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Estimation of surface runoff for Mahatma Phule Krishi Vidyapeeth central campus, Ahilyanagar, Maharashtra, using remote sensing and geographical information system

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Abstract
Runoff drains from a catchment area through a channel after satisfying all surface and subsurface needs. The incidence and magnitude of runoff are contingent upon the attributes of the rainfall event. Non- availability of continuous runoff records in majority of Indian watersheds has led to the development of techniques for estimation of surface runoff. The Soil Conservation Service Curve Number (SCS-CN) method, from the SCS National Engineering Handbook (SCS NEH), is a widely used hydrological design tool.
The study area situated in the Mahatma Phule Krishi Vidyapeeth Central Campus occupying an area of 475 ha located between 19° 19' to 19° 22' North Latitude and 74° 36' to 74° 40' East longitude. The annual runoff of study area was computed for year 2021 using SCS-CN (NRCS) method. Maps such as stream order map, DEM map, HSG map, CN map, and land use/ land cover map were prepared for the micro-watershed Surface runoff in terms of depth and volume is estimated by NRCS Curve number method and later runoff percentage was calculated with the help of rainfall volume and total runoff volume done using ArcGIS 10.5 version.
The MPKV Central Campus (West) watershed experienced 278.97 mm of annual runoff in 2021, equivalent to 28.86% of the 966.40 mm total rainfall. Weighted curve numbers were 53.53 (CN_I), 73.28 (CN_{II}), and 86.32 (CN_{III}) for AMC I, II, and III, respectively. Runoff percentage was calculated as 28.86% in the year 2021. The estimated runoff of 278.97 mm can be utilized for optimum design of the soil and water conservation structures. These estimated runoff before development of MPKV Central Campus watershed can be used for comparison or impact assessment of soil and conservation measures adopted for development of the watershed.

Keywords: Remote sensing, geographical information system (GIS) and curve number

Introduction
Runoff drains from a catchment area through a channel after satisfying all surface and subsurface needs. Rain storms generate runoff. The incidence and magnitude of runoff are contingent upon the attributes of the rainfall event. Beyond rainfall characteristics, several catchment-specific factors directly influence runoff occurrence and volume. These include soil type, slope, vegetation cover and catchment type. Accurate runoff estimations depend on factors such as precipitation, basin recharge, and soil type. However, comprehensive runoff data is scarce in India. This scarcity of continuous runoff records for most Indian watersheds has driven the development of various surface runoff estimation techniques (Chattopadhyay and Choudhury, 2006) [2].
The Soil Conservation Service Curve Number (SCS-CN) method, from the SCS National Engineering Handbook (SCS NEH), is a widely used hydrological design tool (Shi *et al*., 2007, 2009) [7, 8]. The SCS-CN method's applications extend to large-scale river basin runoff estimation and daily hydrological modeling (Soulis, 2021) [11]. Accurate surface runoff estimations are vital for water resource planning and development, mitigating downstream sedimentation and flooding (Ling *et al*., 2019) [14]. Therefore, the SCS-CN method holds significant importance in hydrological research.
Remote sensing and GIS are increasingly important for regional, national, and international natural resource planning, development, and management.

The ability to handle extensive spatial and attribute data makes the SCS-CN method a valuable tool in hydrological modeling. Recently, integrated studies combining runoff modeling, remote sensing, and GIS have become increasingly important for prioritizing suitable sites for water harvesting structures. Geographical Information Systems (GIS) efficiently collect, store, retrieve, transform, and display both spatial and non-spatial data for various applications (Padmavathy *et al*., 1993) [5].

A study was conducted to prepare land use/land cover map to find out the surface runoff for Central MPKV watershed using RS and GIS techniques. The study area situated in the Mahatma Phule Krishi Vidyapeeth Central Campus occupying an area of 475 ha located between 19° 19' to 19° 22' North Latitude and 74° 36' to 74° 40' East longitude.

In the present study, an effort was made to highlight the use of remote sensing and Geographical Information System for the estimation of surface runoff. Initially, watershed delineation was done using ArcGIS 10.5 version. The annual runoff of study area was computed for year 2021 using SCS-CN (NRCS) method. Weighted curve number for the Mahatma Phule Krushi Vidyapeeth Central Campus (West) Watershed was found out based on GIS technique.

Maps such as stream order map, DEM map, HSG map, CN map, and land use/ land cover map were prepared for the micro-watershed Surface runoff in terms of depth and volume is estimated by NRCS Curve number method and later runoff percentage was calculated with the help of rainfall volume and total runoff volume.

Materials and Methods

Study Area

The present study area is Mahatma Phule Krishi Vidyapeeth Central Campus (West) Watershed, located in Rahuri taluka of Ahmednagar district Maharashtra (Fig 1). Ahmednagar district is the largest district of Maharashtra state in western India. The area is located between 19° 19' to 19° 22' North latitude and 74° 36' to 74° 40' East longitude. The total area of the watershed is 475 ha. The MPKV Central Campus watershed is situated under the basin of Mula River. Climatically, the area falls under the tropical zone with an average annual rainfall 511 mm. The average annual temperature is 25.9 °C. The annual mean maximum and minimum relative humidity ranges from 59 to 90 and 21 to 61 percent, respectively.

