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Original Research Paper

Estimation of Rainfall-Runoff using SCS-CN Method with RS and GIS Techniques for Mandavi Basin in YSR Kadapa District of Andhra Pradesh, India



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Abstract

The study aims to estimate the surface runoff in the semi-arid crystalline rock terrain of Mandavi basin using Remote Sensing (RS) and Geographical Information System (GIS) techniques. The rainfall is the only source of water in this basin drains off and little amount percolates into the ground. The study area experiences rigorous groundwater scarcity despite having high rainfall-runoff. Consequently, integrated RS and GIS techniques are used for estimation of the runoff. The weighted curve number (CN) is resolute based on AMC-II (Antecedent Moisture Condition) with the combination of HSGs (hydrologic soil groups) and LU/LC (land use and land cover) categories. The outcomes of study showed 52.292 (CNII) for normal condition, 31.506 (CNI) for dry condition and 71.583 (CNIII) for wet condition. The ungauged watershed exhibits an annual average of rainfall, runoff, runoff volume and runoff coefficients for 20 years are 688.82 mm, 478.06 mm, 699.75 m³ and 0.69, respectively. The annual rainfall-runoff relationship during 1995 to 2014 is indicating the overall increase in runoff with the rainfall in the study area.

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1 INTRODUCTION

A drainage basin is an extent of land where surface water from rain, converges to a single point at a lower elevation, usually the exit of the basin, where the waters join another water body. The assessment of excess precipitation gives a base for hydraulic structure plan and calculation of flood peak discharges. The Soil Conservation Service-Curve Number (SCS-CN) model created by the U.S. Bureau of Agriculture National Resources Conservation Service (NRCS) formerly known as Soil Conservation Service is the mainly prevalent and broadly connected model for direct runoff estimation, is broadly used for the evaluation of direct runoff for a given rainfall event from small agricultural watersheds. Due to its low input data needs and also its simplicity, many watershed models such as SWAT (Arnold *et al.*, 1996), EPIC (Sharpley and Williams, 1990), AGNPS (Young *et al.*, 1989) and CREAMS (Knisel, 1980) used

this method to determine the runoff (Shi *et al.*, 2009). The RS and GIS have been playing significant role for preparation of Curve Number (CN) and it is very essential for runoff estimation. Worldwide water shortage ponders did by various specialists show that roughly two-thirds of the world population will be influenced by water shortage in the following couple of decades (Alcamo *et al.*, 2000; Wallace and Gregory, 2002). Water shortage and over-misuse of groundwater assets are common in numerous places of India (Garg and Hassan, 2007; Tiwari *et al.*, 2009; Tiwari and Singh, 2014). The measurable qualities of high-force, short-duration, convective precipitation are basically autonomous of areas inside a locale and are comparative in many parts of the world (FAO, 1979). The essential cities and towns in India are confronting major issues identified with groundwater level exhaustion and groundwater quality deterioration

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(Tiwari *et al.* 2017; CGWB, 2000; Gagan *et al.*, 2016; Gautam *et al.*, 2015; Krishan *et al.*, 2014; Kumar *et al.*, 2010; Verma *et al.*, 2016). The diminishing water level and the antagonistic effect of modern and rural exercises, mining, urbanization, and worldwide environmental change are expanding the stress on groundwater assets. Accordingly, groundwater administration has turned into a need in the field of water resource research. Frequently, the hydrological studies required records of precipitation and Runoff to comprehend the management of water. (Eric *et al.*, 2016). Watershed characteristics may be most readily compared to estimate the volume of runoff that will result of LULC, rainfall, slope and type of soil (Rawat and Singh, 2017). The population of the study area is mainly rural dependent on subsurface water resources for domestic use and farming purposes. Demand for domestic water needs increasing with increasing population and growing living standards besides the existing irrigation command area. The runoff result shows the water scarcity during the summer season. The

main goal of the study is to estimate the runoff potential for the 20 years using the SCS-CN method, Remote Sensing data and GIS techniques.

2 THE STUDY AREA

The Mandavi River basin (1464.95sqkm) is the tributary of the Cheyyeru River, which is located in Kadapa and Chittoor districts of Rayalaseema region in Andhra Pradesh (Figure 1). The study area lies between 13° 51' 25" and 14° 18' 43" N Latitudes and 78° 34' 00" and 79° 1' 00" E Longitudes. The Mandavi river basin is predominantly underlain by Archean crystalline rocks, consisting of Granite, Granodiorite, Granite gneiss, Migmatite, Basic and Acidic intrusive rocks. It is also partially covered with Cuddapah super group rocks such as Shales, Dolomite/Limestone, Phyllite and Quartzite. Dendritic to sub dendritic drainage pattern is observed. The average annual precipitation is 686.62mm and temperature varies from 20° to 45.5°C. The relief values ranged between 1080m and 195m with a median of 609m above the mean sea level (MSL).

