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Estimation of Surface Runoff from Dapoli Watershed Using Remote Sensing and GIS

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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

Soil and water are the two basic natural resources for the survival of living organisms and the future of the world depends largely on the effective management, utilization and development of these resources. In this present study, Dapoli watershed located in Ratnagiri District of Maharashtra, has been considered as the study area for the estimation of surface runoff by SCS Curve Number method using remote sensing and GIS. SRTM DEM of 30m resolution and SENTINEL 2 satellite imagery of 10m resolution were used to generate thematic maps such as elevation map, HSG map,

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stream order map and LULC map. The results of this study showed that the highest rainfall was observed in the year 2021 and the lowest rainfall was observed in the year 2015. The maximum and minimum annual runoff depth from 1993-2022 were in the years 2021 (2505.14 mm) and 2001 (734.81 mm) respectively. The study revealed that in the past 30 years, 41.68% of the rainfall was contributed to runoff and SCS-CN method coupled with remote sensing and GIS can serve as a useful tool for estimating surface runoff in the coming years for similar watersheds.

Keywords: Surface runoff; curve number; DEM; LULC; HSG; AMC; remote sensing; GIS.

1. INTRODUCTION

Soil and water are the two basic natural resources for the survival of living organisms. These two resources have been interacting with each other in various phases of their respective natural cycle and the future of the world depends largely on the effective management, utilization and development of these resources in a coherent and far-reaching manner [1,2]. "All water resources need to be carefully monitored and managed in order to achieve their sustainability and continue to be beneficial to the society" [3,4,5]. "Surface runoff occurs after satisfying the infiltration and abstraction losses and flows on the surface in the direction of the slope. Surface runoff of rain is a major component of the hydrological cycle and helps to provide suitable circumstances for many types of ecosystems, scheduling of irrigation, water for hydroelectric power plants. Knowing the amount of runoff from a watershed is important particularly for planning the hydraulic structures and taking necessary erosion control measures. In this study, Soil Conservation Services (SCS) Curve Number modified for Indian condition is used for estimation of runoff of the study area. The runoff curve number is based on the area's hydrologic soil group, land use and antecedent moisture condition" [6,7,8]. The study area region is characterized by hilly terrains and heavy rainfall thus making the region prone to soil loss and surface runoff issues. Therefore, an accurate understanding of the hydrological behaviour of the watershed is important for effective watershed management.

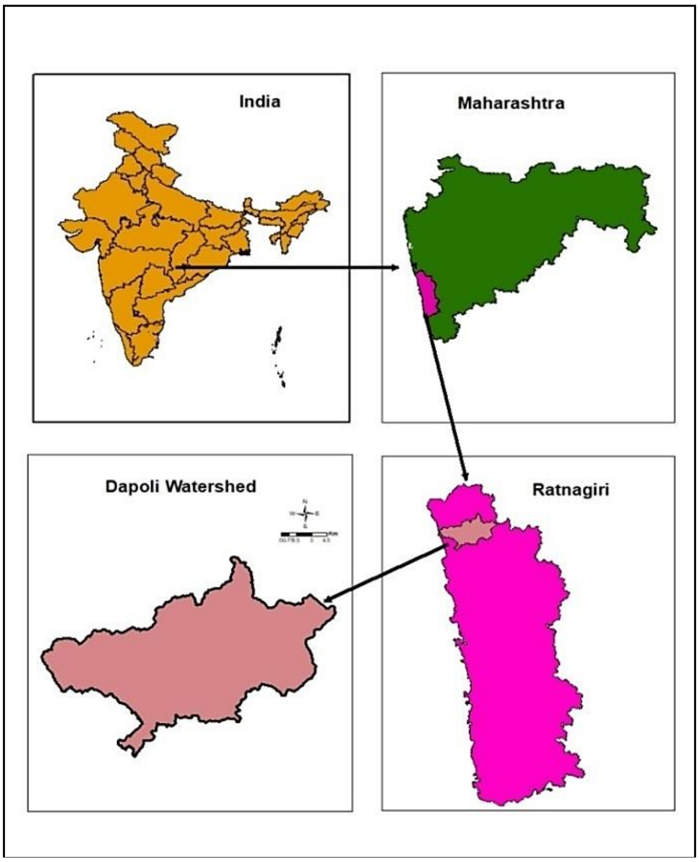

Fig. 1. Location map of study area

1.1 Study Area Details

Dapoli watershed has a total area of 26635.08 ha and is located at Ratnagiri District, in the Konkan region of Maharashtra. The topography of the study area is slightly undulating with small hillocks, maximum area is plain with gentle slope. The location map of the study area is shown in Fig. 1.

