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Surface Runoff Estimation by SCS- Curve Number Method using ArcGIS for Modikuntavagu Watershed, Khammam District, Telangana State

Rajeev Singhal [1], Sanjeev Kumar [2]

[1] Director, Monitoring & Appraisal Directorate, CWC, Hyderabad

[2] Junior Engineer, Monitoring & Appraisal Directorate, CWC, Hyderabad

Abstract:

Reliable estimates of stream flow generated from catchments are required as part of the information sets that help policy makers make informed decisions on water planning and management. Rainfall and runoff are important components contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. In this present study Modikuntavagu watershed which is located in the Khammam District has been taken as case study for the estimation of runoff by Soil Conservation service curve number (SCS-CN) method using Geo-spatial technology. Direct runoff has been calculated based on rainfall, soil type, soil moisture, drainage density, topography, size and shape of watershed, and land cover etc. The thematic layers of soil, land use, and slope have been generated in GIS environment using ArcGIS software. The Curve Number (CN) polygon wise has been estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC). The surface runoff depth has been calculated based on CN value for the years from 2006 to 2015 and found that average percentage of runoff to rainfall as 38.9%. From the runoff depth for ten years, rainfall-runoff relationship has been established for Modikuntacagu watershed. The analysis show that the statistically positive correlation (R^2=0.93) between rainfall and runoff depth. The runoff estimated by SCS-CN method has been compared with runoff derived based on the nearby gauged catchment (Taliperu) and found that mean variation was 9.3%. The present study reveals that SCS-CN method with integration of GIS and remote sensing technology can effectively be used to estimate the runoff in an ungauged river catchment with similar hydrological characteristics.

About the Author:

Mr.Rajeev Singhal

Director, Monitoring & Appraisal Directorate, Central Water Commission, Hyderabad. Having around 18Years' experience in water resource planning, construction and maintenance of irrigation projects.

E mail ID: *singhal_rajeev@yahoo.com*

Contact: +918600998070

Mr.Sanjeev Kumar

Working as a Junior Engineer, Monitoring & Appraisal Directorate, Central water Commission, Hyderabad. Assisting in Monitoring & Appraisal of irrigation projects. Application of GIS integrated Remote sensing techniques in the water resource planning and management.

E mail ID: *sanjeev83.iitm@gmail.com*

Contact: +917032036319

INTRODUCTION

Rainfall-runoff relationship is very complex, influenced by various storm and drainage characteristics. There are several approaches to estimate the runoff. The Soil Conservation Service-Curve Number (SCS-CN) method developed by National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA), 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 was used for estimating the runoff depth in the Modikuntavagu River in Godavari basin. The Modikuntavagu watershed is 193.91 Sq.Km in which 69.67 Sq. Km in Chattishgarh State and the rest 124.24 Sq. Km in Telangana State. The Digital Elevation Model (DEM) of STRM was used for catchment delineation i.e. slope, streams and catchment area of the study area. The NRSC- LISS-III data has been used for land use / land cover and Soil map. IMD rain gauge stations namely Bhupalpatbam, Bizapur and Venkatapuram rainfall data from 2006 to 2015 have been used (data from DPR of Modikuntavagu Project). The objective of this study is to assess the quantity of surface runoff from the study area using GIS based ArcGIS software and to compare the runoff volume estimated from rainfall-runoff relation derived from nearby gauged watershed (Taliperu).The SCS-CN model is then applied to estimate the monthly runoff from the watershed for monsoon (S-W) of ten years (2006-2015).

STUDY AREA

A medium irrigation Scheme across Modikuntavagu a tributary of Godavari River is proposed at about 2.00kms From Krishnapuram (V), Khammam District, Telangana State (Figure:1 & 2). The geographical location of proposed Dam site is latitude 18-32'-47"N longitude 80-26'20"E. The river Modikuntavagu is a Minor tributary of river Godavari rises form the hills near Bastar District in basin and passes in between Krishnapuram & Kadekal village in Wazeedu (M) of Khammam District. The river is bounded by hill ranges and thick forest up to the proposed site, where the total catchment area is 193.91 Sq. Km. (74.87 Sq. Miles) thereafter the ridges gradually widen out. The net commendable area under the project is 5,500 Ha. Out of which 900 Ha on right flank the rest of 4,600 Ha. is on left flank. The catchment area of the Modikuntavagu is influenced by the South-West Monsoons (June to October) and consequently all the inflow is received between June to October only.

