Estimating Runoff for Bamnidhi Watershed using SCS Curve Number approach and Geospatial Technique

Abstract

Water is one of the most valuable natural resources and a vital component of the socioeconomic development of a nation. Water resources in India and throughout the world are under a lot of stress as a result of the limited supply and rising demand. Water availability of a region can be better estimated using rainfall runoff relationship. Runoff is mostly produced as a result of rainfall, which is a significant part of the hydrologic cycle. In this study, the rainfall-runoff relation of the Bamnidhi watershed in Chhattisgarh (India) is studied using SCS CN method. Various inputs such as HSG map and land use land cover were overlaid in ArcGIS platform for estimation of weighted curve number, based on which the runoff is estimated. The results of the study indicate that CN values range from 30 to 97. The lowest runoff potential is observed for forest regions having CN value of around 30, while highest runoff potential is observed for water bodies.The total runoff is found to be around 3.6 Million m^3 for the period 2011 to 2020, whichis about 10 to 25 percent of the total rainfall.

1. Introduction

The rainfall-runoff relationship is a fundamental concept in hydrology that describes how rainfall transforms into runoff. It helps in understanding and predicting the response of a watershed or catchment to a given rainfall event. One widely used method for estimating runoff is the Soil Conservation Service (SCS) curve number method, also known as the NRCS (Natural Resources Conservation Service) curve number method. It was developed by the United States Department of Agriculture's Soil Conservation Service, now known as the Natural Resources Conservation Service. The SCS curve number method is primarily used for small- to medium-sized watersheds. It estimates direct runoff from rainfall by considering various factors such as soil type, land use, and antecedent soil moisture conditions. The method assumes that the rainfall excess, which leads to runoff, depends on the infiltration capacity of the soil.The curve number accounts for factors such as soil properties, land cover, land use, and watershed characteristics. Different land uses and soil types have different curve numbers assigned to them. For example, forests and grasslands typically have lower curve numbers, indicating higher infiltration rates, while urban areas or compacted soils have higher curve numbers, indicating lower infiltration rates. The SCS curve number method uses the curve number along with the rainfall data to estimate the direct runoff volume (Jena et al., 2012). The method assumes that the rainfall excess, which becomes runoff, is a function of the rainfall amount, initial abstraction (an amount of rainfall that does not contribute to runoff initially), and the curve number. The curve number method provides a convenient and widely used way to estimate runoff volumes for various design and analysis purposes in hydrology. Various previous studies such as Bansode et al. (2014), Kadam et al. (2012), Mishra et al. (2004), Saravanan and Manjula (2015), Vinithra and Yeshodha (2016) and Bhura et al. (2015) have used SCS CN method for estimating runoff for different catchments. In this study, runoff estimation of Bamnidhi watershed in Chhattisgarh using SCS CN method is attempted.

2. Study Area

Bamnidhi watershed is situated in lower part of Hasdeo subbasin in Chhattisgarh state covering the district of Korba and Janjgir Champa, where Janjgir Champa is the largest paddy producer in the state. The watershed is located latitude between 82°29’47”E and 82°54’44”E, longitude between 21°40’56”N and 21°54’18”N.The total area of the watershed is 1688 km^2.Normally, average annual temperature in the watershed is 29.56 °C while the minimum and maximum temperature ranges from 8 °C to 49 °C. The monsoon season in the region ranges from July to September, with an averageannual precipitation of about 1157 mm. The Bamnidhi watershed mainly lies in the central plain region of Chhattisgarh and most of the watershed consists of the ~~Sandstone~~ sandstone geological formation. The significant waterways moving through the Janjgirchampa and Korba districts. The location and topography of the study area is shown in Figure 1.

