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Runoff estimation using SCS-CN method for degrading lakes/tanks: a case study of Bilikere and Halebidu tanks, Karnataka (India)

Pradeep Raja K.P.[1]*, Suresh Ramaswwamyreddy[2]

[1]Research Scholar, Department of Civil Engineering, BMS College of Engineering, Basavanagudi, Bengaluru, Karnataka, India -560019.

[2]Department of Civil Engineering, BMS College of Engineering, Basavanagudi, Bengaluru, Karnataka, India -560019.

* Corresponding author: kppradeepraja@yahoo.co.in

ABSTRACT

Rainfall and runoff are essential components of water resources in a watershed. Similarly, the rainfall is a principal source of surface water storage in lakes or tanks. Assessment of water availability for storage, in artificial/manmade structures depends upon the rainfall and runoff characteristics in a catchment. Surface water storage in tanks/lakes is also an important factor in tank irrigation and enhancement of ground water level. It is fairly well known that the runoff in a catchment is governed by several factors like land use/ land cover, amount of rainfall, intensity of rain, type of soil, soil moisture and other hydro-geomorphological features. In view of this, the present study considers two minor irrigation (MI) tanks, Bilikere and Halebidu, which have dried up completely since 2004. The collective catchment (BKHB) of both the tanks is a mini watershed that covers 46.33 km^2 area, in Lakshman Theertha River basin, which is a sub-basin of the river Cauvery flowing through semi-arid region of Mysore district of Karnataka. Soil Conservation Service Curve Number (SCS-CN) method is integrated with RS and GIS technology to estimate the runoff. Study reveals that the volume of runoff is decreasing in recent times due to the change of land use pattern and significant decrease in intensity of rainfall in the studied region.

Key words: Bilikere and Halebidu tanks, Mean daily intensity (MDI), Antecedent moisture condition (AMC), Surface runoff, Soil conservation service curve number (SCS-CN).

INTRODUCTION

The process of surface runoff is intricate in nature and is governed by several inter-connected physical and morphological factors. There are various methods available for estimating the depth of runoff such as the rational method, empirical equations and watershed simulations. Estimation of surface runoff from a catchment area having the records of rainfall is complicated. For the BKHB catchment, which is the area under study, no specific records of runoff are available. SCS-CN method, one of the watershed simulation methods is best suited for such situations, where runoff records are not available. Hence for the present case study, SCS-CN method is adopted for estimating the runoff. The advantage of SCS-CN method is that it includes several influencing factors governing the runoff such as type of soil, antecedent moisture condition (AMC), land use/land cover (LULC) by integrating them into a single dimensionless factor called curve number (CN).

In fact, several methods based on SCS-CN are being used by researchers worldwide. For example, a methodology described by Morel-Seytoux and Verdin (1981) based on the relationship between CN, hydraulic gradient (K) and corresponding storage suction factor (S_f), has been used in calculating the surface runoff by Silveira et al. (2000). A renewed SCS-CN procedure based on soil moisture accounting (SMA) was established by clearing the confusion between intrinsic parameter and initial condition by Michel et al. (2005). Using the volumetric concept, CN was determined for gauged as well as ungauged watersheds that exhibited a power relation between the potential maximum retention and 5-day AMC. This modified SCS-CN was used and found to give similar results between actual and predicted values of runoff (Mishra and Singh 2006). The accuracy of the modified SCS-CN method by incorporating the observed degree of saturation for the estimation of potential maximum retention parameter (S), coupled with a geomorphological unit hydrograph transfer function, was also tested in simulating catchment response (Brocca et al., 2009). Best performance is however achieved by adopting median, geometric mean and asymptotic fit procedures for the determination of standard CN and monthly CN values to estimate runoff (Gundalia and Dholakia 2014).

Earlier studies carried out by many researchers (Pandey et al., 2003; Rao et al., 2011; Dhawale, 2013; Bansode and Patil, 2014; Tailor and Shrimali, 2016; Satheeshkumar et al., 2017) have shown that the SCS-CN method is best suited for Indian conditions. Therefore, in the present case study, runoff estimation is carried out by using modified SCS-CN model for Indian conditions, coupled with Remote Sensing (RS) and Geographical Information System (GIS) techniques.

