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Runoff Estimation in Kajurli Watershed Using SCS-CN and GIS Techniques

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study focuses on estimating surface runoff using the Soil Conservation Service Curve Number (SCS-CN) method, combined with Remote Sensing (RS) and Geographic Information System (GIS) techniques, for the Kajurli Watershed in Ratnagiri District, Maharashtra. Surface runoff is a key factor influencing agricultural productivity, soil erosion, and water management at the watershed level. The SCS-CN method, a widely used tool for runoff estimation, utilizes rainfall, land use, and soil type data. By integrating RS and GIS, the study achieves a more accurate assessment of land use and soil characteristics, which are critical inputs for runoff calculations. The Kajurli Watershed falls under hydrological soil group B, known for moderate runoff potential. The study uses 33 years

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of historical rainfall data (1990-2022) to compute annual runoff using the SCS-CN method. Key parameters such as Curve Numbers (CN) are derived based on land use, hydrological soil groups, and antecedent moisture conditions (AMC). The average annual rainfall in the watershed is found to be 3392.8 mm, with 39.69% of this rainfall contributing to surface runoff. The integration of RS and GIS simplifies spatial analysis, enabling accurate and efficient runoff estimation. The study highlights the sensitivity of the SCS-CN method to CN values, emphasizing the importance of precise land use and soil data for reliable hydrological modelling. These findings offer crucial insights for water resource management, flood control, and agricultural planning in the region.

Keywords: SCS-CN; GIS; hydrologic soil group; runoff model; Konkan.

1. INTRODUCTION

"The SCS-CN (Soil Conservation Service Curve Number) method is a widely used approach for estimating direct surface runoff from rainfall, favored by hydrologists, environmentalists, and irrigation engineers" [1]. **"**Agriculture, environment, and the possibility of flooding are all greatly impacted by surface runoff at the watershed scale. Watershed runoff determines the hydraulic properties, soil erosion condition and even the potential yield of water resources within a given watershed. Runoff from a watershed can be measured daily, monthly or annually depending on rainfall, infiltration rate and the characteristics of watershed. Accurate estimation of surface runoff helps in designing irrigation schema, waterways, water harvesting and ground water resource management" [2]. Estimation of runoff is essential to fulfill increasing water demand by proper planning and management which also helps to reduces loss of nutrient soil as well as sedimentation.

"SCS-Curve Number model has been widely used model over years for runoff simulation. Remote sensing data, like land use and soil type, can be used with this model. Curve number (CN) quantifies the impact of soil and land use on rainfall runoff process. The SCS runoff model is based on the CN information" [3]. "Nowadays planning and management sector have been highly benefited from the use of geospatial and remote sensing technique. Sev-eral methods had been created to choose appropriate locations for rain-water harvesting SCS CN method is a one of those" [4].

"Runoff determination using SCS model are more time consuming and error prone using traditional method than using RS and GIS. SCS model possess all the factors geographic in nature because of this it can be easily modeled into GIS. Thus, RS and GIS techniques are being widely adopted for runoff determination of the watershed. Discrimination of broad physical features such as stream network, land use land cover, soil surface and water bodies are very easy with the help of synoptic concept of satellite images. The important input parameter of SCS model is the land use land cover which could be determined very accurately with help of these techniques. With the help of RS, GIS and SCS model, it is easier to make management plans for usage and development of watershed. The traditional method used for the calculation of composite curve numbers from the readily available tables and curves is very complex and highly time-consuming. In order to overcome this dificulty, the combination of Remote sensing-GIS and SCS-CN methods has been successfully employed to estimate composite curve numbers" [5]. "Remote Sensing (RS) coupled with Geographical Information System (GIS) technique has proved to be an efficient tool in drainage delineation and their updation for morphometric analysis. For detailed study, used four different DEM sources viz., Toposheet, ASTER, SRTM and Cartosat data for delineating watershed boundary and geographical information system (GIS) was used in evaluation of linear aspects of morphometric parameters. The Geographic information systems (GIS) are computer-based systems, which can be utilized to retrieve, analyze, synthesize, store, and represent graphical data for decision-making support" [6]. With the development of the GIS education, this research tool has gradually started to be employed in the field of educational research. Also, it concluded that geospatial technique is foundational method to assess and govern several thematic layers for sustainable rangeland management.

