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Spatial Estimation of Runoff Using SCS-CN Embedded in GIS Environment: A Case Study of Nalgonda District of Telangana, India

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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 main aim of the study was to calculate runoff using the Soil Conservation Service Curve Number (SCS-CN) approach in the Nalgonda district of Telangana, India. The data required for the study was a soil map and a land use land cover map for the calculation of the curve number. The curve number ranges from 1-100 for different land use and soil condition. CN I = 62.57, CN II =

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79.22, and CN III = 89.93 are the hydrological soil groups of the AMC conditions for dry, normal, and wet conditions. Rainfall is the most important factor influencing the runoff. The daily rainfall data from 2011 to 2020 were collected from the NASA POWER data viewer website based on latitude and longitude. The highest rainfall was observed during 2013 and 2020 with 987.05mm and 1136.62mm respectively. The runoff was also observed highest in the years 2013 and 2020 with 89.24mm and 89.60mm respectively. The year 2015 is absorbed as a drought year by the Telangana state government with rainfall of 451.68mm and the runoff was observed the lowest at 0.22mm. The total average annual volume of runoff calculated for the Nalgonda district is 207773154.2 m^3 from the study area of 7148077000 m^2. From 2011 to 2020, the observed percentage of rainfall converting to runoff in the study area was 24.22%. According to this study, it has been concluded that an increase in rainfall results in an increase in runoff. The information is useful for the water resource Engineers to plan the water harvesting methods to increase groundwater resources.

Keywords: SCS-CN; ARCGIS; NALGONDA; NASA; AMC.

1. INTRODUCTION

Water is the most significant resource on the planet, and it plays an important role in the state's and country's socioeconomic growth. Every living entity on Earth requires water in order to survive on the planet. Water covers around 71% of the earth's surface, but most of it is unfit for irrigation or drinking since 95.5% is saline water from oceans, 1% is other saline water, and the remaining 2.5% is fresh water. There are 68.7% glaciers and ice caps, 30.1% groundwater, and 1.2% surface or other freshwater in the 2.5% freshwater. In 1.2% of surface water or other freshwater the ground ice and permafrost is 69.0%, lakes 20.9%, soil moisture 3.8%, Atmosphere 3%, swamps, marshes 2.6%, rivers 0.49%, and living things0.26% [1,2].

The growing population exerts tremendous pressure on water resources due to the annual per capita water availability in India having decreased from 5177 m^3 in 1951 to 1654 m^3 in 2007. It is projected to decrease further to 1341 m^3 by 2025 and 1140 m^3 by 2050, thereby approaching a water-scarce condition of less than 1000 m^3 per year [3].

Runoff is a percentage of rainfall that happens when there is an excess of rainfall that prevents surplus rainwater from flowing into the surface due to the pores in the surface being saturated or impervious [4-7]. When there is a dramatic increase in rainfall over a short period of time, the water does not flow to the ground surface and moves as runoff. The creation of runoff is essentially governed by two different sorts of notions. Both the saturation excess runoff and the infiltration-excess runoff fall within this category [8-10]. According to the infiltration-excess runoff theory, overland flow only happens when the intensity of the rainfall exceeds the pace at which water seeps into the soil. When the soil surface is saturated, the second kind of runoff production also occurs, and any additional rainfall, even at modest intensities, produces runoff that aids stream movement [11,12].

Rainfall and runoff are important factors in the hydrological cycle. Rainstorms cause runoff episodes, and the quantity and frequency are determined by rainfall features such as intensity, dispersion, and duration [13].

One of the critical evaluations in water resource engineering is runoff estimate. Runoff estimates can be used to evaluate various effects, such as erosion of the earth's surface, effects on the ecosystem, floods, problems with agriculture, and more [14,15]. Runoff for a certain rainfall event is frequently done using the Soil Conservation Service Curve Number (SCS-CN) approach. The US Department of Agriculture's Soil Conservation Service was responsible for the invention of this technique. Due to its simplicity, it became one of the most popular techniques among engineers.

2. MATERIALS AND METHODS

2.1 Study Area

The chosen study location is the Nalgonda district of Telangana, situated between N latitudes and E longitudes. It has a total area of 7121.67 km^2 and experiences an average annual rainfall ranging from 670 to 870 mm. The district has an elevation of 260m. The study area has clay and loamy soils. The majority of the study area is characterized by a slope range of 0-2%, indicating a mostly flat to moderately sloped terrain. The study area is a semi-arid region facing prolonged dry spells during crop season, groundwater over-exploitation more than the annual recharge, and acute drinking water scarcity during summer.80 percent of the residents of the study region utilize water from the bore and drilled wells for drinking, cooking, and other household purposes. The bore wells' depth ranged from 90 to 300 feet. The agriculture in the study area is mostly rainfed agriculture. The district has a Nagarjuna Sagar Dam with the river Krishna. The nearby areas of dam or canal areas mostly grow paddy and the district is known as the 'Rice Bowl of India' in other areas they mostly grow cotton. The Nalgonda district has a climate that is ideal for cultivating paddy, cotton, and groundnuts.