Table 1. Details of Satellites and Sensors.

S.No	Name of the Satellite	Sensor	Date of acquisition	Path	Row
1	Land Sat -5	MSS	05/12/1994	144	052
2	Land Sat -5	MSS	06/11/1996	144	052
3	Land Sat -5	MSS	11/09/1999	144	052
4	Land Sat -5	MSS	16/12/2004	144	052
5	Land Sat -5	MSS	31/12/2006	144	052
6	IRS-P6	LISS-III	03/11/2009	099	065

STUDY AREA

Hunsur Taluk of Mysore district has seven MI (Minor irrigation) tanks with overall CCA (Culturable command area or atchkat) of 740 ha (Hectares). Among seven lakes, two major lakes, Bilikere Lake and Halebidu Lake, have dried up completely since 2004. These lakes are situated between 12°21′10.163″N and 12°17′37.353″N latitude and 76°25′46.296″E and 76°31′4.167″E longitude as shown in Figure 1. Both the tanks are rain fed perennial water bodies situated at an altitude of 695 m and 680 m above mean sea level (msl) respectively, towards west of Mysore in a suburban area. The water was usually used for agriculture, horticulture, fish culture and domestic purposes. The combined catchment of BKHB is 46.33 km^2 with a highest elevation of 774 m and lowest elevation of 680 m above msl. Geologically, the area comprises of granites, gneisses and charnockite rock stratum. The catchment is an agricultural terrain, in which major part of the land is a cropland, sparse vegetation and poor soil cover. Inconsistent rainfall lead to recurring drought in the study area. Plate 1 shows the temporal satellite images of the study area and Table 1 shows the details of satellite, sensor, date of acquisition, path and row.

DETAILS OF STUDIED TANKS

There are about 27 water bodies including ponds and lakes ranging from 0.7 ha to 62 ha in the BKHB catchment. This catchment is a part of Lakshman Theertha River which is a sub-basin of Cauvery river. The Bilikere Lake is having a catchment of 23.71 km^2, live capacity of 21 MCft (Million cubic feet) with water spread area of 36.8 ha and a total physiographical area of 62.12 ha. Similarly, the Halebidu Lake has a catchment of 22.62 km^2, live capacity of 18 MCft with a water spread area of 30 ha and a total physiographical area of 58.33 ha. (Minor Irrigation Department, 2014).

DATA

i. Topographic map of 1:50,000 scale from Survey of India (SOI); D43W7 and D43W11; 2005 edition, is used as the base map.
ii. Landsat images from USGS are used to generate the LULC maps by supervised classification.
iii. Stream network is generated using Arc Hydro tools and CARTOSAT-1; (2005-2014) DEM Image-Stereo Data, ISRO, India.
iv. The daily rainfall from 1975-2014 for Hunsur taluk of Mysore district is used for the analysis. The data is collected from Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bengaluru.
v. Soil map is acquired from National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), Bengaluru is used to generate soil map and hydrological soil group map.
vi. Figure 2 depicts the methodology used for estimation of runoff from BKHB catchment.

METHODOLOGY

Estimating runoff: SCS-CN Method

SCS-CN method developed by soil conservation services of USDA in 1969, 1972, 1986 (USDA-NRCS 1986) is a modest, predictable and stable conceptual method for estimation of direct runoff based on storm rainfall depth. It depends on only one parameter, Curve Number (CN). The CN varies for different soils, land use/land cover and hydrological conditions. The method is based on the basic theory of water balance equation of the rainfall in a known interval of time Δt, which can be expressed as

$$\mathbf{P = I_a + F + Q} \qquad 1$$

where P =total rainfall, I_a =initial abstraction, F=cumulative infiltration excluding I_a and Q =direct surface runoff (all in units of volume expressed as depth in 'mm' occurring in time Δt =1day).

