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Application of SCS-CN Method forEstimation of Runoff Using GIS

Ketul Shah[1], A. T. Motiani[2], Indra Prakash[3], Khalid Mehmood[4]

[1]M.E. Student, L. E. College, Morbi
[2]Associate Professor, L. E. College, Morbi
[3]Faculty, BISAG, Gandhinagar
[4]Project Manager,BISAG, Gandhinagar

Abstract —*The study aims to determine the runoff depth using Soil conservation Service(SCS-CN) method in Geographical Information System (GIS) environment. For this Meshwo River Watershed located in Dhansura - Aravalli district of Gujarat has been selected. The Natural Resources Conservation service Curve Number (NRCS- CN) method has been adopted for estimating the runoff depth in the Meshwo River Watershed. Thematic maps such as Soil, Land Use / Land cover and slope have been used in conjunction with hydrological data for determininghydrological soil Group (HSG) and Curve Number (CN) maps.*

Keywords- *Curve Number, ArcGIS, Hydrologic Soil Group, Antecedent Moisture Condition.*

I. INTRODUCTION

Runoff from a watershed is a function of rainfall, infiltration, and watershed characteristics. For any watershed, runoff volume and peak flow directly depend on characteristics of watershed. The Soil Conservation Service (SCS) Curve Number (CN) method is usually a good choice for the estimation of runoff. The SCS-CN model is anempirical model with clearly stated assumptions and few data requirements. Therefore, it has been generally used for water resource management, storm water modeling and runoff estimation for single rainfall events in small agricultural or urban watersheds. The model has also been adopted by many hydrological and ecological models to determine runoff.

To estimate sediment yield and to model soil moisture, the SCS-CN model was extended. Some researchers also integrated the SCS-CN model using ArcGIS into the GIS/RS system to extend the model applicability to complex watersheds. Although the model has been generally used in the world, many researchers question its applicability.

In hydrology, a curve number (CN) is used to determine value of rainfall which infiltrates into soil or an aquifer and how much rainfall becomes surface runoff. A high curve number means high runoff and low infiltration (urban areas), whereas a low curve number means low runoff and high infiltration (dry soil). The curve number is a function of land-use and hydrologic soil group. The Soil Conservation Service (SCS) curve-number method is the common method for predicting storm runoff volume. Many watershed models such as AGNPS (Young, 1987), EPIC (Williams, 1995), SWAT (Arnold, 1996), and WMS use this method to determine runoff. Based on the runoff, sedimentand nutrient transports are calculated. In the present study Meshwo River Watershed located in Dhansura - Aravalli district of Gujarat, India has been selected as a case study.

II. STUDY AREA

The study area the Meshwo River Watershed is located in Dhansura - Aravalli district of Gujarat. Meshwo river basin is a part of watershed of Sabarmati River. The Meshwo Riverflows through Aravalli andSabarkantha districts of Gujarat. Physiographically, the studyarea can be divided into two zones namely the hilly regions and the plains. The hill ranges cover the northern and eastern parts whereas the plains southern part. The land use pattern in the area mainly consists of agriculture, built up (urban and rural settlements), forest, and wasteland.The district receives 69 cm of average annual rainfall.

III. DATA SOURCE

Meteorological data of daily rainfall data of the rain gauge station at Different small villages and cities for last 30 year (1985-2015) has been obtained from the State Water Data Centre (SWDC), Sector-8(A), Gandhinagar Remote sensing data has been collected from state and government agencies and from USGS web site.

