International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.6., Issue.1, 2018
Jan-Feb

RESEARCH ARTICLE

ISSN: 2321-7758

ESTIMATION OF PEAK DISCHARGE IN AN UNGAUGED WATERSHED USING SCS-CN MODEL SUPPORTED WITH GIS AND RS

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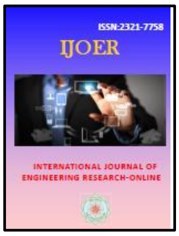

ABSTRACT

Estimation of direct runoff, peak discharge is often necessary in small to medium-sized ungauged watershed. Land use and land cover map forms the backbone for any developmental planning, important role in the study and assess the natural resource in any part of the world. Remote Sensing (RS), integrated with Geographic Information System (GIS), provides an effective tool for analysis of land use and land cover changes at a regional level. The geospatial technology of RS and GIS holds the potential for timely and cost – effective assessment of natural resources. Land use land cover maps developed for a particular region are very useful in estimating the surface characteristics and the various uses that are being carried out over the particular region. Geographic Information System (GIS) may be used to develop maps of such types with relative ease without actually conducting a large scale on site survey. Still GIS offers a relatively precise land use map for the required site. In case of a watershed, these maps may be used to assess the various crop patterns that are in use. On the other hand, Soil Conservation Service – Curve Number (SCS-CN) provides us with the prospects of assessing the runoff for a given area with known precipitation values by using the pre-defined curve number values that are given for various land use prospects. SCS-CN is fairly perfect system for the assessment of runoff. In this paper a case study has been carried out on the Swarnamukhi river to assess the runoff and peak discharge by SCS-CN and to develop a Soil map, land use land cover map in GIS. The obtained results were compared with recorded peak discharge in hydro observation site of watershed. The models of Relative Mean Error (RME), Nash- Sutcliff Error (NSE) and Root of Mean Square Error (RMSE) in watershed were compared with each other.

Key words: Land use Land cover, Soil map runoff, peak discharge, RS and GIS.

INTRODUCTION

Hydrologists of the Soil Conservation Services constantly encounter the problem of estimating direct runoff where no records are available for the specific watershed. Soil Conservation Service (USDA, 1985) curve number method is a well acclaimed tool in hydrology, which uses a land conditions factor called "the curve number". It is reliance an only one parameter and its responsiveness to four important catchment properties, i.e. soil type, land use, surface condition, and antecedent moisture condition, increased its popularity. The runoff curve number (also called a curve number or simply CN) 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 or SCS — the number is still popularly known as a "SCS runoff curve number" in the literature. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope 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. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. Flood means flow and routing is a mathematical procedure for predicting the changing in magnitude, speed and shape of a flood wave as a function of time at one or more times along a river. The flood may change its course, speed, shape, magnitude with respect to time. The Muskingum-Cunge method for channel flood routing has been documented in many textbooks, professional papers. Routing tests performed by Younkin and Merkel (1986, 1988) showed increased accuracy, consistency, and range of physical conditions when compared to both the Modified Att-Kin and Convex flood routing methods which had been used previously (NRCS, 1965 and 1983). The land use land cover maps are gaining popularity these days as they provide us with a lot of information about a given region. Particularly in case of Watersheds, these maps provide us with sufficient data about the land that is being put to use. SCS-CN curve is useful in providing the runoff of a given region with the use of the precipitation values. In this particular case study we shall obtain the runoff and peak discharge values for each day between 2009 & 2013.

STUDY AREA

The area of investigation in this research study is the major part covers Naidupeta and remaining area covers Venkatagiri, sullurupeta in Nellore district, Andhra Pradesh. It is located 13°90' and 14° 25' N and 79° 89' and 80° 12' E and covering an area of 957.92 sq.km. The Study area falls under Palar Sub-basin the area was delineated from India Water Resources Information System (IWRIS) C18PAL41. The study area it is a part of east flowing river between pennar and caurey basin and the river draining into the bay of Bengal. In the study area main river is Swarnamukhi and the length of the river as 56.90 km. In the study area has one hydro observation station and 11 rain gauge stations are located. The hydro observation site is located in Naidupeta in Nellore district.

