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Full Length Research Article

Estimation of Surface Runoff Using Soil Conservation Service (SCS) and Curve Number (CN) Model in Chikkabalapura Taluk: An Eastern Dry Agro-Climatic Zone of Karnataka

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Abstract

Runoff is one of the most important hydrological variables used in most of the land and water resources applications. The determination of surface runoff at micro level is essential to address soil and water conservation practices in a watershed. Understanding the basic relationships between rainfall, runoff and soil loss are studied for effective management and utilization of water resources and soil conservation service. Curve Number (CN) method is mainly used for estimating infiltration characteristics of the watershed, based on the land use property and soil property. The study area chosen is Chikkaballapur taluk. The study area geographically lies between latitude 13° 20'10.7" and 13° 39'59.4" and east longitude 77° 36'04.7" and 77° 52'20.2" with an area of 634.8 km^2. In the present study, an attempt has been made to estimate the surface runoff using SCS-CN method. The curve number depends upon soil and land use characteristics. Hydrological soil group (HSG), land use / land cover Map, Soil and multi spectral remote sensing data are used for the analysis. Hence remote sensing and GIS techniques have been used. These details are useful to identifying runoff potential in study area and developing appropriate soil and water conservation structures.

Key words: Rainfall, Runoff, GIS technology, SCN-CN method, Curve number

Water is one of the most important natural resources and a key element in the socio-economic development of a State and Country. Water influences every sphere of the environment supporting life on earth. Its varying availability in time and space is a matter of concern to the mankind since fresh water is not an ever-present resource. Water resources of the world in general and in India are under heavy stress due to increased demand and limitation of available quantity. Proper water management is the only option that ensures a squeezed gap between the demand and supply. Sustainable water management of a river basin is required to ensure a long-term stable and flexible water supply to meet crop water demands as well as growing municipal and industrial water demands [1].

Water resources management requires a systems approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components. Human modifications of the environment, including land cover change, irrigation, and flow regulation, now occur on scales that significantly affect seasonal and yearly hydrologic variations. A thorough knowledge and understanding of the different hydrological phenomena and hydrological cycle as a whole is required in studying the implications of these changes [2].

Rainfall is the major component of the hydrologic cycle and is the primary source of runoff. It is implicit that the rainfall is a natural phenomenon occurring due to atmospheric and oceanic circulation (local convection, frontal or orographic pattern) and has large variability at different spatial and temporal scales. However, this input is subjected to uncertainty and stochastic errors [3-4]. Worldwide many attempts have been made to model and predict rainfall behaviour using various empirical, statistical, numerical and deterministic techniques [5-13]. They are still in research stage and needs more focused empirical approaches to estimate and predict rainfall accurately. However, the application of a single rain gauge as precipitation input carries lots of uncertainties regarding estimation of runoff [14-15]. This creates a lot of problem for the discharge prediction, especially if the rain gauge is located outside the basin [16]. Many researchers have demonstrated that potential retention from rainfall and runoff data has variable components and is not a constant for a watershed and varies with rainfall. Therefore, such studies are very important [17].

Rainfall generated runoff is very important in various activities of water resources development and management, such as flood control and its management, irrigation scheduling,

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design of irrigation and drainage works, design of hydraulic structures, hydropower generation, and so on. The method of transformation of rainfall to runoff is highly complex, dynamic, nonlinear and, exhibits temporal and spatial variability. It is further affected by many parameters and often inter-related physical factors. Determining a robust relationship between rainfall and runoff for a watershed has been one of the most important problems for agriculturists, hydrologists and engineers. Conventional methods of runoff estimation are time consuming and error prone. Thus, Remote Sensing (RS) and Geographical Information System (GIS) techniques are being used to estimate surface runoff based on different parameters [18].

MATERIALS AND METHODS

Study area

Chikkaballapura district is a newly created district, separated from the existing Kolar district, located in the southern part of Karnataka, spread across 6 Talukas - Gowribidanur, Gudibande, Begepalli, Chikkaballapur, Shidlagatta and Chintamani. District headquarter of Chikkaballapur (50 km from Bengaluru), It is a major site for grape, grain, and silk cultivation. With recent development, it is widely believed that Chikkaballapura will become part of "Greater Bengaluru". Chikballapur taluk of Chikballapur district is located between north latitude 13° 20'10.7" and 13° 39'59.4" and east longitude 77° 36'04.7" and 77° 52'20.2", and is covered in parts of Survey of India toposheet Nos. 57G/10, 57G/11, 57G/14 and 57G/15. Chikballapur taluk with adjacent taluks of Gudibanda taluk on north, Devanahalli taluk on south, Sidlaghatta taluk on east and Gauribidanur taluk on western side. Agriculture is the main occupation with major kharif crops of maize, ragi, tur and vegetables and rabi crops of ragi, maize, horse gram, groundnut, sunflower and fruits. Ragi was grown in 25% and maize was account for 11% of total crop area. Fruits and vegetables are grown in 20% of total crop area. Chikballapur taluk experiences with semiarid to arid climate, Dryness and hot weather prevails in major part of the year and falls under Eastern dry agro-climatic zone of Karnataka and is categorized as drought prone. The entire western portion of the taluk is covered with undulating to plain terrain, hills, and plateaus. The range of elevations was 249 to 911 metres above mean sea level. Three seasonal river basins, the Palar, Ponnaiyar, and Pennar, drain the taluk. Palar flows in a NW-SE direction and has its beginnings in the Ambajidurga hillocks in the Chintamani Taluk. High dendritic density characterizes the drainage. The Pennar river travels northward through parts of Chikballapur taluk after beginning in the Doddaballapura taluk in Bangalore Rural district. The North Pinakani River rises in the Chikballapur Taluk's Nandi Hills and flows north. The South Pinakani River rises in the Nandi Hills and flows through the taluks of Chikballapur and Sidlaghatta. In addition to these rivers, the 2.8 kilometre Arkavathi tributary of the Cauvery also rises in the Nandi Hills and flows into the Chiballapur Taluk. Red loamy soil to red sandy soil and lateritic soil are found in Chikballapur Taluk (Fig 1).

