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

ABSTRACT

The main aim of the study was calculated 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 soil map and land use land cover map for the calculation of the curve number. The curve number ranges 1-100 for different land use and soil condition. The hydrological soil group of the AMC conditions for dry, normal and wet conditions are CN I=62.57, CN II=79.22 and CN III=89.93 were determined respectively. The rainfall is the most important factor to influence the runoff. The daily rainfall data from 2011 to 2020 were collected from 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 year of 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 451.68 mm and the runoff was observed lowest with 0.22 mm. The total average annual volume of runoff is calculated for the Nalgonda district is 207773154.2 m^3 from the study area of 7148077000 m^2. The study area is observed rainfall to runoff percentage is 24.22 % during the year 2011 to 2020. Based on this study concluded that as rainfall increases the runoff also increases. The information is useful for the water resource Engineers to plan the water harvesting methods to increase the groundwater resources.

Key words: SCS-CN, ARCGIS, NALGONDA, NASA, AMC

1. INTRODUCTION

Water is the most significant resource on the planet, and it plays an important part 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 things 0.26%.

The growing population exerts tremendous pressure on water resources due to the annual per capita water availability in India has 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 1000 m^3 per year (MOWR 2008).

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. When there is a dramatic increase in rainfall over a short period of time, the water does not flow to the ground surface and move 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. 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.

The rainfall and runoff are the important factors of the hydrological cycle. Rainstorms cause runoff episodes, and the quantity and frequency are determined by rainfall features such as intensity, dispersion, and duration. (Pradhan *et al.,*2010).

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. 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 technique among the engineers.

2. MATERIALS AND METHODS

2.1 Study area

The study area selected is Nalgonda district of Telangana located between $16^{\circ}22'0''$ to $17^{\circ}22'22''$ N latitudes and $78^{\circ}41'3''$ to $79^{\circ}41'22''$ E longitudes having geographical area 7121.67 km^2 with mean annual rainfall varying from 670 to 870 mm and the elevation 260m. The study area has clay and loamy soils. The most of the study area have the slope range 0-2% which are flat to moderate. 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 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 river Krishna. The nearby areas of dam or canal areas they mostly grow the paddy and the district is known for the ‘Rice Bowl of India’ and in other areas they mostly grow the cotton. The climate in the nalgonda district best suitable for growing paddy, cotton and groundnut crops.