Fig 1: Location Map of the Study Area

METHODOLOGY

The SCS curve number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method was developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture for use in rural areas. It is a versatile and widely used procedure for runoff estimation. The requirements for this method are low, rainfall mount and curve number. The curve number is based on the areas hydrologic soil group, land use treatment and hydrologic condition. As defined by SCS soil scientists, Soils may be classified into four hydrologic groups (A, B, C and D), (USDA, 1985), depend on infiltration, soil classification and other criteria. Land use and treatment classes are used in the preparation of hydrological soil-cover complex, which in turn are used in estimating direct runoff.

The method of peak discharge estimation employed by the Soil Conversion Service (SCS), U. S. Department of Agriculture, uses an average number of natural UHs for watersheds varying widely in size and geographical location. The SCS model permits computing the peak discharge for a watershed that has insufficient observed rainfall–runoff data.

The curve number was determined with respect to land use and soil hydrological group maps in different antecedent moisture conditions (dry, average and moist) and hydrological conditions. The losses estimation is the sum of the interception, infiltration, and transmission of the soil and surface (in mm). The runoff calculation is given below:

$$S = \frac{25400}{CN} - 254$$

where, S= Losses; CN= Curve number;

Runoff was calculated using the following formula;

$$Q = \frac{(P - 0.2 \times S)^2}{(P - 0.8 \times S)}$$

Where, Q =Runoff in mm; P=Precipitation in mm; S = Losses;

The following formula is used to estimate the Peak discharge for an ungauged watershed in SCS-CN Model:

$$Q_p = \frac{(2.083 \times A \times Q)}{t_p}$$

Where, Q_p = Peak discharge (m^3/s); A = Watershed area (Km^2); Q = Runoff (mm) ;

t_p = Time to peak (sec) ;

The following calculation of the concerned catchment area illustrates the fact. In the present work study area has 6 Land cover classes, so it has different curve numbers.

Weighted CN Value:

$$CN_W = \frac{A_1CN_1 + A_2CN_2 + A_3CN_3 + A_4CN_4 + A_5CN_5 + A_6CN_6}{A_1 + A_2 + A_3 + A_4 + A_5 + A_6}$$

MODELS CALIBRATION

Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. However, no comprehensive guidance is available to facilitate model evaluation in terms of the accuracy of simulated data compared to measured flow and constituent values.

1. Comparison between observed and calculated discharges
2. Linear Regression analysis
3. Performance evaluation indices

Performance evaluation indices

a. Nash-sutcliffe efficiency (NSE)

$$\textbf{NSE}=1-\left[\frac{\sum_{i=1}^{n}(y_i^{obs}-y_i^{sim})^2}{\sum_{i=1}^{n}(y_i^{obs}-y^{mean})^2}\right]$$

Where Y_i obs is the i^{th} observation for the constituent being evaluated, Y_i sim is the i^{th} simulated value for the constituent being evaluated, Y mean is the mean of observed data for the constituent being evaluated, and *n* is the total number of observations.

b. Rmse-observations standard deviation ratio (RSR)

RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation

$$\textbf{RSR}=\frac{RMSE}{S\ TDEVobs} = \frac{\sqrt{\sum_{i=1}^{n}(y_i^{obs}-y_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(y_i^{obs}-y^{mean})^2}}$$

c. Statistical Errors

Statistical errors such as Relative Mean Error (RME), Root Mean Square Error (RMSE) are determined by using the following equations

$$\textbf{1. RME}= \sum_{i=0}^{n}\left[\frac{y_{obs}-y_{sim}}{y_{obs}}\right] \times 100$$

$$\textbf{2. RMSE}= \sqrt{\frac{1}{n}\left\{\sum_{i=0}^{n}\left[\frac{y_{obs}-y_{sim}}{y_{obs}}\right]^2\right\}}$$

Where,

y_{obs} = observed past data;

y_{sim} = simulated or predicted data;

n= total number of observed data;

RESULTS AND DISCUSSION

By using the SCS-CN model is estimated on an event based approach. Peak discharge is estimated on an event based approach during the period of 2009 - 2013. Total ' 10 ' events are considered and it was shown in table 1.

