational formula. The sites for water conservation measures not only depend on annual rainfall but also on other terrain factors like, slope, aspect, ground undulations, soil permeability and land use variation in space and time.

II. STUDY AREA

The Darewadi watershed (watershed no. GV-113) having area of 3569 Hectares, is a part of Ahmednagar district in Maharashtra. This area is marked by Deccan basalt and is bounded by Latitudes $19^0$20' to $19^0$30' and Longitudes $74^0$15' to $74^0$25' as per Survey of India topo sheet map 47 I/7 (Table I). The location map of Darewadi watershed is presented in fig. 1. Before 1996 this village was Drought Prone and tanker fed village. The study area is marked by an undulating topography with a Maximum height of 770 Meters and Minimum height of 640 Meters with a height variation of 130 Meters (SOI Toposheet). The area is made up of Lava flows. Perforated and aa type Basaltic rocks are found in the area. Overall slopes in the watershed area are towards South East and gentle.

The villagers were migrating to nearby areas in search of employment and for sugarcane cutting. Due to these problems the villagers approach WOTR to undertake this area for the watershed development under Indo-German Watershed Development Program (IGWDP). Then watershed development programme was started in year 1996.

Table I Details of Survey of India's Topographic Maps

Topo sheet No	Scale	Year of Survey	Year of Publication
47 I/7	1:50,000	1970-71	1972

A. Climate and Rainfall

This region falls in the rain shadow semi arid region of Maharashtra state. The area receives all of its annual rainfall from the south-west monsoon. The rainy session normally starts in the last week of June and is over by the beginning of October. The normal average rainfall is 500-550mm.

B. Temperature

The temperature data has been collected from the Department of Metrology, Pune. As per the data, during the winter, minimum temperature goes down to about 7.3^0C while maximum temperature is in the range of 40^0C to 44^0C.

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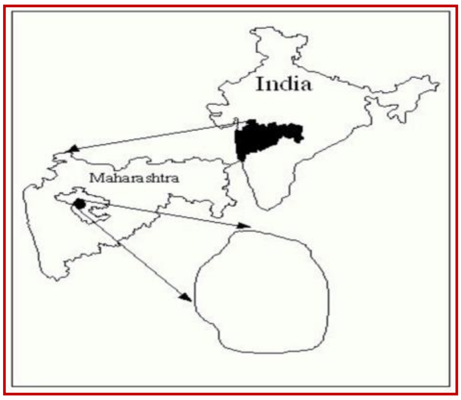

Fig. 1: Location Map of Darewadi Watershed

C. Geomorphology and Geology

The region is a part of Deccan volcanic province (DVP). Deccan Trap covers an area of about half a million square km of the Indian peninsular being spread very large tracts of Gujarat, Maharashtra, Madhya Pradesh and some part of Karnataka. The extravagant size and volume of Deccan volcanic province has been the centre of attraction for the earth scientists. Various aspects of Deccan trap such as geophysics and magnetic surveys and geochemical studies have been carried out by many researchers. Deccan trap are result of stupendous outburst of volcanic energy through fissure eruptions.

The area comprises of thick basaltic flows and form an integral part of the main Deccan volcanism. The basaltic flows are generally horizontal and consist of one or more of the following petro graphic types: Basalts (Massive, vesicular, amygdaloidal), the basalt show weathering and have given rise to black cotton soil in study area.

D. Soil Characteristics

The physical, chemical, and mechanical properties of soils like color, texture, composition, and porosity vary in space. The soils of Darewadi watershed can be divided into three distinct soil zones as,

Soil on the Pathar

The pathar areas have normal soil depth 10 to 20 cm. The productivity of soil is slightly good. Soil texture is mainly sandy clay to clay loam. Beneath the soil layer, there is a layer of hard murum having low infiltration and water holding capacity. The overall productivity of this soil is medium.

Soil on the Slopes

The lands on the slopes have limited soil depth ranging from 0 to 20 cm. Most of lands on the upper slopes have negligible soil cover. Soil texture ranges from gravely sand to gravely loamy sand, hence area is unfit for agriculture.

Soil in the Valley

This soil is formed by deposition of the eroded top soil from the pathar and slopes. This soil is fertile having depth ranging from 20 to 90 cm. The texture is mainly sandy clay loam.

E. Watershed Divisions

For the convenience of further understanding the watershed the Darewadi watershed is divided into three subdivisions as follows:

i) Upper Catchment Area: This area has a highest elevation of 780m above mean sea level. The upper catchment comprises an area of approximately 350 Ha. of which around 295 ha. is under the forest department. The slopes are steep ranging 20 to 40%.

ii) Middle Catchment Area: It is undulating with slopes ranging from 10 to 20%.

iii) Lower Catchment Area: It is mildly undulating with slopes ranging from 1 to 10%.