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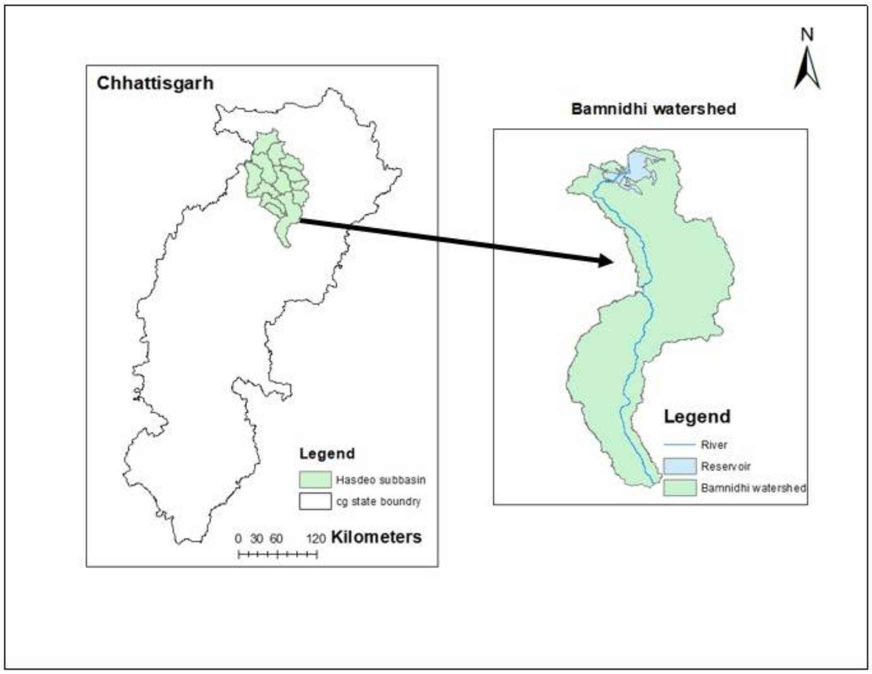

Figure 1. Location map of Bamnidhi watershed

3. Data and methods

3.1 Data used

The boundary of the watershed was delineated using ALOS PALSAR DEM data. Soil texture map was prepared using ArcGIS environment for that raw data was collected from NBSS and LUP. Land use Land Cover (LULC) map of the study area was prepared using Sentinel 2A data for the year 2016 and 2020 and classified in the six categories i.e. forest, waterbody, cultivated, built-up, fallow and barren land. The LULC classified map was rectified by using Google Earth. Daily rainfall measurements were collected from Central Water commission (CWC) for 2011 to 2020.

Table 1: Data types and sources

S. No.	Type	Source	Description

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1.	Soil data	NBSS and LUP	To assign Hydrological soil group
2.	LULC data	Sentinel 2A	To classify land use land cover
3.	Elevation	ALOS PALSAR DEM	Watershed demarcation
4.	Rainfall	Central Water commission (CWC)	Point Rainfall data

3.1.1 Soil classification

The Natural Resource Conservation Service (NRCS) classified the soils into four classes A, B, C and D based on the soil characteristics as shown in Table 2.

Table 2: Hydrological Soil Group for USDA textural classes

S. No.	HSG	Soil texture
1	A	Sand, loamy sand or sandy loam
2	B	Silt or loam
3	C	Sandy clay loam
4	D	Clay loam, silt clay loam, sandy clay or clay

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Different hydrologic soil groups and their characteristics given by United States Department of Agriculture(USDA) were described below:

- Group A- These soils have low runoff potential. Water transmission capacity is high. The percentage of clay is less than 10% and sand or gravel is greater than 90%.
- Group B- These soils have moderately low runoff potential. Water transmission capacity is unimpeded. The percentage of clay is around 10% to 20% and sand is 50% to 90%.
- Group C- These soils have moderately high runoff potential and water transmission is somewhat restricted through the soil. Percentage of clay vary from 20% to 40% and sand less than 50%.

Group D- These soils have high runoff potential and water transmission is restricted or very restricted through the soil. The clay content is greater than 40% and sand is less than 50%.

Three textural groups like sandy loam, Sandy clay loam, Clay loam, sandy clay were identified in the study area using texture classification and shown in Figure 2. The identified soil types are interpolated using Inverse Distance Weighting method in ArcGIS.