Table. 1 Numbers and dates of events studied in an ungauged watershed

S. NO	Date of events	Precipitation P in mm	Events number
1	12-February-2009	3.2	10
2	5,6 -September-2009	18.9	
3	13,14-March-2010	30.8	
4	28,29,30,31-October-2010	221.2	
5	22,23-February-2011	16.4	
6	22,23,24-August-2011	120.4	
7	04-January-12	5.2	
8	3,4,5-November-2012	176.2	
9	19,20-March-2013	95.4	
10	19,20,21,22,23-October-2013	185.2	

Estimation of peak discharge using SCS-CN Model

The SCS-CN Model for the calculation of peak discharge estimation is majorly dependent on Land use and Land cover of the watershed.

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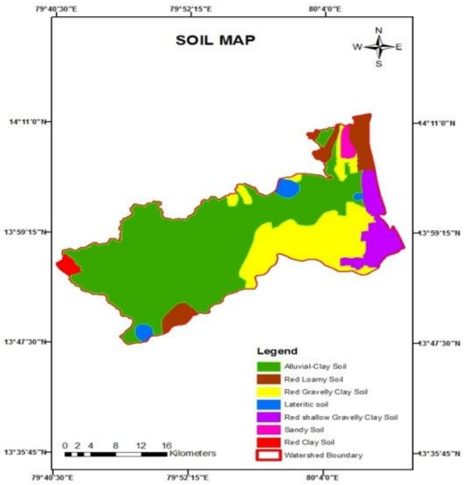

Fig 2: Soil Map

Land use Land cover Maps

The following maps are prepared in Arc GIS on each event, it has each satellite image on the particular day based and calculated the areas changes on one event to another event how it will be varies.

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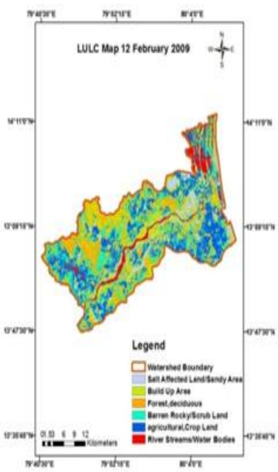

Fig 3 LULC Map on 12 February 2009

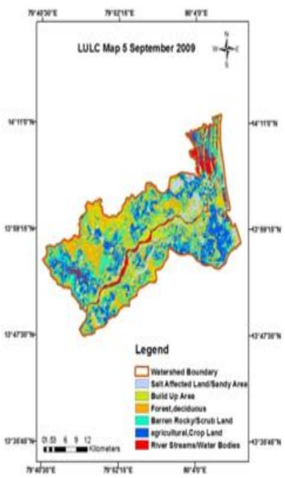

Fig 4 LULC Map on 5 September 2009

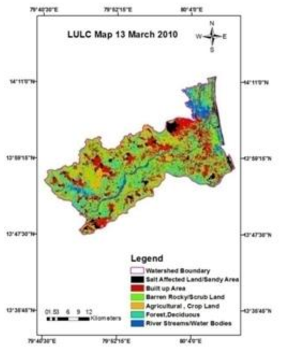

Fig 5 LULC Map on 13 March 2010

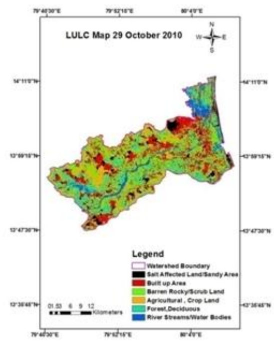

Fig 6 LULC Map on 29 October 2010

Table 2 LULC Classification on 12 February 2009

S. No	LULC Classification	AREA in sq. km	Percentage Area
1	Salt Affected Land/Sandy Area	58.17	6.07
2	Agricultural Land	193.18	20.16
3	River Stream/ Water Bodies	58.93	6.15
4	Barren Rocky/ Open Scrub Land	148.62	15.51
5	Forest Area	254.10	26.52
6	Build up Area	244.91	25.56
	Total	957.92	100