2. MATERIALS AND METHODOLOGY

2.1 Description of Study Area

Kajurli village, in Guhaghar tehsil of Ratnagiri district of Maharashtra State, has been selected for the study. It belongs to Konkan Division. It is located 59 km towards North from District headquarters Ratnagiri and 60 km from Dapoli. Kajurli is situated in Ratnagiri District, Maharashtra with Latitude 17° 14' 28.32''N and Longitude 73° 23' 53.52'' E. The location map of the study area is shown in Fig. 1.

2.2 Methodology

"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 watershed coefficient is called as the curve number (CN), which represents the runoff potential of the land cover soil complex. This model involves relationship between land cover, hydrologic soil class and curve number. The method is based on an assumption of proportionality between retention and runoff in the form. Normally the SCS model computes direct runoff with the help of following relationship" [7].

"The various steps are involved in the following manner as shown in Fig. 2, the land use land cover map is obtained in Arc GIS from satellite image LISS III, Soil texture data was obtained from NBSS and LUP, Nagpur and Rainfall data (1990-2022) collected form HDUG Nashik.

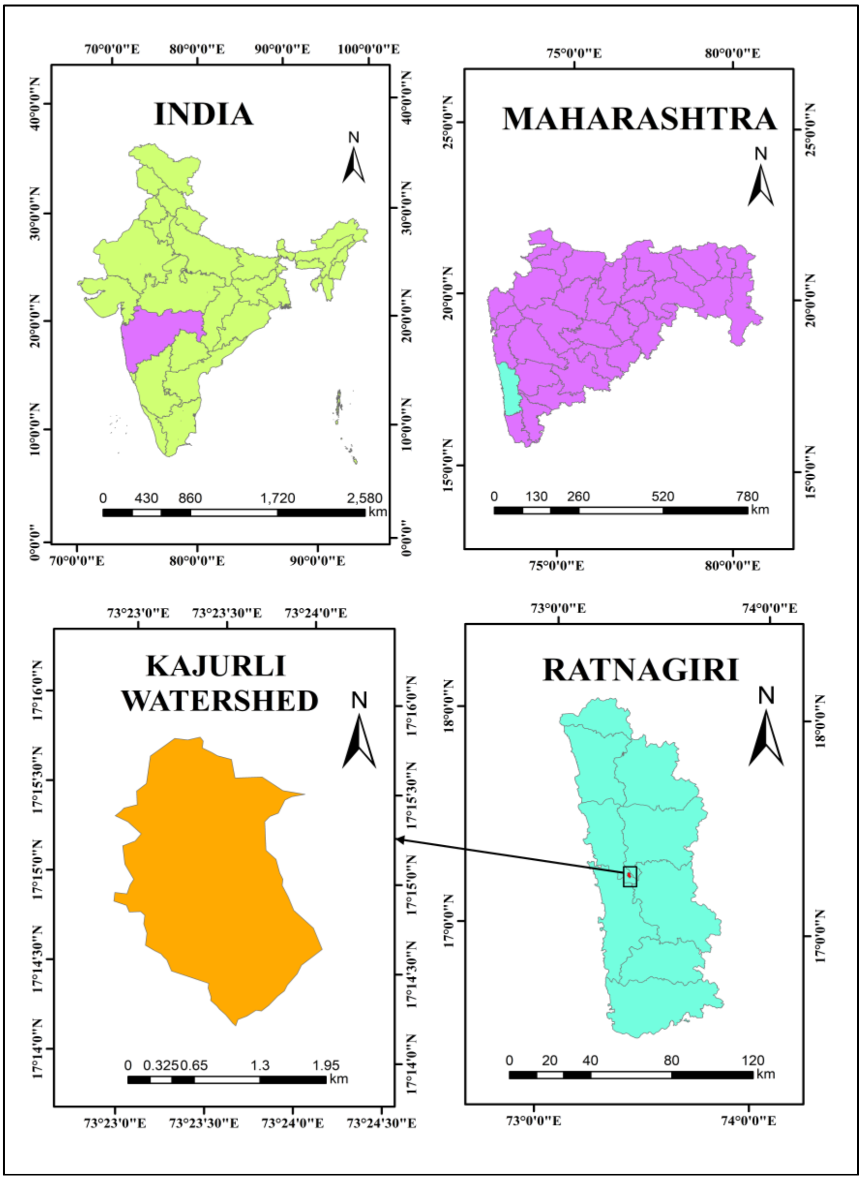

Fig. 1. Location map of the study area

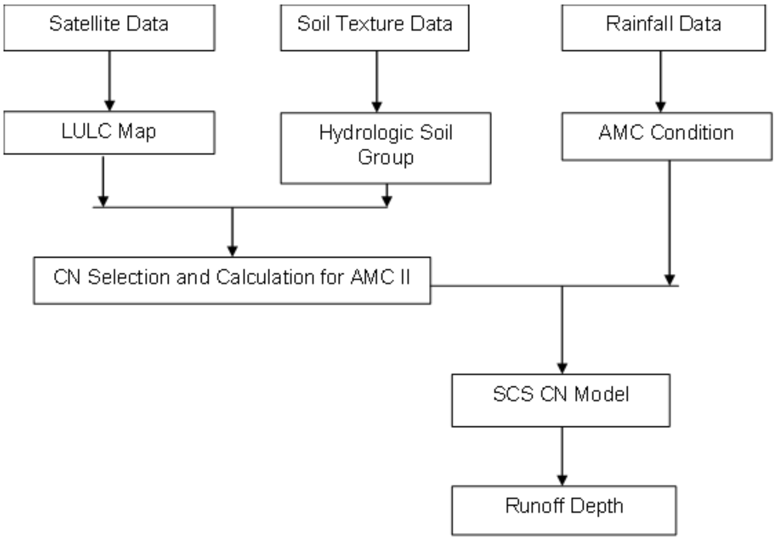

Fig. 2. Flow chart for runoff estimation using SCS CN method

Table 1. Classification of antecedent moisture conditions (Handbook of Hydrology, 1972)

AMC	Soil characteristics	Five-day antecedent rainfall in mm	
		Dormant season	Growing season
I.	Wet condition	Less than 13	Less than 36
II.	Average condition	13-28	36-53
III.	Heavy condition	Over 28	Over 53