The total catchment area at the site is 193.91 Sq. Kms. and is influenced by three rain gauge stations viz. (1) Venkatapuram (2) Bhopalapatnam and (3) Bizapur. Out of the total catchment area, 69.67 Sq. Kms is in Chattishgarh state and the rest 124.24 Sq. Km is in Telangana state.

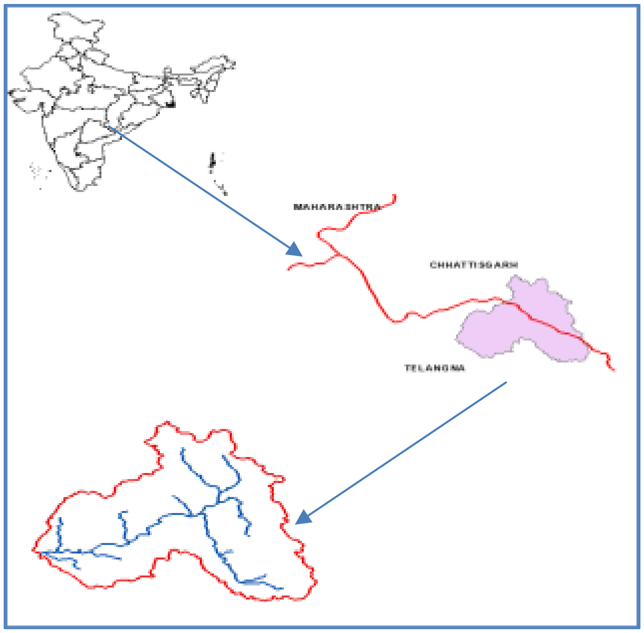

Figure 1: Location Map of Study Area

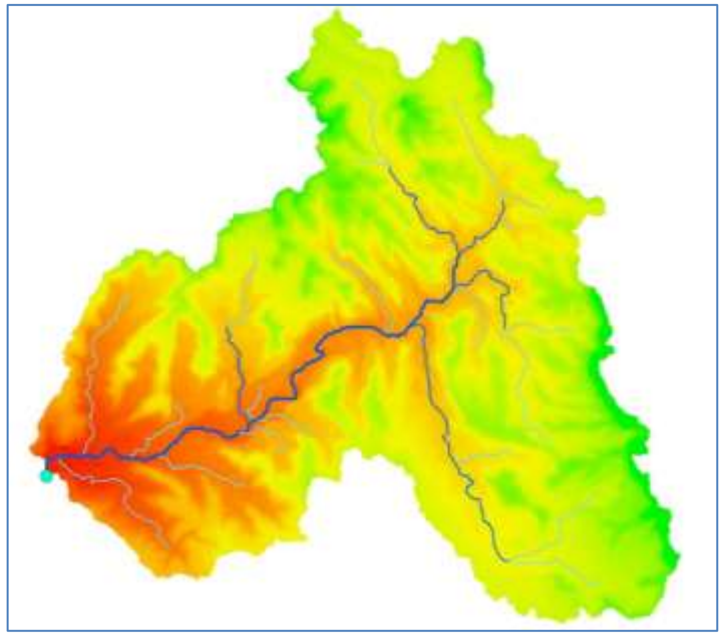

Figure 2: Modikuntavagu Watershed

MATERIALS AND METHOD

In the present study, monthly surface runoff of Modikuntavagu watershed by SCS-CN method was adopted using ArcGIS 10.2 software with Spatial Analyst toolbox. Digital Elevation Model (DEM) data for delineation of watershed, the SRTM DEM data of 1 arc-second global elevation data set was considered. For watershed delineation, Slope, Flow Direction, Flow Accumulation, Stream network and watershed area analysis were done using hydrology toolbox in ArcGIS. The definition of stream network was done by considering the threshold value of 5000 (4.5 Sq.km). For Soil and land use/land cover maps, the National Remote Sensing Center (NRSC), Hyderabad data has been used for this study. The rainfall data of three IMD rain gauge stations which were influencing the study area namely Bhopalpatnam, Bijapur and Venkatapuram were considered. The rainfall distribution by Thiessen poly Modikuntavagu lopted. The monthly wise rainfall data has been converted as raster data set using conversion toolbox in ArcGIS. The Curve Number has been assigned for the Modikuntavagu watershed considering combination of soil data and land use/land cover. The average CN value (AMC II) has been slope adjusted and converted to CN I, dry condition (AMC-I) based on Antecedent Moisture Condition (AMC) of the study area. Map algebra-raster