Data Collection and Software used

As per the requirements of study, varieties of data were collected from various sources, as detailed below:

1. Digital Elevation Model (DEM) (http://bhuvan-noeda.nrsc.gov.in)
2. Digital Imagery Data: Sentinel 2 MSI L1C (http://scihub.copernicus.eu)
3. Soil data
4. Rainfall data, mm

Rainfall data for year 2021 were collected from IMD observatory located at AICRP on Irrigation Water Management, MPKV, Rahuri, shown in Fig 2.

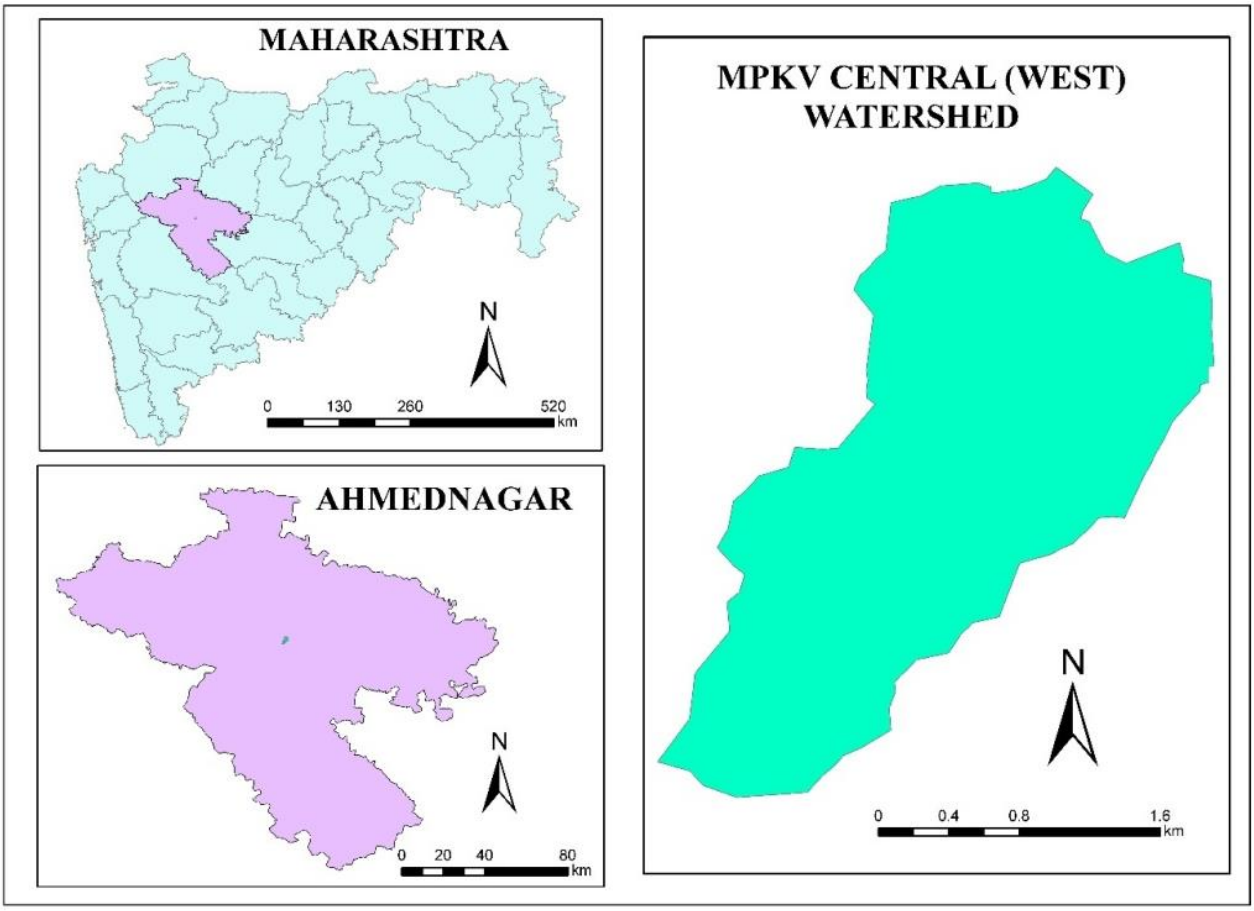

Fig 1: Location of the Study Area

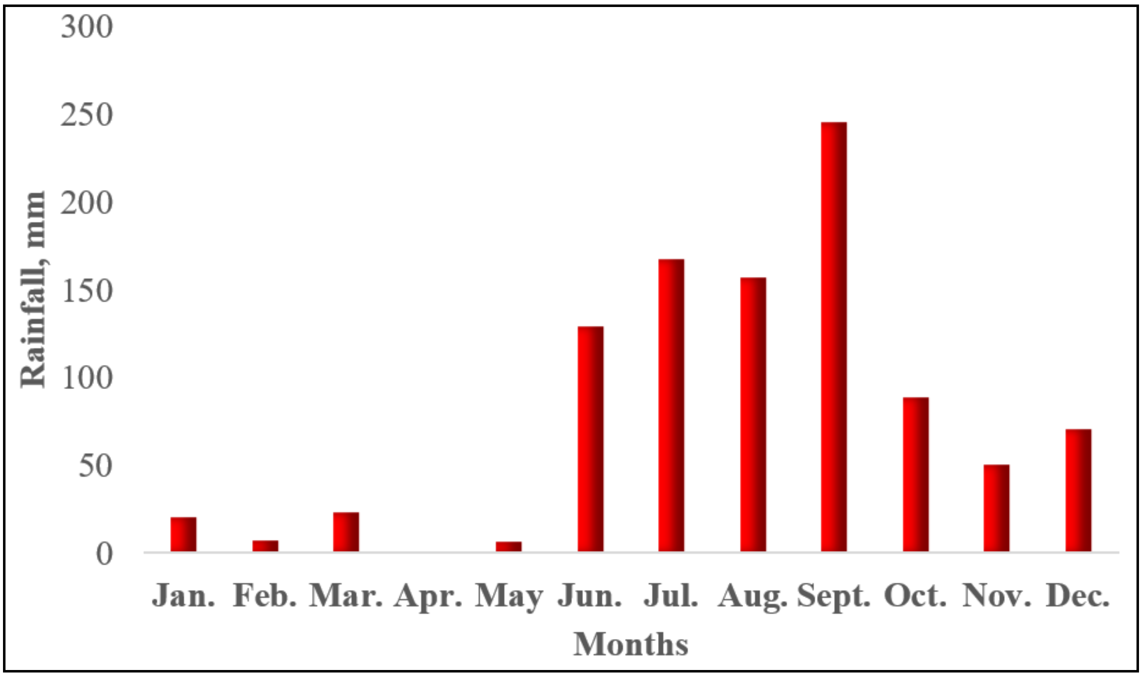

Fig 2: Monthly rainfall data (mm) for year 2021

Software and System
Arcs-GIS 10.5 and MS-Office suit were used for data creation, data analysis and output generation. Arcs-GIS 10.5 is advanced tool used for mapping, geographic analysis, spatial analysis, hydrology, overlay analysis, data editing etc. MS-Office was used for documentation analysis purpose.