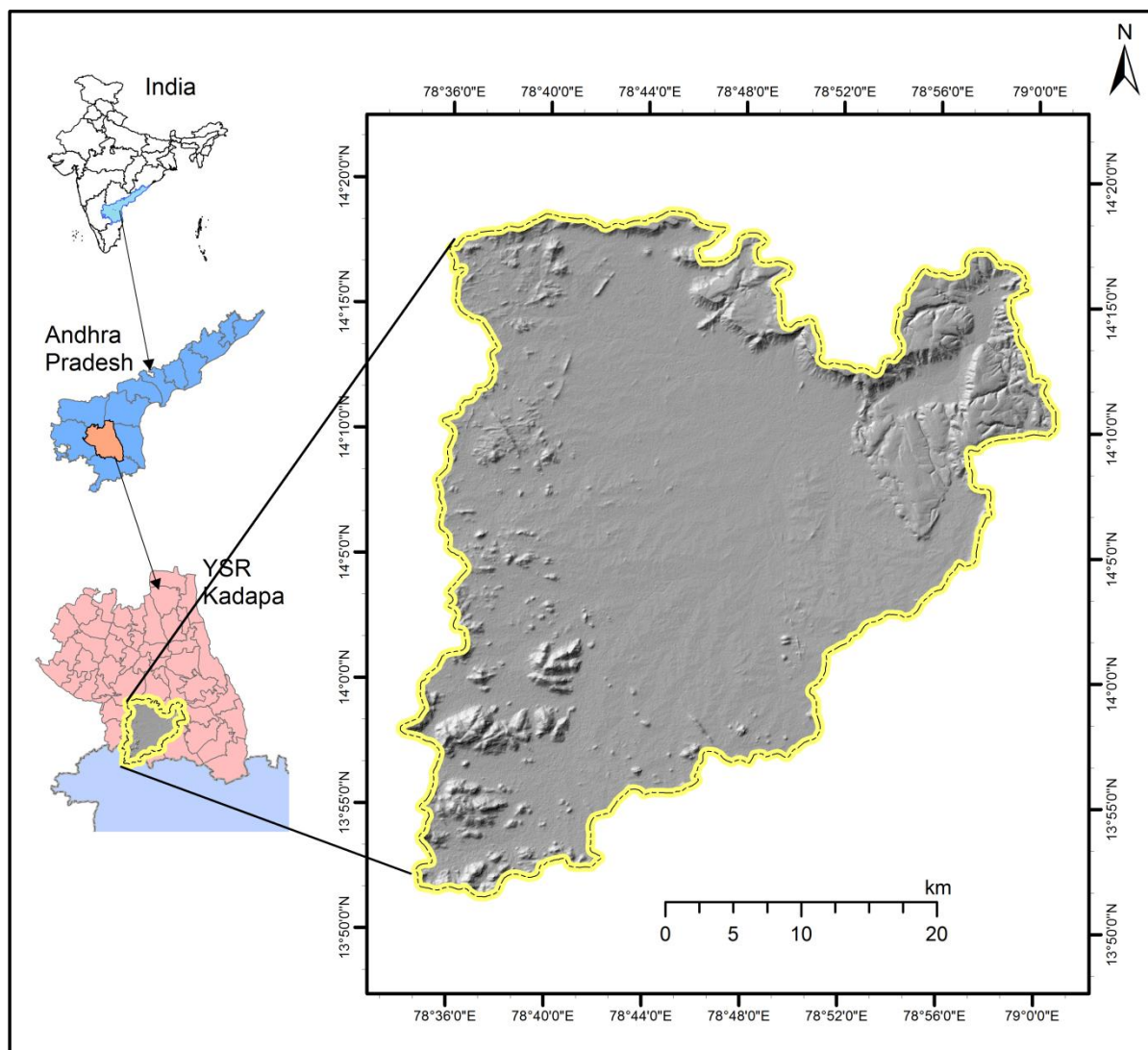


Figure 1. Study area: Mandavi river basin.

3 METHODS AND DATA COLLECTION

Rainfall-runoff estimation using SCS-CN method apart from this, basic layers such as land use/cover (LULC), location rain gauge stations, etc. are extracted from SOI topographic maps (scale 1:50,000) and LULC map has been updated to IRS P6 LISS IV satellite. Soil map is procured from Food and Agriculture Organization (FAO) and Rainfall Data (1995-2014) collected from chief planning office at Kadapa. Shuttle Radar Topography Mission (SRTM)-30m data have been downloaded from <https://earthexplorer.usgs.gov/> website and it is used for preparation of slope map. For mapping and analysis purposes ArcGIS 9.3 and MS-Excel were used. Methodology of the analysis is shown in (Figure 2). In this method, after overlaying the land use map on the hydrologic group maps we can get land

use hydrologic soil group polygon layer and find out the area of each polygon then allotted a CN to each polygon, as per SCS and curve number (Figure 7). The CN is given for basin of area-weighting calculated from the land use soil group polygons surrounded by the drainage basin boundaries (Satheeshkumar et al., 2017; Kudoli et al., 2015). SCS and Curve Number method is especially sensitive to CN values, demand for accurate determination of this parameter. CN is again as a function of HSG (Hydrological Soil Group), LU (Land Use) and AMC (Antecedent Soil Moisture Conditions). Hence, estimation of rainfall-runoff for different combinations of land use/land cover, soil groups and antecedent moisture conditions class are estimated by following the procedure of SCS-CN method.

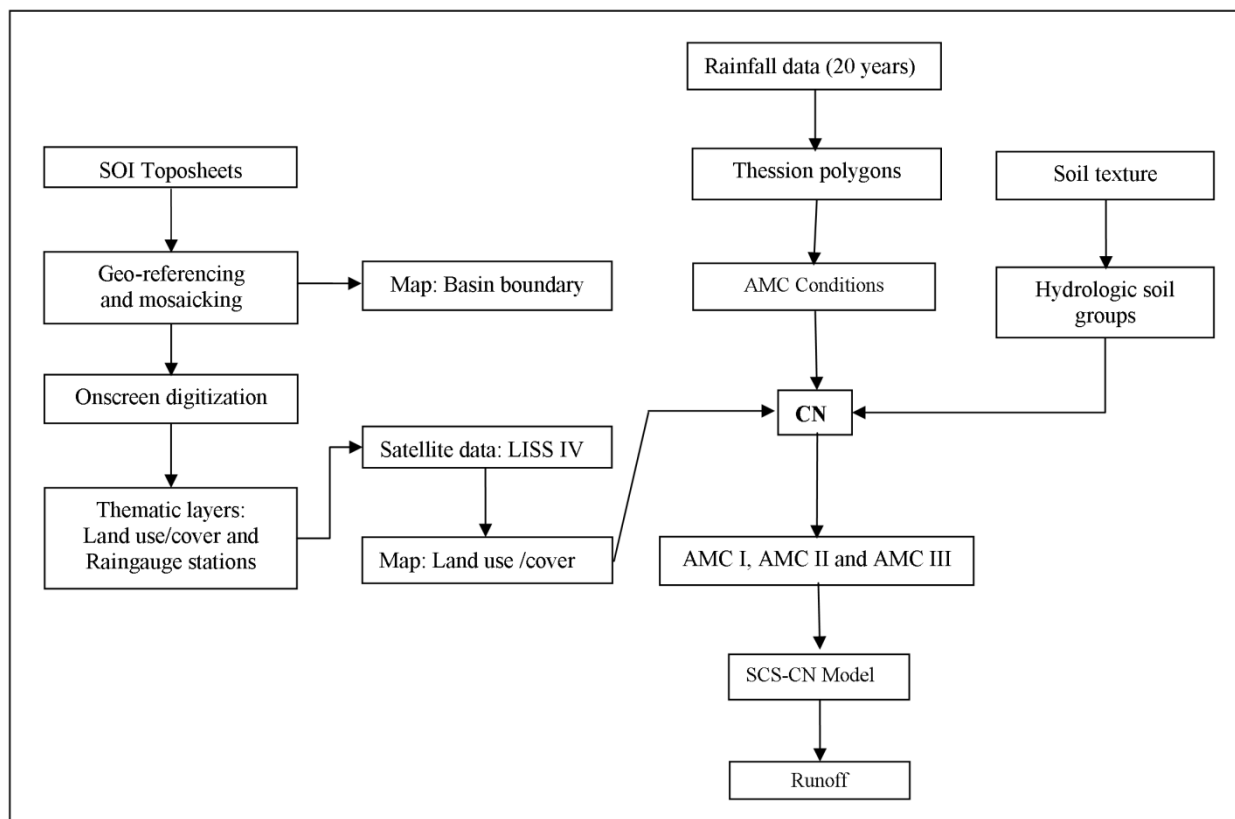


Figure 2. Methodology

Table 1. Antecedent soil moisture conditions (AMC) classification and the corresponding curve numbers.