calculator of ArcGIS was used for maximum potential retention (S), initial abstraction (I_a) and excess runoff depth (Q). The surface runoff depth of 2006-2015 were estimated and established the rainfall-runoff relationship for the study area. Also the runoff volume of ten years (2005-2015) of study area has been compared with runoff volume estimated from Rainfall-Runoff relation derived from nearby gauged watershed (Taliperu).

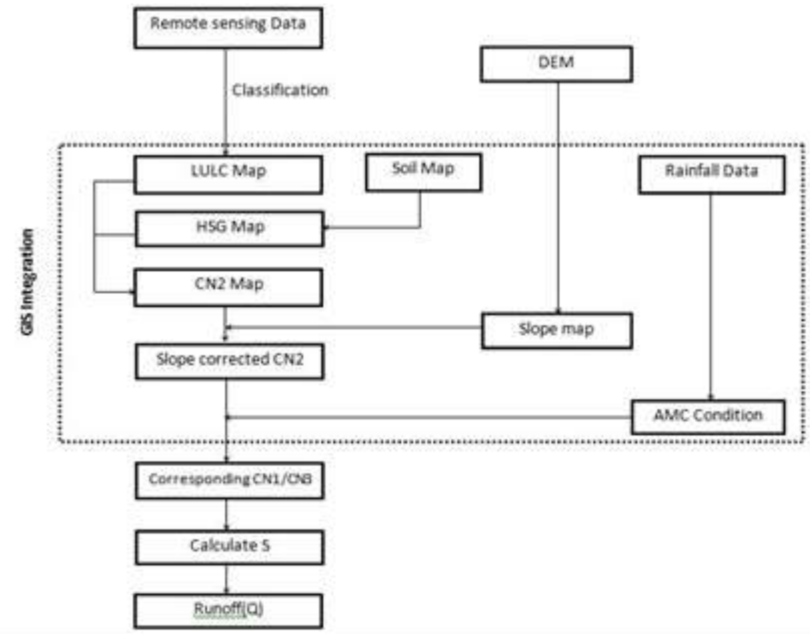

Figure 3: Flow Chart Runoff Estimation Using SCS-CN Integrating RS and GIS

SCS-CURVE NUMBER MODEL

The Curve Number Method was originally developed by the Soil Conservation Service (Soil Conservation Service 1964; 1972) for conditions prevailing in the United States. Since then, it has been adapted to conditions in other parts of the world. Although some regional research centres have developed additional criteria, the basic concept is still widely used all over the world.

(i) Derivation of Empirical Relationships

When the data of accumulated rainfall and runoff for long-duration, high-intensity rainfalls over small drainage basins are plotted, they show that runoff only starts after some rainfall has accumulated, and that the curves asymptotically approach a straight line with a 45-degree slope. The Curve Number Method is based on these two phenomena. The initial accumulation of rainfall represents interception, depression storage, and infiltration before the start of runoff and is called initial abstraction. After runoff has started, some of the additional rainfall is lost, mainly in the form of infiltration; this is called actual retention. With increasing rainfall, the actual retention also increases up to some maximum value: the potential maximum retention.