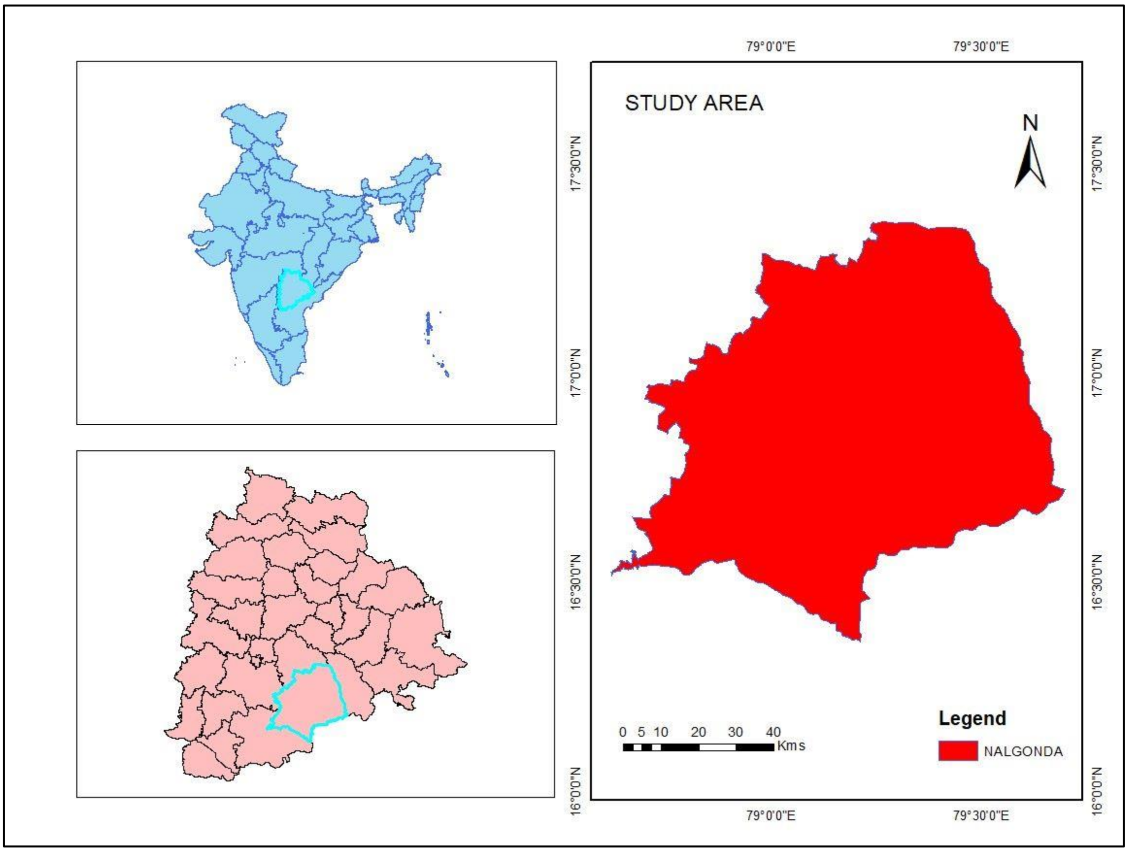

Fig. 1. Study area

2.2 Data Collection

Table 1. Data sources

Datasets	Data source
DEM	https://webmap.ornl.gov/ogc (SRTM DEM 30m resolution)
Soil map	ICAR-CRIDA (1:50000 NBSS&LUP)
LULC	ICAR-CRIDA (1:50000 NRSC-Hyderabad)
Daily rainfall	https://power.larc.nasa.gov/data-access-viewer/ (Collection of daily rainfall for 10 years from 2011 to 2020 based on longitude and latitude)

2.3 Methodology

The NRCS-CN method, developed by the Soil Conservation Service (SCS) and now the Natural Resource Conservation Service of the United States Department of Agriculture (USDA), is a suitable methodology for calculating runoff.

$$Q=\frac{(P-I_a)^2}{P-I_a+S} \text{ for } P>0.2*S \qquad \text{(i)}$$

$$Q=0 \text{ for } P\leq 0.2*S \qquad \text{(ii)}$$

Where P=Daily precipitation (mm), Q=Surface runoff (mm), and S=Potential maximum retention or infiltration (mm). The value of S is given as:

$$S=\frac{25400}{CN}-254 \qquad \text{(iii)}$$

Where CN is the Curve Number.

CN (Curve Number) is dependent on the AMC conditions (antecedent moisture condition) of the area. CN is a dimensionless number and its value ranges from 0 to 100.