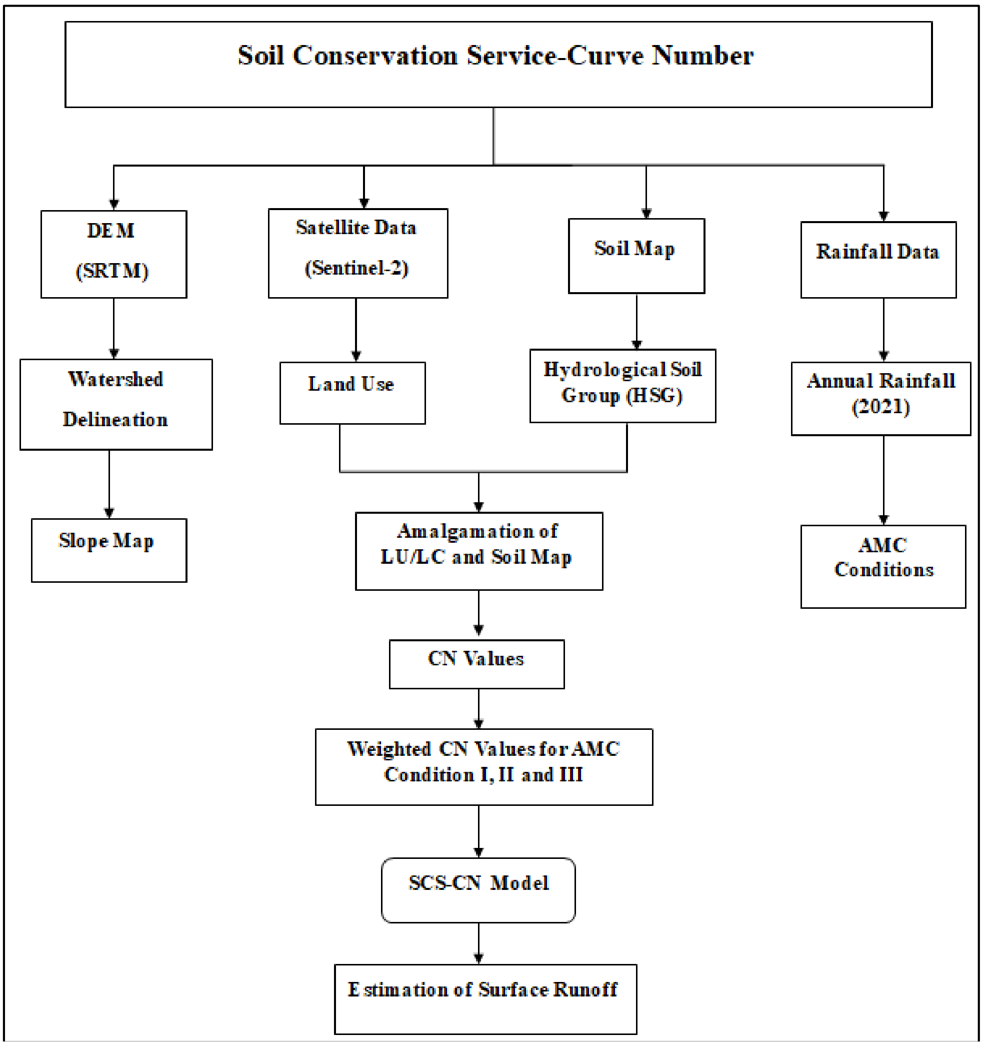

Fig 3: Flow chart for Runoff Estimation

Delineation of Watershed

Arcs-GIS 10.5 was used for the purpose of watershed delineation using Survey of India toposheet (1:50,000 scale). Toposheet provide information related to the location, drainage network and contours. 47 I/11 numbered toposheet were used for watershed delineation. The flow chart of methodology is presented in Fig 3, which shows various steps involved in utilization of inputs parameters like toposheet, satellite data for getting final output of water resources conservation plan

Generation of Thematic maps

All the thematic maps viz., base map, stream order, DEM, slope, flow direction, flow accumulation, HSG, CN map and land use/land cover were generated in ArcGIS 10.5 version software. Stream order map was generated from DEM data. The flow accumulation and flow direction maps were prepared by processing on DEM data in ArcGIS software which is further used to generate a stream network. After generating the stream network, identify the stream order in watershed. The stream order map is presented in (Fig 5).

Land Use/Land Cover

The identification of land use/land cover is an important aspect for various planning and management activities in the watershed Land cover refers to vegetation, water bodies, rocks/soil, artificial cover and others resulting due to transformations. Land use / land cover map of the study area was prepared by Supervised Classification using cloud-free Satellite image, Sentinel 2 MSI L1C 2021 was downloaded from (https://scihub.copernicus.eu).

Soil Mapping and Hydrological Soil Groups

Hydrological Soil Groups (HSGs), which categorize soils by infiltration and water transmission rates, significantly influence runoff. The SCS-CN (NRCS) method uses HSGs to define hydrological parameters, primarily the infiltration rate of bare, saturated soil. The four HSGs are:
Hydrologic Soil Groups (HSGs) are classified as follows:
Group A: High infiltration rates, even when saturated (e.g., deep, well-drained sands and gravels).
Group B: Moderate infiltration rates when saturated (e.g., moderately deep, well-drained soils with moderate textures).
Group C: Low infiltration rates when saturated (e.g., soils with restrictive layers or fine textures).
Group D: Very low infiltration rates when saturated (e.g., clay soils with high swelling potential, high water tables, or shallow soils over impermeable layers).
The curve number for different hydrological soil group with antecedent moisture content II were used for estimation of weighted curve number which is given in Table 1.

Table 1: Curve Number for HSG under AMC-II conditions (Ahmad *et al.* 2015) [1]

Classes	Hydrological Soil Group			
	A	**B**	**C**	**D**
Agriculture Land	76	86	90	93
Built up	69	79	84	87
Forest	26	40	58	61
Barren Land	71	80	85	88
Waterbodies	97	97	97	97

Runoff Estimation by SCS-CN (NRCS) Method

The Curve Number (CN) method, originally developed by the U.S. Soil Conservation Service (SCS) (1964, 1972) and now known as the NRCS method, estimates runoff based on a water balance equation for a specified time interval, which is given as.

$$P = I_a + F + Q \quad (1)$$

Where,
P = Total precipitation, mm
I_a = Initial abstraction, mm
F = Cumulative infiltration, mm
Q = Direct surface runoff, mm

Runoff was estimated using the SCS-CN (NRCS) method, taking into account different combinations of soil groups, land use types, and antecedent moisture conditions (AMC).Daily rainfall data were used with the Curve Number method, which doesn't explicitly account for time. In ungauged basins, this method estimates direct runoff depth from rainfall, using a runoff response index. Its simplicity and flexibility contribute to its widespread use. The method centers on the watershed's potential maximum retention (S), determined by AMC and watershed characteristics. Overall methodology adopted in the study for estimating runoff is depicted in the Fig. 3.
The retention capacity (S) of the watershed can be predicted in terms of a dimensionless parameter curve number (CN) and given by,

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

Where,
S = maximum recharge capacity of watershed after 5 days antecedent rainfall
CN = curve number

The direct runoff of the watershed is given by the following equation,

$Q = 0$	If P<=0.2S (3)
$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$	If P>=0.2S (4)

Where,
Q = runoff depth, mm
P = rainfall, mm
S = maximum recharge capacity of watershed after 5 days antecedent rainfall

Calculation for CN

A CN map was created in a GIS environment by integrating HSG and land use maps. The weighted curve numbers for each micro-watershed were determined by multiplying the area of each land use class by its respective curve number. A weighted CN map was generated using following equation,

$$CN = \frac{\sum CN_i \times A_i}{A} \quad (5)$$

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

Antecedent Moisture Condition (AMC)
The CN method uses three antecedent moisture conditions (AMCs): AMC-I (dry), AMC-II (normal), and AMC-III (wet). Table 2 shows the seasonal rainfall limits for each AMC.