Data sources

The Land use/ Land cover and soil data for the study area are collected from the KSRSAC, Bangalore. The rainfall data collected from the KSNDMC, Bangalore, for a period of 33 years (1990-2022) has been checked for consistency and used for runoff estimation. (Fig 2-3) shows the land use/ land cover and soil map. (Table 1-2) shows the land use/land cover and soil classification of the study area.

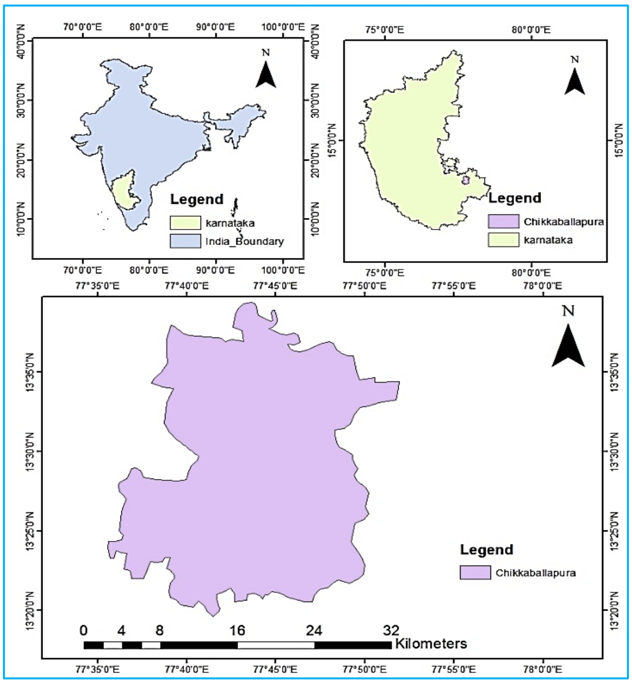


Fig 1 Location map of study area

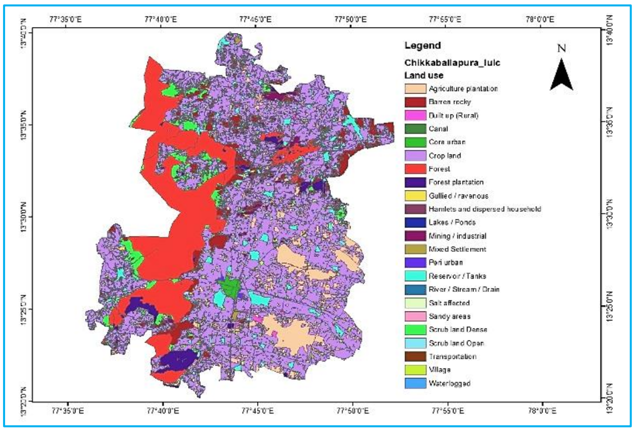


Fig 2 Land use land cover map of study area

Table 1 Land use / Land cover classification of study area

Description	Area	%Area
Agriculture plantation	58.095	9.15165
Barren rocky	35.6424	5.61471
Built up (Rural)	2.52696	0.39807
Canal	0.00638	0.00101
Core urban	2.95527	0.46554
Crop land	309.789	48.8007
Forest	114.807	18.0854
Forest plantation	15.7002	2.47323
Gullied / ravenous	1.23972	0.19529
Hamlets and dispersed household	0.92637	0.14593
Lakes / ponds	0.0999	0.01574
Mining / industrial	11.5076	1.81279
Mixed settlement	0.80707	0.12714
Peri urban	0.81102	0.12776
Reservoir / tanks	17.8521	2.81223
River / Stream / Drain	3.41899	0.53859
Salt affected	1.4386	0.22662
Sandy areas	0.7268	0.11449
Scrub land dense	23.812	3.75108
Scrub land open	17.2165	2.71209
Transportation	3.83846	0.60467
Village	11.3759	1.79203
Waterlogged	0.21122	0.03327
Total	634.804	100