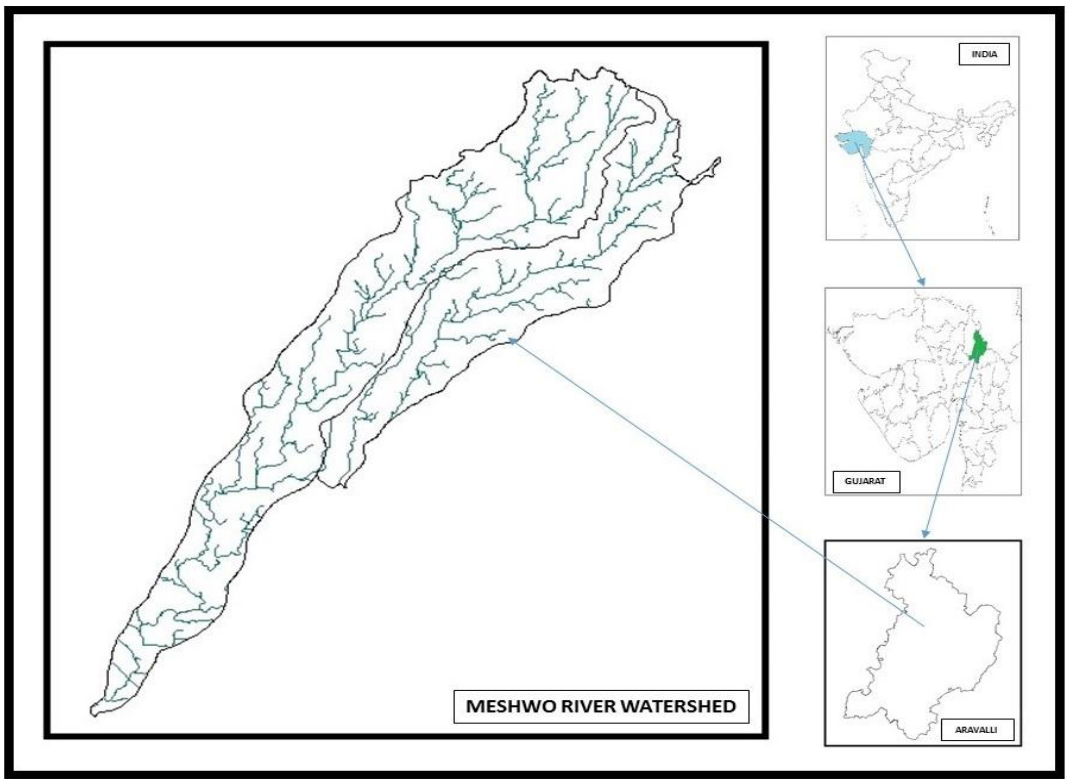

Fig. 1: Location Map of the Study Area

IV. METHODOLOGY AND ANALYSIS OF DATA

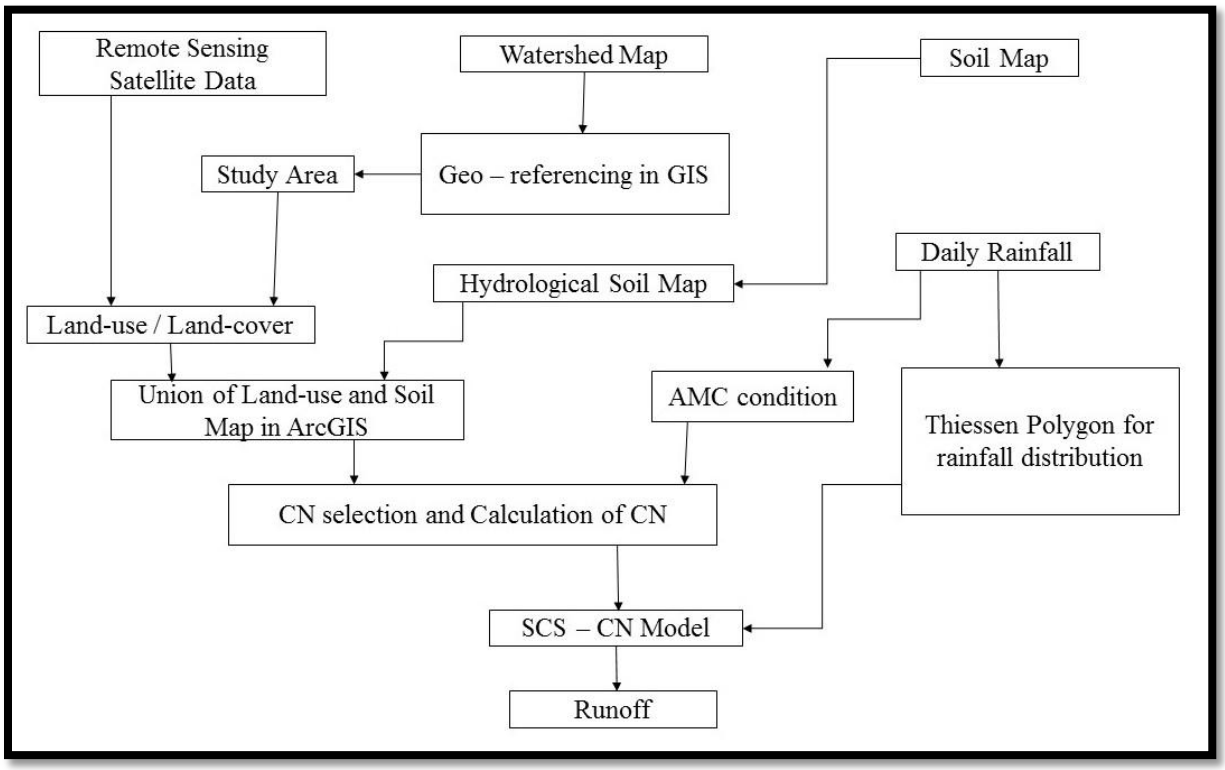

Fig. 2: Methodology for Rainfall-Runoff Estimation

V. SCS CURVE NUMBER METHOD

Soil Conservation Model is distributed watershed modeling. The soil conservation service (SCS) model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs. The general equation for the SCS curve number method is as follows:

$$\frac{Q}{P-\mathrm{Ia}} = \frac{F}{S} \quad (1)$$

Where,
F = actual retention (mm),
S = potential maximum retention (mm),
Q = actual direct runoff (mm),
P = total rainfall (mm),
I = initial abstractions (mm).

From the continuity principle,

$$P = \mathrm{Ia} + \mathrm{F} + \mathrm{Q} \quad (2)$$

The value of the initial abstraction Iato be approximately equal to 30% of the watershed storage S.

$$\mathrm{Ia} = 0.3 \times \mathrm{S} \quad (3)$$

Solving equation 1 and 2 simultaneously,

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \quad \text{For P>0.3S} \quad (4)$$

The watershed storage S and Curve Number CN related by,

$$S = \frac{25400}{CN} - 254 \quad (5)$$

$$CNw = \frac{\sum(CNi * Ai)}{A} \quad (6)$$

Where,
CNw = the weighted curve number,
CNi = the curve number from 1 to any number N,
Ai = the area with curve number CNi,
A = the total area of the watershed.

The parameter Curve Number, having a range of values between 0 and 100 is called the curve number. In SCS CN method, a curve number (CN) is assigned to each watershed or portion of watershed based onland-use, antecedent moisture condition (AMC) and soil type.

VI. ANTECEDENT MOISTURE CONDITION (AMC)

Antecedent moisture condition of the rainfall-runoff event under consideration refers to the moisture content present in the soil at the beginning. It is well known that initial abstraction and infiltration are governed by AMC.

TABLE-1: Classification of Antecedent Moisture Condition

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

The other two conditions of AMC relationship, CNii conversion can be done through the use of the following equations.

For AMC-I:

$$CNi = \frac{CNii}{2.281 - 0.01281\,CNii} \quad (7)$$

For AMC-III:

$$CNiii = \frac{CNii}{0.427 + 0.00573\,CNii} \quad (8)$$

VII. LANDUSE/LANDCOVER MAP

Land-use/land-cover map is prepared by mapping form the satellite map in GIS. Land-use map is prepared using visual interpretation technique from satellite image and with the help of google maps.