To describe these curves mathematically, SCS assumed that the ratio of actual retention to potential maximum retention was equal to the ratio of actual runoff to potential maximum runoff, the latter being rainfall minus initial abstraction. In mathematical form, this empirical relationship is

$$\frac{F}{S} = \frac{Q}{P - I_a} \tag{1}$$

Where
F = actual retention (mm)
S = potential maximum retention (mm)
Q = accumulated runoff depth (mm)
P = accumulated rainfall depth (mm)
Ia = initial abstraction (mm)

After runoff has started, all additional rainfall becomes either runoff or actual retention (i.e. the actual retention is the difference between rainfall minus initial abstraction and runoff).

$$F = P - I_a - Q \tag{2}$$

Combining Equations (1) and (2) yields

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{3}$$

To eliminate the need to estimate the two variables I, and S in Equation (3), a regression analysis was made on the basis of recorded rainfall and runoff data from small drainage basins. The data showed a large amount of scatter (Soil Conservation Service 1972). The following average relationship was found

$$I_a = 0.2S \tag{4}$$

Combining Equations (3) and (4) yields

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \; for \;\; P > 0.2S \tag{5}$$

Equation (5) is the rainfall-runoff relationship used in the Curve Number Method. It allows the runoff depth to be estimated from rainfall depth, given the value of the potential maximum retention S. This potential maximum retention mainly represents infiltration occurring after runoff has started. This infiltration is controlled by the rate of infiltration at the soil surface, or by the rate of transmission in the soil profile, or by the water-storage capacity of the profile, whichever is the limiting factor.

The potential maximum retention S has been converted to the Curve Number CN in order to make the operations of interpolating, averaging, and weighting more nearly linear. This relationship is

$$S = \left(\frac{25400}{CN}\right) - 254 \tag{6}$$

As the potential maximum retention S can theoretically vary between zero and infinity, Equation (6) shows that the Curve Number CN can range from one hundred to zero. For paved areas, for example, S will be zero and CN will be 100; all rainfall will become runoff. For highly permeable, flat-lying soils, S will go to infinity and CN will' be zero; all rainfall will infiltrate and there will be no runoff. In drainage basins, the reality will be somewhere in between.

(ii) Hydrologic Soil Group (HSG)

The soil texture of the study area was assigned in ArcGIS software by using NRSC soil map. Different soil textures were digitized up to boundaries and the polygons representing may soils classes were assigned and different colors for recognition (Figure.4). The hydrologic soil groups (HSG) divided into A, B,C and D was carefully thought about in the classification of soils in the watershed. The study area contains hydrologic soil groups of C and D (Table-1). The soil group of C indicated moderately fine to moderately rough textures, moderate rate of water transmission and the soil of group D indicated slow infiltration and possible high runoff.

(iii) Antecedent Moisture Condition (AMC)

Antecedent moisture condition (AMC) is considered when little prior rainfall and high when there has been considerable preceding rainfall to the modeled rainfall event. For modeling purpose, AMC II in watershed is essentially an average moisture condition. Runoff curve numbers from LU/LC and soil type taken for the average condition (AMC-II) and dry condition (AMC-I) or wet condition (AMC-III), equivalent curve number (CN) can be computed by using the following equation (7) & (8)

Table 1: Antecedent Moisture Condition (AMC)

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 53mm
III	More than 28mm	More than 53mm

Sobhani (1975)

$$\mathrm{CN}_1 = \frac{CN_2}{2.334 - 0.01334CN_2} \quad (7)$$

$$CN_3 = \frac{CN_2}{0.4036 - 0.005964CN_2} \quad (8)$$

(iv) Curve Number for AMC Group II (CN II)

The Curve Numbers for average antecedent soil moisture condition (AMC-II) based on the soil data and land use pattern (Figure-5) has been assigned for the Modikuntavagu watershed as shown in Table.2. The watershed polygons were assigned using Spatial Join tool in ArcGIS and the Curve Number map of Modikuntavagu watershed was converted from vector data to raster data with pixel size of 31mx31m.