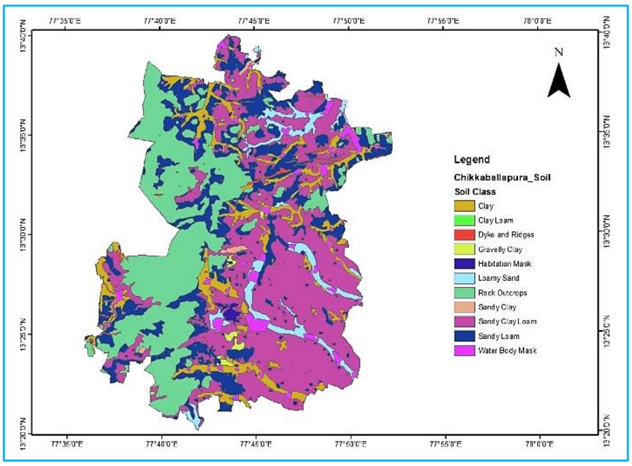


Fig 3 Soil map of study area

Table 2 Soil classification of study area

Description	Area	%Area
Clay	60.208	9.485
Clay Loam	0.125	0.020
Dyke and Ridges	3.437	0.541
Gravelly Clay	2.164	0.341
Habitation Mask	8.318	1.310
Loamy Sand	25.532	4.022
Rock Outcrops	161.611	25.458
Sandy Clay	2.141	0.337
Sandy Clay Loam	228.916	36.061
Sandy Loam	122.028	19.223
Water Body Mask	20.322	3.201
Total	634.802	

Runoff due to rainfall is very significant for drawing any hydrologic structure, forecasting floods which are very sudden, flashy and of short duration and acquiring quick suggestion for solution [19].

Soil Conservation Service (SCS) and Curve Number (CN) model is used for surface runoff estimation. The advantage of the SCS-CN method is, it is a simple conceptual method for predicting direct surface runoff from a storm rainfall amount, and is well supported by empirical data and wide experience, it is easy to apply and useful for ungauged watersheds, the method relies on only one parameter CN, and the parameter CN is a function of the watershed characteristics and, hence the method exhibits responsiveness to major runoff-producing watershed characteristics [20].

RS and GIS techniques lend to estimate surface runoff based on different parameters. Different parameters, namely the land use/land cover, hydrological soil characteristics, rainfall data (P), Potential Maximum Retention (S), Antecedent Moisture Condition (AMC), Weighted Curve Number (CN), that are the mandatory inputs to SCS model. (Fig 4) shows the methodology of SCS-CN model.

SCS-CN method

The SCS-CN method also known as the Hydrologic Soil Cover Complex Method is developed in 1954 by the USDA Soil Conservation Service [19], and is described in the Soil Conservation Service (SCS) National Engineering Handbook Section 4: Hydrology, for use in rural areas. It is a versatile and widely used procedure for runoff estimation. The requirements for this method are low rainfall amount and curve number. The curve number is based on the areas hydrologic soil group, land use characteristics and hydrologic condition [20].

The SCS- CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention. The second hypothesis states that the amount of initial abstraction is some fraction of the potential maximum retention [21].

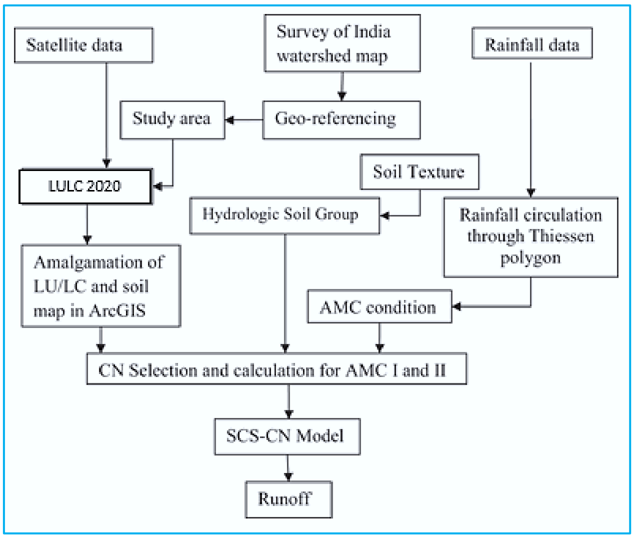


Fig 4 Flow chart for runoff estimation using SCS-CN method

Water balance equation:

$$P = I_a + F + Q \quad \text{……….} (1)$$

Where; P (mm) is rainfall,

I_a(mm) is initial abstraction,

F (mm) is cumulative infiltration; it does not include I_a,

Q (mm) is direct runoff.

The equal proportions assumption can be described as the ratio of runoff and rainfall equals to the ratio of cumulative infiltration and the potential maximum retention. And the equation can be expressed as follows:

$$\frac{Q}{P-I_a} = \frac{F}{S} \quad \text{……….} (2)$$

Where; S is the potential maximum retention (mm) after runoff begins.