Table 2: Group of Antecedent Soil Moisture Classes (AMC)

AMC Group	Soil characteristics	Five-day antecedent rainfall (mm)	
		Dormant season	Growing season
I	Soil is dry but not to wilting point. Satisfactory cultivation has taken place (Dry condition)	Less than 13	Less than 36
II	Average condition	13-28	36-53
III	Sufficient rainfall has occurred within the immediate past 5 days. Saturated soil conditions prevail (Wet condition)	Over 28	Over 53

To calculate CN values for AMC-1 and AMC-III conditions, following equations were used (Chow *et al.*, 1988),

CN for AMC I

$$CN_{\mathrm{I}} = \frac{4.2\times \mathrm{CN_{II}}}{10-(0.058\times \mathrm{CN_{II}})} \quad (6)$$

CN for AMC III

$$CN_{\mathrm{III}} = \frac{23\times \mathrm{CN_{II}}}{10+(0.13\times \mathrm{CN_{II}})} \quad (7)$$

Where,
CN I = curve number for dry condition
CN II =curve number for normal condition
CN III= curve number for wet condition

Daily rainfall data from 2021 and the maximum potential retention (S) values derived from the watershed's CN were used to estimate runoff using the SCS-CN (NRCS) model.

Results and Discussion
Delineation of watershed
MPKV Central Campus (West) boundary was delineated using the Survey of India toposheet (1:50,000) (Fig 1) and ASTER DEM (30 m resolution) (Fig 4) in ArcGIS. Further, Georeferencing, rectification and delineation were carried out in ArcGIS.

Land Use/Land Cover map
Land use/land cover and soil maps were used to determine curve numbers for runoff estimation using the NRCS method. Hydrologic soil groups A, B, C, and D were delineated within the Central MPKV watershed. A land use/land cover map, generated through GIS software, facilitated the computation of area distributions for each land use class. The details of land use/land cover categories and their area is presented in the Table 4 and discussed as follows. In the present study satellite imagery of Sentinel 2 MSI L1C were used to prepare the land use/land cover map. Merging of higher resolution data helped for better classification of land use/land cover categories accurately. The study area was classified into 5 main categories viz., Agricultural land, Barren land, Forest, Built up, and Waterbodies.
After the supervised classification of MSI L1C satellite image under ArcGIS software, the areal extent of land use types viz., Agricultural land, Barren land, built up area, Forest and Waterbodies were found to be 0.07789, 3.18664, 0.58167, 0.57971, 0.32507 km^2 respectively (Table 4). The obtained results indicate that, watershed had more barren land area followed by built up area, and there was only a small portion of agricultural area. For classifying using supervised method, the selected areas were identified by some ground truth values. The land use/land cover map of study area using supervised classification was shown in Fig 6.

Hydrologic Soil Group
It was observed that watershed consists of Hydrologic Soil Group A, Soil Group B, Soil Group C, Soil Group D as shown in Fig 8.

CN values
Curve Numbers were assigned to watershed as given in Table 3 for AMC condition II (I_a=0.2S), based on standard tables suggested by Soil Conservation Services, 1972.

Table 3: Spatial distribution of land use features in Central MPKV Watershed and corresponding CN values

LULC Classes	HSG	CN	Area (km^2)	% Area	% Weighted Area	WCN
Agricultural Land	A	76	0.0383	0.8065	0.6129	AMC I = 53.53 AMC II = 73.28 AMC III = 86.32
	B	86	0.0031	0.0651	0.0560	
	C	90	0.0180	0.3798	0.3419	
	D	93	0.0184	0.3880	0.3608	
Barren Land	A	71	2.0072	42.2474	29.9957	
	B	80	0.2999	6.3120	5.0496	
	C	85	0.7729	16.2683	13.8280	
	D	88	0.1067	2.2455	1.9760	
Built up	A	69	0.3864	8.1337	5.6122	
	B	79	0.0368	0.7736	0.6112	
	C	84	0.1320	2.7779	2.3334	
	D	87	0.0265	0.5581	0.4855	
Forest	A	26	0.2512	5.2869	1.3746	
	B	40	0.0117	0.2453	0.0981	
	C	58	0.2658	5.5940	3.2445	
	D	61	0.0511	1.0757	0.6562	
Water bodies	A	97	0.1929	4.0611	3.9392	
	B	97	0.0142	0.2979	0.2889	
	C	97	0.0964	2.0297	1.9688	
	D	97	0.0216	0.4536	0.4400	
Total			4.7510	100.00		

The obtained CN map is as shown in Fig 7. The weighted CN values are further corrected using slope in m/m (initially estimated in degree and then converted to radian).

Runoff Depth
The Rainfall data for year 2021 was collected from IMD observatory located at AICRP on Irrigation Water Management, MPKV, Rahuri and runoff was estimated by SCS method. The annual rainfall for the year 2021 in the MPKV watershed was 966.40 mm whereas annual runoff was 278.97 mm, amounting 28.86 percent of the total rainfall received.