Determined the soil type and converted them into hydrological soil groups like A, B, C, D according to their infiltration capacity of soil. In this method, after overlaying the land use map on the hydrologic group maps, we can get land use hydrologic soil group polygon layer and find out the area of each polygon then allotted a CN to each polygon, as per SCS and curve number. The CN is given for basin of area-weighting calculated from the land use soil group polygons surrounded by the drainage basin boundaries" [8]. "SCS and Curve Number method is especially sensitive to CN values, demand for accurate determination of this parameter. CN is again as a function of HSG (Hydrological Soil Group), LU (Land Use) and AMC (Antecedent Soil Moisture Conditions). Hence, estimation of rainfall-runoff for different combinations of land use/land cover, soil groups and antecedent moisture conditions class are estimated by following the procedure of SCS-CN method" [9]. For mapping and analysis purposes ArcGIS 10.4 and MS Excel were used. Methodology of the analysis is shown in (Fig. 2).

2.3 Assessment of Surface Runoff

"The SCS-CN approach is used for experimental strategies to estimate the direct surface runoff from a watershed. The infiltration losses are combined with surface storage by the relation of surface storage, interception, and infiltration prior to runoff in the watershed" [10].

In the mathematical form, the empirical relationship is

$$\frac{F}{S} = \frac{Q}{P-Ia} \tag{2.1}$$

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

37 Initial abstraction represents the depression storage, interception and infiltration before runoff. Actual retention is the part of rainfall lost in the form of infiltration before runoff. The potential maximum retention is the maximum value of actual retention [11].