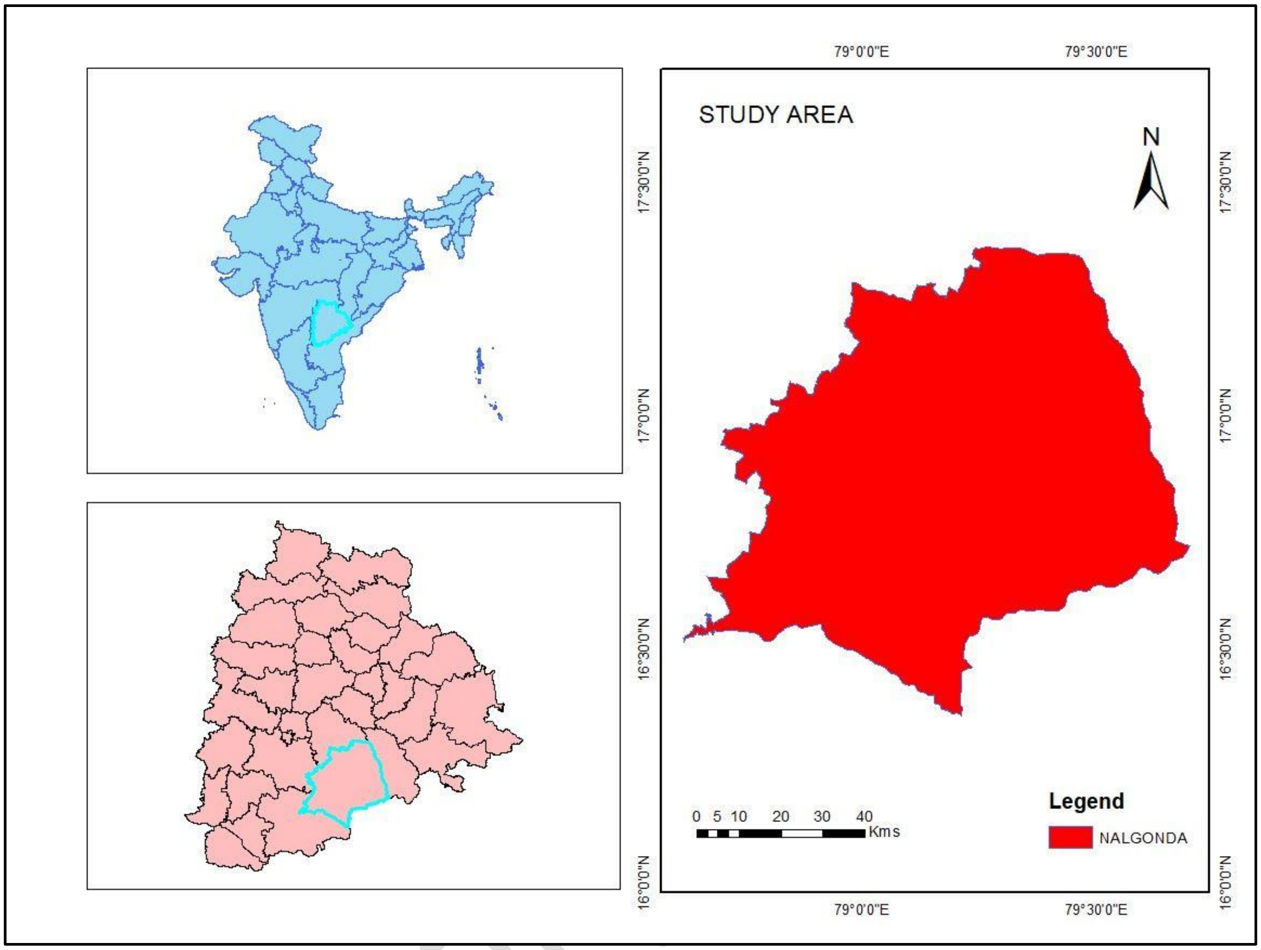

Fig 1: Study area.

2.2 Data collection

Datasets	Data source
DEM	https://webmap.ornl.gov/ogc
Soil map	ICAR-CRIDA (NBSSLU&P)
LULC	ICAR-CRIDA
Daily rainfall	https://power.larc.nasa.gov/data-access-viewer/

Table: 1 Data sources

2.3 Methodology

The methodology used by the NRCS-CN method developed by the Soil Conservation Service (SCS) now Natural Resource Conservation Service of United States Department of Agriculture (USDA) it a suitable method for the calculation of the 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 (antecendent moisture condition) of the area. CN is a dimensionless number and its value ranges from 0 to 100.

2.3.1 Antecendent moisture condition

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

Table 2: Classes of Antecendent 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

The following equation are used in case of AMC-I and AMC-III (Chow et al. 2002):

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

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

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.

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

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 characters 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 textural map is generated. The most of the study is covered with gravelly loam calcareous and gravelly loam.