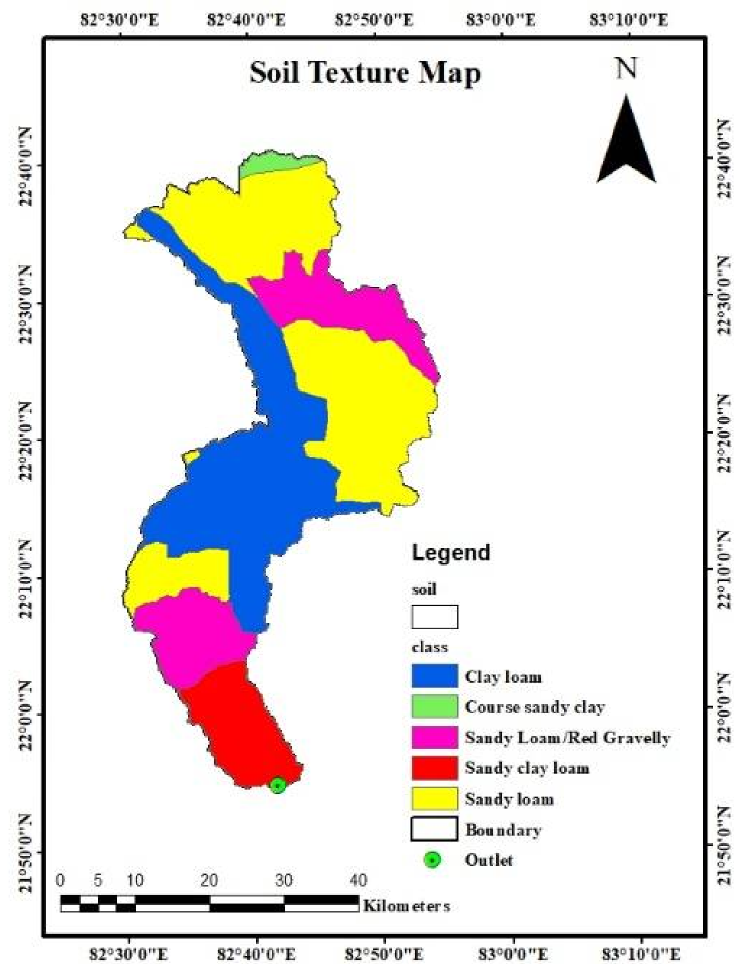

Figure 2. Soil map of Bamnidhi watershed

3.1.2 Land use Land cover (LULC) classification

Sentinel-2A is a satellite mission operated by the European Space Agency (ESA) as part of the Copernicus program, which aims to provide comprehensive Earth observation data for environmental monitoring and land management (Gascon et al., 2017). The primary objective of Sentinel-2A is to monitor Earth's land and coastal areas, providing high-resolution imagery with a spatial resolution of 10 meters (visible and near-infrared bands) and 20 meters (shortwave infrared bands). It captures images in 13 spectral bands, ranging from the visible to the shortwave infrared region of the electromagnetic spectrum. The data collected by Sentinel-2A has various applications, including monitoring changes in vegetation, assessing land cover and land use, mapping urban areas, monitoring coastal zones, and supporting disaster management efforts. Sentinel 2A images were used for the land use/cover classification (Figure 3). The various land use classes, areas and percentage of total areas are given. The area were classified into river/water body, forest, crop land, fallow land, barren land, and built-up land.

3.1.3 ALOS PALSAR data

ALOS PALSAR (Advanced Land Observing Satellite Phased Array Synthetic Aperture Radar) (Rosenqvist et al., 2007) is a radar satellite mission developed and operated by the Japan Aerospace Exploration Agency (JAXA). The satellite was launched on January 24, 2006, and was in operation until April 2011. PALSAR was equipped with an L-band synthetic aperture radar (SAR) sensor, which uses microwave signals to obtain high-resolution images of the Earth's surface. It had an active phased array antenna that emitted radar pulses and collected the signals reflected back from the ground. By analyzing these radar signals, PALSAR could provide valuable information about various features on Earth's surface, regardless of weather conditions or daylight.

3.1.4 IMD gridded rainfalldata

India Meteorological Department (IMD) gridded rainfall data (Pai et al., 2014)provides information on rainfall patterns across India. This dataset is typically available in a gridded format, meaning that it divides the geographical area of India into a grid of cells and provides rainfall data for each cell. The IMD gridded rainfall dataset is based on observations collected from a network of rain gauges located across the country. These rain gauges measure the amount of rainfall at specific locations, and the data is then interpolated to create a continuous grid of rainfall values.The grid resolution of the IMD gridded rainfall data is 0.25 degrees latitude by

0.25 degrees longitude, which corresponds to roughly 25 kilometers by 25 kilometers at the equator. This dataset is widely used for various applications, including climate research, hydrological modeling, and agricultural planning. It provides valuable information about the spatial distribution of rainfall across India, allowing researchers and policymakers to analyze rainfall patterns, monitor drought conditions, and assess water resources availability in different regions.