AMC	Soil characteristics	5-Days antecedent rainfall (mm)	
		Non-growing season	Growing season
I	Wet condition	<12.7	<35.6
II	Average condition	12.7–27.9	35.6–53.3
III	Heavy rainfalls	>27.9	>53.3

Table 2. Soil classification

Type of soil	Area in km ²	Percentage (%)
Gravelly clay soils	706.5	48.2
Gravelly loam soil with stony surface	519.5	35.4
Gravelly loam soil with very low AWC	11.0	0.8
Gravelly loam soils	26.1	1.8
Loamy soils	201.7	13.8
Total	1464.9	100.0

3.1 Assessment of Surface Runoff

The SCS-CN (1985) method had built up in 1954 by the USDA SCS (Rallison, 1980), characterized in the SCS by National Engineering Handbook (NEH-4) Section of Hydrology (Ponce and Hawkins, 1996). The SCS & CN approach depends on the water equilibrium calculation and two fundamental and two key assumptions had been proposed (Jun et al., 2015). The main proposal states about that the proportion of the real quantity of direct runoff to the maximum possible runoff is equivalent to the proportion of the ratio of the amount of real infiltration to the quantity of the potential maximum retention. The second assumption expresses that the amount of early abstraction is some fraction of the probable maximum retention. Often, the SCS-CN approach is used for experimental strategies to estimate the direct surface runoff from a watershed. The infiltration losses are combined with surface storage by the relation of surface storage, interception, and infiltration prior to runoff in the watershed.

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad (1)$$

The empirical relation was developed for the term I_a and it is given by, the empirical relationship is,

$$I_a = 0.3 S \quad (2)$$

Where,

Q = Runoff in mm

P = Rainfall in mm,

I_a = Initial abstraction in mm

For Indian condition, the form S in the potential maximum retention and it is given as follows,

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

Here

CN = Curve number

It can be taken from SCS Handbook of Hydrology (NEH-4), section-4 (USDA, 1972). The formula can be rewritten as,

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \quad (4)$$

Where

Q= Actual direct runoff in mm

P= Precipitation in mm

S= Potential maximum retention of water by soil

The runoff value is calculated by using the equations (3) and (4).

4 RESULT AND DISCUSSION

The potential maximum retention parameter (S) is various in spatially, due to land use changes in slope and soils and temporally because of changes in soil water content. For convenience in assessing antecedent rainfall, soil conditions, land use and conservation practices (Rao et al., 2010). As per the US-SCS soils are divided into four HSG such as A, B, C and D according to the rate of runoff and infiltration competence.

4.1 Land Use/Land Cover

Geo-referenced and rectified LISS IV satellite images were classified according to the NRSC (2006). Visual interpretation techniques have been used for classification of the land use/land cover phenomena which take into concern various image properties such as, color, tone, texture, size, shape, association and pattern. After classification field checking with GPS has carried out in the doubtful areas. The various land use and land cover classes interpreted broadly in the study area include, agricultural land, builtup land, forest area, river/stream, wastelands and water bodies. Figure 3 is showing the detailed Land use and Land cover map. Topography of watershed is mostly plain land and partly hills and steep slopes.