The second assumption is based on water balance equation is

$$F = P - I_a - Q \tag{2.2}$$

Combining equation 3.1 and 3.2

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \tag{2.3}$$

Soil Conservation Services gives the average relationship between Ia and S is,

$$Ia = 0.2\ S \qquad (2.4)$$

Runoff will generate only when rainfall will be more than I_a i.e., Q= 0

Combining equations 3.4 and 3.3 yields

$$Q = \frac{(P-0.2S)^2}{\mathrm{P+0.8\ S}} \quad \text{For P > 0.2 S} \qquad (2.5)$$
$$Q = 0 \quad \text{For P < 0.2 S}$$

The initial abstraction Ia was found to be 20 % of the potential maximum retention. For Indian conditions, depending upon antecedent moisture conditions and hydrological soil type initial abstraction can be 10% or 30% of the potential retention.

3. RESULTS AND DISCUSSION

The volume of runoff generated from the watershed is significantly depends on shape and size of watershed, rainfall, soil texture, land use/land cover, Antecedent Moisture Condition (AMC) condition, slope and other topographic features. The SCS-CN method is useful for calculating volume of runoff from land surface. Determination of land use land cover (LULC), hydrologic soil group (HSG), and antecedent moisture condition (AMC) is necessary for deciding curve number and further to calculate runoff.

3.1 Land use Land cover Map (LULC)

"Land use land cover plays a significant role in the generation of runoff from a watershed Visual interpretation technique have been used for classification of the land use/land cover phenomena which take into concern various image properties such as, colour, tone, texture, size, shape, association and pattern. The various land use and land cover classes interpreted broadly in the study area include, agricultural land, built-up land, forest area, river/stream, wastelands and water bodies. Fig. 3 is showing the detailed Land use and Land cover map. Topography of watershed is mostly hilly land and partly plane and steep slopes" [8].

3.2 Hydroloical Soil Group

A hydrological soil group map was prepared by using the soil texture data collected from NBSS and LUP Nagpur. Kajurli watershed indicates only one types of hydrological soil groups i.e. Soil group B. A hydrological soil group map Kajurli watershed is shown in Fig. 4. Soil group B shows moderate runoff potential. 100% area of watershed is covered by hydrological soil group B.

3.3 Calculation of Curve Number

"The curve number (CN) is a hydrologic number used to describe the storm water runoff potential for drainage area" [12]. On the basis of land use land cover and hydrological soil group the Curve numbers for watershed were selected in Table 2. The weighted curve number was calculated and the calculation procedure of curve number is explained in the section of 3.5 of chapter III. The CN value further calculated for AMC I, II and III. CN I is 46.04, CN II is 66.18 and CN III is 82.02. on the basis of land use land cover and hydrological soil group is shown in Table 2.

CN II values were obtained from land use land cover map and used for the average condition (AMC-II). For dry conditions (AMC-I) or wet condition (AMC-III), equivalent curve numbers can be computed by using following equations [13].

For AMC-I condition $CN\ (I) = \frac{\mathrm{CN\ II}}{2.281-0.0128\mathrm{CN\ II}}$ (2.6)

For AMC-III condition $CN\ (III) = \frac{\mathrm{CN\ II}}{0.427+(0.00573\mathrm{CN\ II})}$ (2.7)

Were,

CN (I) = curve number for dry condition,
CN (II) = curve number for normal or average condition,
CN (III) = curve number for wet condition.

3.4 Calculation of Runoff

"By using SCS Curve Number method runoff of Kajurli watershed was calculated. Daily rainfall data for past 33 years (1990-2022) has been collected from Hydrology Data Users Group Nashik. Annual rainfall-runoff depth values of Kajurli watershed for last 33 years (1990- 2022) are represented in Table 3. The average annual rainfall for last 33 years was 3392.80 mm and average annual runoff was 1346.90 mm. It was observed that, only 39.69% rainfall was contributed as runoff from the year 1990 to 2022, during 33 years period. Fig. 5 shows annual rainfall and runoff depth of Kajurli watershed from 1990-2022. Similar result found" at Kale et.al (2022) [14].