2.3.1 Antecedent moisture condition

These classifications of AMC I, II, and III are based on the 5-day continuous previous rainfall.

The equations below are utilized for AMC-I and AMC-III [16]:

$$CN(I)=\frac{CN(II)}{2.281-0.0128CN(II)} \qquad \text{(iv)}$$

$$CN(III)=\frac{CN(II)}{0.427+0.00573\,CN(II)} \qquad \text{(v)}$$

Where, CN(I) is the curve number for the dry conditions, CN(II) is the curve number for the normal conditions and CN(III) is the curve number for the wet conditions.

$$CN_{W=\sum CN_i} * A_i/A \text{vi}$$

Where CN_W is the weighted curve number; CN_i is the curve number from 1 to 100; A_i is the area with curve number CN_i; and A is the total area of the study area.

2.3.2 Rainfall

The rainfall data is used for estimating the runoff of the study area. The SCS-CN method requires the daily rainfall data for the calculation of the runoff. From the daily rainfall data, the 5 antecedent (5 days previous continuous) rainfall is chosen and the AMC conditions are given based on the soil characteristics like dry, normal, and wet conditions. The 10 years rainfall from 2011 to 2020 is collected from NASA Power Data View which is chosen based on the latitude and longitude of the study area.

2.3.3 Soil map

The soil map is critical in identifying the ability of the soil's drainage qualities. The soil is classified based on the texture and the textural map is generated. Most of the study is covered with gravelly loam calcareous and gravelly loam.

2.3.4 Land use and land cover

The Land use land cover map is used to study the land use pattern of the study for different categories like Agriculture, Buildup, Current fallow, Forest, wasteland, and Water bodies. Most of the study area is covered with Agriculture and the least area with Buildup. Land use and land cover are dynamic in nature and it provides a comprehensive understanding of the interaction and relationship of anthropogenic activities with the environment [17,18].

2.3.5 Hydrological soil groups

The Hydrological soil group map is digitized from the soil map and the groups are classified into A, B, C, and D classes based on the soil texture for water transmissions into the ground.

Table 2. Classes of antecedent moisture conditions

AMC	Total 5 days antecedent rainfall(mm)		
	Dormant Season	**Growing Season**	**Average**
I	<13	<36	<23
II	13-28	36-53	23-40
III	>28	>53	>40