Total Runoff Estimation

This study employed a modified SCS-CN (NRCS) model for rainfall-runoff estimation, integrating factors such as soil type, vegetation cover, slope, and watershed characteristics. The rainfall-runoff relationship was examined by accounting for initial abstraction, runoff, and actual retention. The curve number (CN) for the basin was derived through a combination of land use, soil type, and antecedent moisture conditions (AMC).

The study area constitutes different land use/ land cover. About 67.07 percent area is occupied by Barren land, 12.24 percent by Built up, 12.21 percent by Forest, 6.84 percent by Waterbodies and remaining 1.64 percent of the area is occupied by Agricultural Land. Hence, among the different land cover types the Barren land plays the major role in the direct surface runoff. The SCS-CN method is used and both Curve Number and weighted Curve Number are calculated based on the overlaid LULC map (Table 3). Weighted CN_I and weighted CN_{III} were calculated using the formula. Antecedent Moisture Condition (AMC) values were assigned according to the total rainfall received over the five days preceding the event. Weighted curve number values (CN_I, CN_{II} and CN_{III}) with respect to the Antecedent Moisture Condition (AMC-I, AMC-II and AMC-III) were found to be 53.53, 73.28 and 86.32 respectively. The annual rainfall for the year 2021 in the MPKV watershed was 966.40 mm whereas annual runoff was 278.97 mm, amounting 28.86 percent of the total rainfall received and the rainfall data is shown in Table 5.