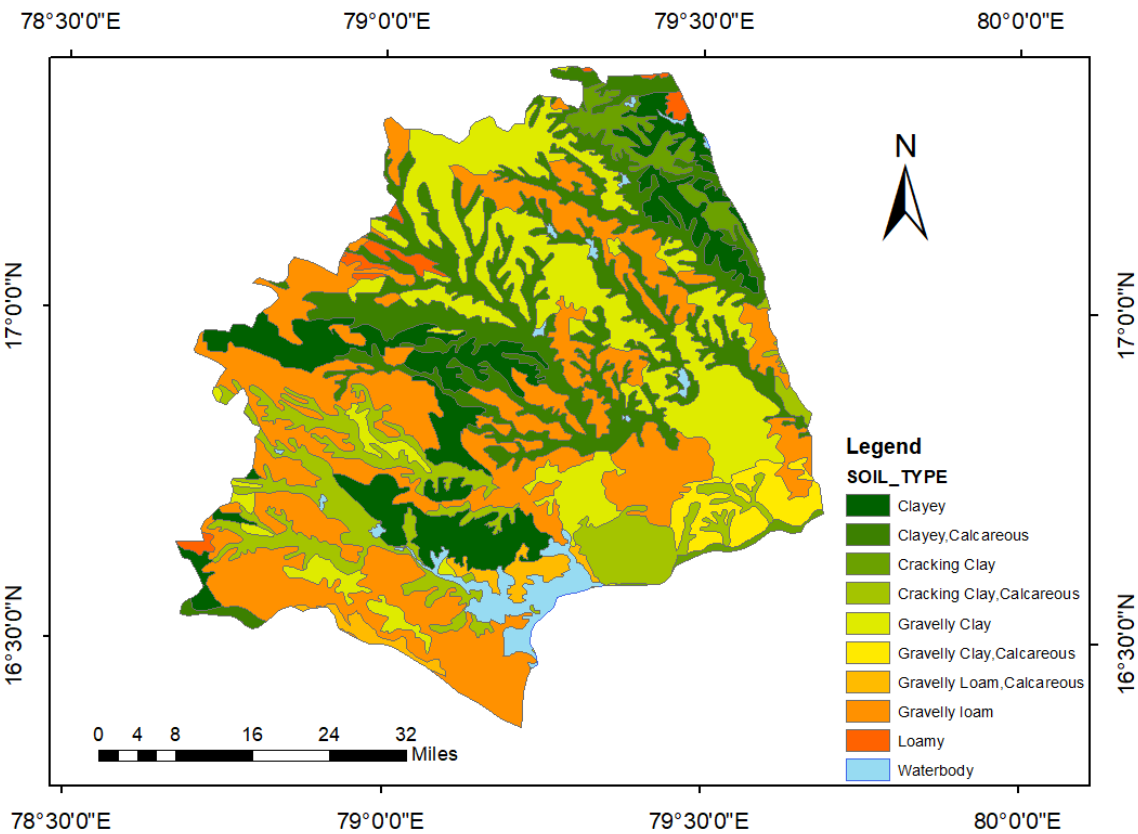

Fig 2: Soil map (NBSS&LUP) ICAR-CRIDA.

2.3.4 Land use and land cover

The LULC is used to study the land use pattern of the study for different categories like Agriculture, Build up, Current fallow, Forest, waste land, Water bodies. The most of the study area is covered with Agriculture and least area with Buildup. Land use and land cover is dynamic in nature and it provides a comprehensive understanding of the interaction and relationship of anthropogenic activities with the environment (Prakasam, 2010; Yadav *et al*., 2012).