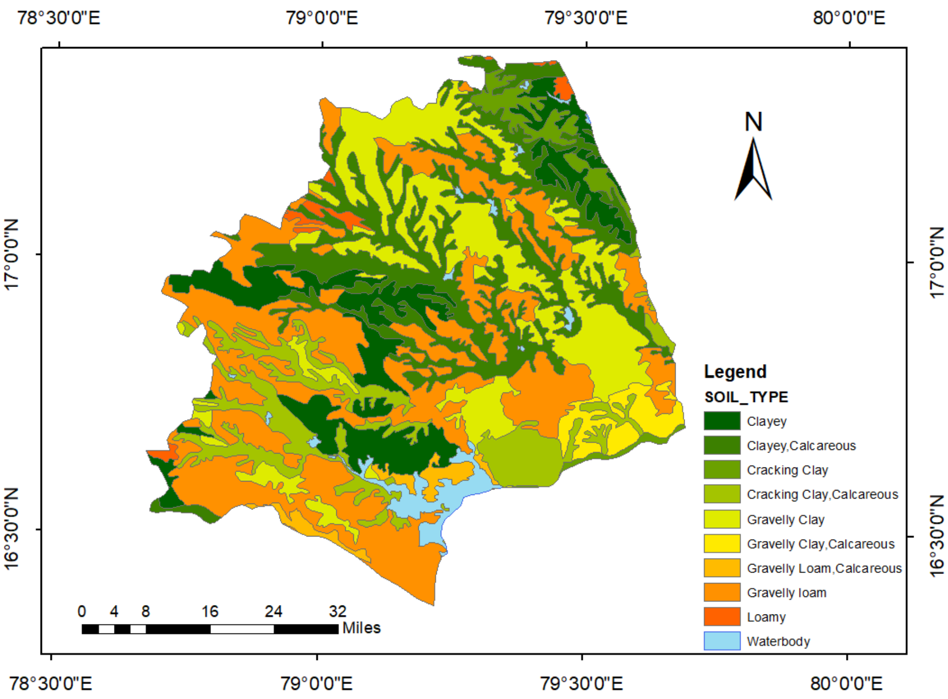

Fig. 2. Soil map (NBSS&LUP) ICAR-CRIDA

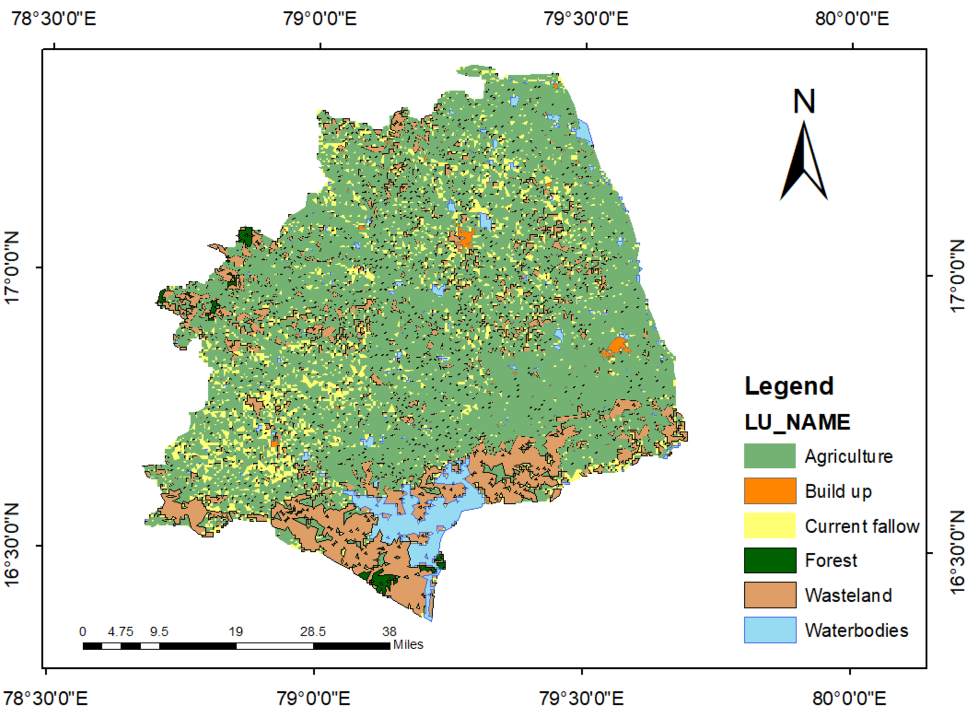

Fig 3. Land use land cover ICAR-CRIDA

Table 3. Classification of land use land cover

S. No.	Land use and Land cover	Area(km^2)	Area(%)
1	Buildup	53.37	0.74
2	Agriculture	4527.01	63.40
3	Current fallow	805.27	11.27
4	Forest	41.01	0.57
5	Wasteland	1438.53	20.14
6	Water bodies	274.65	3.84
	Total	**7139.87**	**100**

Table 4. Different hydrological soil groups and its properties

HSG	Soil texture
Group A	Sand, Loamy sand, or sandy loam
Group B	Silt or loam
Group C	Sandy clay loam
Group D	Clay loam, Silt clay loam, Sandy clay, Silt clay, or Clay

2.3.5.1 Classification of the HSGs based on infiltration rates

HSG A consists of soils with high infiltration rates. These are typically sandy or loamy soils with low clay content, allowing water to easily penetrate without causing surface runoff.

HSG B soils have moderate infiltration rates and are usually moderately well-drained with a mixture of sand, silt, and clay. They can absorb water well, but some surface runoff may occur during heavy rainfall.

HSG C includes soils with slow infiltration rates. These are often poorly drained with a high clay content or shallow water tables. Surface runoff is common, and these soils may have limited ability to absorb water.

HSG D comprises soils with very slow infiltration rates or surfaces that are unable to absorb water, such as urban areas, paved surfaces, or rocky terrains. These generate significant surface runoff during rainfall events.

Table 5. Classification of hydrological soil groups

HSG	Area(km^2)	Area%
A	2226.30	31.18
B	72.11	1.01
C	1669.50	23.38
D	2985.60	41.81
Others(water bodies)	186.01	2.60
Total	**7139.54**	**100**

2.3.6 Calculation of weighted curve number by integrating land use & land cover (LULC) map and Hydrological soil Groups (HSG) map

Table 6. Calculation for weighted CN

Land use land cover	Soil Type (HSG)	Area(km^2)	CN	Weighted CN	Weighted CN for AMC
Agriculture	A	1244.7761	67	83399.9987	AMC-I=62.57
	B	56.0247	77	4313.9019	AMC- II=79.22
	C	1225.2213	83	101693.3679	AMC- III=89.93
	D	2001.7274	87	174150.2838	
Build up	A	8.111	57	462.327	
	C	29.735	81	248.535	
	D	15.4222	86	1326.3092	

Land use land cover	Soil Type (HSG)	Area(km^2)	CN	Weighted CN	Weighted CN for AMC
Current fallow	A	230.5703	39	8992.2417	
	B	7.1262	61	434.6982	
	C	182.3114	74	13491.0436	
	D	385.2114	80	30816.912	
Forest	A	36.0015	30	1080.045	
	C	1.00145	70	70.1015	
	D	4.0148	77	309.1396	
Wasteland	A	598.5367	71	42496.1057	
	B	13.3205	80	1065.64	
	C	327.6027	85	27846.2295	
	D	498.8679	88	43900.3752	
Water bodies	A	96.0865	100	9608.65	
	B	26.2799	100	2627.99	
	C	48.4527	100	4845.27	
	D	103.4631	100	10346.31	
Total		**7139.865**		**565685.5**	