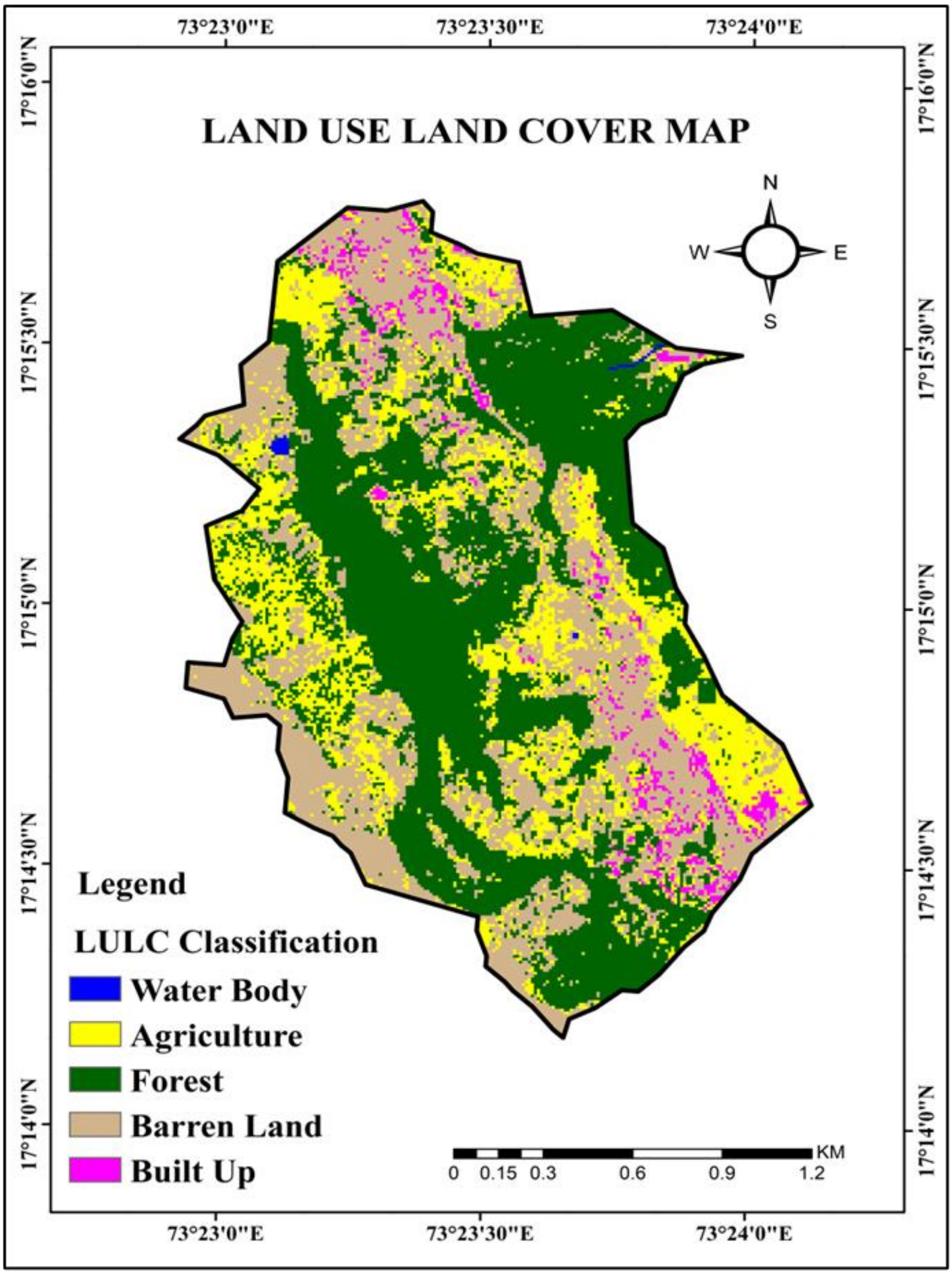

Fig. 3. Land Use Land Cover map of Kajurli Watershed for Year 2022

Table 2. Calculation of runoff Curve Numbers for different soil groups

Land Use Class	Total Area (%)	Hydrologic Soil Group B		
		Area	CN	Product
Waterbodies	0.16	0.58	100	58
Forest Land	43.15	155.65	40	6226
Settlement	3.05	10.99	86	945.14
Agriculture	21.66	78.15	95	7424.25
Barren Land	31.97	115.34	80	9227.2
Total	**100**	**360.80**		**23880.59**