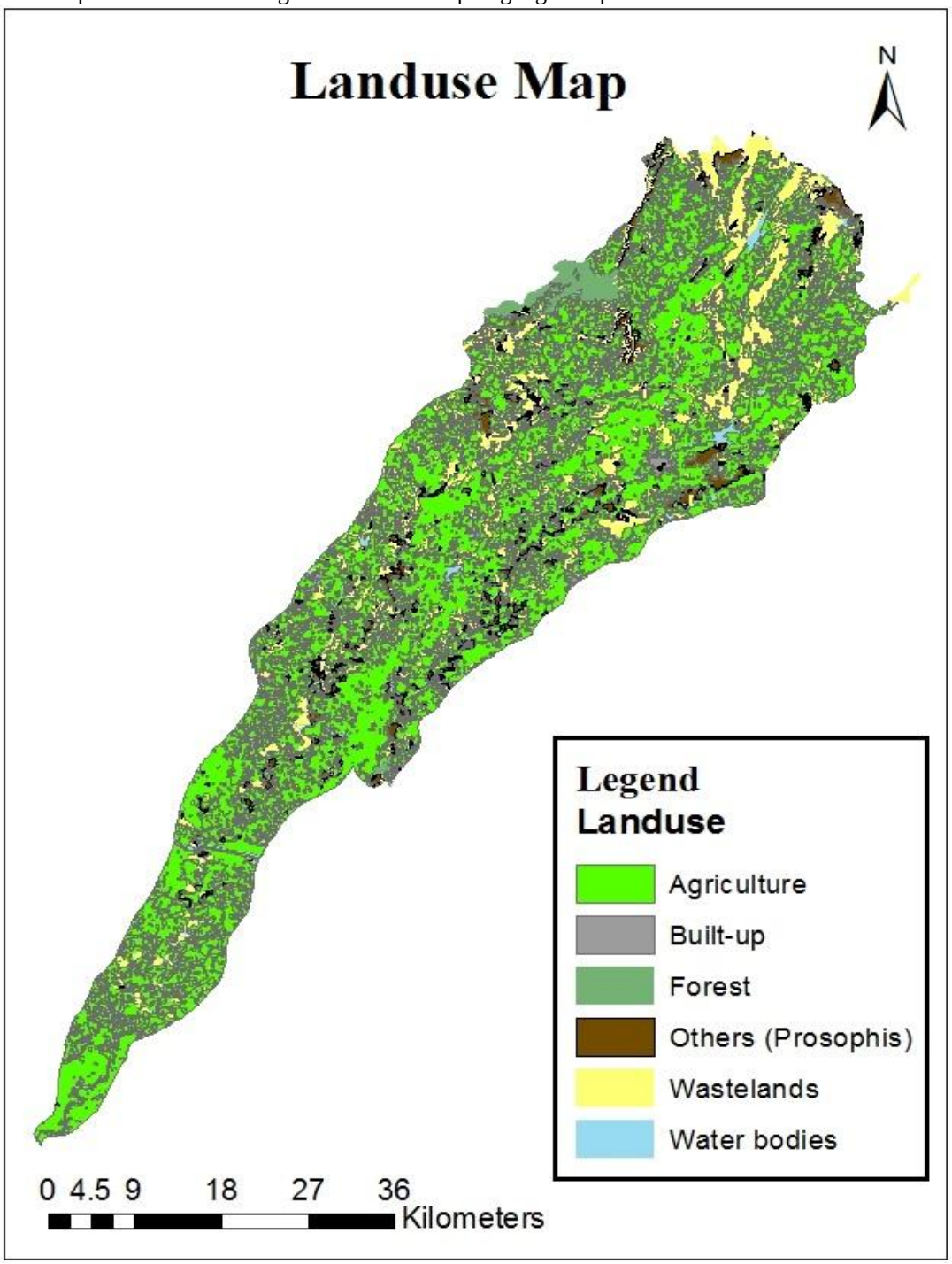

Fig. 3: Land-use/Land-cover Map

VIII. CURVE NUMBER MAP

The Curve Number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service (SCS). The runoff curve number was developed from an empirical analysis of

runoff from small catchments and hillslope plots monitored by the USDA. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area.