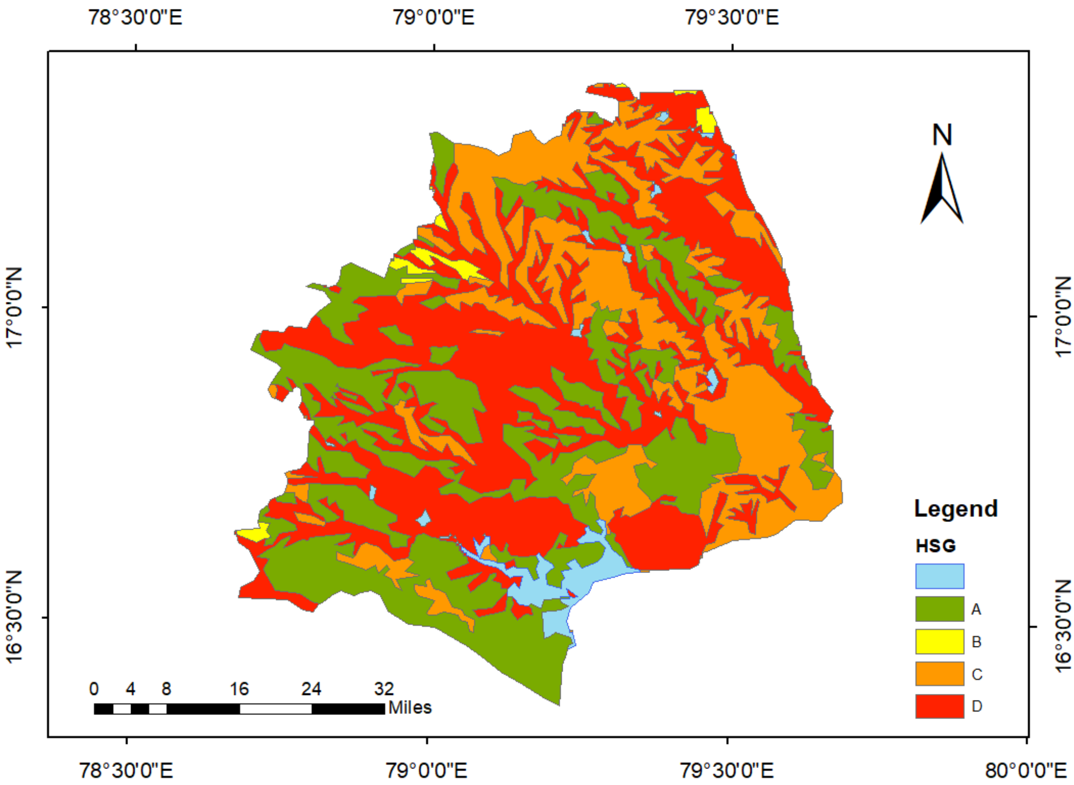

Fig. 4. Hydrological soil groups map

3. RESULTS AND DISCUSSION

The calculated curve number for the Dry, Normal and Wet conditions of AMC are 62.57, 79.22, and 89.93. The rainfall ranges from 451.68 mm to 1136.62mm and runoff ranges from 0.22mm to 89.60 mm during the year 2011-2020.

Table 7. Calculation of the average annual volume of the runoff in the Nalgonda district

Years	Rainfall(mm)	Runoff(mm)	Runoff(m)	Volume=runoff*area(m^3)
2011	481.66	11.54	0.01154	82488808.58
2012	666.14	7.53	0.00753	53825019.81
2013	987.05	89.24	0.08924	637894391.48
2014	619.64	26.22	0.02622	187422578.94
2015	451.68	0.22	0.00022	1572576.94
2016	638.68	8.4	0.0084	60043846.8
2017	818.78	52.12	0.05212	372557773.24
2018	528.05	2.21	0.00221	15797250.17
2019	712.64	3.59	0.00359	25661596.43
2020	1136.62	89.60	0.0896	640467699.2
Total	7040.94	290.67	0.29067	2077731542
Average	704.094	29.067	0.029067	207773154.2

During the 10 years of average annual rainfall from 2011 to 2020, the average runoff volume is 207773154.2 m^3 for an area of 7148077000m^2. The highest rainfall in the year 2020 has recorded at with1136.62mm and the lowest rainfall in the year 2015 has recorded at 451.68mm as shown in Fig. 4.and the highest runoff absorbed in 2020 with 89.60mm and the lowest runoff in year 2015 with 0.22mm as shown in Fig. 5.