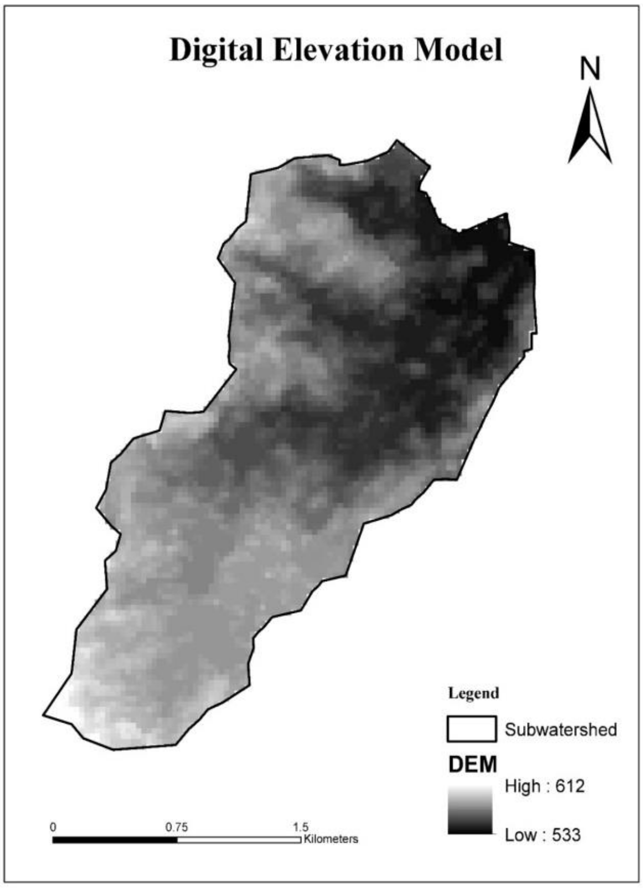

Fig 4: Digital Elevation Model of MPKV Cental (West) Watershed

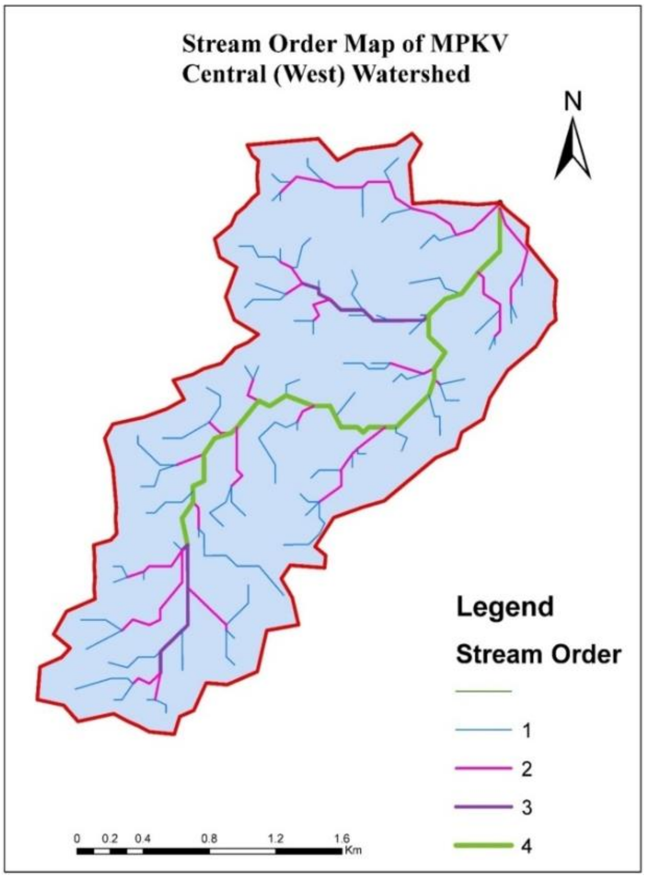

Fig 5: Stream Order Map of MPKV Cental (West) Watershed

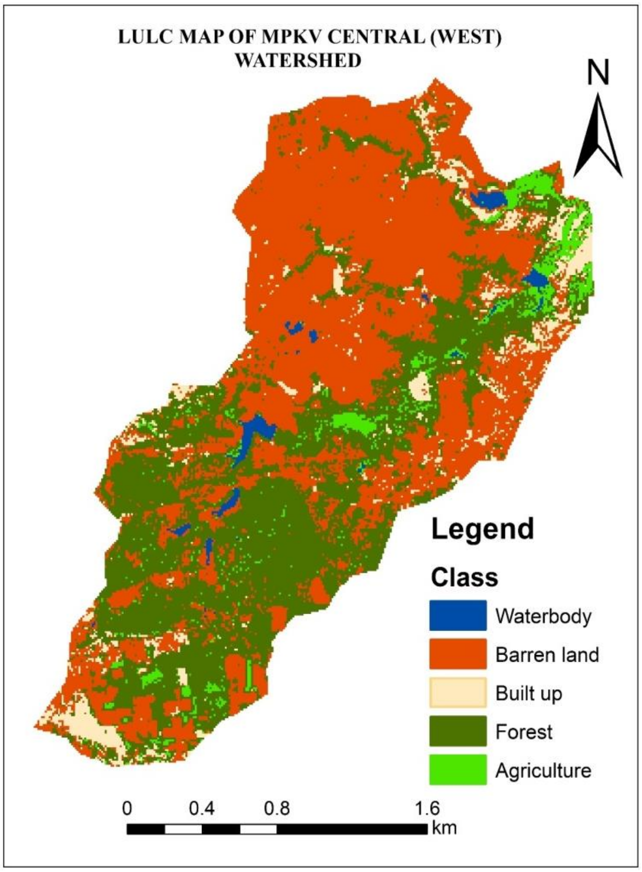

Fig 6: LULC Map of MPKV Cental (West) Watershed

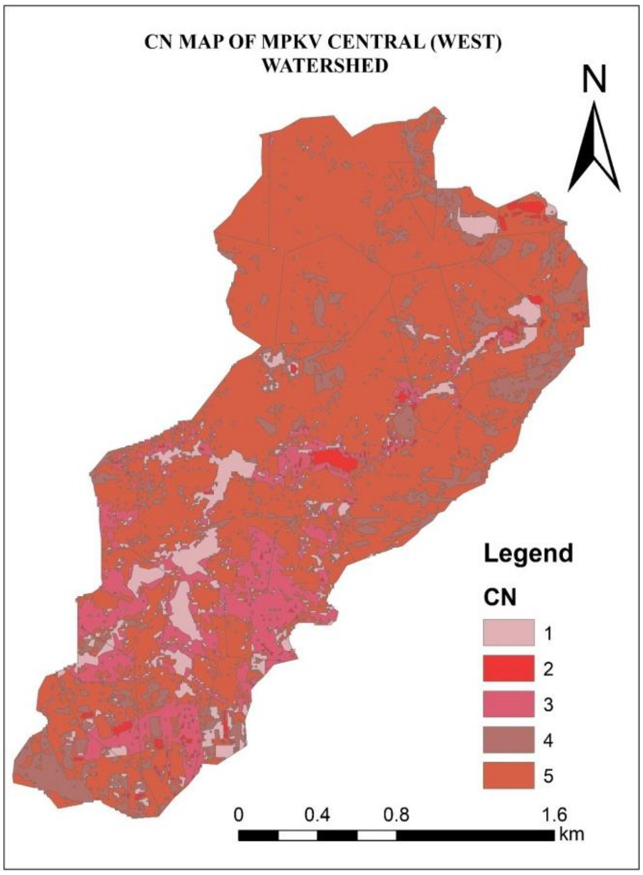

Fig 7: CN Map of MPKV Cental (West) Watershed

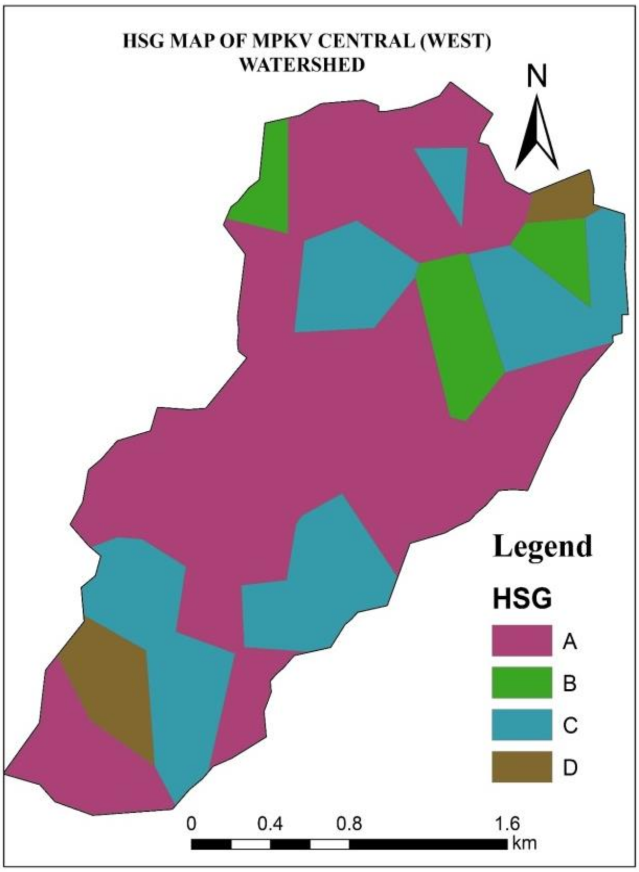

Fig 8: HSG Map of MPKV Cental (West) Watershed

The land use and land cover characteristics of the study area and its subdivisions are analyzed using the land use/land cover (LU/LC) map presented in Fig. 6, along with the associated statistical data. The LU/LC in the study area using Sentinel 2 MSI L1C image shown in Fig 9 was classified in to five classes and the statistics are given in Table 4 and depicted in Fig 9. The agricultural land was in light green colour, waterbodies with dark blue, forest with dark green, built up in dark red and barren land in orange appearance. The rainfall-runoff relationship was depicted by Fig 10.