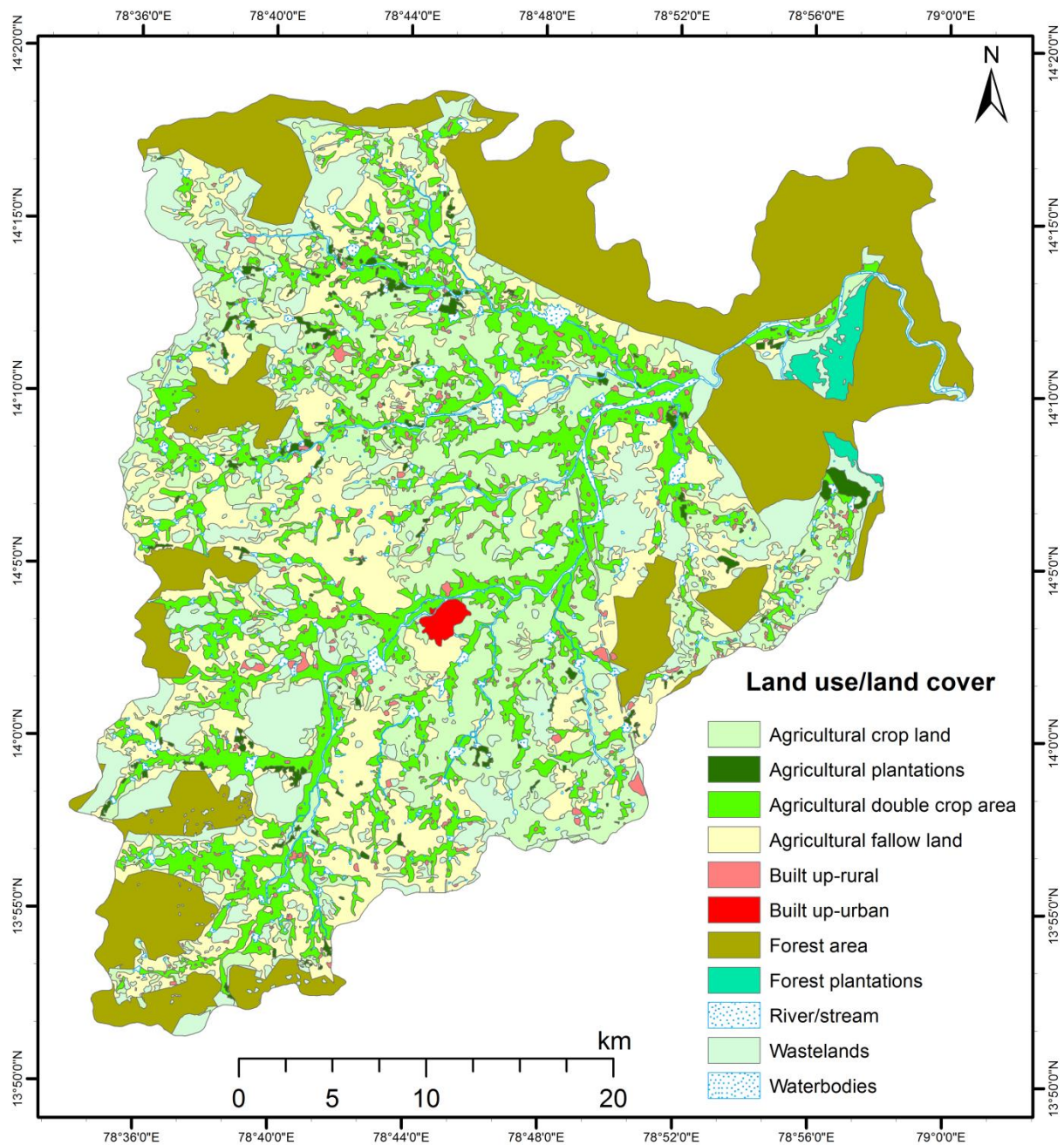


Figure 3. Land use/land cover

4.2 Antecedent Moisture Condition (AMC)

It is measured when little prior precipitation and high when there has been significant earlier rainfall to the modeled rainfall event. For modeling purposes, AMC II in the watershed is mostly a normal moisture condition. Runoff curve numbers from LU/LC (Figure 3) and soil type (Figure 4; Table 2) engaged for the normal

condition (AMC II) and dry conditions (AMC I) or wet condition (AMC III), related CN can be processed with the aid of the accompanying equations 5 and 6.

The CN values recognized in the case of AMC-II (USDA, 1986) (Table 1). The accompanying equations are used in the cases of AMC-I and AMC-III (Satheeshkumar et al., 2017).

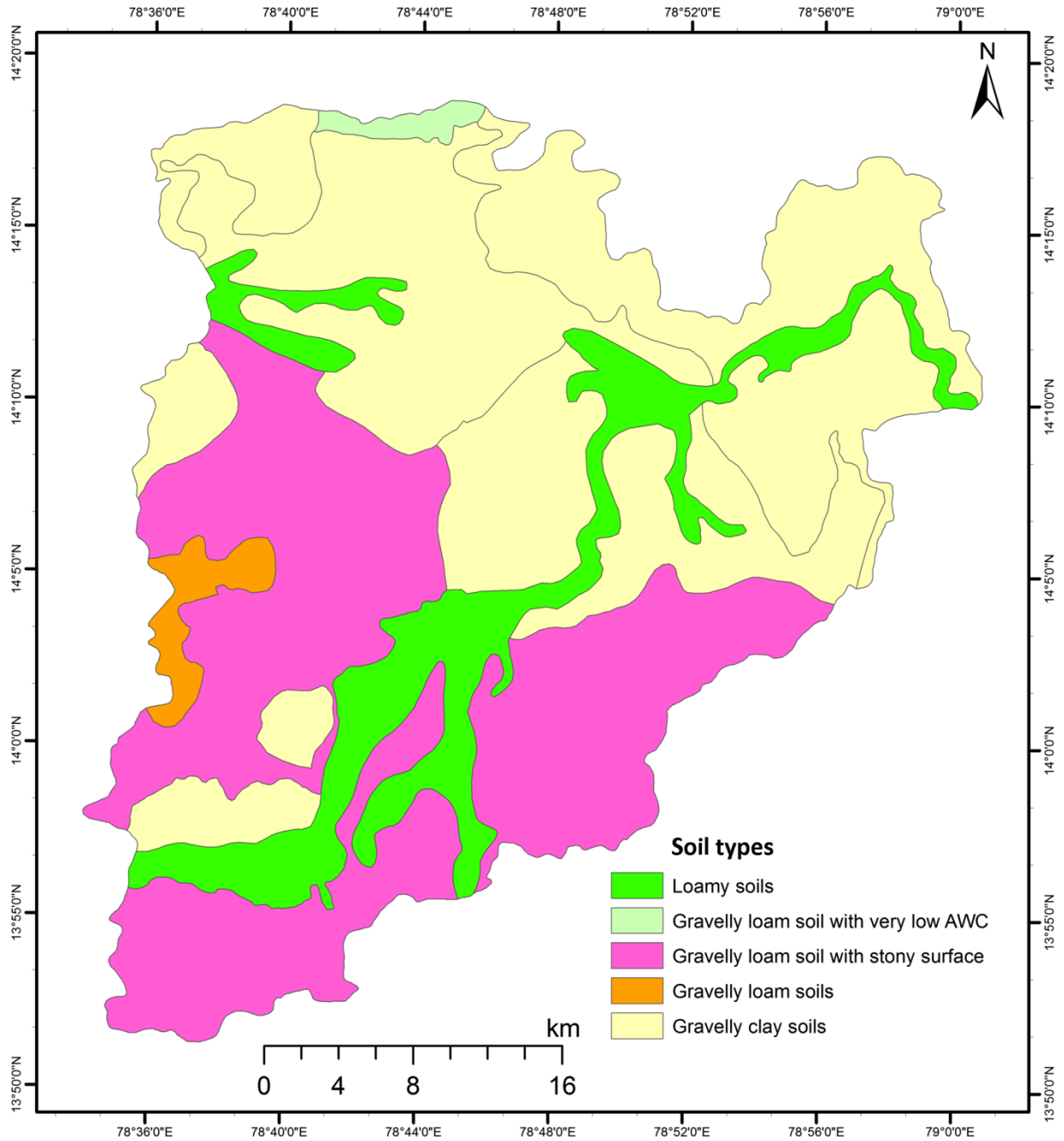


Figure 4. Soil map of the Mandavi basin

$$CN(I) = \frac{CN(II)}{2.281 + 0.0128 CN(II)} \quad (5)$$

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

Where, CN (II) = Curve number for normal condition,
 CN (I) = Curve number for dry condition,
 CN (III) = Curve number for wet conditions.

$$CN_w = \sum CN_i * A_i / A \quad (7)$$

Where,

CN_w = Weighted curve number;
 CN_i = Curve number from 1 to any number, N;
 A_i = Area with curve number, CN_i

A = Total area of the watershed.

When runoff starts, the potential maximum retention (S) is found from the equation (3).

To compute the surface runoff depth, apply the hydrological equations from (3) to (4). These equations are depending on the value of rainfall (P) and watershed storage (S) which are calculated from the familiar curve number. Therefore, before applying equation (3) the value of (S) must be determined for every antecedent moisture condition (AMC) as mentioned below. There are three conditions to hydrologic condition results are summarized in Table 3.

