IMPACT ASSESSMENT OF LAND USE CHANGE ON RUNOFF GENERATION USING REMOTE SENSING & GEOGRAPHICAL INFORMATION SYSTEMS

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Abstract: Estimation of runoff in a watershed is a prerequisite for design of hydraulic structures, reservoir operation and for soil erosion control measures. Water resource planning and management is an important and critical issue in arid and semi-arid regions. Runoff from a watershed is affected by several geo-morphological parameters and for a particular watershed land use change affects the runoff volume and rate significantly. Therefore, a hydrologic model that emphasizes land use is required to estimate runoff volume and rate. Soil Conservation Service Curve Number (SCS-CN) method that computes the surface runoff volume for a given rainfall event from small agricultural, forest, and urban watersheds is applied in the study. Traditional approach of computing runoff using SCS-CN method are lengthy, time consuming and inaccurate, and therefore, in this study, remote sensing (RS) imagery and geographic information systems (GIS) are applied in combination with the SCS-CN method for precise and timely estimation of surface runoff volume and rate. Remote sensing imagery including SRTM, LISS-III and LANDSAT ETM+ and soil maps are pre-processed and thematic maps are generated using ERDAS IMAGINE 11.0 and ArcGIS 10.0 softwares. In addition to quantification of surface runoff in this study, the effect of land use change on runoff generation is assessed by considering two different years in Limkheda watershed, Gujarat, India. Four rainfall events including one extreme event were identified and performance of the SCS-CN method coupled with RS and GIS was assessed. Initially, it is observed in this study that forest area is decreased and agricultural land is increased in the past 12 years from 2000 to 2012. This study revealed that SCS-CN method coupled with RS and GIS is capable of simulating runoff pattern and runoff volume successfully. It is also observed in this study that due to changing land use pattern volume and runoff rate are changed significantly in the watershed.

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Introduction

Estimation of runoff from storm rainfall is frequently needed for water resource planning, design of hydraulic structures and environmental impact analysis. Land use change is the most important and dynamic component of the watershed management and its effect on hydrologic components is important especially for runoff. Remote sensing and GIS techniques are widely applied and have shown their capabilities in generating development plans for the watershed area in accordance with the production potential and limitation of terrain resources. The Soil Conservation Service Curve Number (SCS-CN) method is widely used for predicting direct runoff volume for a given rainfall event. This method was originally developed by the US Department of Agriculture, Soil Conservation Service and documented in detail in the National Engineering Handbook, Sect. 4: Hydrology (NEH-4) SCS, 1956, 1964, 1971, 1985, 1993). This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate results (Gupta and Panigrahy 2008). Generally the model is well suited for small watersheds of less than 250 km^2 and it requires details of soil characteristics land use and vegetation condition (Sharma et al. 2001). Due to its simplicity, it soon became one of the most popular techniques among the engineers and the practitioners, mainly for small catchment hydrology (Mishra and Singh, 2006).

Remote Sensing and Geographical Information System (GIS) play a very important role in estimation of different parameters required by the SCS-CN method. Remote sensing along with GIS help to restore, collect, analyze, manipulate, retrieve and interpret the spatially referenced and non-spatial data on large scale and is very much helpful to classify the satellite imagery in to features of interest and analyze interaction of parameter such as land use, soils, topographic and hydrological conditions. The parameters and information obtained using RS and GIS coupled with hydrological model such as SCS-CN method can be used to estimate runoff volume and rate precisely and timely compared to conventional methods.

The SCS-CN method provides a rapid way to estimate runoff change due to land use change (Shrestha 2003; Zhan and Huang 2004). The following study was conducted with following objectives:

1. To assess the land use change in a watershed in the semi-arid middle region of Gujarat.
2. To map spatial distribution and temporal variation of CN for year 2000 and 2012 in the watershed.
3. To develop SCS-CN model for estimation of runoff volume and runoff rate in the watershed.
4. To assess the effect of land use change on runoff volume and rate in the watershed.