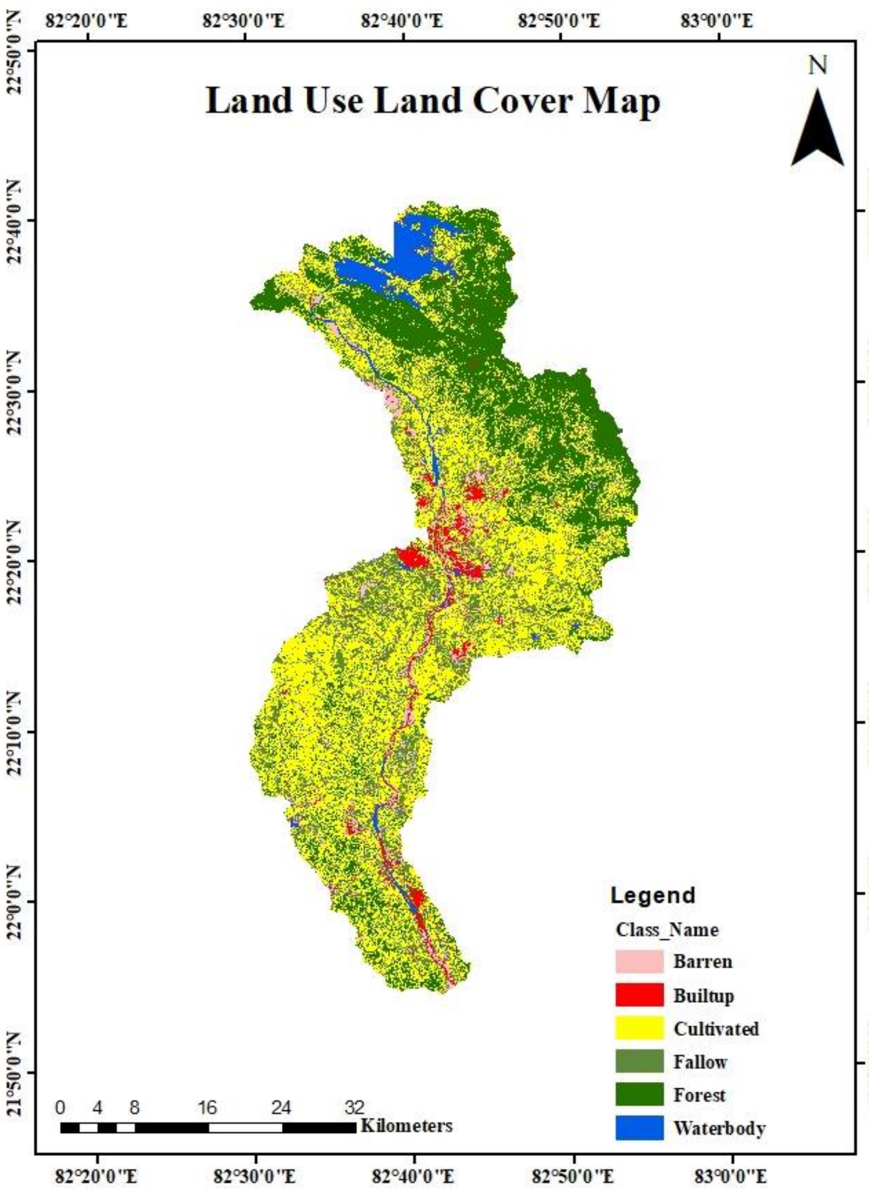

Figure 3. Land use land cover map of Bamnidhi watershed

3.2 Methodology

3.2.1 SCS Curve Number Method

The Soil Conservation Service (SCS) model developed by 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 (Hand book of Hydrology, (1972).

$$S = \left(\frac{24500}{CN}\right) - 254 \qquad (1)$$

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

$$CN = \frac{\sum Ci * Ai}{A} \qquad (3)$$

Where,

CN = weighted curve number.

CN is the runoff curve number of hydrologic soil cover complex, which is a function of soil type, land cover and antecedent moisture condition (AMC), Q is the actual direct runoff in mm, P is the total storm rainfall in mm, S is the~~the~~ potential maximum retention of water by the soil in mm, Ci is the curve number from 1 to any no. N, and Ai is the area corresponding to the curve number Ci. Visual interpretation technique was followed to prepare the land use/land cover map of Bamnidhi watershed.

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3.2.2 Antecedent Moisture Condition (AMC)

AMC indicates the moisture content of soil at the beginning of the rainfall event. The AMC is an attempt to account for the variation in curve number in an area under consideration from time to time. Three levels of AMC were documented by SCS AMC I, AMC II & AMC III. The limits of these three AMC classes are based on rainfall magnitude of previous five days and season (dormant season and growing season). AMC for determination of curve number is given in Table 3.