The above equation is modified with two fundamental hypotheses, which are stated as (i) ratio of the actual direct runoff (Q) to the maximum potential runoff (P-I_a) is equal to the ratio of the actual infiltration (F) to the potential infiltration (S) and (ii) the amount of initial abstraction is some fraction of the potential maximum retention (S) and is given by

$$\frac{\mathbf{Q}}{(\mathbf{P-I_a})} = \frac{\mathbf{F}}{\mathbf{S}} \qquad 2$$

$$\mathbf{I_a = \lambda S} \qquad 3$$

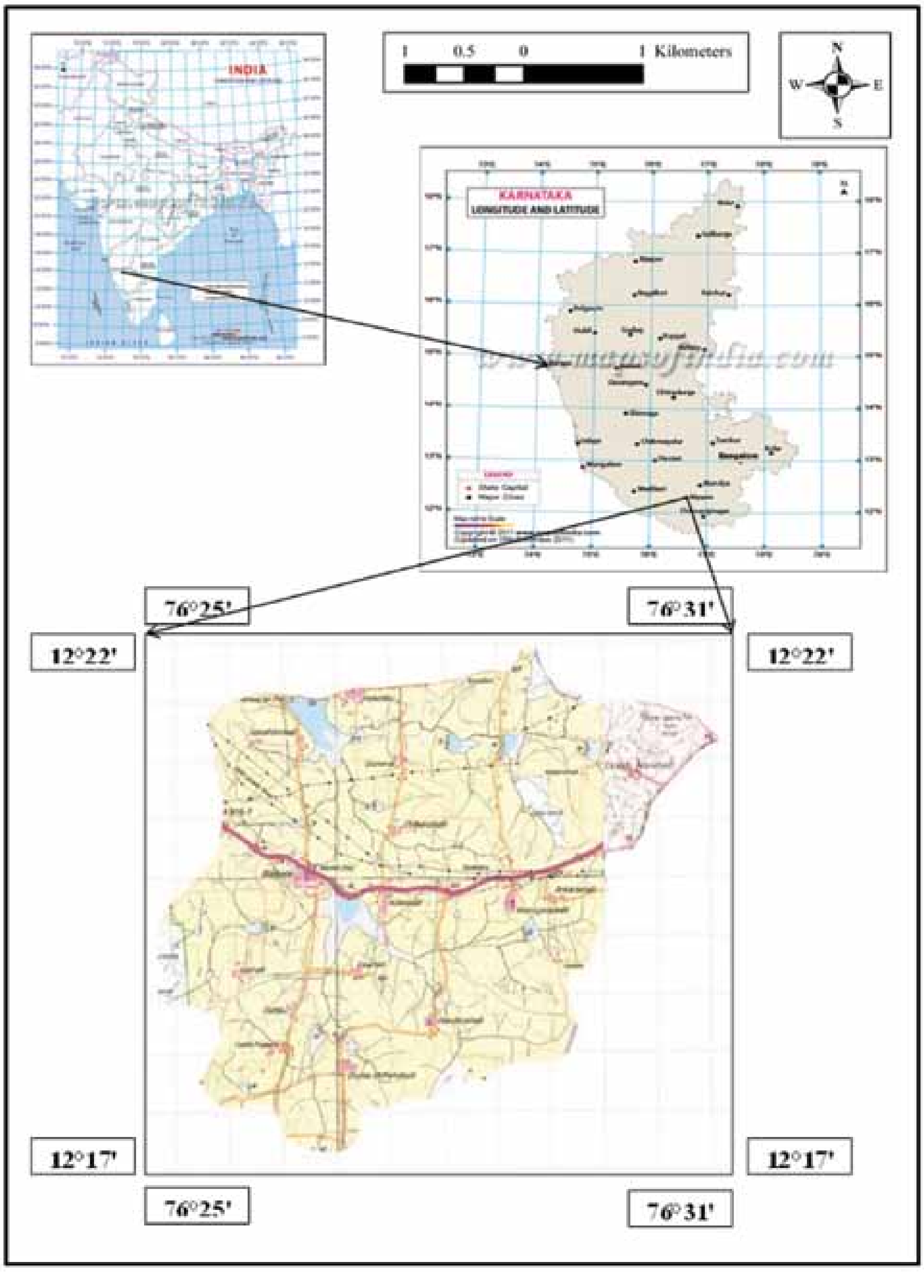

Figure 1. Location map of the study area.