The initial abstraction assumption which shows the relation between initial abstraction and the potential maximum retention **S** can be expressed as follows:

$$I_a = \lambda S \text{……….} (3)$$

where $\boldsymbol{\lambda}$ is regional parameter, it depends on the geographic and climatic factors.

According to the Eq. (1) and Eq. (2), the SCS model could be expressed in its general form as follows:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad \text{………} (4)$$

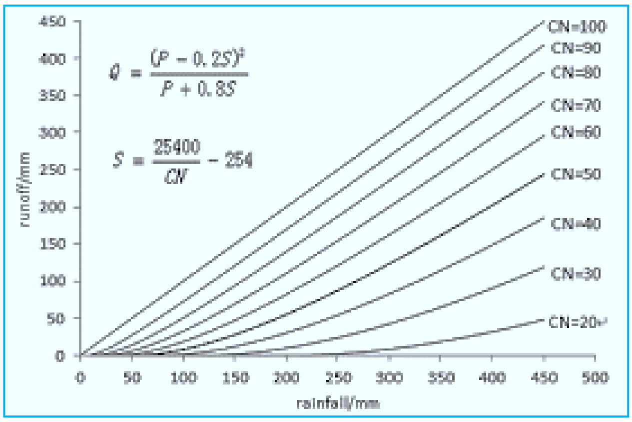
The SCS-CN model originally estimated the initial abstraction as a constant 20% of the maximum potential retention (S), based on available rainfall-runoff measurements in 1954. When $\boldsymbol{\lambda}$ is set to 0.2, the Eq. (4) becomes the well-known original SCS-CN model as below:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{……} (5) \quad \text{For P>0.2S, else Q=0.}$$

According to the Eq. (5), the relationship graph between them when CN is in different values as shown in (Fig 5).

In order to calculate S the Curve Number is cited. The empirical relationship between S and CN is:

$$S = \frac{25400}{CN} - 254 \quad \text{…………….} (6)$$



Source: Rao *et al.* [22]

Fig 5 Relationship between runoff and rainfall

CN = values determination

A. *Hydrological soil group*: The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting [23].

There are mainly four hydrologic soil groups. Namely,

Group A: The soils have low run off potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep well to excessively drained sands or gravels. Sand, loamy sand or sandy loam belong to this group and infiltration rate is greater than 8-12 mm/hr when wet.

Group B: The soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately well-to-well drained soils with moderately fine to moderately coarse textures. Silt loam or loamy soil enter to this group and infiltration rate is 4-8 mm/hr when wet.

Group C: The soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes down ward movement of water and soils with moderately fine to fine texture. Sandy clay loam enter in this group and infiltration rate is 1 -4 mm/hr.

Group D: The soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist mainly of Clay loam, silt clay loam, sandy clay and silty clay or clay belong to this group and infiltration rate is 0 to 1.0 mm/hr [24].

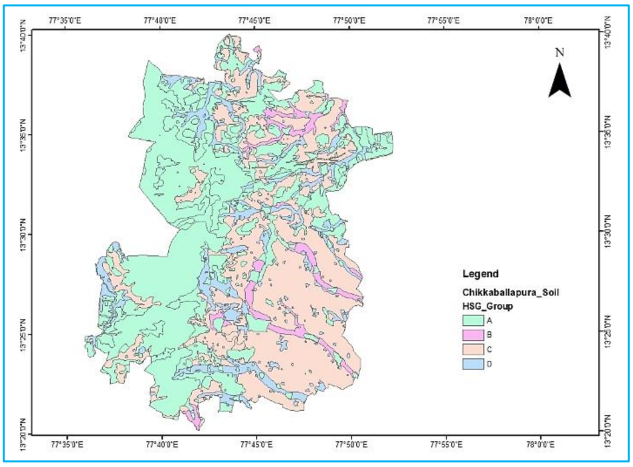


Fig 6 Hydrologic soil group of study area

(Fig 6) shows the HSG classification of study area. When the Hydrologic soil groups are determined, the CN II values can be obtained through National Engineering Handbook integrated with the vegetation, land use and hydrologic conditions. Data depicted in (Table 3) shows the curve numbers based on hydrological soil group and land use/land cover classification.

Table 3 Curve numbers assigned for different land use / land cover and soil types

Land cover	Hydrologic soil group			
	A	B	C	D
Agriculture plantation	45	56	67	72
Barren land	45	66	77	83
Crop land	72	81	88	91
Fallow land	77	86	91	94
Industrial area	81	88	91	93
Habitation with vegetation	57	72	81	86
Lake / Tanks	100	100	100	100
Land with scrub	36	60	73	79
Land without scrub	45	66	77	83
Industrial waste land	71	87	89	91
Mixed vegetation	62	71	88	91
Prosophys Juliflora	61	70	74	78
River / Stream	97	97	97	97
River island	100	100	100	100
Salt affected land	76	86	94	94
Sandy area	76	86	94	94
Town / Cities	80	85	90	95
Tree groves	36	60	73	79
Village	72	82	87	91

Antecedent soil moisture

Antecedent Moisture Condition (AMC) is an indicator of watershed wetness and availability of soil moisture storage prior to a storm. Recognizing its significance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall in the 5-day period preceding a storm [25].

Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. The appropriate moisture group AMC I, AMC II and AMC III is based on a five-day antecedent rainfall amount and season category (Dormant and Growing seasons, NEH-4, 1964). Different AMC class limits are provided for the dormant and growing seasons based on five-day antecedent precipitation. Generally, December to June is taken as the dormant season and the remaining period of the year July to November as the growing season. Data in (Table 4) shows the seasonal rainfall units for the AMC classification and curve number. The formula of API is: $API = \sum_{i=1}^{5} P_i$……..... (7)
where P_i is the rainfall amount.

Table 4 Classification of antecedent moisture condition

Antecedent moisture condition (AMC)	5 days antecedent rainfall (mm)	
	Dormant season	Growing season
I	<12.7mm	<35.56mm
II	12.7–27.94mm	35.56–53.34mm
III	>27.94mm	>53.34mm

The CN values in normal wetness conditions can be determined through NEH integrated with other conditions, such as land use and hydrologic conditions. The values of other two AMC levels can be got according to the conversion formulas as shown below

$$CN_1 = \frac{CN_2}{2.281 - 0.01281 CN_2} \quad \text{……………} (8)$$

$$CN_3 = \frac{CN_2}{0.427 + 0.00573 CN_2} \quad \text{…………...} (9)$$

When the CN values are determined, the runoff estimation can be made combined with given rainfall account.

Data in (Table 5) shows the weighted curve number obtained for the study area and (Fig 7) shows the curve number map of study area.

Table 5 Weighted curve number for study area

Watershed	Area (km^2)	CN I	CN II	CN III
Chikkaballapura	634.80	65	81	91

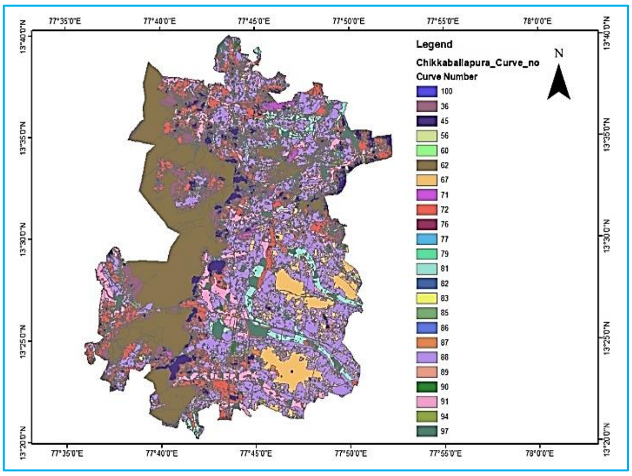


Fig 7 Curve number map of study area

(Fig 8) shows the rain gauge influencing the study area and the corresponding rainfall data has been used for estimation of runoff and (Fig 9) shows the contribution of each rainfall station for runoff in study area.

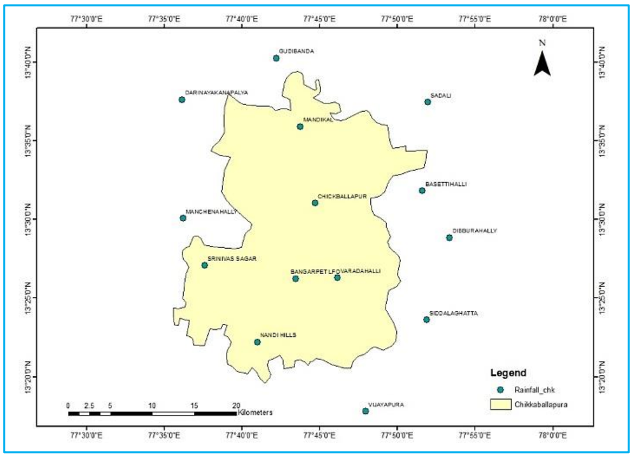


Fig 8 Rainfall station which has influence on study area

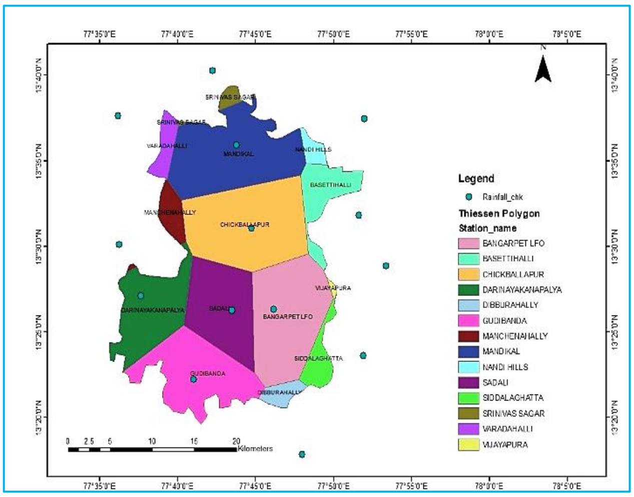


Fig 9 Thiessen polygon map of the study area

Data depicted in (Table 6-7) shows Thiessen weight and area of influence Rainfall, runoff estimated using SCS-CN of the study area. (Fig 10) shows the runoff distribution in study area.