Table 2: Curve Number Considered for this Study

Land Use	Hydrologic Soil Group	
	C	D
Build up	79	84
Current Fallow	91	94
Deciduous Forest	58	61
Crop	90	93
Grass Land	79	84
Scrub Land	58	61
Other Wasteland	85	88

(v) Slope Correction and Curve Number for AMC-I

In the original SCS-CN method the effect of slope has not been taken into account while calculating CN. Moreover, land slope parameter has been considered as an important factor in determining water movement (El-Hassanin et al., 1993; Barros et al., 1999; Ahmad, 2001; Haggard et al., 2002; Chaplot and Bissonnais, 2003; Huang et al., 2006).The average CN values of AMC-II were slope corrected by the equation (9) and converted to equivalent antecedent moisture condition (AMC-I), for dry condition of the study area by using the equation (7). The converted raster data of CN I map has been shown in Figure.6.

$$CN_{2\alpha} = CN_2 \frac{322.79+15.63(\alpha)}{\alpha+323.52} \text{ (Huang et, al. 2006)} \qquad (9)$$

Where,

α= Slope in m/m

(vi) Thiessen Polygon Method

Rainfall distribution by Thiessen polygon method has been adapted using create Thiessen Polygon tool in ArcGIS. For this present study, the three IMD rain gauge stations has been located using geographical coordinates and created thiessen polygons. The rainfall distribution of the threes rain gauge stations was found that 65%, 31% and 4% for Venkatapuram, Bijapur and Bhopalpatnam respectively and shown in Figure: 7. The monthly wise rainfall data map for the monsoon 2006-2015 was created based on the Thiessen polygons with corresponding rain gauge station rainfall data and converted as raster data with pixel size of 31mx31m (Figure:8) to perform the raster calculation in map algebra.

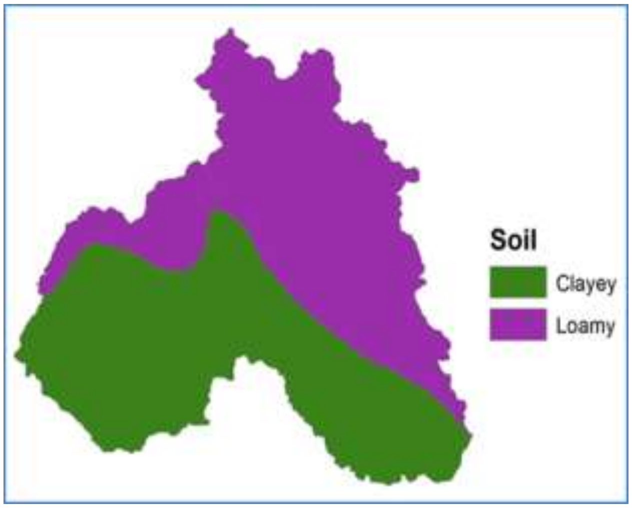

Figure 4: Soil Map of Modikuntavagu Watershed (Source: NRSC)

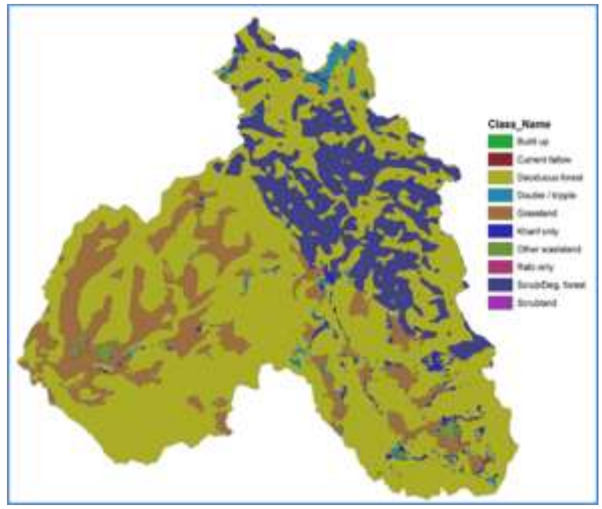

Figure 5: Land Use/Land Cover of Modikuntavagu Watershed (Source: NRSC)