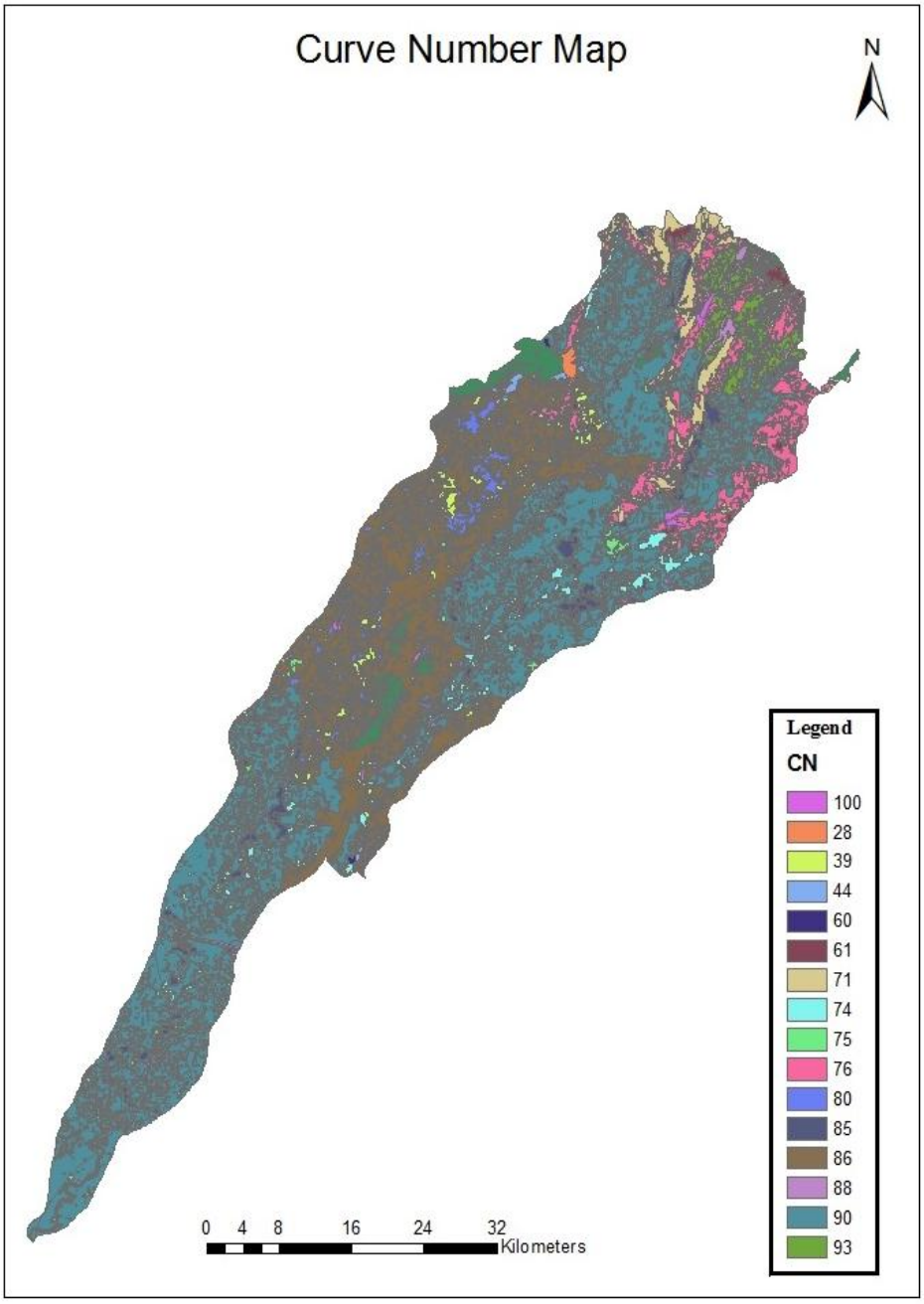

Fig. 4: Curve Number Map of Study Area

IX. HYDROLOGIC SOIL GROUPS

The Soil Conservation Service (SCS) Curve Number (CN) method is usually a good choice for the estimation of runoff. SCS developed soil classification system that consists of four groups, which are identified as A,B,C,and D according to their minimum infiltration rate. Table 2 shows the hydrological soil group classification. CN values were determined from hydrological soil group and antecedent moisture conditions of the watershed. The Curve Number values for AMC-I and AMC-III were obtained from AMC-II (Chowet al. 1988) by the method of conservation.