Table 3. Classification of hydrologic soil group

HSG	Area	
	Km ²	%
B	732.32	49.99
C	732.63	50.01
Total	1464.95	100

Table 4. Hydrologic calculations

AMC	Formula	CN
AMCI	$CNI=4.2*CNII/10-(0.058*CNII)$	31.506
AMCII	$S=25000/CN \text{ (waited)}-254$	52.292
AMCIII	$CNIII=23*CNII/10+(0.13*CNII)$	71.583

Table 5. Slope classification

Slope	Area		Runoff potential
	Km ²	%	
Level to nearly level	121.39	8.28	Low surface runoff
Very gentle	652.70	44.55	Low surface runoff
Gentle	272.18	18.58	Low to medium surface runoff
Moderate	168.02	11.47	Medium surface runoff
Moderately steep	73.21	5.00	Moderate to high surface runoff
Steep	145.24	9.91	High runoff
Very steep	32.12	2.19	Very high runoff

4.3 Hydrologic Soil Group (HSG)

Soil texture map is getting from FAO and it was projected, geo-referenced and digitized in ArcGIS environment. Soil texture map is represented in [figure 4 \(table 3\)](#) with B and C hydrologic soil groups (HSG) are

recognized in [figure 5](#). The soils of group B indicated moderate infiltration rate, moderately well drained to well drained. The soils of group C pointed to moderately fine to moderately rough textures, moderate rate of water transmission ([Table 3](#)).

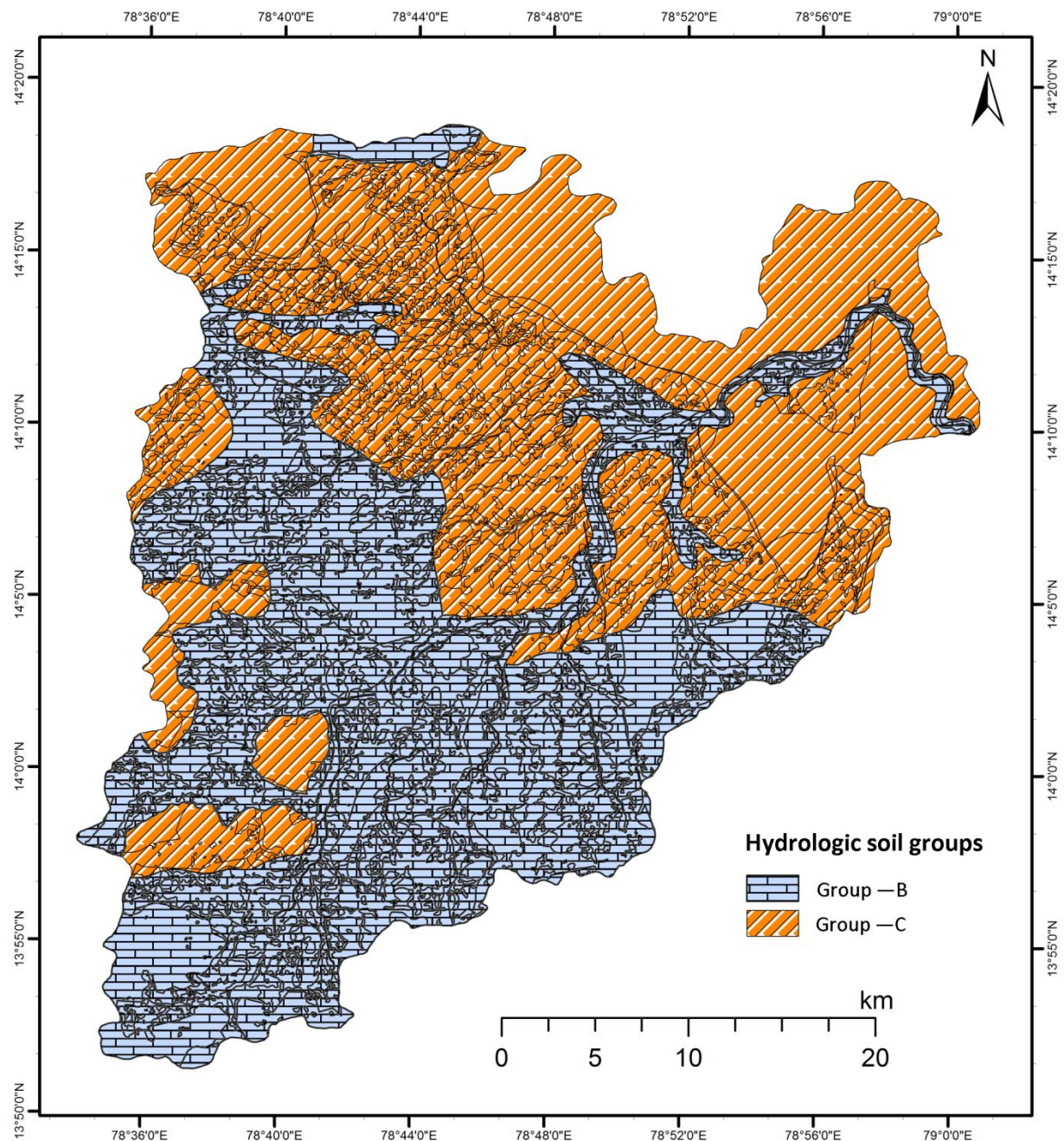


Figure 5. Hydrologic Soil Groups

4.4 Thiessen or Voronoi Polygon Method

Alfred H. Thiessen (1911), an American meteorologist introduced Thiessen polygons/Voronoi polygons in practical application, for example, regional rainfall averages. According to him any location in a Thiessen polygon is closer to the corresponding point inside it than to any other member of the point set (Yamada, 2017). Nearest neighbor methods are rigorously analyzed by pattern recognition procedures. Despite

their inherent simplicity, nearest neighbor algorithms are considered versatile and robust. Even though more sophisticated substitute methods have been developed since their inception, nearest neighbor methods remain very popular (Ly et al., 2013). Thiessen polygons with raingauge stations presented in figure 6. The application of raingauge as rainfall input conveys lots of vulnerabilities. The temporal and spatial distributions of precipitation at basin scale within the GIS environment are found to be extremely powerful in the study area.