Table 4: Distribution of land use pattern in central MPKV Watershed

Sr. No	Land Use/Land Cover	Area (km^2)	% Area
1	Agriculture Land	0.07789	1.64
2	Barren Land	3.18664	67.07
3	Built up	0.58167	12.24
4	Forest	0.57971	12.21
5	Waterbodies	0.32507	6.84
	Total Area	4.75098	100.00

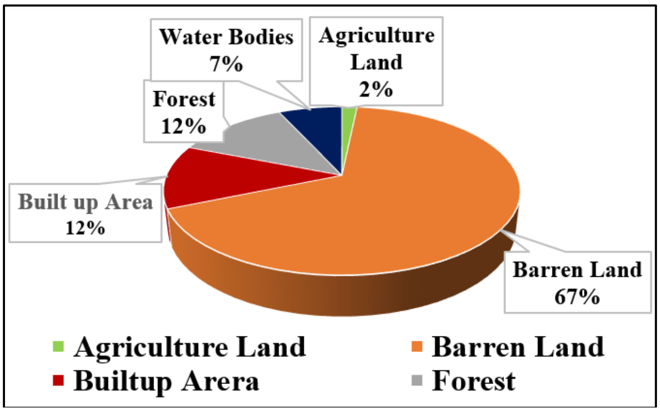

Fig 9: Pie Chart of percent Area in Land Use / Land Cover

Table 5: Monthly and annual rainfall and runoff (mm) for MPKV Central Campus (West) Watershed for the year 2023

Month	Rainfall, mm	Runoff, mm	Month	Rainfall, mm	Runoff, mm
Jan	20.6	3.75977	July	167.6	64.0965
Feb	7.2	0	Aug	157	58.9921
March	23.4	5.15095	Sept	245.4	78.5282
April	0	0	Oct	88.6	22.836
May	6.4	0	Nov	50.4	6.5532
June	129.2	17.0243	Dec	70.6	22.0274
Annual	Rainfall, mm	966.4	Runoff, mm	278.968	

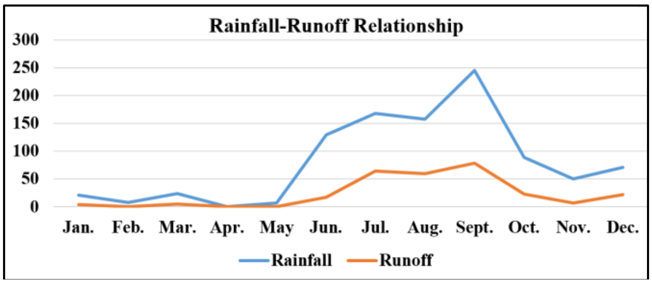

Fig 10: Rainfall-Runoff Relationship

Summary and Conclusions

The annual runoff in the MPKV Central Campus (West) watershed for the year 2021 was 278.97 mm amounting 28.86 percent of the annual rainfall received 966.40 mm. Weighted curve number values CN_I, CN_{II} and CN_{III} with respect to the Antecedent Moisture Condition AMC-I, AMC-II and AMC-III were found to be 53.53, 73.28 and 86.32 respectively. Runoff percentage was calculated as 28.86% in the year 2021. This result suggested that runoff is directly proportional to the amount of rainfall received, i.e., runoff is more when rainfall is more and runoff is less when the rainfall is less. The estimated runoff of 278.97 mm can be utilized for optimum design of the soil and water conservation structures.

These estimated runoff before development of MPKV Central Campus watershed can be used for comparison or impact assessment of soil and conservation measures adopted for development of the watershed.

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