2. MATERIALS AND METHODS

"Various data and information were collected from different sources for carrying out this present study. The boundary maps of the state and country were obtained from DIVA GIS website" (https://www.diva-gis.org/website). "Digital elevation model (DEM) of shuttle radar topographic mission (SRTM) having 30m resolution was downloaded from USGS Earth Explorer website" (https://earthexploral.usgs.gov/) for delineating the watershed of the study area. Sentinel 2 satellite imagery downloaded from Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu) was used to prepare the land use land cover map of the year 2022. Soil data was collected from the National Bureau of Soil Survey Land Use Planning (NBSS LUP), Nagpur and the rainfall data was obtained from the Agro-meteorology Observatory, Department of Agronomy, DBSKKV, Dapoli.

2.1 Software Used

The ArcGIS 10.8 software which is available in the Department of Soil and Water Conservation Engineering, CAET, DBSKKV, Dapoli was used to view, edit geospatial data, delineate and to create thematic maps. MS Office Suit 2019 was used for documenting, calculating and organizing notes related to this study. Google Earth Pro 10.8 was used for checking the accuracy of the land use land cover (LULC) map.

2.2 Soil Conservation Service- Curve Number (CN) Method

"SCS- Curve Number method, developed by Soil Conservation Service (SCS) of USA in 1969, is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. This method, also known as the Hydrologic Soil Cover Complex Number method, is based on the recharge capacity of the watershed. The recharge capacity is determined by antecedent moisture conditions and by the physical characteristics of the watershed. The flowchart for estimation of surface runoff using SCS Curve Number method is shown in Fig. 2" [9].

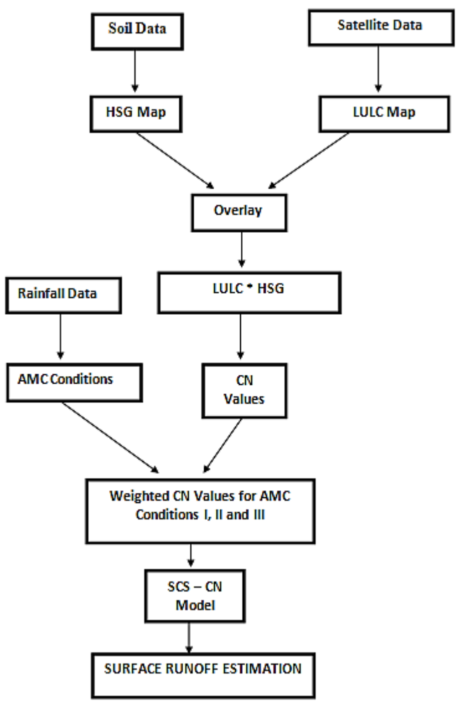

Fig. 2. Flow chart for estimation of runoff using SCS CN method

The depth of the runoff is estimated using the formula-

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \text{for } P \geq 0.2\ S \quad (1)$$

$$Q = 0 \text{for } P < 0.2\ S$$

Where,
Q = runoff depth (mm), P = rainfall (mm) and S = potential retention

For convenience in practical application, the Soil Conservation Services (SCS) has expressed a relationship between the potential maximum retention 'S' and the dimensionless curve number parameter CN as –

$$CN = \frac{25400}{254+S} \quad (2)$$

Where,
S = the potential retention/infiltration after the runoff begins given by following equation-

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

CN is dimensionless and its value varies from 0 to 100. For CN=0, watershed is completely pervious (ideal condition) and for CN=100, watershed is completely impervious. As CN increases, imperviousness also increases. In other words, the value of Curve Number near or equal to 0 indicated low runoff. The requirements for this method are rainfall data and curve number. The value of Curve Number (CN) is different for different land use conditions and hydrologic soil group.