Table 6 Thiessen weight of each rain gauge station

Rain gauge station	Area of influence (km^2)	Thiessen_wt
Chickballapur	114.568	0.180
Manchenahally	14.370	0.023
Darinayakanapalya	12.777	0.020
Gudibanda	5.061	0.008
Sadali	7.009	0.011
Dibburahally	1.027	0.002
Basettihalli	31.361	0.049
Siddalaghatta	15.731	0.025
Vijayapura	9.702	0.015
Bangarpet Lfo	70.650	0.111
Nandi Hills	79.282	0.125
Srinivas Sagar	65.689	0.103
Varadahalli	98.633	0.155
Mandikal	108.952	0.172
Total	634.809	

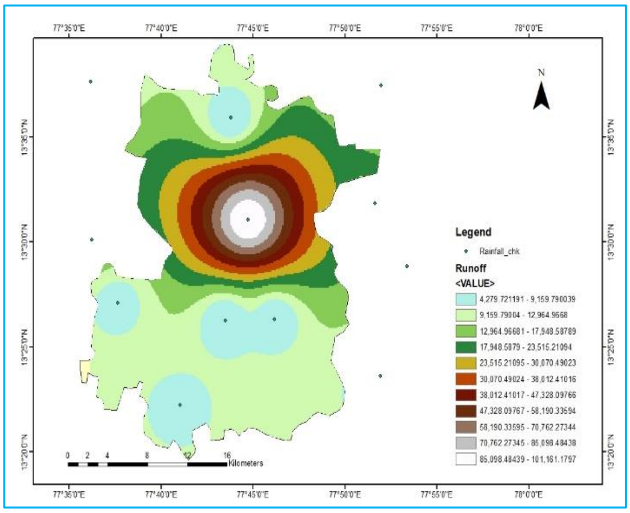


Fig 10 Runoff distribution in study area

CONCLUSION

Understanding the basic relationships between rainfall and runoff have significance for effective management and utilization of water resources and soil conservation service. In SCN-CN method, Antecedent moisture condition of the soil plays a very consequential role because the CN number varies according to the soil and that is considered while estimating runoff depth. It is observed that all four Hydrological Soil Groups (A, B, C, D) were found to be in the study area. Most part of the study area is covered by Group B soil which has moderate infiltration rate. It is concluded that SCS-CN method is a simple conceptual method for predicting direct surface runoff from rainfall and is well supported by empirical data. This method relies on only one parameter CN. The parameter CN is a function of the watershed characteristics and hence this method exhibits responsiveness to major runoff- producing watershed characteristics. It is observed that variability of CN is also due to the effect of spatial variability of storm, watershed properties and temporal variability of storm, i.e., storm intensity, quantity of measured data, antecedent rainfall and associated soil moisture. Use of RS and GIS techniques in the analysis helps to determine hydrological behavior and physiographic information of the basin. Based on this soil and water conservation measures need be planned and implemented in the basin for controlling runoff and soil loss. It was concluded that the runoff behavior of the study area varied with respect to the land use / land cover type, soil condition and rainfall amount. The higher the CN value, the runoff was found to be high while lower CN value accounted for lesser runoff and it was found that 28.98% of runoff occurred in the study area.

Acknowledgements

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Table 7 Rainfall-runoff of study area