The good panned soil and water conservation measures should be implemented based on the runoff potential map as shown in Fig. 6. Most of the study area is under the gentle to moderate slopes with 0-1%, 1-2%, and 2-3% which are suitable for water harvesting by contour bunds, percolation ponds, contour trenches and recharge wells. Which increases the groundwater resources. This water harvesting should be done in the northern zones of Telangana because there are no other water resources such as dams and must depend on rainwater resources and groundwater resources. And the southern zone of Nalgonda is provided with Nagarjuna Sagar Dam with river Krishna.

During the year from 2011 to 2020, the drought year is absorbed in the year 2015 by the Telangana state government with the lowest rainfall at 451.68 and runoff is also observed lowest at 0.22mm.

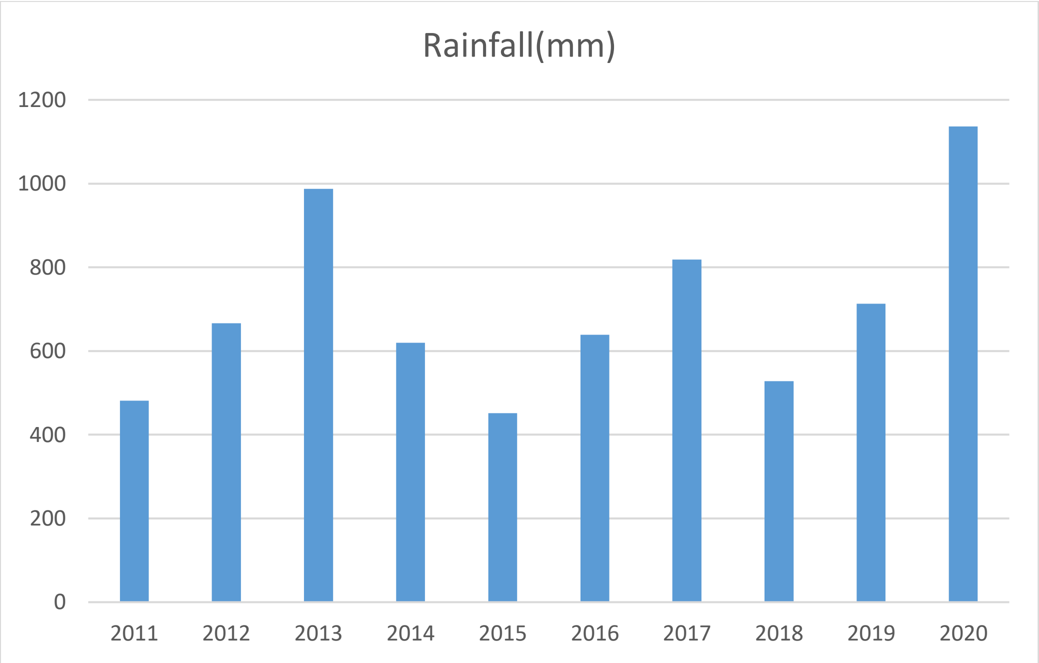

Fig. 5. Graphical representation of rainfall in mm

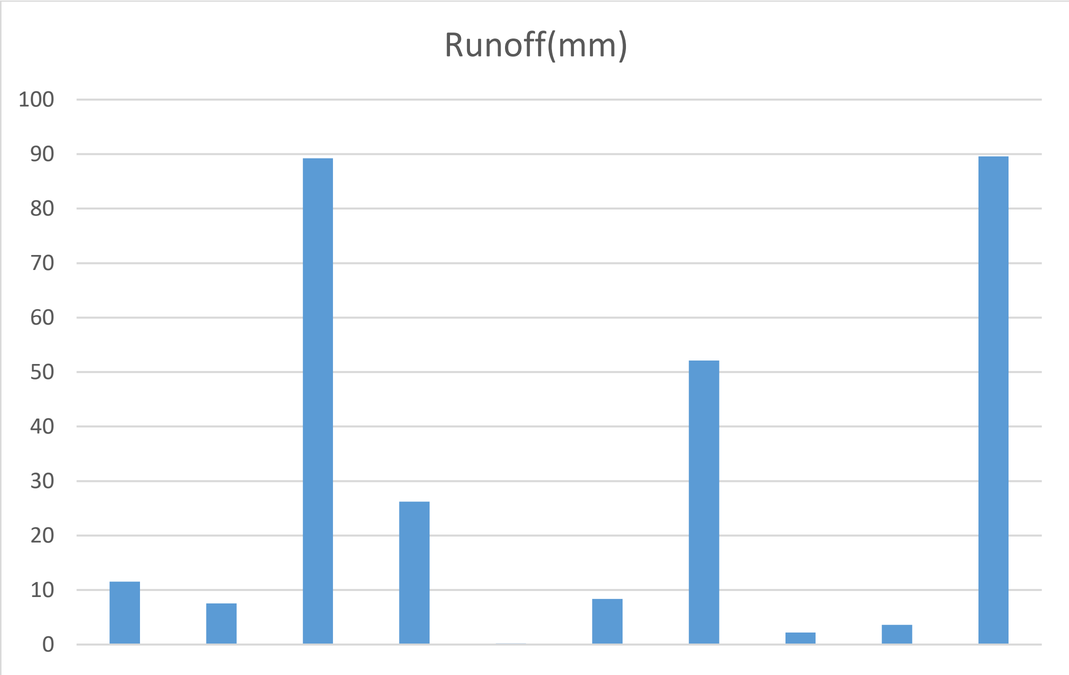