TABLE-2: Runoff Curve Numbers (AMC II) For Hydrologic Soil Cover (Ref-TR 55(1986))

LAND USE	*HYDROLOGIC SOIL GROUP*			
	A	*B*	*C*	*D*
AGRICULTURE	*76*	*86*	*90*	*93*
BUILT-UP AREA	*75*	*75*	*75*	*75*
FOREST	*28*	*44*	*60*	*64*
OTHERS (PROSOPHIS)	*61*	*39*	*74*	
WASTE LANDS	*71*	*80*	*85*	*88*
WATERBODIES	*100*	*100*	*100*	*100*

In the present study determination of CN, the hydrological soil classification is adopted. Soils are classified in to four classes A, B, C, and D based upon the structure, infiltration, texture and degree of swelling when saturated. Soil groups are formed by finding the soil group classification for soil available in study area. The figure 5 shows the HSG map of studyarea.

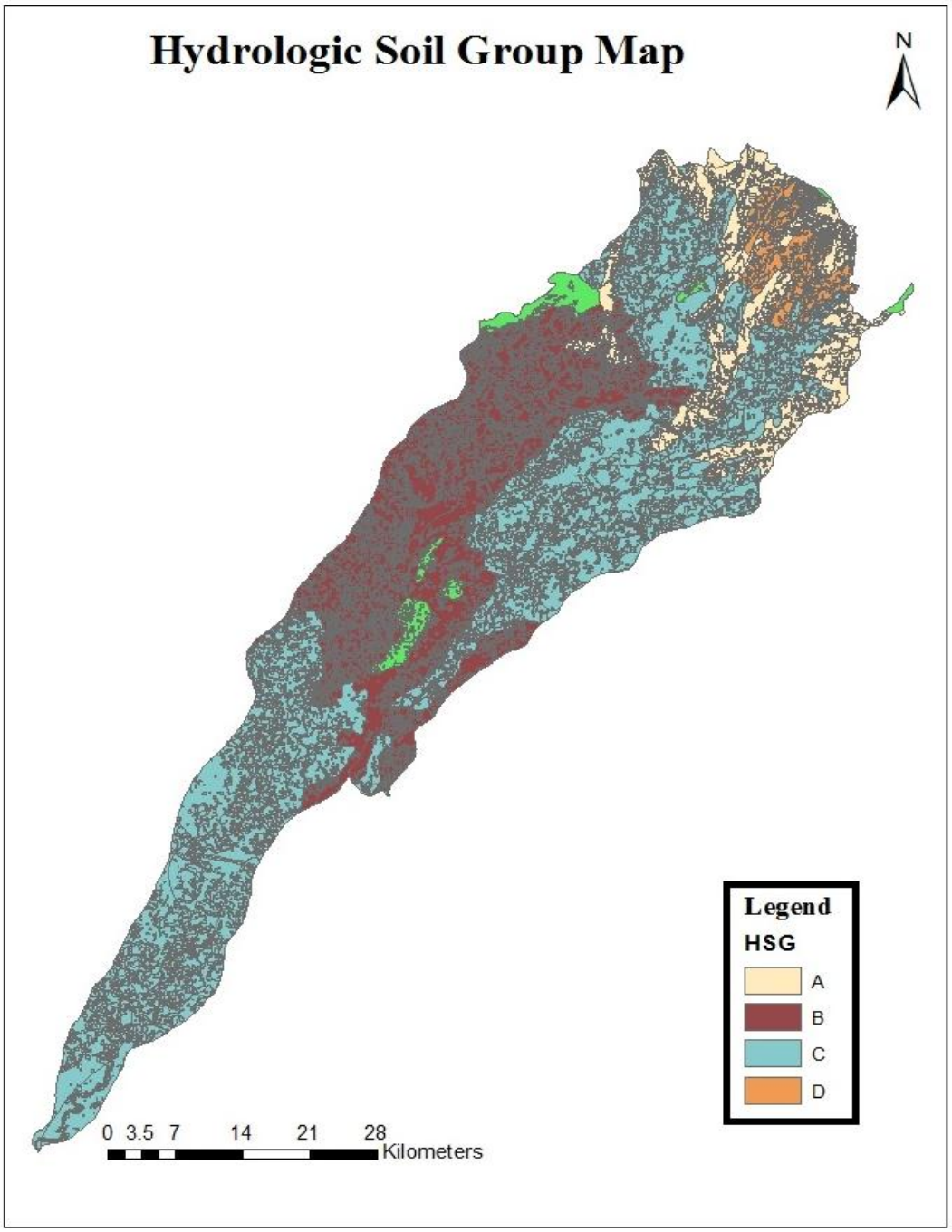

Fig. 5: Hydrological Soil Group Map of Study Area

X. WEIGHTED CURVE NUMBER

The CN value for each soil hydrologic group and corresponding land use classes are presented in Table 2

Table-3: Curve Number Calculation

LAND USE	*HSG*	*CN*	*TOTAL AREA IN sq. km*	*% AREA*	*% WEIGHTED CN*	*WEIGHTED CN*
AGRICULTURE	*A*	*76*	*1126.9717*	*10.9707*	*8.3378*	*AMC II = 85*
	B	*86*	*3039.4873*	*29.5885*	*25.4461*	
	C	*90*	*4888.3614*	*47.5867*	*42.8281*	
	D	*93*	*194.0680*	*1.8892*	*1.7570*	
BUILT-UP AREA	*A*	*75*	*10.3273*	*0.1005*	*0.0754*	
	B	*75*	*12.7595*	*0.1242*	*0.0932*	
	C	*75*	*21.8315*	*0.2125*	*0.1594*	