Study Area and Data Applied:

The Limkheda agricultural watershed located in the Middle Gujarat is selected for rainfall runoff modelling in this study. Major geographical area of the watershed lies in Limkheda Taluka in the middle Gujarat. Limkheda is located at 22°49′0″N 73°59′0″E at an elevation of 207 metres (680 ft). Water availability in the study area is an important factor influencing crop yields, which are significantly below potential yields. Being situated in semi-arid region, there is huge scope of improving the potential of the watershed for increasing the availability of water for agriculture and other uses. Hence, it is highly important to understand the underlying hydrological processes and rainfall runoff relationship of the watershed. Different data required for rainfall-runoff simulation and there source are listed in Table 1.

Table 1
Hydro-meteorological and Remote Sensing Data

Data	Description	Source
Hydrological and meteorological data	Daily rainfall, daily discharge	➢ State Water Data Center, Gandhinagar. ➢ Sevasadan Department, Godhra.
Remote Sensing data	Landuse/ landcover map, soil map, slope map, drainage map.	➢ National Remote Sensing Center, Hyderabad. ➢ Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhingar.
	Digital elevation model (DEM)	➢ SRTM (Shuttle Radar Topography Mission) united state geological survey
	Base map/ Topography sheet	➢ Survey of India
Software Used	Erdas Imaginne 11.0, ArcGIS 10.0	

SCS-CN Method and Model Development

The standard SCS-CN method is based on the following relationship between rainfall, *P* (mm), and runoff, *Q* (mm) (SCS-USDA 1986; Schulze et al. 1992):

$$\begin{cases} \dfrac{(P-I_a)^2}{P-I_a+S} & P>I_a \\ 0 & P \le I_a \end{cases} \quad (1)$$

where *S* (mm) is potential maximum retention after runoff begins.

I_a is all loss before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and land cover parameters. By removing I_a as an independent parameter, a combination of *S* and *P* to produce a unique runoff amount can be approximated. Substituting I_a = 0.2S gives

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

The variable *S*, which varies with antecedent soil moisture and other variables, can be estimated as

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

where *CN* is a dimensionless catchment parameter ranging from 0 to 100. A *CN* of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A *CN* of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount. The curve number can be determined from empirical information. The SCS has developed standard tables of curve number values as functions of catchment land use/cover conditions and HSG. These are listed in the *SCS User Manual* (SCS-USDA 1986). The Curve Numbers as mentioned are calculated for AMC II and then adjusted by addition to simulate AMC III or subtraction to simulate AMC I. The process to estimate runoff from a watershed is presented in Fig. 1. It depicts the overall methodology for CN generation using the GIS.

After CN generation SCS-CN method is used to estimate the surface runoff. Further effect of land use change on runoff intensity and runoff volume is analysed for two different years i.e. 2000 and 2012. To conduct this study remote sensing imagery for these two year are collected. For year 2000, LANDAT images are download from "Global Land Cover Facility (GLCF)" website, whereas for year 2012, LISS_III remote sensing images were used obtained from National Remote Sensing Center (NRSC), Hyderabad. The details of the two images are shown in Table 2.