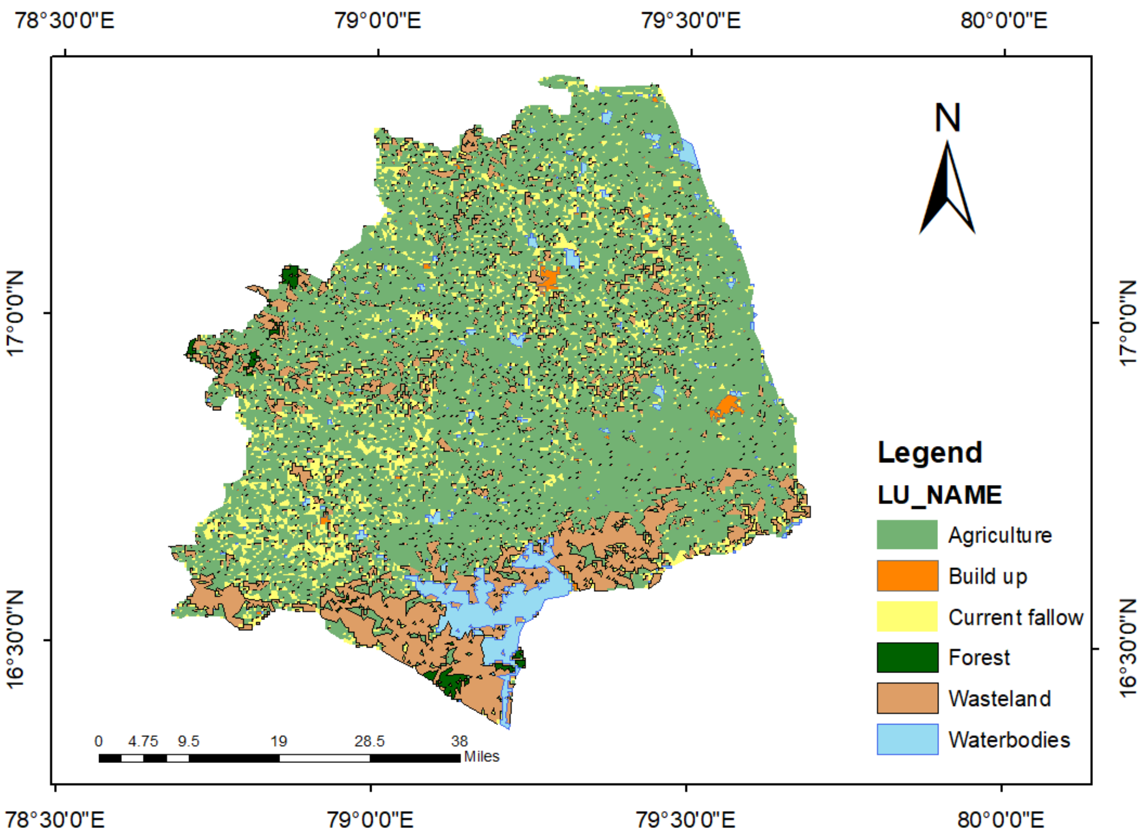

Fig 3: Land use land cover ICAR-CRIDA

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**

2.3.5 Hydrological Soil Groups

The HSGs are 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 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

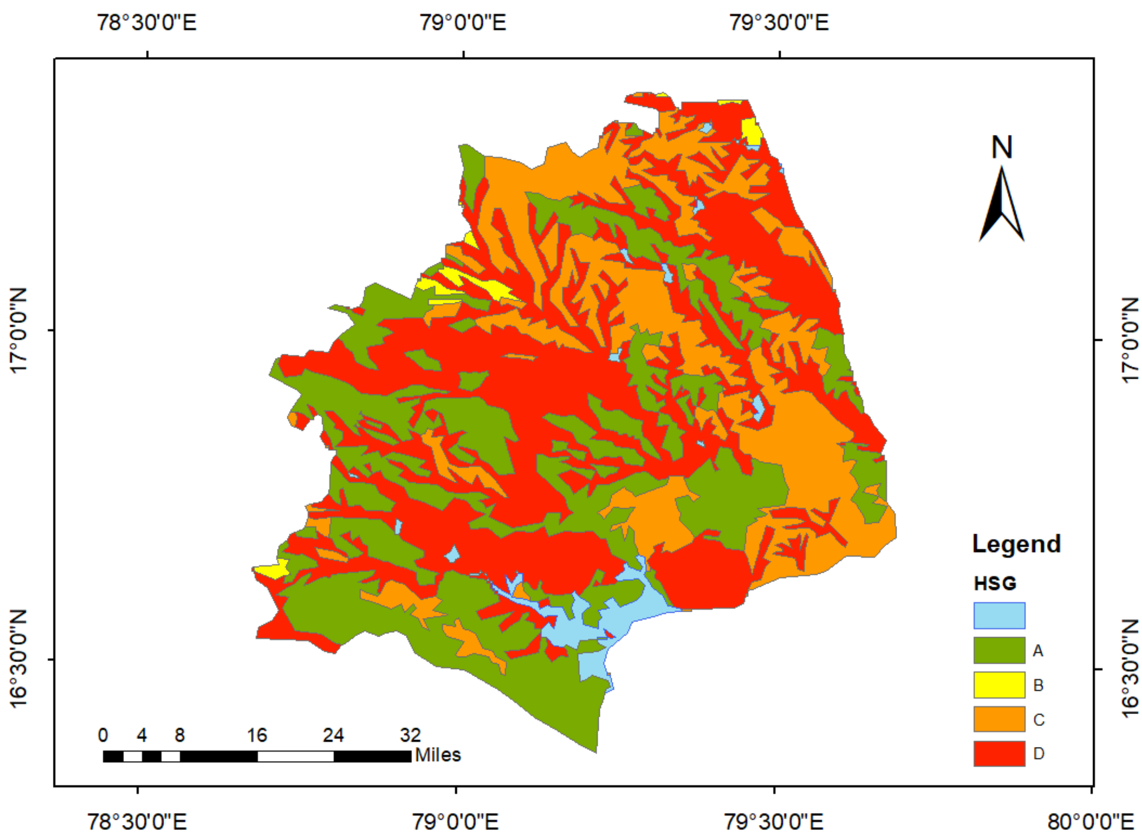

Fig 4: Hydrological Soil Groups map

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**

Calculation of Weighted Curve Number by integrating Land use & land cover (LULC) and Hydrological Soil Groups (HSG)

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	
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		42496.1057	
	B	13.3205		1065.64	
	C	327.6027		27846.2295	
	D	498.8679		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**	

3. RESULT 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 451.68mm to 1136.62mm and runoff ranges from 0.22mm to 89.60mm during the year 2011-2020.