The value of the Curve Number (CN) is determined by –

i. Land Use Land Cover (LULC)
ii. Hydrological Soil Group (HSG)
iii. Antecedent Moisture Condition (AMC)

2.3 Land Use Land Cover (LULC) Map

Land Use Land Cover (LULC) maps are used to provide information to help understand a particular area or landscape based on the natural and human activities. Supervised classification method was adopted for preparing the LULC map of the study area. The Kappa Coefficient is generated to evaluate the accuracy of the classification. The accuracy of land use land cover for Dapoli watershed was calculated using the Kappa coefficient and the formulae used is shown in Table 1. A better understanding on the values of Kappa coefficient and its interpretation is shown in Table 2.

2.4 Hydrological Soil Group (HSG) Map

Based on US Soil Conservation Services (SCS), soils are divided into four hydrologic soil groups- A, B, C and D with respect to rate of runoff probable and final infiltration for the classification of soils in the watershed. The SCS classification for Hydrologic Soil Group was referred from USDA [10]. The important soil characteristics that influence hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and permeability.

Table 1. Formulae used to calculate Accuracy and Kappa coefficient of LULC map [11]

Sr. No.	Accuracy Type	Formula
1.	Producer's Accuracy	PA = $\frac{No.of correctly classified pixels in each category}{Total no.of classified pixels in that category} \times 100$
2.	User's Accuracy	UA = $\frac{No.of correctly classified pixels in that category}{Total no.of reference pixels in that category} \times 100$
3.	Kappa Coefficient	Ka = $\frac{(TS \times TCS) - \sum(Column Total \times Row Total)}{TS^2 - \sum(Column Total \times Row Total)} \times 100$ Where,TS = Total Sample TCS = Total Corrected Sample

Table 2. Rating criteria of Kappa statistics [11]

Kappa statistics	Strength of agreement
Below 0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 - 1	Almost Perfect

Table 3. Group of antecedent soil moisture classes [12]

AMCClass	Soil Characteristics	5-Days Antecedent Rainfall (mm)	
		Dormant Season	**GrowingSeason**
I	Wet Condition	Less than 13	Less than 36
II	Average Condition	13 - 28	36 - 53
III	Heavy Rainfall	> 28	> 53

2.5 Hydrological Soil-cover Complex and Computation of Weighted CN

A combination of the hydrological soil group (HSG) and the land use land cover (LULC) is called Hydrological Soil-Cover Complex. Based on the hydrological soil-cover complex, curve number values are given to the different soil classes using the values for Indian conditions (AMC-III).

Weighted Curve Number (CN) for the watershed is calculated using the following formula:

$$CN = \frac{\sum CN_i \times A_i}{A} \quad (4)$$

Where,CN = Weighted Curve Number, CN_i = Curve Number from 1,2,3,….,i

A_i = Area with curve number CN_i ,A = Total area of the watershed

The curve numbers for the Indian conditions (AMC III) used in this study was referred from the Handbook of Hydrology, 1972.

2.6 Antecedent Moisture Condition (AMC)

Antecedent Moisture Condition (AMC) refers to the moisture content present in the soil at the beginning of the rainfall-runoff event. It is determined by total rainfall in 5-day period preceding a storm as shown in Table 3. SCS developed three antecedent soil-moisture conditions and labelled them as I, II, III, according to soil conditions and rainfall limits for dormant and growing seasons.

To get the curve number values for AMC I and III, the correction factors were applied. The curve numbers for AMC-I and AMC-III had been obtained by conversion of AMC-II (weighted CN) using the following formulae:

For AMC-I:

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281 CN_{II}} \quad (5)$$

For AMC-III:

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573 CN_{II}} \quad (6)$$

Where,
CN I = Curve Number for dry condition.
CN II = Curve Number for normal or average condition.
CN III = Curve Number for wet condition.