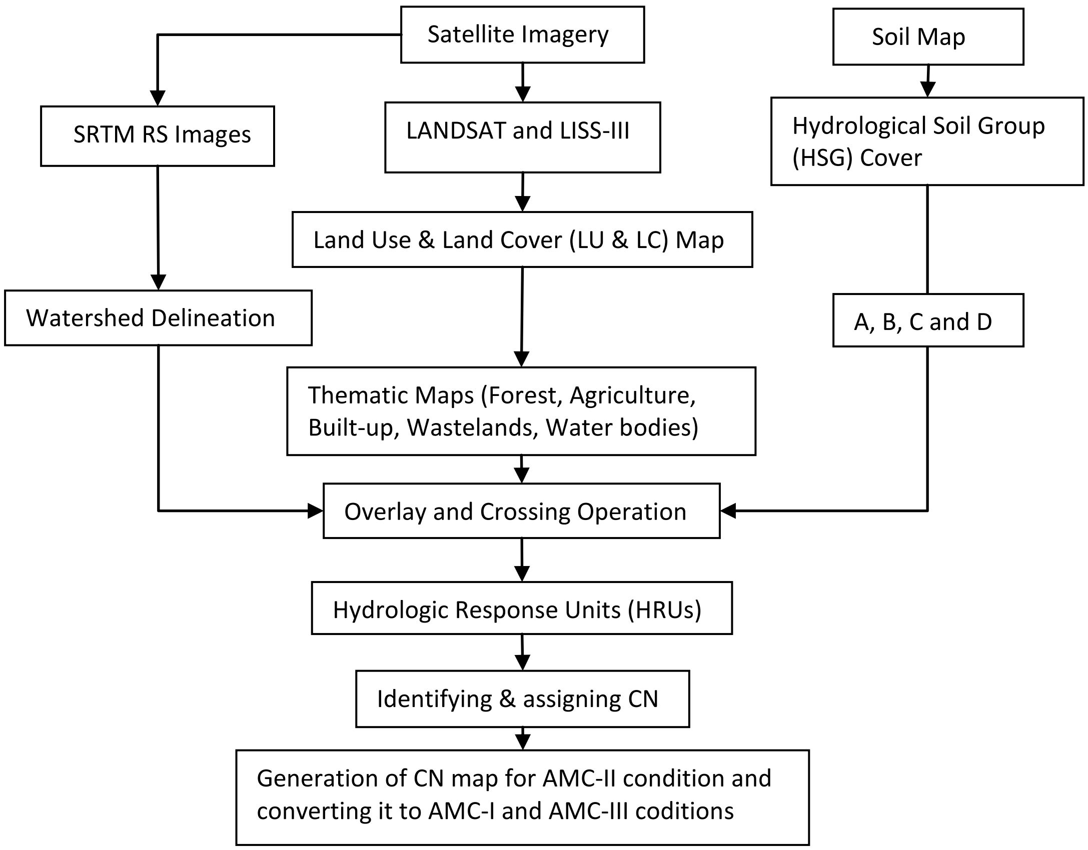


Fig:1- Flowchart Showing the Process of CN Generation

Tables 2
Different Characteristics of Satellite Imagery Used

Satellite	Corresponding month and year	Sensor	Spectral rage (lm)	Bands used for classification	Pixel size (in meter)
LANDSAT 7	22/10/2000	Enhanced Thematic Mapper Plus (ETM)+	0.525-0.605 µm, 0.63-0.69 µm, 0.75-0.90 µm	2,3,4	30 m
LISS III	20/12/2012	Linear Imaging Self-Scanning Sensor (LISS-III)	0.52 - 0.59 µm, 0.62 - 0.68 µm, 0.77 - 0.86 µm	2,3,4	24 m

Results and Discussion:

(i) Watershed Delineation
Remote sensing imagery called SRTM (Shuttle Radar Topographic Mission) was used in this study to demarcate the watershed boundary. The outlet of the watershed boundary was taken on river at Limkheda town in Dahod district of Gujarat. The demarcated watershed is shown in Fig. 2 along with drainage network and elevation map.

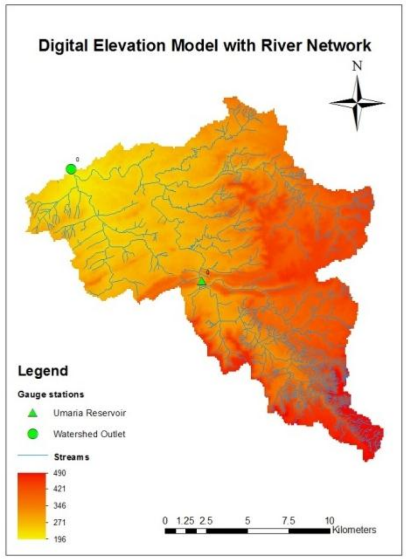
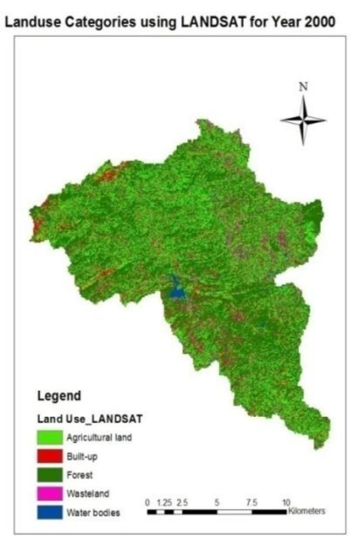