Table 7: Calculation of 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 207773154.2m^3 for the area 7148077000m^2. The highest rainfall in the year 2020 has recorded with1136.62mm and the lowest rainfall in the year 2015 has recorded with 451.68mm as shown in fig. 4.and the highest runoff is absorbed in the 2020 with 89.60mm and the lowest runoff in the year 2015 with 0.22mm as shown in fig. 5.

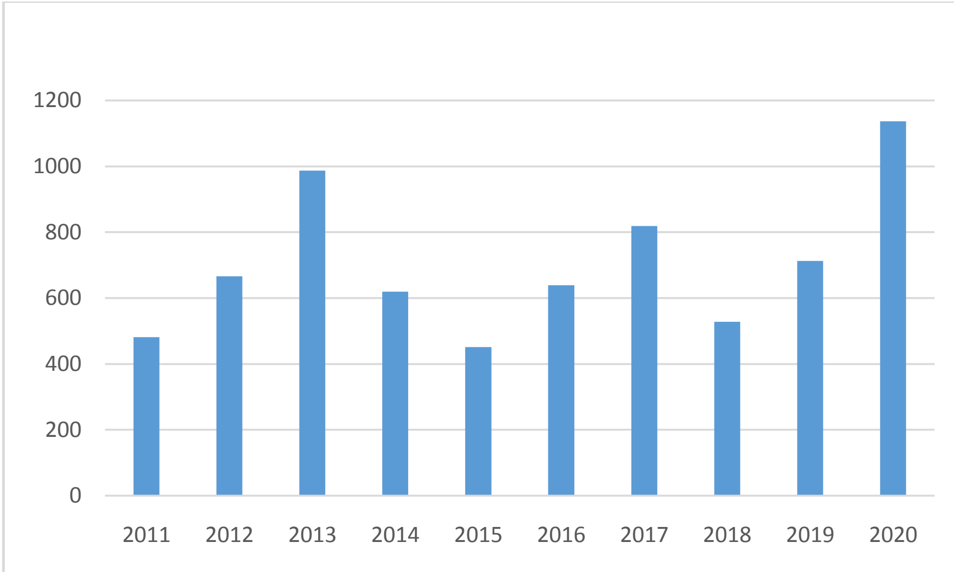

Fig 5: Graphical representation of Rainfall in mm.

The good panned soil and water conservation measures should be implemented based on the runoff potential map as shown in fig. 6. The 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 increase the groundwater resources. These water harvesting should be done in northern zones of the Telangana because there is no other water resources such as dams and must depend on rain water resources and groundwater resources. And the southern zone of nalgonda is provided with Nagarjuna Sagar Dam with river Krishna.

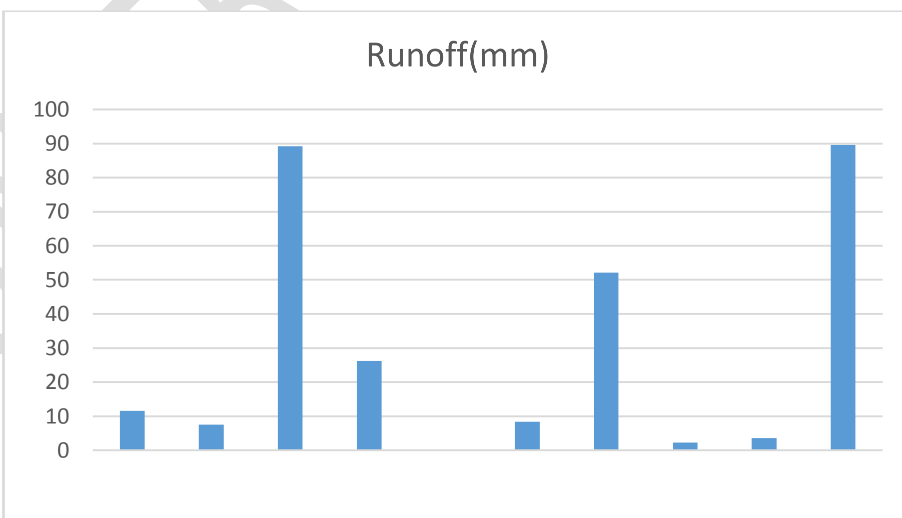

Fig 6: Graphical representation of Runoff in mm.