Combining equation 2 and 3 and solving

$$\mathbf{Q} = \frac{(P-\lambda S)^2}{P+(1-\lambda)S} \quad \text{for } P > \lambda S \text{ and } Q = 0 \text{ for } P \leq \lambda S \qquad 4$$

Generally the value of 'λ' varies from 0.1 to 0.3 for Indian conditions. In this study it is considered as 0.2, hence the equation 4 reduces to

$$\mathbf{Q} = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{for } P > 0.2S \text{ and } Q = 0 \text{ for } P \leq 0.2S \qquad 5$$

The parameter 'S' in mm representing the potential maximum retention depends upon the soil-vegetation-land use complex of the catchment and also upon the AMC in the catchment just prior to the commencement of the rainfall event. It is expressed in terms of a dimensionless parameter CN as

$$\mathbf{S} = \frac{25400}{CN} - 254 \qquad 6$$

The CN (varies from 0 to 100, a value of 100 represents S=0 and a value of '0' represents S=∞) is determined using a data table, based on land cover, hydrological soil groups (HSG) and AMC. CN value is obtained from technical release TR-55 (USDA-NRCS, 1986).

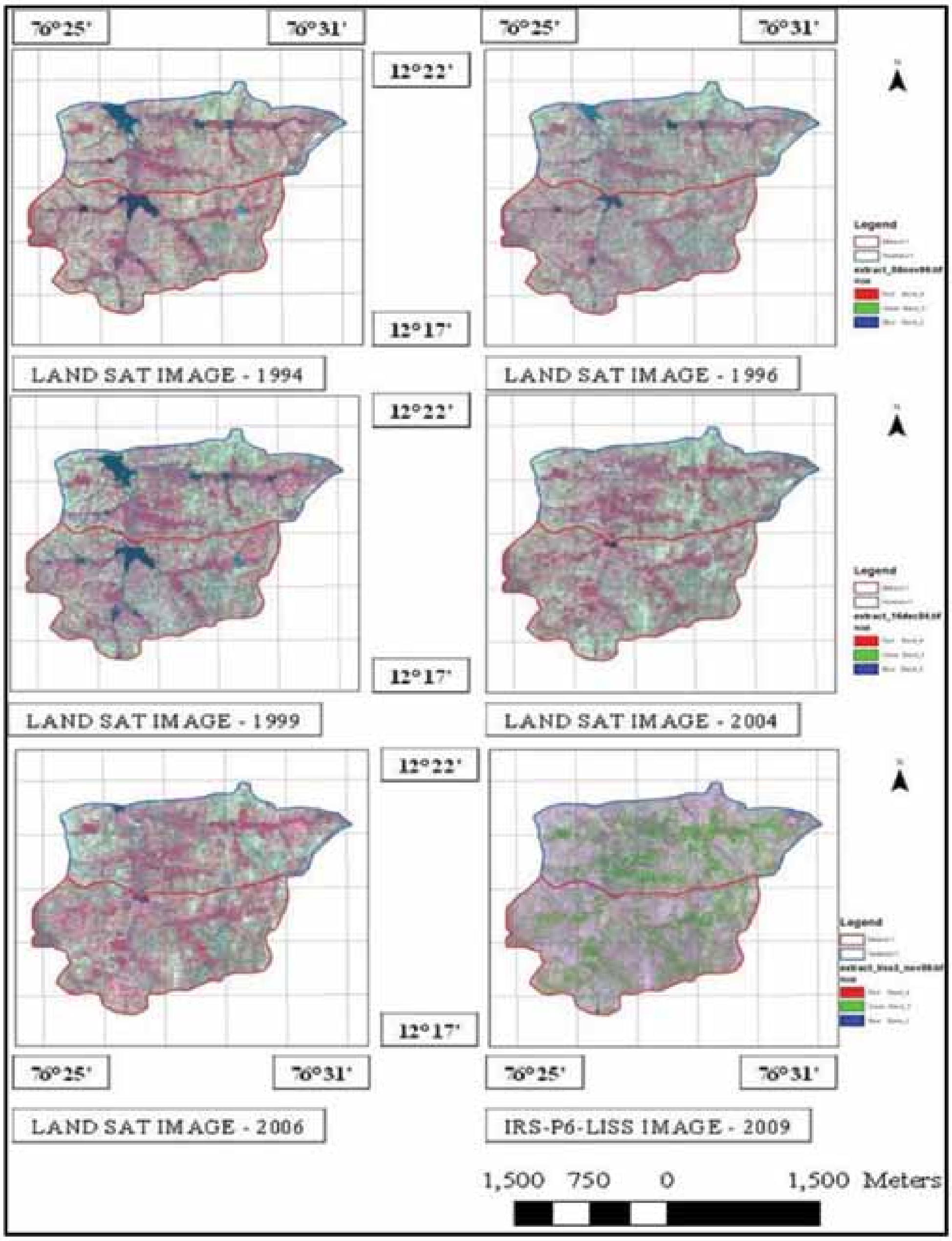

Plate 1. Temporal satellite images of the study area

The modified SCS-CN method for larger watersheds, by weighted curve numbers with respect to watershed/land cover area and is given