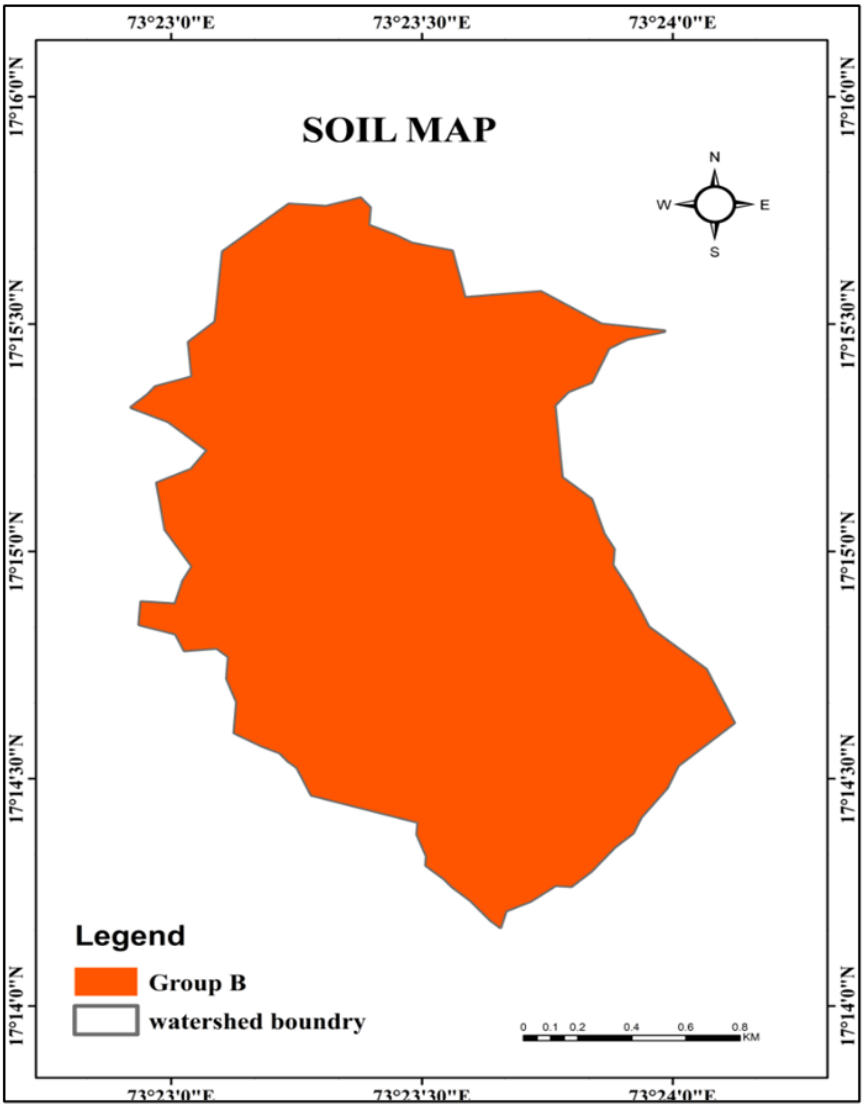

Fig. 4. Hydrological soil group map of Kajurli watershed

Table 3. Annual rainfall-runoff depth of Kajurli watershed (1990-2022)

Sr.No	Year	Annual Rainfall(mm)	Annual Runoff(mm)	% Runoff
1.	1990	2457.20	635.06	25.84
2.	1991	3451.30	1380.70	40.01
3.	1992	1800.32	549.03	30.50
4.	1993	3695.60	1623.49	43.93
5.	1994	2802.80	984.80	28.00
6.	1995	3571.30	1543.49	43.21
7.	1996	3289.50	1094.91	27.20
8.	1997	2703.84	868.26	32.29
9.	1998	2768.00	1024.67	47.96
10.	1999	4871.40	2245.14	49.09
11.	2000	3399.90	1165.33	34.27
12.	2001	3222.70	1173.83	36.42
13.	2002	3336.10	1551.52	46.50
14.	2003	3252.40	1364.89	41.96
15.	2004	3953.80	1580.35	39.97