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

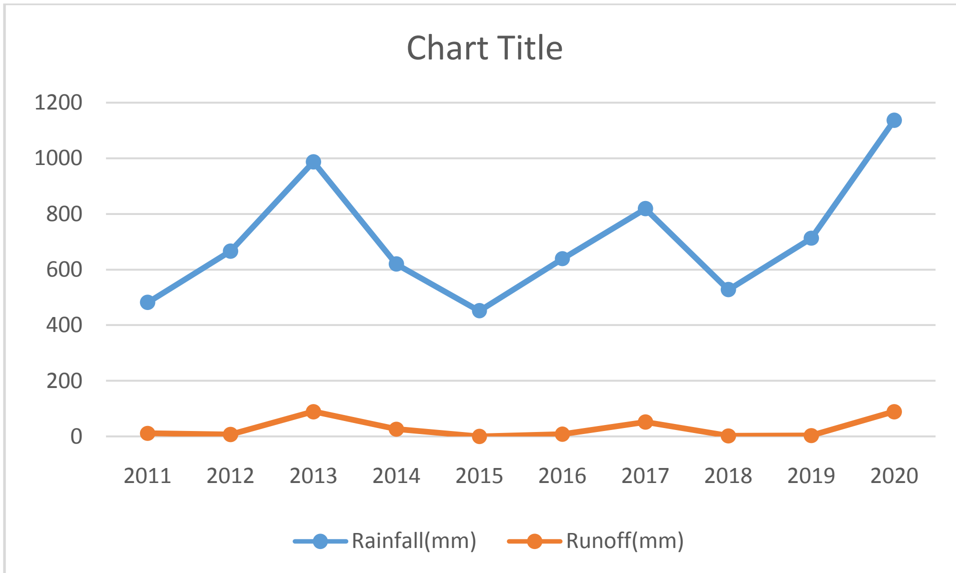

Fig 7: Graphical representation of Rainfall and Runoff for comparison.

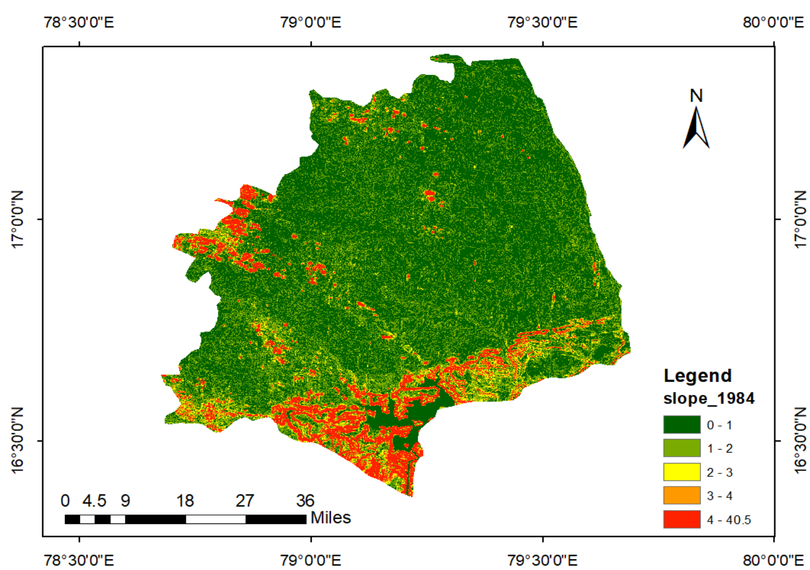

Fig 8: Slope map of the Nalgonda district.