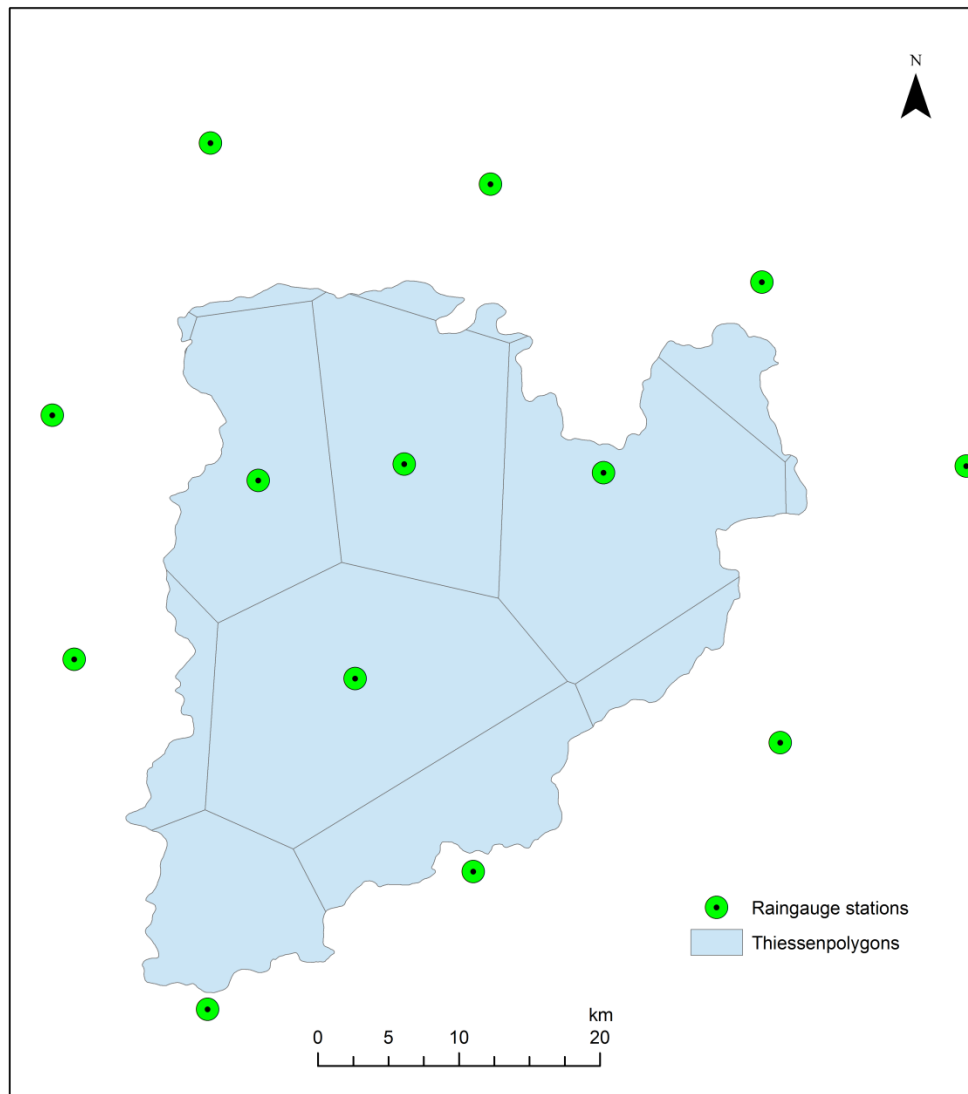


Figure 6. Thiessen polygons with raingauge stations

4.5 Rainfall-Runoff of Mandavi Basin

Mandavi basin falls under nearly level to very steep slope class (low to high surface runoff) representative water holding for a longer time and therefore improving the possibility of infiltration and recharge in this study area. This is a suitable site for artificial recharge structures, for example, minor and major check dams and percolation tanks adjacent to drainage network. Slope classification is given in [table 5](#). In the present work, two type of soil erosion is observed, first one is sheet erosion and another one is stabilized dunes ([figure 8](#)).

By applying the SCS-CN method the overall study results are as follows average annual surface runoff depth for the last twenty years in Mandavi basin is 10262.546 mm, with this value is multiplied by the area of the watershed ($A = 1464940000 \text{ sqm}$) gives the total average volume of runoff as 700326772 m^3 .

$$\begin{aligned} \text{Total average volume of runoff} &= \\ \text{Average annual surface runoff depth} * \\ \text{Area of watershed} & \quad (8) \end{aligned}$$

The land use categories, Hydrologic soil group and curve numbers are represented in [table 6](#). The calculated normal, wet and dry conditions, curve numbers are 31.506, 52.292 and 71.583 ([Table 4](#)). The present study reveals that the rainfall from 1995 to 2014 is varying between 340 to 1008mm similarly runoff is 229 to 706mm. [Figure 9](#) is showing the relationship between rainfall and runoff. The twenty years average annual runoff and runoff volume are 478.06 mm and 699.75 mm^3 , respectively. Rainfall and runoff values are strongly correlated to runoff coefficient (r) value being 0.69. Annual average rainfall, runoff depth, runoff volume and runoff coefficient of the study area is given in [table 7](#).