RGS	Nandhi Hills		Manchenahally		Darinayakanapalya		Gudibanda		Sadali	
Year	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)
1990	6134.00	3204.36	497.50	88.33	689.80	140.67	676.20	69.95	579.70	104.17
1991	6560.00	3232.65	1186.50	317.05	756.20	115.18	477.60	130.70	484.70	116.33
1992	5510.00	2531.96	774.30	92.73	235.60	24.59	527.40	115.90	850.50	319.40
1993	6171.00	3008.29	805.30	120.86	426.10	53.51	661.90	104.15	895.10	194.01
1994	6440.00	3336.36	818.20	123.04	374.70	67.70	297.20	11.72	574.30	99.78
1995	6881.00	3480.12	982.60	305.81	476.40	98.07	754.70	359.22	362.80	69.31
1996	6180.00	3015.83	926.30	204.93	525.80	188.24	133.00	18.01	553.60	195.98
1997	5891.00	2609.27	814.20	117.66	880.80	230.67	665.90	209.29	816.20	208.47
1998	5727.00	2695.03	837.90	56.18	1025.90	157.54	674.40	183.55	558.40	53.88
1999	5652.00	2899.72	789.30	120.10	882.10	245.97	642.30	184.51	766.70	211.41
2000	6418.00	3174.03	1147.50	152.92	669.20	88.05	506.10	200.23	902.20	157.67
2001	5208.00	2477.39	569.70	47.21	815.70	139.55	636.60	111.14	888.10	260.98
2002	4900.00	2313.49	1082.40	266.00	609.30	120.18	600.80	37.84	603.90	114.97
2003	4349.00	1958.85	888.10	231.89	792.40	84.59	655.90	102.01	496.70	85.76
2004	5634.00	2695.42	1076.10	230.89	492.00	28.45	902.00	112.25	445.90	137.84
2005	6845.00	3525.12	1146.80	361.47	936.00	155.47	973.50	173.23	493.70	58.96
2006	5354.00	2708.05	838.10	86.89	771.00	105.43	3148.00	2301.11	668.00	102.03
2007	6239.00	3300.86	549.50	104.32	689.40	76.98	1508.30	413.35	114.40	0.09
2008	6364.00	3226.04	1190.30	484.12	484.90	33.92	1006.00	366.01	947.00	304.13
2009	6134.00	3204.36	395.40	68.54	1260.80	506.65	1425.20	457.97	868.70	142.73
2010	6926.00	3568.06	558.40	45.96	122.70	0.22	941.00	286.67	2418.10	2104.73
2011	6404.00	3168.81	958.10	234.41	762.20	161.03	357.00	56.16	545.40	96.60
2012	5290.00	2762.88	2709.40	2025.55	509.70	66.92	476.40	113.44	314.90	7.94
2013	6716.00	3415.95	814.60	144.75	833.90	144.16	341.80	101.62	839.40	133.34
2014	5657.00	2947.91	858.00	106.03	626.80	79.89	300.60	41.20	386.50	15.49
2015	6997.00	3624.30	4464.70	3959.90	491.60	106.36	560.30	151.90	864.10	123.87
2016	5498.00	2924.68	3298.50	2422.10	1284.50	539.25	316.30	30.46	754.40	142.62
2017	6862.00	3594.09	721.90	90.41	755.00	185.91	603.00	0.00	473.70	101.58
2018	5626.00	2901.61	4740.40	3992.27	721.60	52.86	154.00	6.93	405.20	11.06
2019	6007.00	3050.30	793.20	165.52	555.00	24.74	627.10	42.91	568.80	189.91
2020	6086.00	3188.97	654.80	71.67	733.20	198.99	850.50	322.60	811.00	149.01
2021	7409.00	3951.46	895.60	152.29	912.60	133.79	1003.40	194.19	722.00	90.47
2022	6560.00	3462.19	744.80	85.55	2713.80	2165.52	942.80	288.49	546.60	60.27
Total	200629.00	101158.41	39528.40	17077.34	24816.70	6521.04	24347.20	7298.71	22520.70	6164.80
% Runoff		50.42		43.20		26.28		29.9776		27.3739

Table 7 Rainfall-runoff of study area

RGS	Dibburahally		Basettihalli		Siddalaghatta		Vijayapura		Bangarpet LFO	
Year	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)
1990	1189.10	324.89	776.80	163.70	1165.90	312.65	837.40	111.12	713.40	158.62
1991	2531.30	2049.08	887.30	200.85	585.50	81.64	1059.10	165.06	756.80	98.34
1992	3018.70	2202.24	1023.60	94.56	951.00	128.04	874.60	190.17	769.60	213.75
1993	791.40	159.00	802.10	223.56	1342.10	349.11	1072.80	342.93	403.60	82.25
1994	1225.20	290.43	622.30	101.19	879.70	114.61	515.30	104.88	858.70	189.26
1995	1018.70	170.21	1336.50	285.27	797.30	193.91	1052.50	223.61	728.10	83.55
1996	956.90	295.73	787.60	182.92	1063.70	144.98	584.10	110.54	922.30	249.84
1997	964.70	127.50	3482.40	2708.02	655.40	48.45	904.50	176.13	897.40	67.81
1998	967.70	133.94	2925.00	2231.01	924.60	203.84	748.80	78.04	998.80	143.71
1999	954.50	217.33	1030.20	250.22	697.40	89.86	781.50	129.52	628.30	63.50
2000	2969.20	2122.04	779.50	122.34	681.80	57.76	886.30	89.19	928.30	124.72
2001	743.40	107.69	779.70	204.22	787.10	138.50	708.90	137.58	456.70	39.34