Table 3 LULC Classification on 5 September 2009

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	56.37	5.86
2	Agricultural Land	143.29	14.94
3	River Stream/ Water Bodies	83.97	8.79
4	Barren Rocky/ Open Scrub Land	173.62	18.12
5	Forest Area	254.42	26.53
6	Build up Area	246.12	25.77
	Total	957.92	100

Table 4 LULC Classification on 13 March 2010

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	56.78	5.86
2	Agricultural Land	203.15	21.21

3	River Stream/ Water Bodies	58.32	6.15
4	Barren Rocky/ Open Scrub Land	133.62	13.92
5	Forest Area	252.04	26.31
6	Build up area	253.12	26.50
	Total	957.92	100

Table 5 LULC Classification on 29 October 2010

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	60.17	6.28
2	Agricultural Land	163.15	17.03
3	River Stream/ Water Bodies	61.25	6.46
4	Barren Rocky/ Open Scrub Land	166.62	17.39
5	Forest Area	232.42	24.23
6	Build up Area	273.12	28.59
	Total	957.92	100

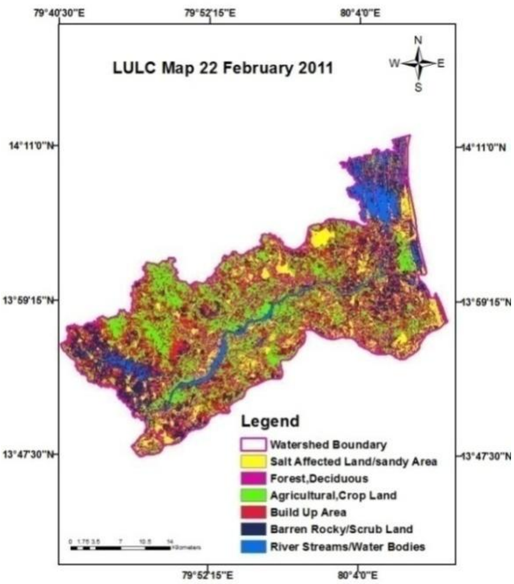

Fig 7 LULC Map on 22 February 2011

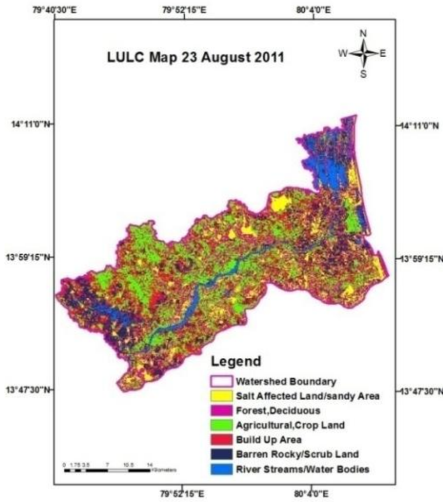

Fig 8 LULC Map on 23 August 2011

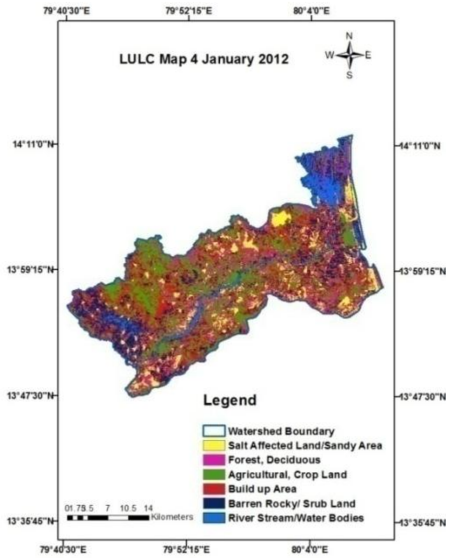

Fig 9 LULC Map on 4 January 2012

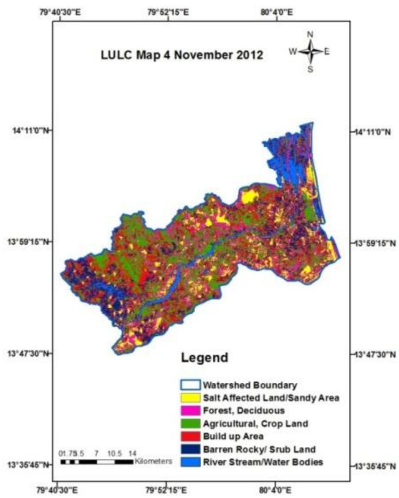

Fig 10 LULC Map on 4 November 2012

Table 6 LULC Classification on 22 February 2011

1	Salt Affected Land/Sandy Area	60.9	6.35
2	Agricultural Land	208.15	21.72
3	River stream/ Water Bodies	59.95	6.25
4	Barren Rocky/ open Srub Land	156.62	16.35
5	Forest area	198.12	20.68