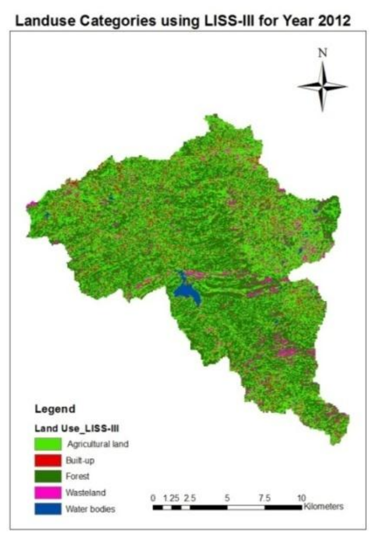
Fig:2-Location Map of Study Area Showing Discharge and Rainfall Gauge Sites

(ii) Land Use Classification

The Limkheda watershed was classified into five dominant land use land cover categories viz. Forest, Agriculture, Water bodies, Wastelands and Built-up. In the watershed, land use was classified for two years i.e. 2000 and 2012. For this LISS-III image was obtained from NRSC Hyderabad for year 2012 whereas LANDSAT image was downloaded from "Global Land Cover Facility" website. Both images were then classified using supervised classification. ERDAS IMAGINE 11 was used to classify these remote sensing images. Land use categories for the year 2000 are presented in Fig. 3(a), whereas Fig. 3(b) shows the land use categories in the year 2012 in the Limkheda watershed.



(a)



(b)

Fig:3-Land Use and Land Cover Categories using (a) LANDSAT for Year 2000 and (b) LISS-III for Year 2012 of the Watersheds

Table 3 shows the area under different land use categories during year 2000 and 2012 classified using LANDSAT and LISS-III remote sensing imagery.

Table 3
Changes in Land Use/Land Cover in Limkheda Watershed

Landuse Class	LANDSAT		LISS-III		Landuse Changes	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Agricultural Land	76.39	34.64	98.24	44.55	21.86	9.91
Forest	116.26	52.73	93.47	42.39	-22.79	-10.34
Wasteland	14.28	6.47	15.20	6.89	0.93	0.42
Water bodies	2.20	1.00	2.21	1.00	0.00	0.00
Built-up	11.37	5.16	11.40	5.17	0.03	0.01
Total	220.49		220.52			

(iii) Hydrology Soil Groups

A hydrologic soil group map generated with GIS tool is shown in Fig 4. Out of all hydrologic groups such as A, B, C, and D only three groups B, C and D were found in the Limkheda watershed. Group B soils having a moderately low runoff potential due to moderate permeability rate (3.81–7.62 mm/h), group C soils having a moderately high runoff potential due to slow permeability rate (1.27–3.83 mm/h) and finally group D soils with a high runoff potential due to very slow permeability rate (< 1.27 mm/h)(USDA-SCS, 1993). 21.45% of soil was placed in group B, 51.65% in group C and 26.90 % of soil was placed in group D (Table 4).