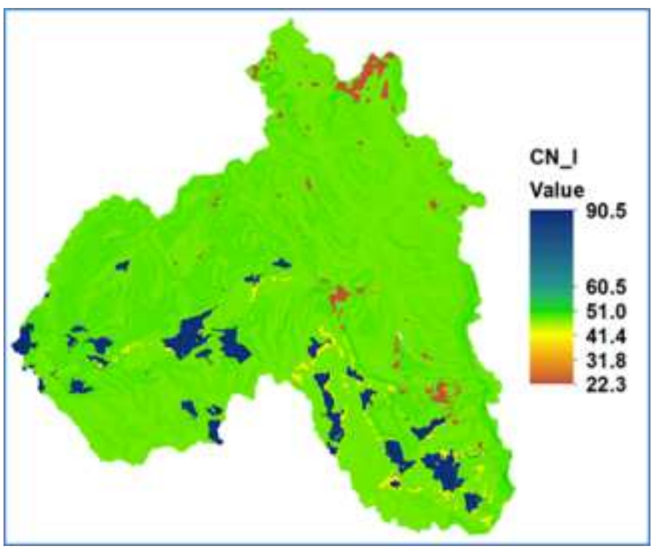

Figure 6: Slope Corrected Curve Number Map of Study Area (AMC-I)

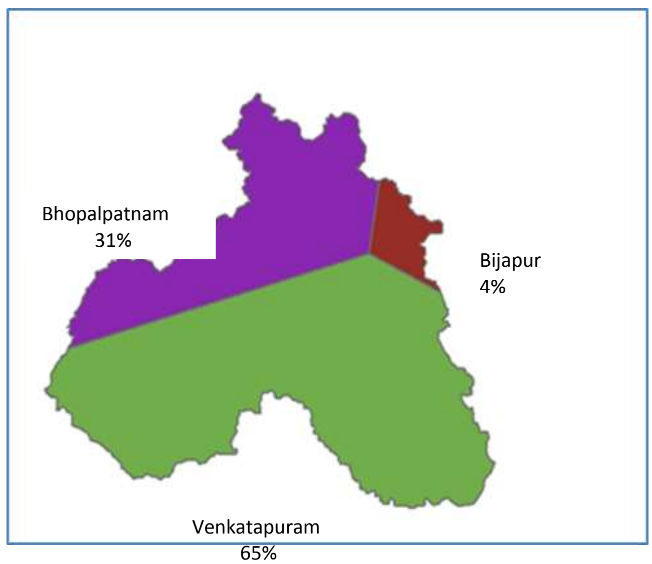

Figure 7: Rainfall Distribution by Thiessen Polygon

RESULTS

The CN value of each polygon was used to calculate maximum potential retention S for each polygon thus has been estimated with the help of Equation (6). The runoff of each polygon thus has been estimated with the help of Equation (5). The Monsoon (June-October) runoff depth has been estimated for years 2006-2015 and shown in Table.3. Then average percentage runoff to rainfall has been found as 38.9%. The average runoff volume of Modikuntavagu watershed was worked out from 2006-2016 and found as 83.66MCM. The rainfall-runoff depth relationship has been established for ten years (2006-2015) and found that the statistically positive correlation (R^2=0.93) between rainfall and runoff depth (Figure:10).