Fig. 6. Graphical representation of runoff in mm

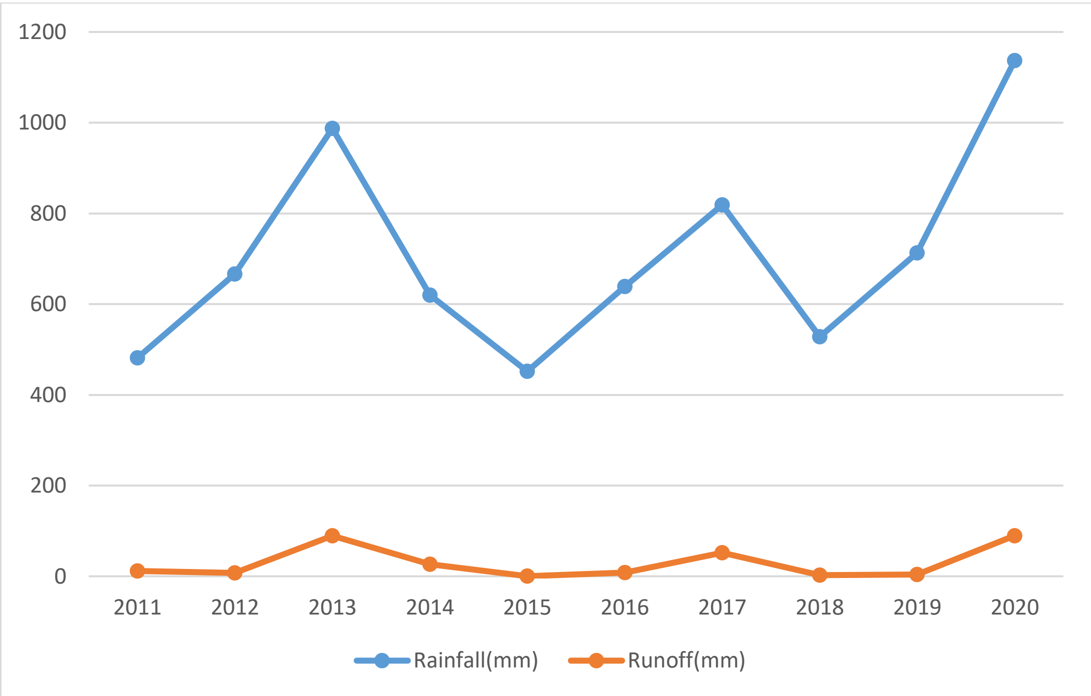

Fig. 7. Graphical representation of rainfall and runoff for comparison

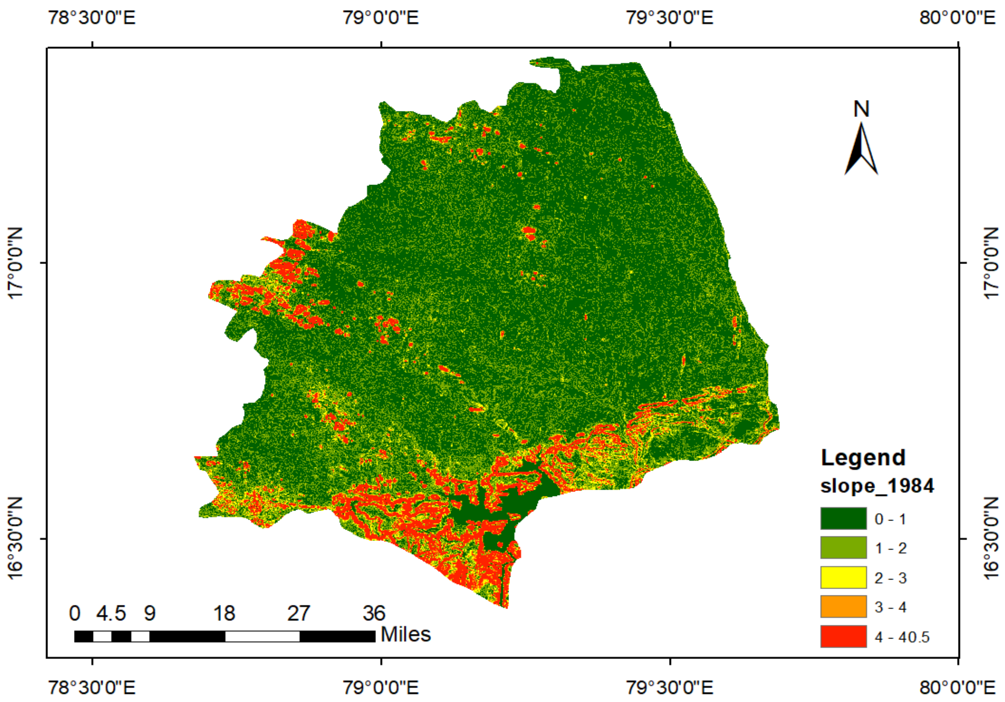

Fig. 8. Slope map of the Nalgonda district

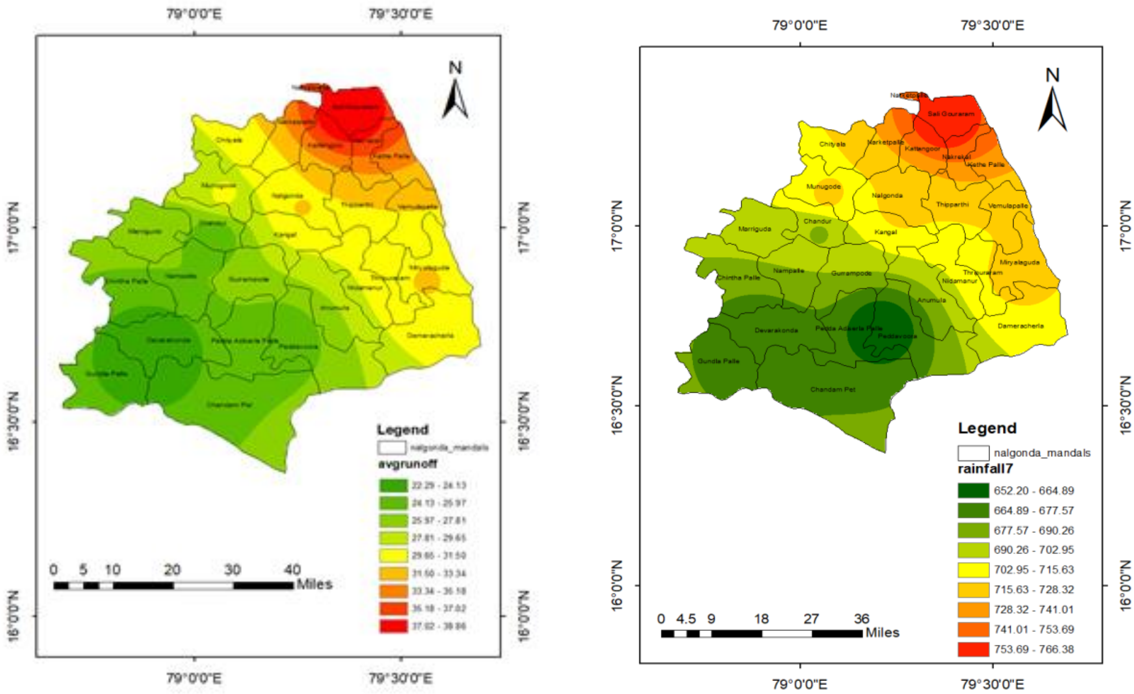

Fig. 9. Average annual rainfall and Average annual runoff

4. CONCLUSION

This study utilized the Soil Conservation Service Curve number method and Arcgis10.7.1 software to calculate runoff. The integration of land use and land cover map and soil map was presented in the work. Curve number values (ranging from 0-100) were obtained based on the AMC conditions, which describe Dry, Normal, and Wet conditions of the soil AMC-I with CN=62.57, AMC-II with CN=79.22, and AMC-III with CN=89.93, respectively. The amount of runoff represents 24.22% of the total average annual rainfall of 10 years from 2011 to 2020. Most of the rainfall is observed in the northern zone of the Nalgonda with 700mm to 770mm. The highest runoff is in the northern zones of Nalgonda with runoff ranges from 30mm to 40mm. The maximum runoff-prone areas are indicated by the high rate of soil erosion and the low infiltration rate. Most of the study area in the northern parts of Nalgonda ranges from 0-2% (flat or gentle) slope which is suitable for water harvesting or infiltration into the groundwater by the methods such as contour bunds, percolation ponds, contour trenches and recharge wells. In most open land areas, runoff is controlled by growing the green pastures that abstract the flow of water from one place to another and thus increase the time of concentration to infiltrate into the ground surface. The Soil Conversations Service's Curve Number methodology has been proven to be an efficient and simple way to calculate large areas. It can handle vast data sets and cover a broader environmental region, making the process faster and more manageable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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