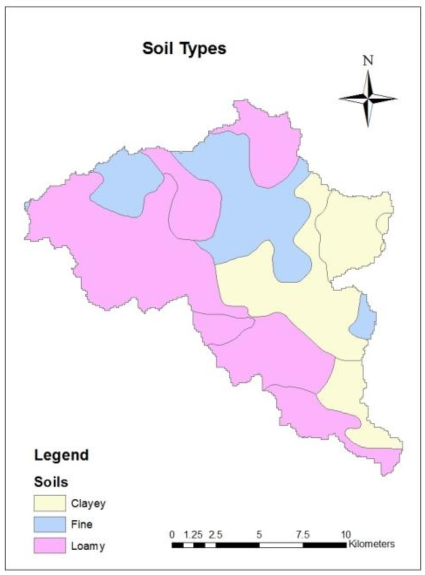


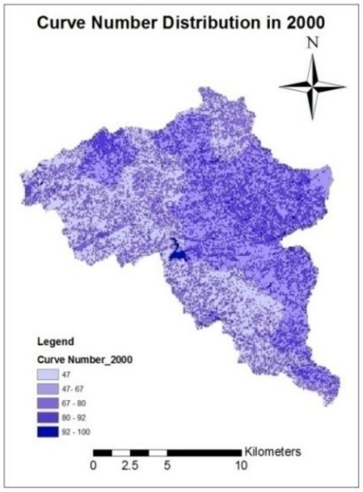
Fig:4-Soil Types in the Study Area

Table 4
Percentage Soil Type in Limkheda Watershed

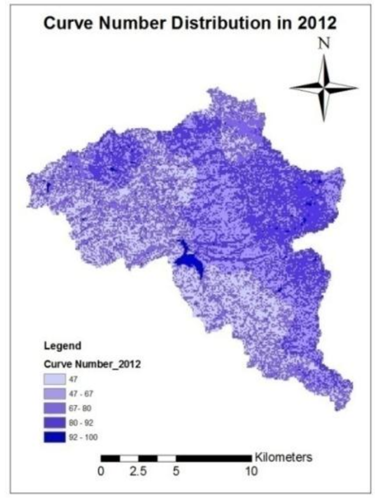
Soil Type	Area (m^2)	Area (%)
Fine	47.29	21.45
Loamy	113.88	51.65
Clayey	59.31	26.90
Total	220.49	100

(iv) CN Values

The CN values for each hydrologic soil group and corresponding land use class during years 2000 and 2012 are presented in Fig. 5. In comparison with year 2000, in year 2012 CN value is increased from 69.03 to 71.72 that is due to the reason that agricultural land is increased significantly in year 2012, as in year 2000 total agricultural land was 76.39 km^2 that has increased to 98.24 km^2 in year 2012. Another reason is that forest land is decreased significantly from year 2000 to year 2012 as in year 2000 total forest land was 116.26 km^2 that has been reduced to 93.47 km^2. No significant changes are observed in, water bodies, built-up and wastelands.



(a)

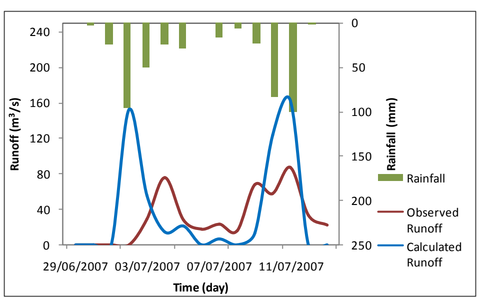


(b)

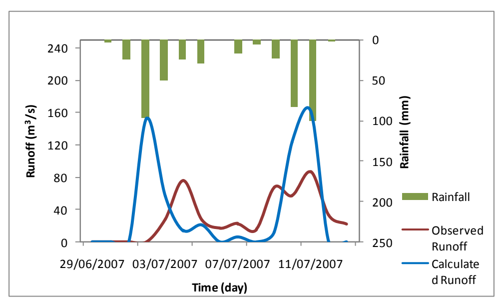
Fig:5-Spatial Distribution of CN in Limkheda Watershed for Years (a) 2000 and (b) 2012.

(v) Simulation Results

Performance of SCS-CN method to simulate runoff for these four events in Limkheda watershed is shown in Fig.6. Besides comparison between observed and simulated values comparison is also carried out in observed and simulated values in year 2000 and 2012. Fig.6 depicts the comparison between observed and simulated values for Event-1 during year 2000 and 2012. It can be observed that calculated runoff over-estimate the observed values but shows a satisfactory behaviour of the observed values. It can also be observed that for same event SCS-CN method shows higher peak values during 2012 compared to 2000. It is due to the reason that forest areas are decreased whereas agricultural lands are increased.



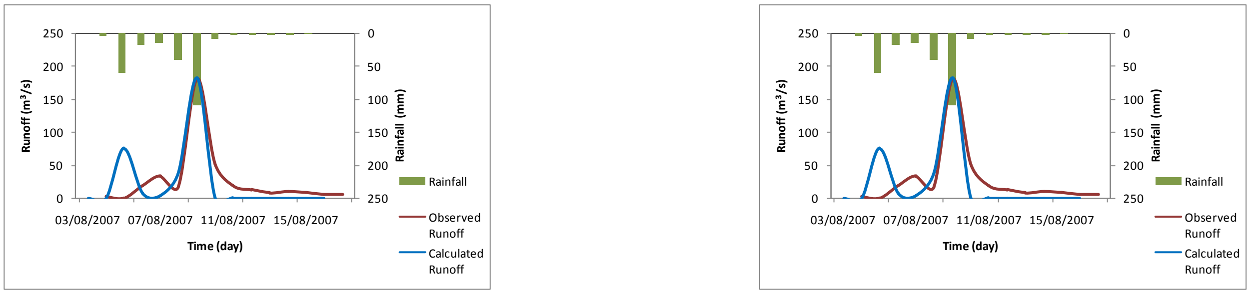
(a)



(b)

Fig:6-Observed versus Predicted Runoff for Event-1 using (a) LANDSAT and (b) LISS-III.