6	Build up area	273.12	28.59
	Total	957.92	100

Table 7 LULC Classification on 23 August 2011

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	60.93	6.35
2	Agricultural Land	168.85	17.55
3	River stream/ Water Bodies	60.95	6.36
4	Barren Rocky/ open Srub Land	189.62	19.79
5	Forest area	196.04	20.47
6	Build up area	281.12	29.42
	Total	957.92	100

Table 8 LULC Classification on 4 January 2012

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	61.9	6.46
2	Agricultural Land	212.5	22.15
3	River stream/ Water Bodies	64.9	6.77
4	Barren Rocky/ open Srub Land	157.62	16.45
5	Forest area	178.12	18.59
6	Build up area	282	29.53
	Total	957.92	100

Table 9 LULC Classification on 4 November 2012

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	62.04	6.47
2	Agricultural Land	185.15	19.33
3	River stream/ Water Bodies	60.25	6.36
4	Barren Rocky/ open Srub Land	186.62	19.48
5	Forest area	173.42	18.07
6	Build up area	289.9	30.26
	Total	957.92	100

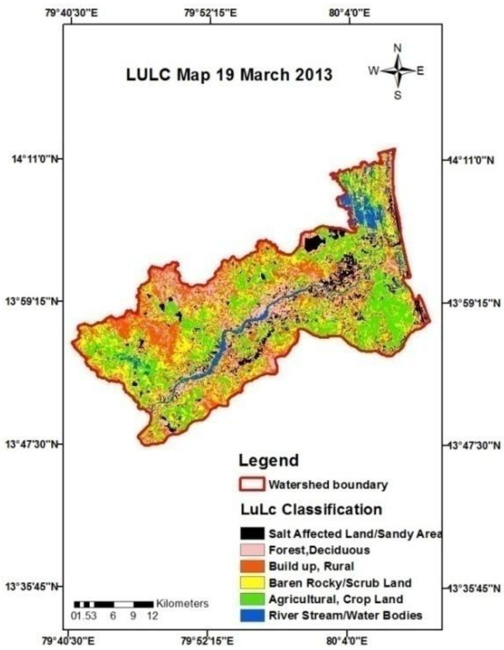

Fig 11 LULC Map on 19 March 2013

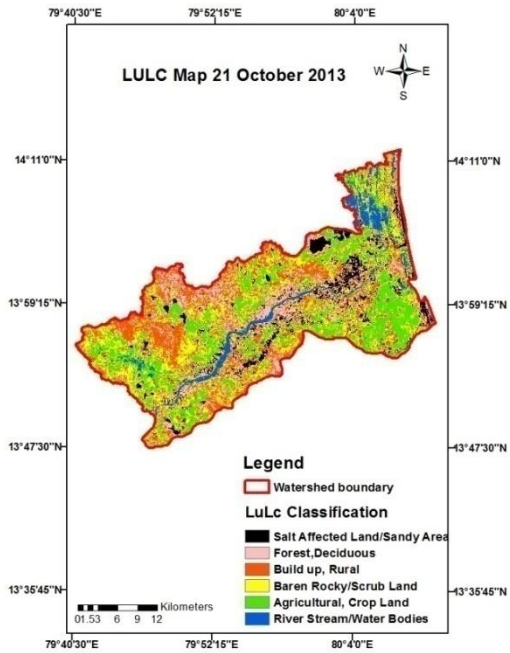

Fig 12 LULC Map on 21 October 2013

Table 10 LULC Classification on 19 March 2013

S. No	LULC Classification	AREA in sq. km	Percentage Area
1	Salt Affected Land/Sandy Area	62.5	6.52
2	Agricultural Land	225.85	23.50
3	River stream/ Water Bodies	58.32	6.15
4	Barren Rocky/ open Srub Land	149.62	15.61
5	Forest area	170.42	17.75
6	Build up area	290.92	30.36
	Total	957.92	100