III. SATELLITE DATA

Space technology is improving day-by-day giving us improved satellite and sensors for acquisition of remote sensing data. Recently, on 17th August, 2004 India has launched its new satellite IRS-P6 (Resource Sat). IRS-P6 carries three cameras with vastly improved spatial resolutions, a high resolution Linear Imaging Self Scanner (LISS-IV) operating with 5.8 meter spatial resolution, steerable up to ± 26^0 across track to obtain stereoscopic imagery and achieve five day revisit capability. A medium resolution LISS-III operating in three spectral bands visible, VNIR and SWIR band with 23.5 meter spatial resolution; and an Advanced Wide Field Sensor (AWiFS) operating in three spectral bands in VNIR and one band in SWIR with 56 meter spatial resolution. Within LISS-3 the spatial resolution of SWIR band is 23.5 meter, which was previously used to come at 70.5 meters. Multi date satellite data is acquired from RRSSC Nagpur table II shows the details of satellite data used for the study area.

Table II Details of Satellite Data Used

Pat/ Row	Satellite ID	Sensor	Product Date
95/59	IRS 1D	LISS III	20-01-1999
95/59	IRS P6	LISS III	09-01-2007

IV. METHODOLOGY

The Curve Number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex method is a versatile and widely used procedure for runoff estimation. In this method several important properties of the watershed namely soil's permeability, land use and antecedent soil water conditions are taken into consideration. Their runoff producing capability is expressed by a numerical value varying between 0-100. The main reason behind the selection of SCS method is that in the past 30 years the SCS method has been consistently usable results for runoff estimation. Once the data has been gathered, the typical process for estimating the curve number for drainage is as follows:

i. Define and map the boundaries of the drainage basin(s) for which curve number(s) will be calculated. Determine the area of the drainage basin(s)

ii. Map the soil types and land use for the drainage basin(s) of interest.

iii. Converts the soil types to hydrologic soil groups.

iv. Overlay the land use and hydrologic soil group maps, identify each unique land use soil group polygon, and determine the area of each polygon.

v. Assign a curve number to each unique polygon, based on standard SCS curve number tables.

vi. Overlay the drainage basin map on the land use soil group polygons.

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vii. Calculate the curve number for each drainage basin by area-weighting the land use-soil group polygons within the drainage basin boundaries.

A. Soil Conservation Services (SCS) Runoff Model

Curve number (CN) is an index that represents the combination of hydrologic Soil group and land use and land treatment classes. Empirical analysis suggests that the CN was a function of three factors, the soil group complex and antecedent moisture conditions. The value of curve number (CN) for different land use conditions and hydrologic soil group were given in standard curve number tables. These values were shown in table III applied to antecedent moisture condition AMC-II only, which is for average soil moisture condition.

To get the curve number values for AMCs (i.e. I and III), the correction factors were applied. AMC-I, this indicates the lowest runoff potential because the soils are dry enough and AMC-III indicates highest runoff potential of the soil, which practically happens when areas of watershed are saturated from antecedent rains. The curve numbers for AMC-I and AMC-III had been obtained using the following formulae.

$$\text{CN for AMC-I} = \frac{(23 \times \text{CN-II})}{(10+0.13 \times \text{CN-II})} \quad \text{--------------(1)}$$

$$\text{CN for AMC-III} = \frac{(4.2 \times \text{CN-II})}{(10-0.058 \times \text{CN-II})} \quad \text{--------------(2)}$$

B. Estimation of Direct Run-Off Potential Using GIS

For the estimation of the amount of direct run-off that will be produced from a given precipitation from a basin, various hydrologic models are available. These models range from complex to simple, having different structures and input data requirements. Amongst these models, soil Conservation Service (SCS) model is most widely used for the estimation of direct run-off. Fig. 2 shows the flow chart of runoff estimation using SCS-CN model and GIS. For calculating CN values and runoff, daily rainfall data for the year 1996, 1999, 2004 and 2007 was used.

The SCS approach involves the use of simple empirical formulas and readily available tables and curves, developed by the Soil Conservation Service U.S.D.A. Scientists. The SCS model is attractive because the major input parameters are defined in terms of land use and soil type. As satellite data can be used for estimating the land cover distributions, hence these provide useful input support for SCS model. In developing a relationship for Q (Run-off depth) the SCS derived the expression,

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \quad \text{------------------ (3)}$$

Where,
Q = Runoff depth in mm, P = Storm rainfall in mm
I_a = Initial Abstraction ,
S = Potential maximum retention

The Central Soil and Water Conservation Research Training Institute (ICAR) Dehradun has suggested some of the empirical relations for Indian conditions which are as follows and these are used in the present study.