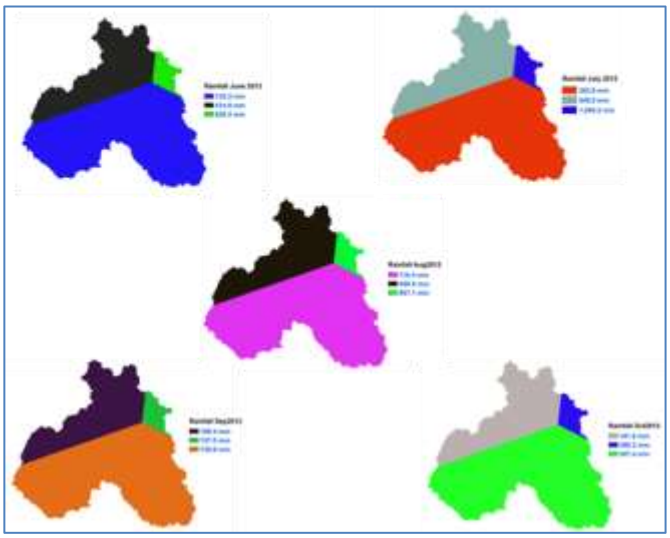

Figure 8: Rainfall Distribution Map of June-Oct2013

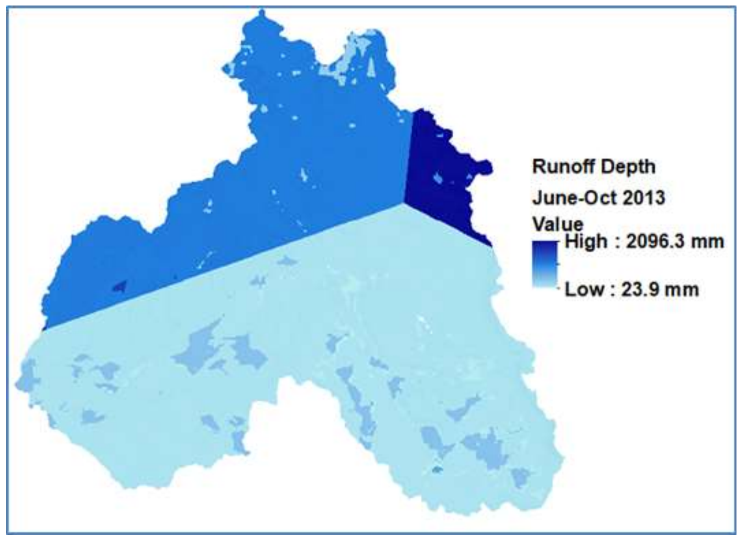

Figure 9: Runoff Depth of June-Oct 2013

The runoff volume of Modikuntavagu watershed was calculated for the monsoon of 2006-2015 and compared with the runoff volume estimated using rainfall-runoff relationship established by gauged nearby Taliperu watershed (Figure:11). The average variation between the runoff volumes estimated for 2006-2015 by two methods were found as 9.3%.

Table 3: Rainfall-Runoff for Monsoon 2006-2015

Year	Rainfall (mm)	Runoff (mm)	Year	Rainfall (mm)	Runoff (mm)
2006	1046	461	**2011**	1314	572
2007	1223	538	**2012**	675	179
2008	1384	605	**2013**	1166	467
2009	1185	436	**2014**	996	295
2010	729	234	**2015**	1083	415