3. RESULTS AND DISCUSSION

Land use land cover map: The LULC map of Dapoli watershed is divided into seven classes i.e. agricultural land, forest land, scrub land, barren land, orchards, settlement and waterbodies as shown in Fig. 3. Supervised classification with maximum likelihood classification was performed for Dapoli watershed. The overall accuracy of the LULC map for Dapoli watershed for the year 2022 was found to be 90.47%. The validation of land use mapping was done using Kappa coefficient and it was observed that the grade of accuracy was excellent as per [11]. The kappa coefficient for the LULC map of Dapoli watershed was 0.89. The area covered by different LULC classes is shown in Table 4.

Table 4. Area covered by different LULC classes in Dapoli watershed

Sl. No.	LULC	Area (ha)	Percentage (%)
1	Forest Land	11200.17	42.05
2	Orchards	7062.53	26.52
3	Scrub Land	4700.27	17.65
4	Agricultural Land	1666.03	6.26
5	Settlement	953.95	3.58
6	Barren Land	848.67	3.19
7	Waterbodies	203.46	0.76
	Total	**26635.08**	**100**

Hyrologic soil group (HSG) map: Dapoli watershed indicates two types of hydrological soil group i.e. soil group C and soil group D. Maximum area of the watershed is covered by HSG- C i.e. 88.26% (23508.23 ha) and HSG- D covers 11.74% (3126.85 ha). Hydrologic soil group map is shown in Fig. 4 and the area covered by different hydrological soil group in Dapoli watershed is shown in Table 5.

Computation of weighted Curve Number (CN): The land use land cover map and hydrologic soil group map are combined on the ArcGIS software using the Union tool in the Arc toolbox. A curve number is assigned to each uniqueland use-soil group polygon, based on the SCS curve number values. The CN grid map of Dapoli watershed is shown in Fig. 5. The curve number for AMC II condition of Dapoli watershed is calculated by area-weighting the land use-soil group polygons within the watershed using equation (4) the calculated value of the weighted CN for AMC II is 67.83.