Table 3: AMC for determination of CN value

S. No.	AMC	Total Rain in Previous 5 days	
		Dormant Season	Growing Season
1	I	< 13 mm	< 36 mm
2	II	13 to 28 mm	36 to 53 mm
3	III	> 28 mm	> 53 mm

4. Result

The daily rainfall and CN values were used to compute daily runoff in the SCS-CN model built on ArcGIS platform. The anticipated runoff for different AMC circumstances for various curve numbers were calculated. Each study area's unique composite curve number was calculated under the AMC II condition. Monthly and yearly values were computed from the daily runoff. Table 4 presents a sample of the computation of daily and monthly runoff. Fig. 4 depicts the link between rainfall and runoff, and displays the runoff depths computed for each rainfall event for the years 2011 to 2020.The hydrological soil group A, C, and D were found in the most part of the study area. For individual soil group,according to the land use land cover category i.e. forest, waterbody, built-up, cultivated, barren and fallow land, weighted CN values were assigned. The weighted number was determined as the product of soil type and curve number which is found on the basis of the land use land cover map.

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The curve numbers ranged from 30 to 95. These values represented the runoff potential of a catchment. Higher curve numbers suggested a high potential for runoff. The maximum curve number 97, characterized for waterbody areas with an HSG A which had the highest runoff potential. Meanwhile, 89 for built-up, 76 for fallow land, 77 for barren land with an HSG A were computed. Runoff for forest land was represented by the curve number 30, indicating the lowest runoff potential. Similarly the maximum curve number 97 wascharacterized for waterbody areas with an HSG C which had the highest runoff potential. Meanwhile, (70, 94, 90, 90, 91) and (77, 93, 93, 93, 94)for forest, built-up, cultivated, fallow and barren land with an HSG C and D respectively. This curve number was assigned mostly for the plain area. Curve numbers assigned to the catchments in dense built-up areas, barren land and waterbody were relatively high. Catchments with higher curve numbers are expected to have high runoff depths. However, the computation for the runoff depth also depends on how much rain falls into a catchment. Since the water bodies in the study area are water storage structures, it does not produceany surface runoff (Anjana and Jinu 2019).

Table 4: Weighted curve number calculation

S. No.	LULC	Area (km2)	% Soil Area (A)	% Soil Area (C)	% Soil Area (D)	WCN
			58.09	9.24	**32.66**	
1	Forest	442	15.19	2.42	8.55	
2	water	74	2.54	0.40	1.43	
3	cultivated	683	23.48	3.74	13.22	74.86
4	Built-up	54	1.85	0.29	1.04	
5	Fallow	333	11.44	1.82	6.44	
6	Barren	101	3.47	0.55	1.95	

Table 5:Estimated annual runoff

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Year	Annual Rainfall (mm)	Annual Runoff (mm)	Q (cubic m)	% Runoff
2011	1232.99	287.33	485025789.4	23.30
2012	1160.72	156.69	264507017	13.50
2013	1170.24	150.97	254837567.4	12.90
2014	1176.48	280.21	473000693.4	23.81
2015	880.42	101.62	171539811.3	11.54
2016	1263.99	251.66	424818661.7	19.91
2017	1043.83	157.00	265024646.2	15.04
2018	985.17	148.33	250393533.4	15.05
2019	1287.90	282.09	476169293.5	21.90
2020	1533.51	305.84	516264686.1	19.94
Sum	**11735.29**	**2121.79**	**3581581699**	

5. Conclusion

Runoff is the term for surface water that drains from the land into an outlet. Runoff water has the ability to transfer and separate soil particles, which causes severe erosion. The productivity and quality of the land will decline due to runoff and subsequent erosion. In this study, runoff of the Bamnidhi watershed is estimated using SCS CN method, based on the HSG map, soil map and land use maps. Based on the HSG and LULC of the site, CN values were assigned. The normal condition's weighted curve number is 74.86. It is 56.63 and 64.57 in 2016 for dry and wet weather, respectively. In 2020, the weighted curve number for dry and wet conditions 60.34 and 64.38 respectively. The findings of the analysis revealed that the rate of ground water recharge is decreasing as the runoff percentage increases. This causes the water table to drop, which causes a water shortage. It is essential to use the generated runoff to replenish the ground water because the demand for water is rising owing to population growth and shortages of resources.The total runoff is found to be around 3.6 Million m^3(3,581,581,699 m^3) for the period 2011 to 2020 and percent converted in runoff after rainfall were 10 to 25 percent.

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