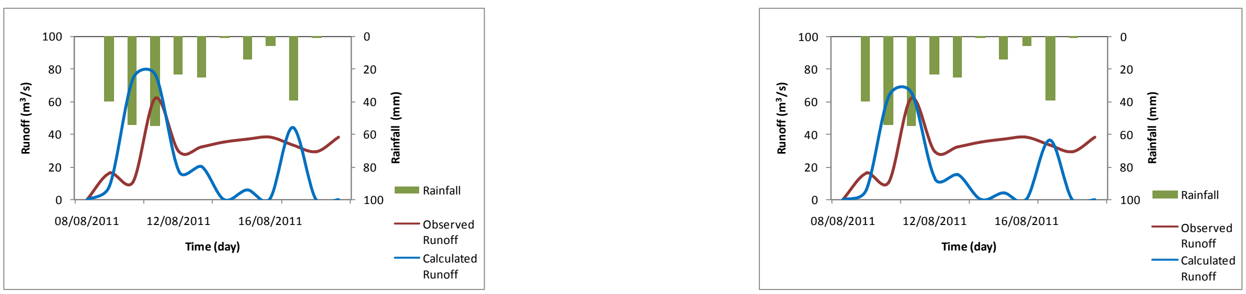
For Event-2, SCS-CN method simulated observed values very well and shows the general behaviour of the observed values as shown in Fig. 7. Peak value is simulated very well, but similar to Event-I increased peak value is observed in year 2012 compared to 2000.



(a) (b)

Fig:7-Observed versus Predicted Runoff for Event-2 using (a) LANDSAT and (b) LISS-III.

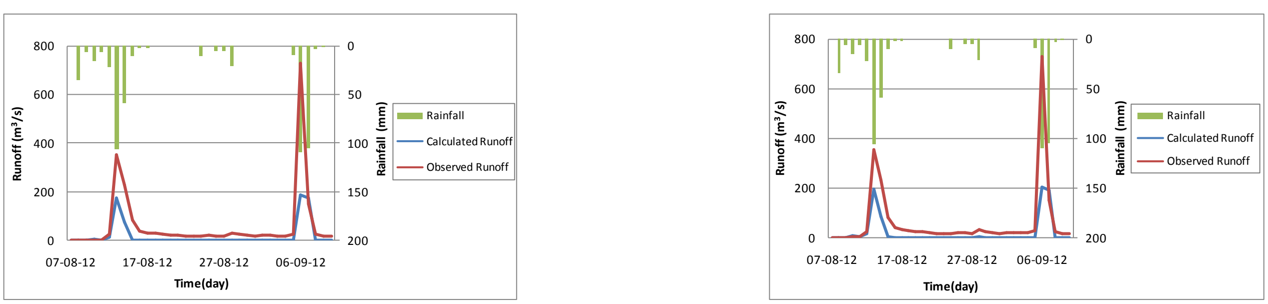
During Event-3, it can be observed that similar to previous two events, SCS-CN method is capable of simulating the runoff very well as observed and simulated values are very close to each other. Further, it can be observed that during initial phase hydrograph characteristics of the observed values are simulated very well but in later phase simulation is weak that is due to the reason that in such a large watershed (catchment area= 220.49 km^2) response of rainfall to watershed is delayed, whereas SCS-CN method calculated excess runoff for each day. Another important point is that peak values are simulated very well that is very important for water resource planning and management such as soil and water conservation structure design, flood control, water supply, reservoir operation, etc. Further, it can be observed that similar event produces higher peak values in the year 2012 compared to 2000 as shown in Fig. 8.



(a) (b)

Fig:8-Observed versus Predicted runoff for Event-3 using (a) LISS-III and (b) LANDSAT.