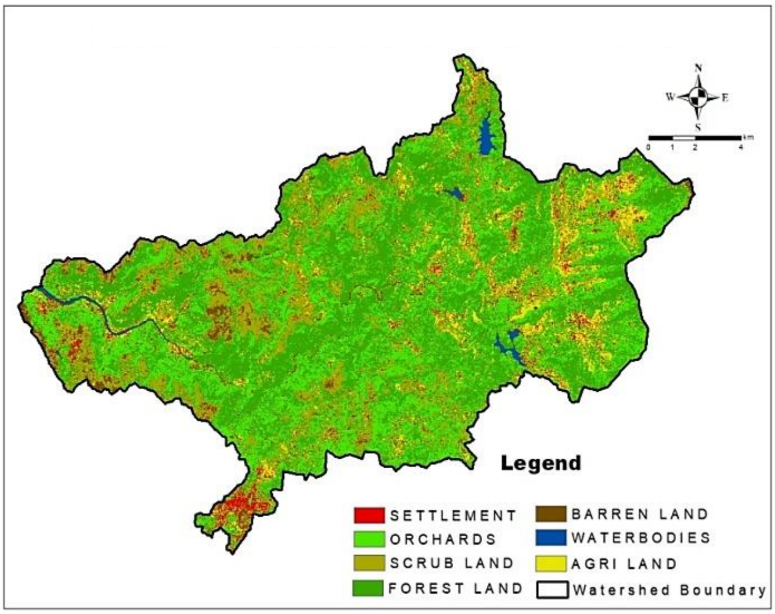

Fig. 3. Land Use Land Cover Map of 2022

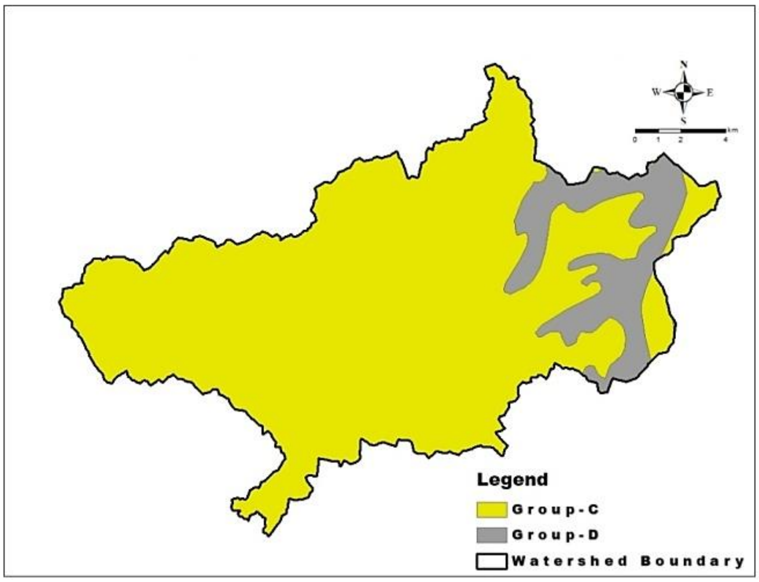

Fig. 4. Hydrological Soil Group Map

Table 5. Area covered by different hydrological soil group in Dapoli watershed

Sr. No.	Hydrological Soil Group	Area (ha)	Area (%)
1.	Group – C	23508.23	88.26
2.	Group – D	3126.85	11.74
	Total	26635.08	100

Table 6. Annual rainfall-runoff depth of Dapoli watershed (Year 1993-2022)

Sr. No.	Year	Annual Rainfall (mm)	Annual Runoff (mm)	Annual Runoff (%)
1	1993	3848	1588.89	41.29
2	1994	2918.5	928.69	31.82
3	1995	3140.1	1052.51	33.52
4	1996	3112.5	1147.29	36.86
5	1997	3843.1	1736.43	45.18
6	1998	3829.6	1568.67	40.96
7	1999	4226.2	1745.28	41.30
8	2000	4619.05	2339.71	50.65
9	2001	2403.4	734.81	30.57
10	2002	2739.5	936.61	34.19
11	2003	3004	1155.28	38.46
12	2004	3535.6	1427.89	40.39
13	2005	3654.2	1547.35	42.34
14	2006	3558.8	1226.37	34.46
15	2007	4261.97	2031.72	47.67
16	2008	3011.4	1215.77	40.37
17	2009	2697.3	879.81	32.62
18	2010	4721.1	2132.91	45.18
19	2011	4932.2	2349.25	47.63
20	2012	3654	1555.19	42.56
21	2013	4748	2202.77	46.39
22	2014	3370.2	1552.17	46.06
23	2015	2330.6	788.77	33.84
24	2016	4504.1	2027.3	45.01
25	2017	3633.5	1452.62	39.98
26	2018	3071.8	1154.27	37.58
27	2019	5130.9	2342.41	45.65
28	2020	4145.4	1604.92	38.72
29	2021	5421.2	2505.14	46.21
30	2022	2989.1	1362.84	45.59
Mean		**3701.85**	**1543.12**	

Antecedent moisture condition (AMC): Antecedent moisture condition has been labelled according to the soil condition and rainfall limits for dormant and growing seasons viz. AMC I for dry soils but not to wilting point, AMC II for average conditions and AMC III for when sufficient rainfall has occurred within the immediate past 5 days. The curve number values further calculated for AMC I and AMC III were 48.03 and 83.16 respectively.

Estimation of surface runoff: Comparison of the annual rainfall and runoff depth of Dapoli watershed for 30 years is shown in Fig. 6. In the year 2021, the highest rainfall was recorded i.e. 5421.2 mm and the lowest rainfall was recorded in the year 2015, i.e. 2330.6 mm. The average annual rainfall for last 30 years is 3701.85 mm. The maximum runoff observed was 2505.14 mm in the year 2021 i.e. 46.21% of the annual rainfall. The minimum runoff observed was in the year 2001 with a depth of 734.81 mm i.e. 30.57 % of the annual rainfall. The average annual runoff depth of Dapoli watershed for 30 years is 1543.12 mm. The annual rainfall-runoff depth of Dapoli watershed is shown in Table 6. It was observed that from the year 1993 to 2022, 41.68% of the rainfall was contributed to runoff.The rainfall and runoff was strongly correlated with a correlation coefficient of 0.94 as shown in Fig. 7.