	D	*75*	*0.3756*	*0.0037*	*0.0027*	
FOREST	*A*	*28*	*32.8865*	*0.3201*	*0.0896*	
	B	*44*	*35.2892*	*0.3435*	*0.1512*	
	C	*60*	*67.3884*	*0.6560*	*0.3936*	
OTHERS (PROSOPHIS)	*A*	*61*	*40.6901*	*0.3961*	*0.2416*	
	B	*39*	*57.5273*	*0.5600*	*0.2184*	
	C	*74*	*79.1366*	*0.7704*	*0.5701*	
	D		*8.9646*	*0.0873*	*0.0000*	
WASTE LANDS	*A*	*71*	*131.9344*	*1.2843*	*0.9119*	
	B	*80*	*93.1661*	*0.9069*	*0.7256*	
	C	*85*	*163.9630*	*1.5961*	*1.3567*	
	D	*88*	*42.1893*	*0.4107*	*0.3614*	
WATERBODIES	*A*	*100*	*27.9676*	*0.2723*	*0.2723*	
	B	*100*	*78.8216*	*0.7673*	*0.7673*	
	C	*100*	*112.3664*	*1.0939*	*1.0939*	
	D	*100*	*6.0541*	*0.0589*	*0.0589*	
TOTAL			*10272.5274*		*85.9120*	

From the Table, CNii = 86
Now from the equation (7), CNi = 73
And from the equation (8), CNiii = 93

XI. RUNOFF CALCULATION USING SCS-CN METHOD

- Antecedent moisture condition is decided from the previous 5 day rainfall
- According to AMC condition potential maximum retention (S) and initial abstraction (Ia) is calculated.
- From equation (4) Runoff depth is calculated and annual runoff is estimated.
- Runoff volume is calculated by multiplying runoff depth with study area.
- Runoff volume is calculated for whole study area for watershed management purpose. Runoff volume helps to management of water from any location to in natural streams.