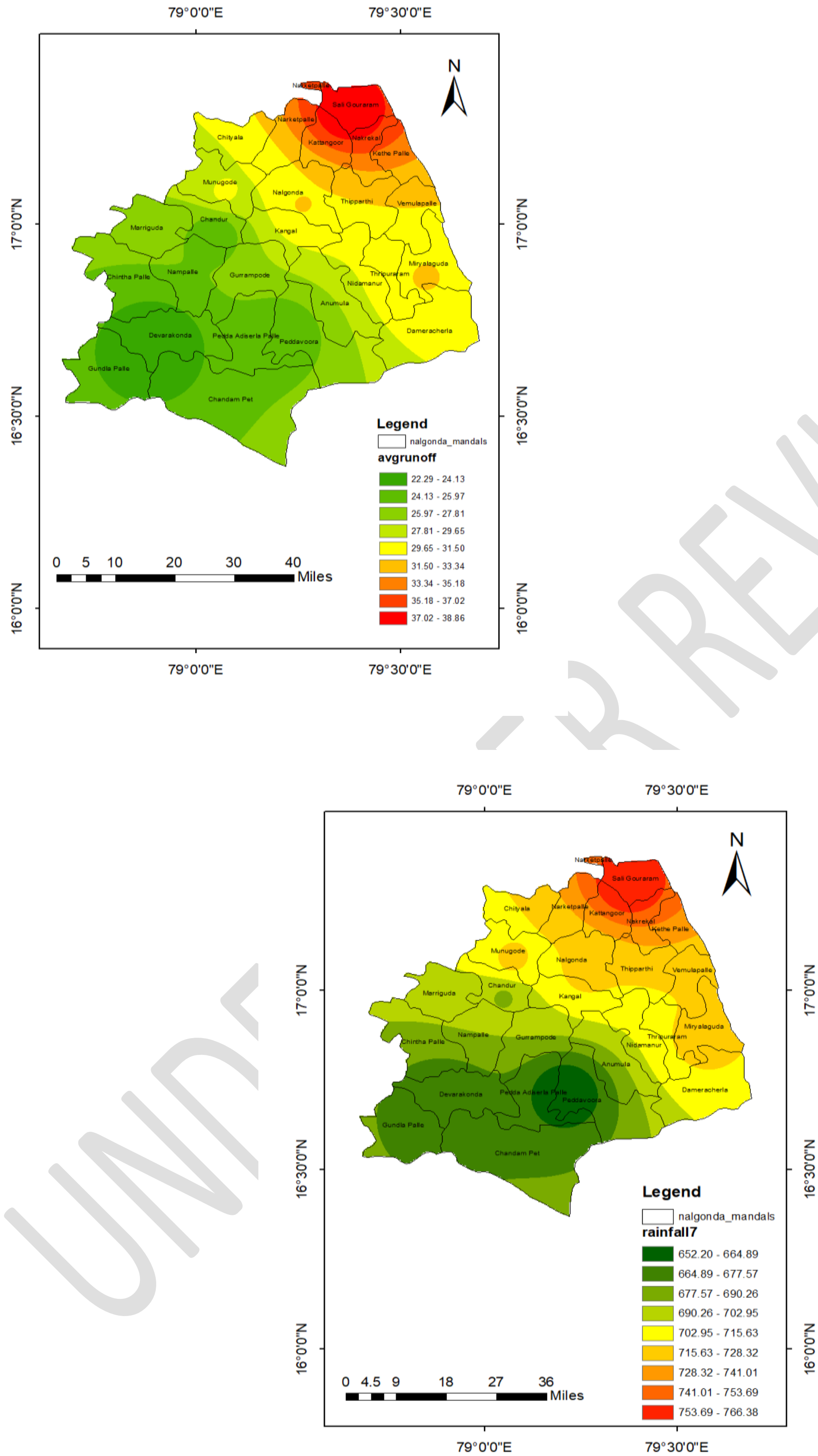

Fig 9: Average annual rainfall and Average annual runoff.

CONCLUSION

In this study the runoff is calculated by using Soil Conservation Service Curve number method and the software used is Arcgis10.7.1. The work is presented by integration of land use and land cover map and soil map. The curve number values (0-100) are obtained by the AMC conditions which plays a very important role in describing in 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. The most of the rainfall is observed in the northern zone of the nalgonda with 700mm to 770mm. The highest runoff in northern zones of nalgonda with runoff ranges from 30mm to 40mm. The maximum run off prone areas are indicated the high rate of soil erosion and the low infiltration rate. The most of the study area in the northern parts of nalgonda is ranges from 0-2% (flat or gentle) slope which are suitable for water harvesting or infiltration into the groundwater by the methods such as contour bunds, percolation ponds, contour trenches and recharge wells. The most of the 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. Finally, the Soil Conversations Service -Curve Number methodology has been efficiently shown as a better way for identifying site selection of artificial recharge structures that consumes less time and capacity to handle vast data sets as well as a broader environmental region.

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