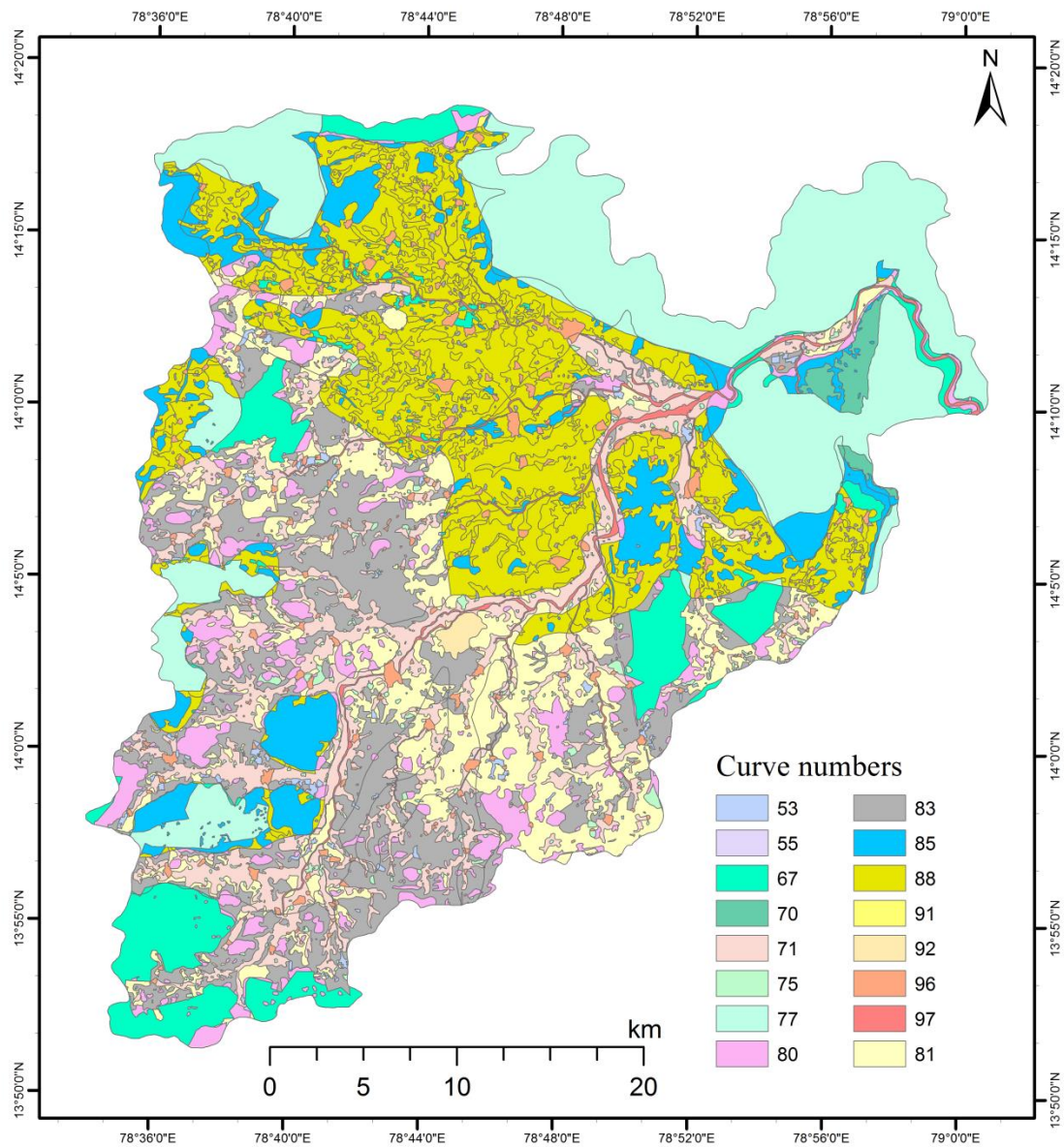


Figure 7. Curve numbers

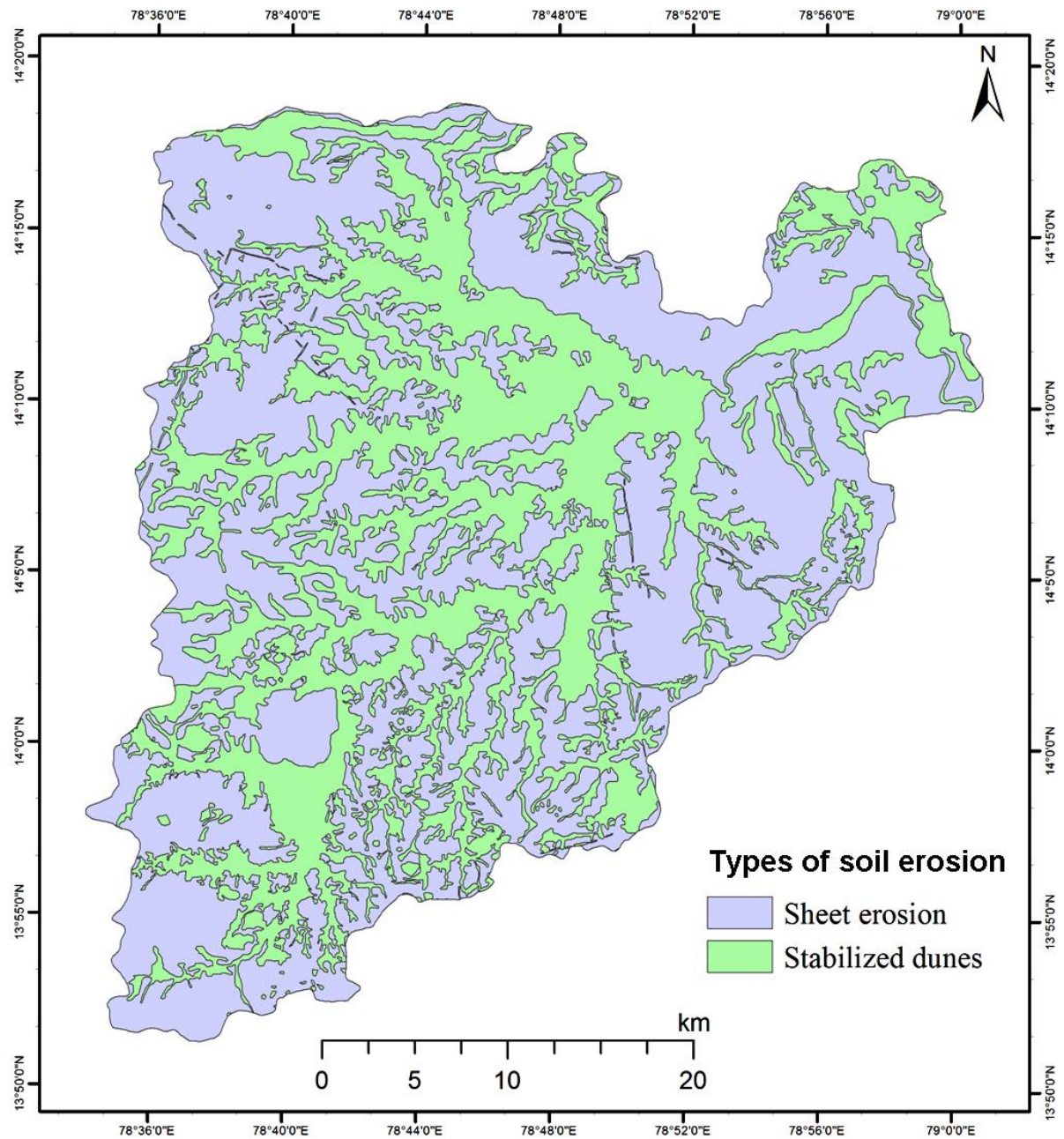


Figure 8. Soil erosion

Table 6. Distribution of curve numbers, land use categories and hydrologic soil group.