2002	1020.60	117.60	556.00	55.21	632.00	71.26	986.80	199.43	656.20	39.40
2003	791.90	112.36	859.70	106.26	955.80	189.56	792.70	138.36	773.20	157.56
2004	1210.40	352.35	833.20	219.68	766.90	86.70	1093.40	191.43	998.70	265.43
2005	722.60	89.33	920.50	189.01	933.40	176.67	732.80	125.84	564.60	99.43
2006	776.00	147.36	1175.50	318.97	856.80	142.29	1182.00	284.82	790.10	113.05
2007	746.60	136.01	3462.70	2354.28	890.80	184.55	758.50	182.19	533.80	73.08
2008	864.60	99.54	792.80	120.18	1248.20	306.97	1221.70	135.73	911.20	191.14
2009	757.40	216.27	3146.20	2254.98	583.10	26.29	1521.70	479.43	654.30	119.96
2010	642.10	54.01	839.40	185.03	1036.10	100.96	473.20	20.36	655.60	91.58
2011	1146.20	336.19	663.80	158.25	903.10	74.08	833.90	154.62	958.80	226.70
2012	801.40	143.76	847.30	270.93	674.60	150.25	475.60	3.28	847.70	148.37
2013	1198.60	432.03	1016.30	186.02	536.70	25.61	1024.30	462.68	1272.90	379.01
2014	892.70	170.71	684.60	171.60	813.90	120.91	772.70	199.48	551.80	82.23
2015	514.80	11.50	671.50	78.68	728.60	94.51	324.00	1.30	362.60	49.12
2016	1338.50	446.12	2931.60	2144.77	1758.90	763.14	1124.50	328.80	1151.90	405.38
2017	844.60	130.40	918.10	92.81	881.10	147.55	675.20	101.04	578.80	37.98
2018	1060.60	204.50	1319.40	514.67	641.50	94.38	948.50	250.91	617.40	68.57
2019	579.90	21.05	5151.00	4249.85	1002.20	189.67	659.70	135.47	299.20	0.15
2020	1081.00	195.07	757.70	116.43	365.80	43.19	746.80	89.68	342.60	0.24
2021	1203.40	290.96	968.20	164.60	490.60	12.99	830.40	138.88	596.30	154.68
2022	1239.50	383.47	1175.00	352.25	1166.00	435.09	1052.20	334.13	495.80	55.46
Total	36764.20	12290.66	44923.50	21072.32	28397.60	5299.97	28256.40	5816.64	23675.50	4273.20
% Runoff		33.43105		46.91		18.66		20.59		18.05

Table 7 Rainfall-runoff of study area

RGS	Chickballapur		Srinivas Sagar		Varadahalli		Mandikal	
Year	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)	Rainfall (mm)	Runoff (cumec)
1990	742.60	133.59	1067.40	146.96	612.90	187.78	983.00	136.79
1991	762.20	222.13	786.10	87.32	584.20	61.25	983.90	285.02
1992	1166.80	201.69	777.20	121.01	868.70	176.10	499.00	10.63
1993	638.60	96.24	933.20	185.64	856.10	141.70	772.00	247.02
1994	651.60	161.17	1197.30	350.49	622.20	166.77	308.00	0.81
1995	692.70	135.98	852.40	111.25	392.20	14.85	789.10	260.73
1996	1182.60	163.53	790.80	91.44	786.90	218.21	781.80	100.95
1997	872.60	203.89	1116.10	296.89	472.10	42.75	642.70	85.52
1998	677.90	148.22	1618.10	711.48	505.60	90.87	1794.40	714.68
1999	805.10	110.05	1283.40	337.50	877.90	276.27	955.90	151.95
2000	1145.00	187.01	782.10	152.77	928.80	165.63	649.20	169.40
2001	2922.70	2005.14	838.40	153.58	803.50	177.75	1557.10	692.48
2002	600.90	20.38	890.20	182.29	536.10	100.07	771.80	99.47
2003	908.60	141.52	1156.60	261.71	403.60	51.55	946.40	170.07
2004	1086.60	221.19	1012.60	179.15	257.60	0.23	1006.90	176.57
2005	660.90	75.99	1134.00	282.29	498.90	50.68	701.70	98.92
2006	703.50	100.18	641.70	121.27	675.40	117.40	835.60	175.60
2007	747.90	259.60	691.50	90.09	605.00	104.80	698.60	229.69
2008	714.90	128.99	764.40	125.23	1297.60	308.57	971.60	256.14
2009	968.80	211.68	711.10	327.83	742.40	94.01	527.90	137.27
2010	1124.10	239.36	1318.50	410.57	812.70	150.08	657.00	103.06
2011	1423.80	689.75	558.70	196.44	1525.40	574.94	861.20	193.19
2012	831.00	159.32	743.00	161.62	416.40	27.06	0.00	0.00
2013	754.30	118.51	1002.10	263.23	472.30	171.00	0.00	0.00
2014	967.20	247.02	357.30	55.35	696.00	119.55	0.00	0.00
2015	871.00	210.49	476.10	120.95	576.50	27.57	0.00	0.00
2016	923.10	177.01	879.60	214.72	948.00	179.59	0.00	0.00
2017	765.70	108.96	1197.20	277.88	706.40	168.18	0.00	0.00
2018	657.40	59.12	474.00	47.54	978.20	308.15	0.00	0.00
2019	515.20	11.89	764.70	162.75	624.60	120.62	0.00	0.00
2020	431.00	31.66	857.80	33.76	703.20	88.65	0.00	0.00
2021	885.20	177.43	506.00	61.28	845.20	119.76	0.00	0.00
2022	574.60	79.87	497.80	46.45	955.30	123.77	0.00	0.00
Total	29376.10	7238.54	28677.40	6368.76	23587.90	4726.18	18694.80	4495.95
% Runoff		24.64		22.21		20.04		24.05

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