Performance of SCS-CN method was also evaluated for one of the extreme events during year 2012 (Event-4) and the performance is shown in Fig. 9. It can be observed that simulated runoff under estimated the observed values. Total depth of rainfall during the event was observed as 532.00 mm and SCS-CN method generated 272.18 mm depth of excess runoff. It clarifies the discrepency in the observed and simulated runoff as the runoff measured shows the runoff volume at a particular time (08:00 am), whereas excess runoff converted into volume shows the average discharge for the whole day. There is a chance that runoff obtained at this particular time may be the peak value. This is the reason predicted values are underestimating the observed runoff. Further, it can be observed that if similar event was occurred during year 2000, the depth of excess runoff would be produced as 244.41 mm.



(a) (b)

Fig:9-Observed versus Predicted Runoff for Event-4 using (a) LANDSAT and (b) LISS-III.

For the same event depth of rainfall and depth of simulated excess runoff for year 2000 and 2012 are shown in Fig. 10. It can be observed that correlation coefficient is 0.97 is between excess rainfall and depth of rainfall for both the years 2000 and 2012. Further, it can be observed that same rainfall event generates higher amount of excess runoff in year 2012 compared to year 2000.

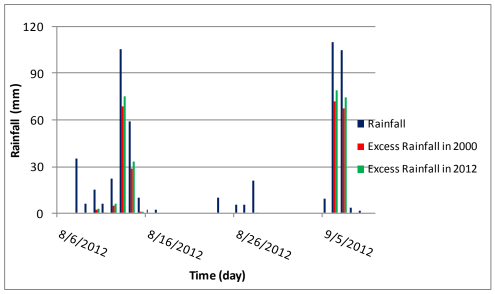


Fig:10-Potential Excess Rainfall during 2000 and 2012 for Extreme Event-4.

(vi) Effect of Land Use on Runoff Potential

The effect of land use on excess runoff potential is calculated using monsoon season rainfall for year 2007-2012 and the results are presented in Table 5.5. It can be observed that for land use and land cover conditions in 2000 could have generated 1965.7 mm excess runoff compared to 2288.3 mm excess runoff due to land use/land cover conditions in year 2012. It is due to the condition that land use changes from year 2000 to 2012, that also increases 16.41 % of surface runoff in year 2012 compared to year 2000. It clearly shows that additional water harvesting structures are required to conserve the water in the watershed as runoff is excessively draining out due to change in land use from 2000 to 2012 in the Limkheda watershed.

Table 5
Comparison of Runoff Generation Potential using CN values of 2000 and 2012.

Year	Rainfall (mm)	Calculated Surface Runoff (mm)		Calculated Surface Runoff Volume (MCM)	
		2000	2012	2000	2012
2007	880	855.1	973.5	188.54	214.65
2008	469	64.2	86.9	14.16	19.16
2009	319	46.7	61.7	10.30	13.60
2010	568	116.8	152.7	25.75	33.67
2011	543	210.9	259.6	46.50	57.24
2012	759	672.0	753.8	148.17	166.21
Total	3538	1965.7	2288.3	433.42	504.53

One of the only irrigation project in the Limkheda watershed is Umaria irrigation project, having net storage capacity 13.07 MCM, and the found results suggest higher potential for storage of surface runoff in the watershed.

Conclusions:

In this study it was found that SCS-CN method is capable of simulating runoff pattern and runoff volume successfully. Another important finding in this study was that intensity of peak values are increasing due to deforestation in the watershed from 2000-2012. The weighted curve number in this study was found to be 69.03 and 71.72 in year 2000 and 2012, respectively. It was found that the runoff yield decreased by 13.85% during the years as the calculated excess runoff depth during 2007 was 855.1 mm and for the same event excess runoff depth during 2012 was 973.5 mm. The major findings from the study are listed below:-

1. The SCS-CN methodology is able to simulate runoff in the Limkheda watershed that is situated in semi-arid region of Gujarat.
2. Theis study shows that in the watershed forest area is decreasing and agricultural land is increasing.
3. At watershed outlet even for similar rainfall event higher peak values will be observed due to changing land use pattern.
4. Higher amount of water will be draining out from the watershed, emphasizing need of soil and water conservation structures in the watershed.
5. As the performance of SCS-CN method is found suitable in estimating runoff volume precisely, it can be utilized for runoff estimation in un-gauged watershed of semi-arid region of Gujarat, India.

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