Land Use	HSC	CN	Area	CN*A
Agricultural crop land	B	91	164.60	14978.59
	C	88	126.54	11135.33
		Total	291.14	26113.92
Agricultural double crop area	B	71	145.94	10361.39
	C	88	82.51	7260.48
		Total	228.44	17621.87
Agricultural fallow land	B	83	196.25	16288.63
	C	88	101.46	8928.24
		Total	297.71	25216.87
Agricultural plantations	B	53	9.10	482.51
	C	67	7.81	523.41
		Total	16.92	1005.91
Built up rural	B	75	12.77	957.50
	C	83	5.52	458.11
		Total	18.29	1415.62
Built up urban	B	92	3.63	334.26
		Total	3.63	334.26
Forest area	B	67	91.72	6144.98
	C	77	272.56	20986.75
		Total	364.27	27131.73
Forest plantations	B	55	0.19	10.18
	C	70	11.58	810.36
		Total	11.76	820.54
River/stream(Dry)	B	97	12.81	1242.11
	C	97	3.55	344.30
		Total	16.35	1586.41
Wastelands	B	80	79.57	6365.56
	C	85	106.67	9066.79
		Total	186.24	15432.35
Water bodies	B	96	15.75	1512.44
	C	96	14.45	1387.03
		Total	30.20	2899.46

Table 7. Annual average rainfall, runoff depth, runoff volume and runoff coefficient.

Year	Rainfall in mm	Runoff(Q) in mm	Volume(mm3)= Runoff*Area/1000	Runoff Coefficient= Q Runoff / P Rainfall (cm)
2014	340	229	334.94	0.68
2013	748	520	761.29	0.70
2012	543	374	546.77	0.69
2011	565	389	569.78	0.69
2010	922	644	943.27	0.70
2009	598	413	604.24	0.69
2008	646	447	654.79	0.69
2007	1008	706	1033.73	0.70
2006	528	363	531.18	0.69
2005	975	683	999.37	0.70
2004	704	489	715.98	0.69
2003	575	397	580.98	0.69
2002	412	280	410.00	0.68
2001	922	644	943.19	0.70
2000	690	479	700.49	0.69
1999	421	287	420.18	0.68
1998	761	530	775.60	0.70
1997	712	495	724.08	0.70
1996	962	673	985.16	0.70
1995	747	519	760.13	0.70
Average	688.82	478.06	699.75	0.69

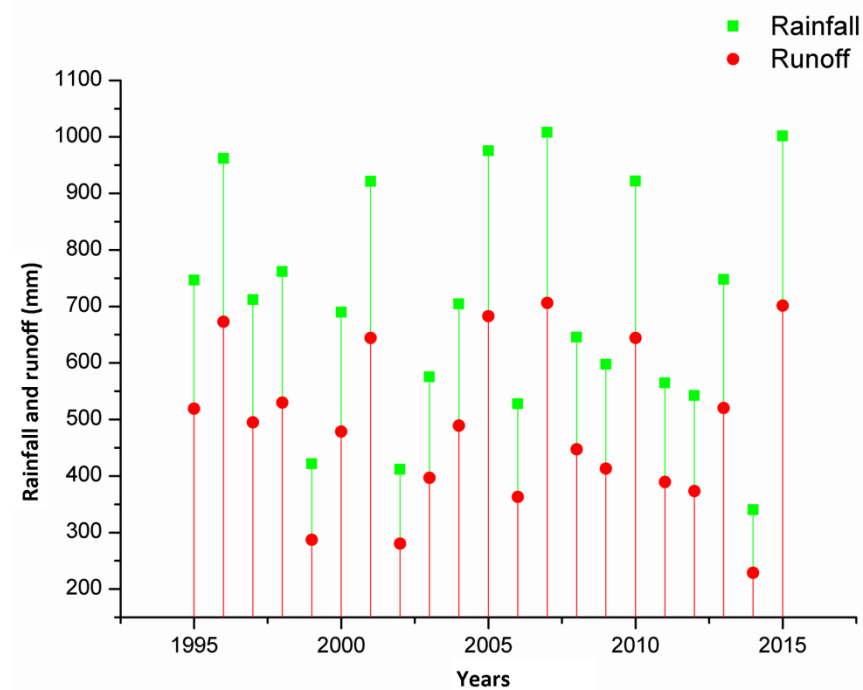


Figure 9. Rainfall and runoff

5 CONCLUSION

Integrated RS, GIS and SCS-CN method is proved as an efficient method in estimation of rainfall-runoff. Estimation of Surface rainfall-runoff is essential for conservation and management of water resource in drought-prone areas for sustainable water resource management. In this study, hydrological soil group map is getting through the amalgamation of land use and cover, and soil maps in ArcGIS environment. The weighted CN is resolute based on AMC-II with a combination of HSG and land use/land cover categories. After analysis, it is concluded that the annual rainfall-runoff association throughout the years from 1995 to 2014, it is represented that the overall increase in a runoff with the rainfall. The outcome of work showed 52.292(CNII) of normal condition, of dry condition 31.506(CNI) and of wet condition 71.583, respectively. The ungauged watershed exhibits an annual average of 20 years of rainfall, runoff, runoff volume and runoff coefficients are 688.82mm, 478.06mm, 699.75m³ and 0.69, respectively (Table 7). Due to its simplicity, its predictability, stability, its reliance on only one parameter and its responsiveness to major runoff-producing watershed properties (soil type, land use, surface condition, and antecedent condition) SCS and CN method have been used for runoff assessment in the Mandavi basin. According to the Mockus (1964) the SCS-CN method does not contain any expression for a time and ignores the impact of rainfall intensity and its temporal distribution. The predictable hydrological data are usually not available for the purpose of the design and operation of water resources systems at the watershed level. In such cases, RS and GIS are suitable techniques for the determination of run-off, river catchment characteristics, such as land use/land cover, slope, etc. The combination of RS and GIS and SCS model makes the run-off estimation more accurate and also fast.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ABBREVIATIONS

AMC: Antecedent Moisture Condition; **AGNPS:** Agricultural Non-point Source; **CN:** Curve Number; **CREAMS:** Chemicals Runoff and Erosion from Agricultural Management System; **EPIC:** Environmental Policy Integrated Climate; **FAO:** Food and Agriculture Organization; **HSG:** Hydrological Soil Group; **MSL:** Mean Sea Level; **NEH:** National Engineering Handbook; **NRCS:** Natural Resources Conservation Service; **SCS:** Soil Conservation Service; **SCS-CN:** Soil Conservation Service-Curve Number;

SRTM: Shuttle Radar Topography Mission; **SWAT:** Soil and Water Assessment Tool; **US-SCS:** United States Soil Conservation Service.

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