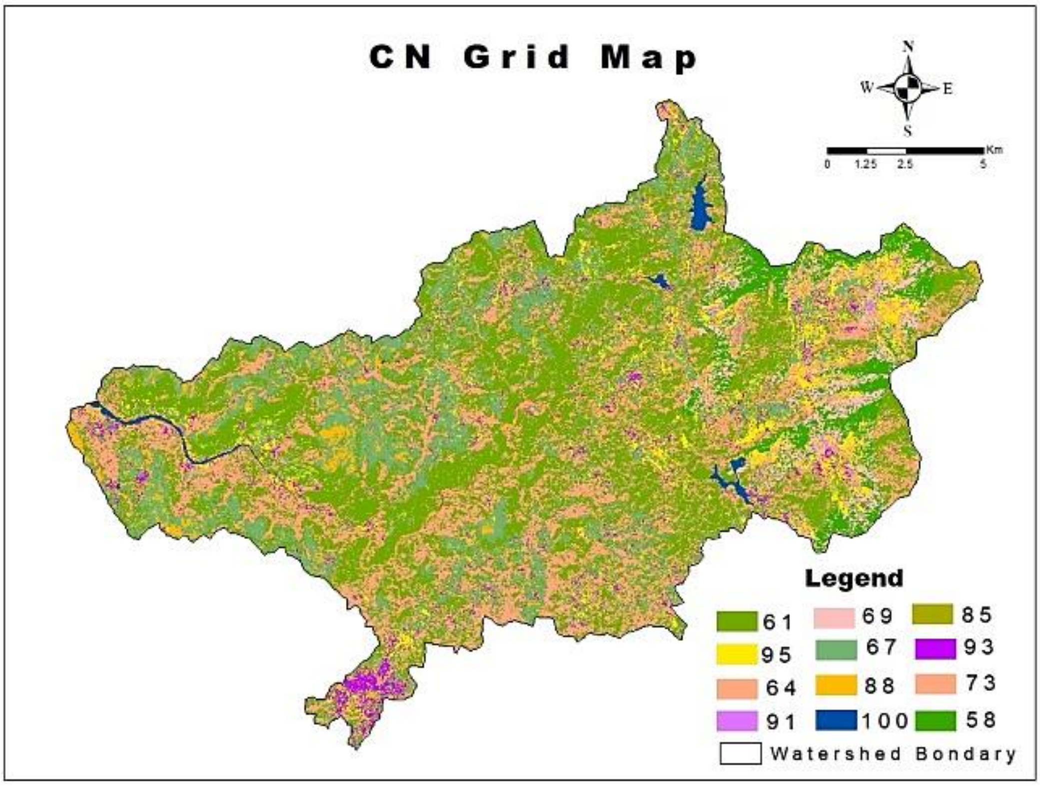

Fig. 5. Curve Number grid map of Dapoli watershed

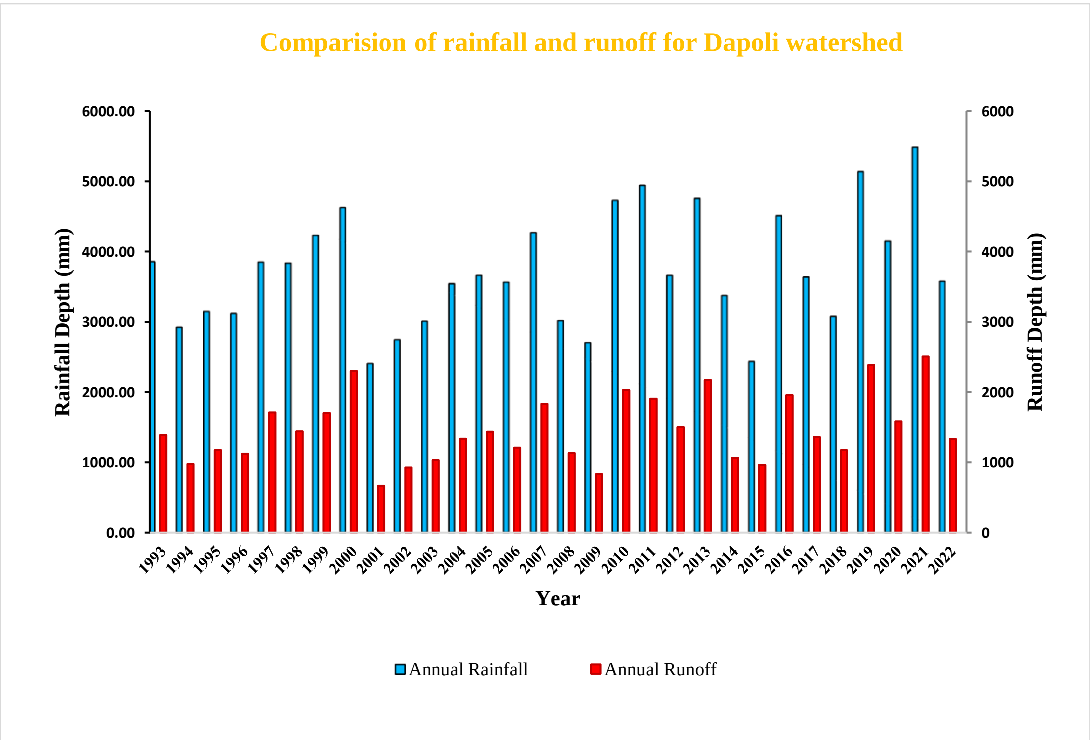

Fig. 6. Comparison of annual rainfall-runoff of Dapoli watershed (Year 1993-2022)

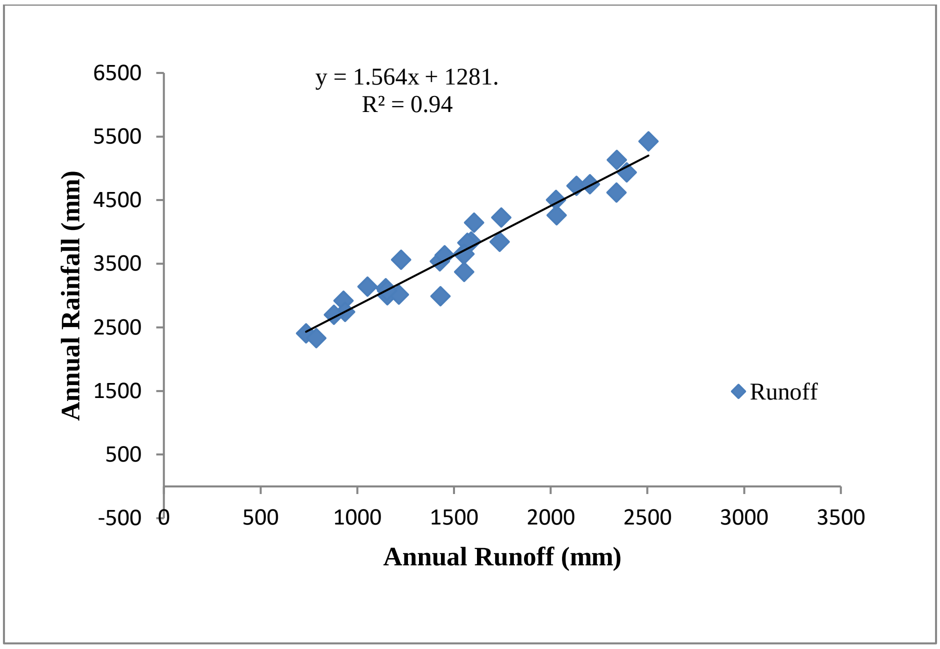

Fig. 7. Scatter plot between rainfall and estimated runoff

4. CONCLUSION

In this present study, the SCS Curve Number method coupled with remote sensing and GIS has made the estimation of surface runoff more convenient and efficient. The LULC map showed that in Dapoli watershed, forest land covered maximum area and least area was covered by waterbodies. The calculated curve number for Dapoli watershed for AMC I, II and III are 48.03, 67.83 and 83.16 respectively. Based on the results of this study, it was concluded that 41.68% of the total rainfall for 30 years was contributed to runoff where the rainfall and runoff was strongly correlated with a correlation coefficient of 0.94 This method could also be applied for estimation of surface runoff in the coming years in similar watersheds for effective watershed management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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