$$CN_w = \frac{\sum CN_i A_i}{A} \quad (7)$$

where CN_w = weighted curve number, CN_i = curve number from 1 to any number 'i', Ai = area with curve number CN_i and A = total area of the catchment (Subramanya, 2008).

Antecedent soil moisture condition (AMC)

Antecedent moisture condition denotes the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration is governed by AMC. For purposes of practical application three levels of AMC are recognized by SCS as shown in Table 2. These values are applied only to AMC-II to get the values CN-II. In turn, the values of CN-I and CN-III for AMC-I and AMC-III is determined using the equation 8 and 9.

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281 CN_{II}} \quad (8)$$

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573 CN_{II}} \quad (9)$$

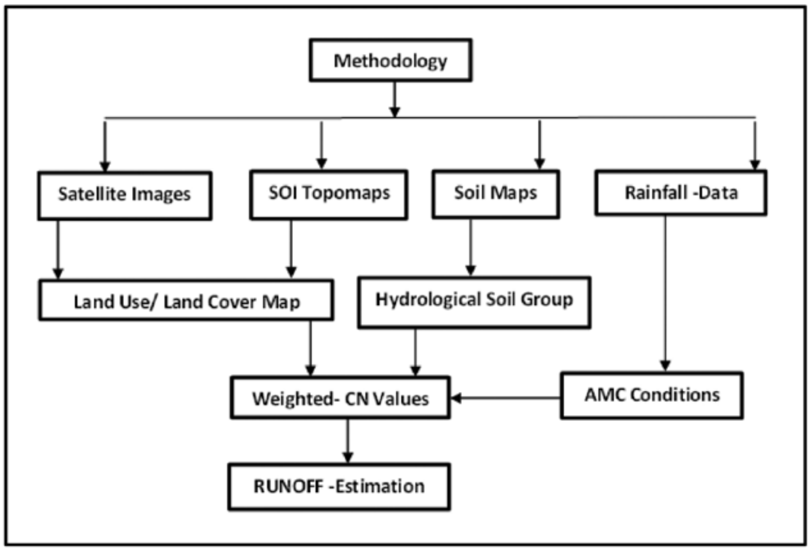

Figure 2. Methodology for the calculation of runoff from BKHB catchment

Table 2. AMC Conditions for calculating CN - as per USDA-NRCS

AMC Type	Condition of soil	Total rain in previous 5 days (mm)	
		Dormant season	Growing season
I	Soils are dry but not to wilting point	<13	<36
II	Average conditions	13 to 28	36 to 53
III	Saturated soil condition prevails	>28	>53