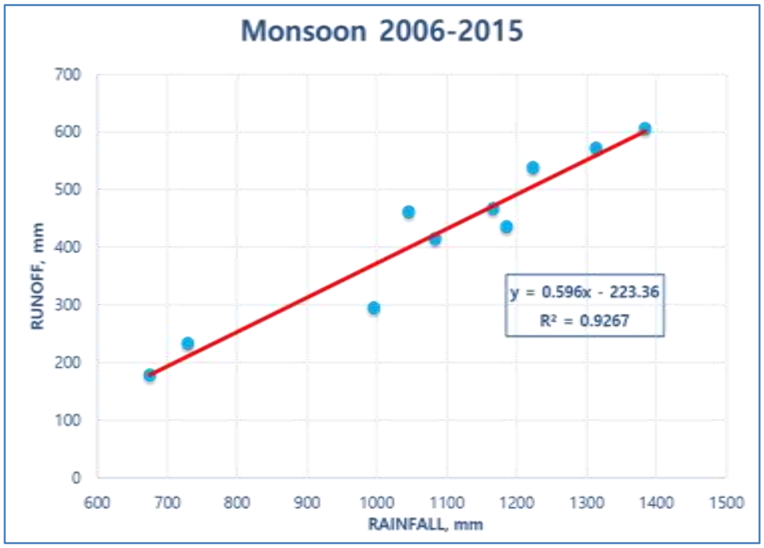

Figure 10: Rainfall-Runoff Relationship for years 2006-2015

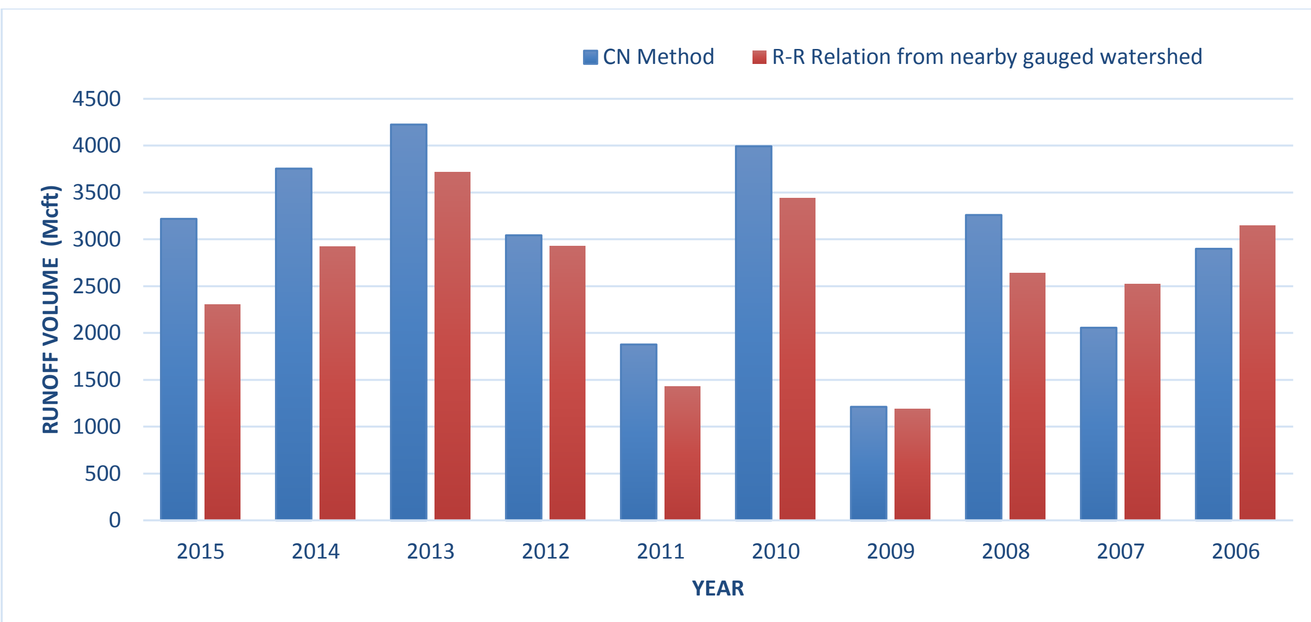

Figure 11: Runoff Volume from CN Method and Estimated from Rainfall-Runoff relation based on nearby gauged Watershed

CONCLUSION

Soil Conservation Service - Curve Number model have been utilized in the present work by land use/land cover map and soil map described in ArcGIS, as input. The monthly rainfall-runoff simulation has been found good in the Modikuntavagu watershed, Khammam district, Telangana. The comparison of runoff volume between the SCS-CN model and estimated using rainfall-runoff relationship established by gauged nearby Taliperu watershed, indicates good performance of model (Figure:11). The mean difference between the two methods was found 9.3% and with minimum of 1.7% to maximum 28%. The present model could be used as means to estimate runoff depth in the study area and also develop runoff potential map and may be used for future water availability study for the proposed Modikuntavagu Irrigation Project.

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