Table 11 LULC Classification on 21 October 2013

S. No	LULC Classification	AREA in sq.km	Percentage Area
1	Salt Affected Land/Sandy Area	62.9	6.56
2	Agricultural Land	195.15	20.37
3	River stream/ Water Bodies	60.95	6.36
4	Barren Rocky/ open Srub Land	179.62	18.75
5	Forest area	166.42	17.34
6	Build up area	292.92	30.57
	Total	957.92	100

The land use and land cover analysis on the study area has been attempted based on thematic mapping of the area consisting of built-up land, Agriculture land, water bodies, forest and waste land using the satellite image.

The following table shows the hydrological soil group and standard curve number and calculated the weighted curve number on each event.

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Table 12 Standard Curve numbers as per NRSC guidelines

S. No	Land Cover Type	Hydrologic Soil Groups	CN
1	Salt Affected Land, Sandy Area	A	98
2	Agricultural Land	C	83
3	River Streams / Water Bodies	A	100
4	Barren Rocky / Open Scrub Land	A	76
5	Forest Area	C	70
6	Build up Area	A	77

By using the SCS-CN Model, the procedure for calculation of peak discharge estimation is shown below, considering a randomly chosen event; 12-February-2009.

Event	Dates	CN	Precipitation P in mm	Losses, $S = \frac{25400}{CN} - 254$	Runoff, $Q = \frac{(P - 0.2 \times S)^2}{(P - 0.8 \times S)}$ in mm	Peak discharge, $Q_p = \frac{(2.083 \times A \times Q)}{t_p}$ in (m^3/s)
1	12-February-2009	76.93	3.2	76.17	0.16	6.92
2	5,6 -September-2009	77.84	18.9	72.31	2.07	14.02
3	13,14-March-2010	79.28	30.8	66.35	157.62	6.83
4	28,29,30,31-October-2010	78.82	221.2	68.25	3.44	132.79
5	22,23-February-2011	79.88	16.4	63.97	0.19	29.38
6	22,23,24-August-2011	79.1	120.4	67.11	65.73	90.81
7	04-January-2012	80.27	5.2	62.39	118.54	9.36
8	3,4,5-November-2012	79.92	176.2	63.81	1.01	116.92
9	19,20-March-2013	83.02	95.4	51.95	134.57	58.02
10	19,20,21,22,23-October-2013	80.65	185.2	60.94	48.03	129.36

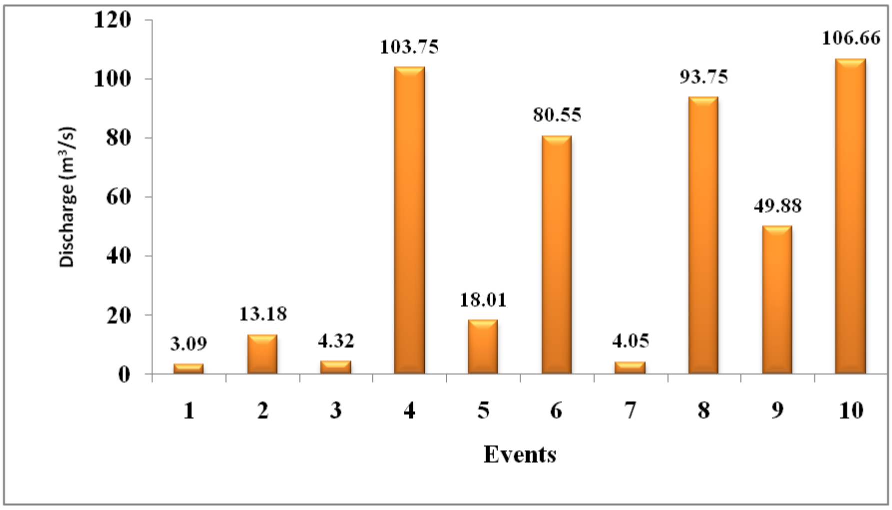

Fig 13 Ordinate graph SCS-CN Model

The ordinate graph on SCS-CN Model is plotted on the variations of peak discharge values ($Q_{(SCS-CN)}$) for various events. By the plot, the Peak discharge values for the events 4, 6, 8 and 10 can be observed being comparatively high because the corresponding events belong to monsoon period.