Table 3. Results of LULC classification

S. No	Land use/land cover classification	Area - ha	
		1994	2004
1	Water in lakes and ponds	141.57	8.19
2	Settlement - Rural	195.30	268.20
3	Vegetation – Open forest and wetlands	257.31	574.38
4	Vegetation – Agricultural plantations, Trees Etc.,	586.26	311.58
5	Stony scrub and Rock out crops Etc.,	25.38	40.05
6	Agricultural crop lands – Both kharif and rabi	3427.38	3430.80
	Total	4633.20	4633.20

RESULTS AND DISCUSSION

Land use/land cover classification (LULC)

Loss of vegetation cover and agricultural land, deforestation and destruction of important wet lands is a complex feature of environmental degradation. LULC is a significant process of detecting the historical changes of landforms. The land cover features are classified from the satellite data using supervised classification (Lillesand and Kiefer, 2007) method in conjunction with Google Earth Images and ground truth data. Thematic maps are generated using Arc GIS software (ESRI, 2010). The land cover features identified in the study area are water in lakes and ponds, rural settlement, open forest and wetland vegetation (consisting more of eucalyptus plantations), Agricultural plantations are mainly of coconut plantations, rock outcrops and stony scrub, agricultural crop land includes both Kharif and Rabi seasons with straight row treatment practice. The main crops in the study area are ragi and tobacco (Raithamitra, 2014). Classification is carried for two different years, one for the year 1994 (Figure 3) and other one is for 2004 image (Figure 4). It is observed from LULC maps that, water spread area in tanks and ponds reduced significantly from 2004 onwards. An increase in wet land plantations especially eucalyptus plantations near and surrounding the dry lakes (The units are confirmed by field visits). Simultaneously, there is a reduction in