Table- 4: Average Runoff of Year 2015

MONTH	*RAINFALL (in mm)*	*RUNOFF (in mm)*
Jun-15	*622.00*	*4.76*
Jul-15	*1126.00*	*54.14*
Aug-15	*192.80*	*0.00*
Sep-15	*384.40*	*0.00*
Oct-15	*0.00*	*0.00*
TOTAL	*2325.20*	*58.90*

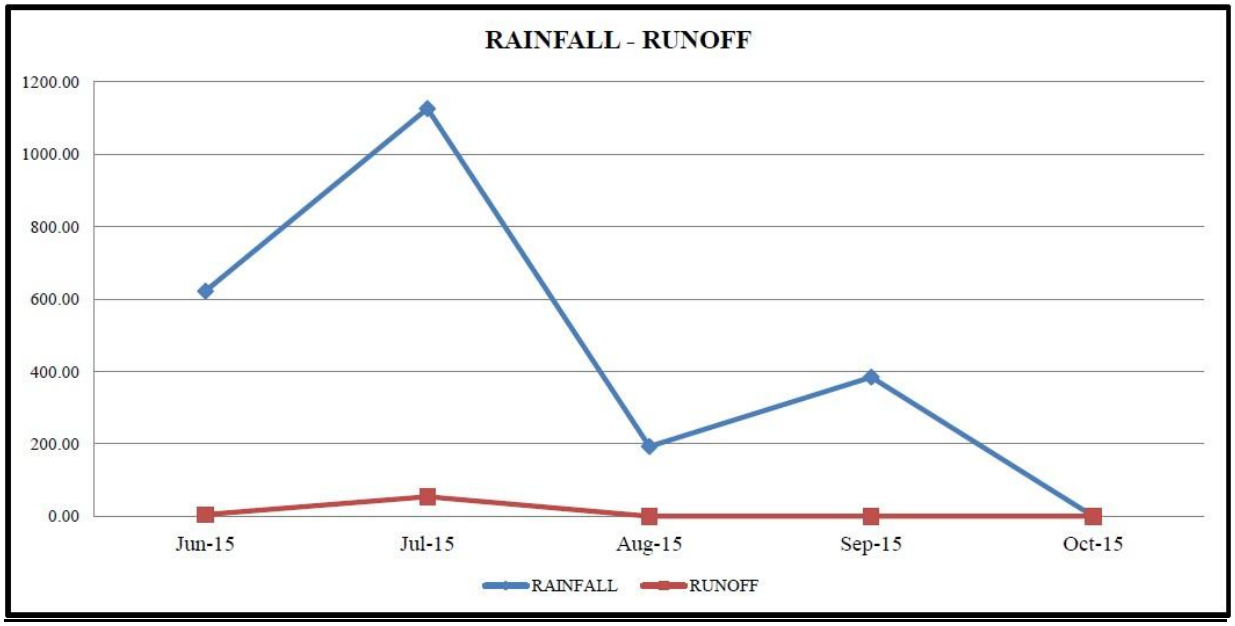

Fig. 6: Rainfall – Runoff graph of the study area for the period July 15 to Oct 15

XII. CONCLUSIONS

The Soil Conservation Service (SCS) Curve Number (CN) method has been used for the estimation of runoff of Meshwo River Watershed located in Dhansura - Aravalli district of Gujarat. Maps have been prepared of Hydrological Soil Group (HSG), CN, Land Use/ Land Cover and other thematic maps and integrated in GIS environment with hydrological data to find out the runoff of study area. A, B, C, D types of soil present in the areaand CN value ranges 28, 39, 44, 60, 61, 71, 74, 75, 76, 80, 85, 86, 88, 90, 93 and 100. Using SCS-CN Method, Average runoff was calculated from the average rainfall data. In the present study runoff has been calculated for the year 2015. Analysis of the data shows that rainfall for this year is 225.20mm. Runoff value estimated by SCS-CN methodis 58.90mm. Determination of runoff will be useful in proper planning and management of Meshwo River watershed.

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