Black Soils region AMC-II and III Ia = 0.1S
Black Soils region AMC-I Ia = 0.3S
All other regions Ia = 0.3S

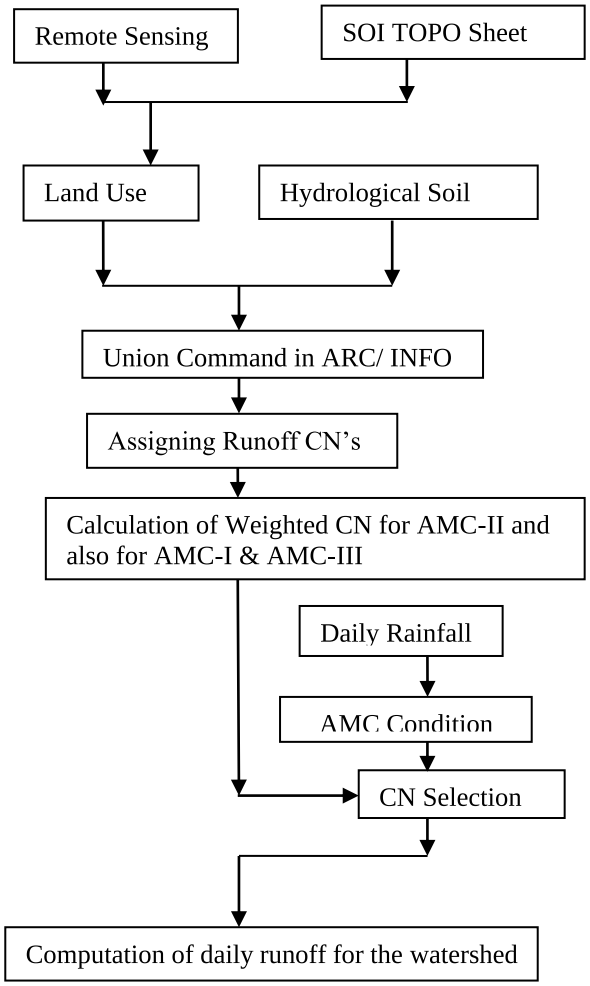

Fig. 2: Flow Chart for Watershed Runoff Estimation by SCS-CN Method

The Curve Number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex method is a versatile and widely used procedure for runoff estimation. In this method several important properties of the watershed namely soil's permeability, land use, and antecedent soil water conditions are taken into consideration. Their runoff producing capability is expressed by a numerical value varying between 0-100. The main reason behind the selection of SCS method is that in the past 30 years the SCS method has been consistently usable results for runoff estimation. The SCS method with initial abstraction consideration is given below:

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Table III Runoff curve numbers for the Indian conditions (AMC-II)

Sr. No	Land use	Treatment / Practice	Hydrologic Condition	Hydrologic Soil group			
				A	B	C	D
1.	Cultivated	Straight row	------	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			Good	62	71	77	81
		Bunded	Poor	67	75	81	83
			Good	59	69	76	79
		Paddy (rice)	------	95	95	95	95
2.	Orchards	With under stony cover	------	39	53	67	71
		Without under stony cover	------	41	55	69	73
3.	Forest	Dense	------	26	40	58	61
		Open	------	28	44	60	64
		Shrubs	------	33	47	64	67
4.	Pasture	------	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5.	Waste Land	------		71	80	85	88
6.	Hard surface	------		77	86	91	93

$$S = \frac{25400}{CN} - 254 \quad \text{----------- (4)}$$

$$Q = \frac{(P - 0.3S)^2}{(P - 0.3S)} \quad \text{------------ (5)}$$

Where,
Q = Runoff depth, mm
P = Rainfall, mm
S = Maximum recharge capacity of watershed after 5 days antecedent rainfall, mm
I_a = 0.3S (initial abstraction of rainfall by soil and vegetation, mm)
CN = curve number, CN is found out from the table.

$$CN = \frac{\sum (CN_i \times A_i)}{A} \quad \text{------------------------(6)}$$

Where, CN = weighted curve number,
CN_i = Curve number from 1 to any number N,
A_i = area with cure number CN_i
A = The total area of the watershed.

The area with a particular soil type and land use are ascribed a CN, then it was multiplied by the area it covers. The total area of the watershed to give rise to the weighted CN then divides the total sum of these CN. The CN values for AMC II can be converted in to CN values for AMC I and AMC III by using available conversion factors (suresh, 1997). This weighted curve number is finally fitted to find the recharge capacity 'S', then the S value is fitted to the curve number formula (5) to determine the direct runoff of the watershed. Daily rainfall value was used to calculate the annual runoff yield. After having estimated the annual yield for a period of three years the mean annual yield was calculated.

V. CONCLUSION

For un-gauged watersheds accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. But this information is essential in dealing with watershed development and management problems. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. In this study SCS CN modified for Indian condition has been used for generation of runoff of the watershed.

The manual calculation of CN's for large areas or many drainage basins can be cumbersome and time consuming, therefore a GIS is an appropriate tool to use for such an application. Using SCS-CN model for Darewadi watershed the average curve number obtained for pre and post treatment are 85 and 75.88. The maximum recharge capacity of watershed after 5 days antecedent rainfall changes from 44.82 mm to 80.72 mm. (i.e. 35.90mm overall increase).

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