Comparison between observed and calculated discharges

Table 14 Comparison between observed and calculated peak discharges

EVENTS	DATES	$Q_{(observed)}$	$Q_{(calculated)}$
1	12-February-2009	11.18	6.92
2	5,6 -September-2009	17.32	14.02
3	13,14-March-2010	7.85	6.83
4	28,29,30,31-October-2010	145.72	132.79
5	22,23-February-2011	37.41	29.38
6	22,23,24-August-2011	104.84	90.81
7	04-January-2012	13.10	9.36
8	3,4,5-November-2012	126.63	116.92
9	19,20-March-2013	69.22	58.02
10	19,20,21,22,23-October-2013	145.57	129.36

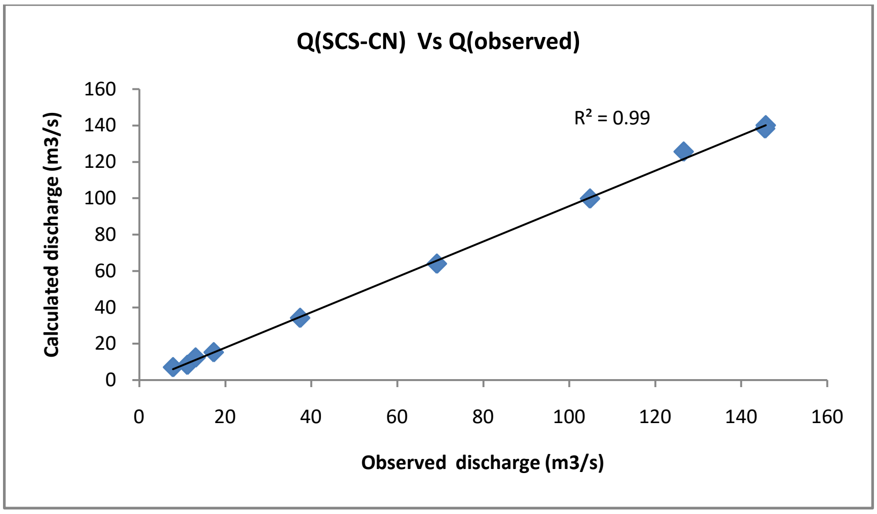

Fig 5 Graph drawn on Q_{SCS-CN} Vs Q_{obs}

A correlation graph is plotted between the observed and calculated discharges from SCS-CN Model to get the R^2 value. By observation, as the R^2 (0.99) value is more nearer to 1.0, it can be stated that the SCS-CN Model is fit for ungauged watershed.

The Performance evaluation indices values were also calculated and given in below Table 5 it can observed in models calibration the SCS-CN is the better one to estimate the peak discharge an ungauged watershed.

Table 5 Performance evaluation indices

S. NO	MODEL	RME	RMSE	NSE	RSR
1	SCS-CN	8.06	0.39	0.89	0.61

CONCLUSIONS

Remote sensing data are of great use for the estimation of relevant hydrological data when conventional hydrological data are inadequate for the purpose of design and operation of water resources system. Remote sensing data can be used as model input for determination of catchment characteristics, such as land use/ land cover, morphology, depth elevation model, drainage maps. By using the SCS-CN curve, calculate the runoff and rainfall for the watershed. With this develop a frequency curve which can predict the rainfall as well as the runoff at any recurrence time interval. The runoff estimated using SCS curve number model are comparable with the runoff measured by the conventional method and the analysis can be extended further to assess the impact of land use changes after construction of the proposed dam on the rainfall-runoff relationship.

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