Sr.No	Year	Annual Rainfall(mm)	Annual Runoff(mm)	% Runoff
16.	2005	2521.00	911.19	36.14
17.	2006	4817.90	2183.16	45.31
18.	2007	2296.10	778.39	33.90
19.	2008	2146.05	651.49	30.35
20.	2009	2924.20	1080.81	36.94
21.	2010	3203.00	1275.74	39.82
22.	2011	4308.40	2052.02	47.62
23.	2012	3033.00	888.12	29.30
24.	2013	3450.00	1104.88	32.02
25.	2014	2959.30	1100.23	37.20
26.	2015	3092.80	1240.89	40.12
27.	2016	4902.60	2546.55	51.93
28.	2017	4224.00	1834.32	43.60
29.	2018	6098.60	3310.86	54.29
30.	2019	4143.43	1275.28	30.77
31.	2020	3633.32	1513.34	41.65
32.	2021	3138.27	1044.68	33.27
33.	2022	2495.14	870.24	34.87
Average		**3392.80**	**1346.90**	**39.69%**

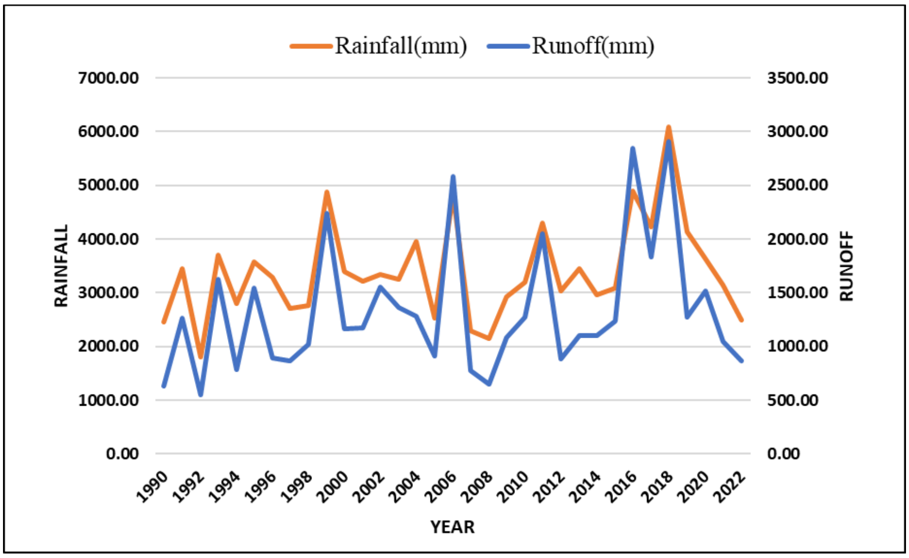

Fig. 5. Line graph of annual rainfall- runoff depth of Kajurli watershed from year 1990-2022

4. SUMMARY AND CONCLUSION

The study on runoff estimation for the Kajurli Watershed using the SCS-CN method integrated with Remote Sensing (RS) and Geographic Information Systems (GIS) demonstrated the effectiveness of this approach for watershed management. The analysis spanned 33 years (1990-2022) of rainfall and runoff data, highlighting that the SCS-CN model is a robust tool for estimating surface runoff by incorporating land use/land cover, soil type, and antecedent moisture conditions. The results indicated that the average annual rainfall in the Kajurli Watershed was 3392.8 mm, with 39.69% of this rainfall contributing to surface runoff. The calculated runoff values ranged from 635.06 mm in 1990 to a peak of 3310.86 mm in 2018, showcasing the significant influence of rainfall variability, land cover changes, and soil characteristics on runoff generation. The study revealed that integrating GIS and RS techniques simplifies the spatial analysis of watershed characteristics, enabling accurate runoff estimation. Moreover, the sensitivity of runoff estimation to Curve Number (CN) values underscores the importance of precise data on land use and hydrological soil groups. These findings are critical for sustainable water resource management, flood control, and agricultural planning within the region. Thus, the SCS-CN model, combined with modern GIS and RS tools, provides a reliable framework for hydrological assessments, supporting decision-making processes in watershed management and conservation practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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