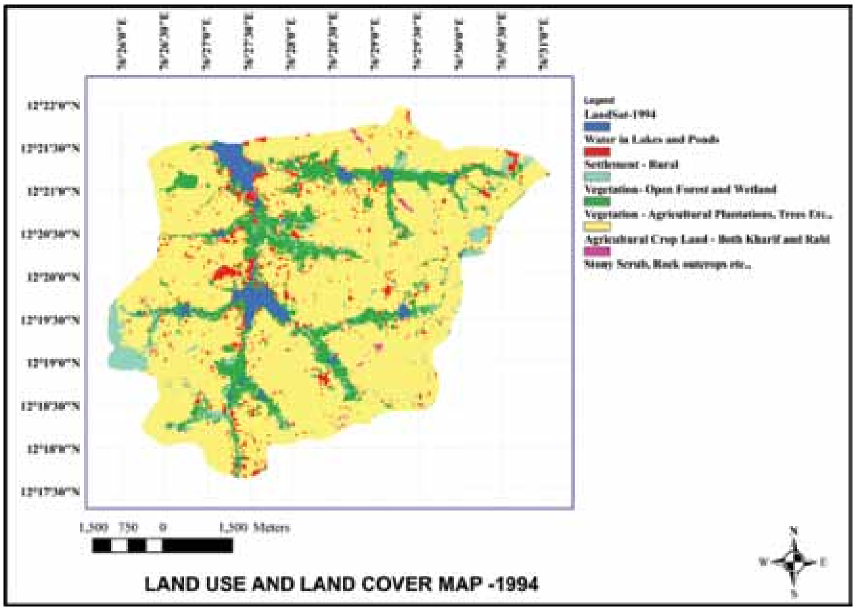

Figure 3. Land Use/Land Cover map of BKHB catchment – 1994 Image

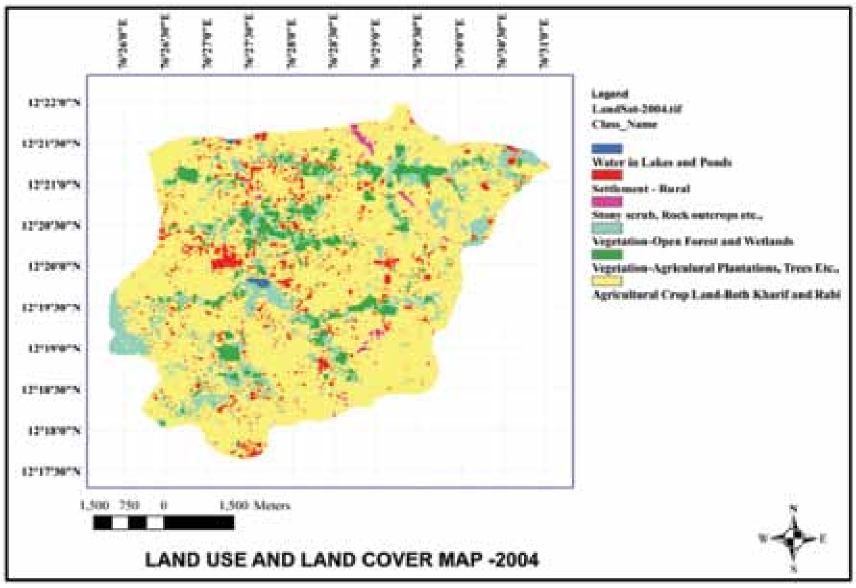

Figure 4. Land Use /Land Cover map of BKHB catchment – 2004 Image.

agricultural plantations. No change in cropland area is observed. Increase of rock out crop is observed and this is caused due to quarry extraction/mining. Results are presented in Table 3 and Figures 5 and 6.

Soil map and hydrological soil map

Soil texture

Six varieties of soil texture have been identified in the study area which are gravelly sandy loam, loamy sand, sandy clay, sandy clay loam, clay and rock outcrops with dyke ridges. The soil map is shown in Figure 7 and is generated using the map from NBSS and LUP. Maximum depth of gravelly sandy loam, loamy sand and sandy clay is 20 m, sandy clay loam varies up to 9 m and clayey soil ranges upto 16 m.

Hydrological soil group (HSG) mapping

Soils are classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups based on the soil's runoff potential. The four Hydrologic Soils Groups are A, B, C and D (USDA-NRCS 1986).

***Group A*:** Sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates, even when thoroughly wetted. They consist primarily of

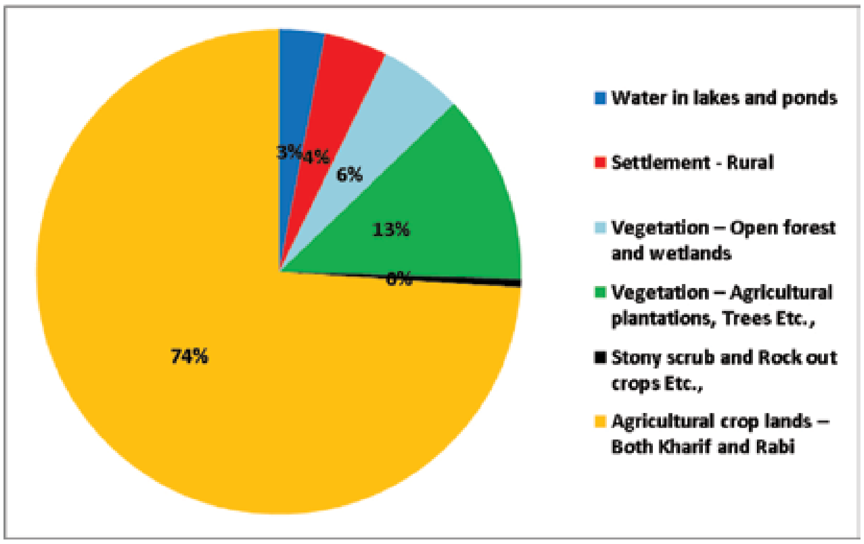

Figure 5. Percentage area distribution of LULC for the year 1994.

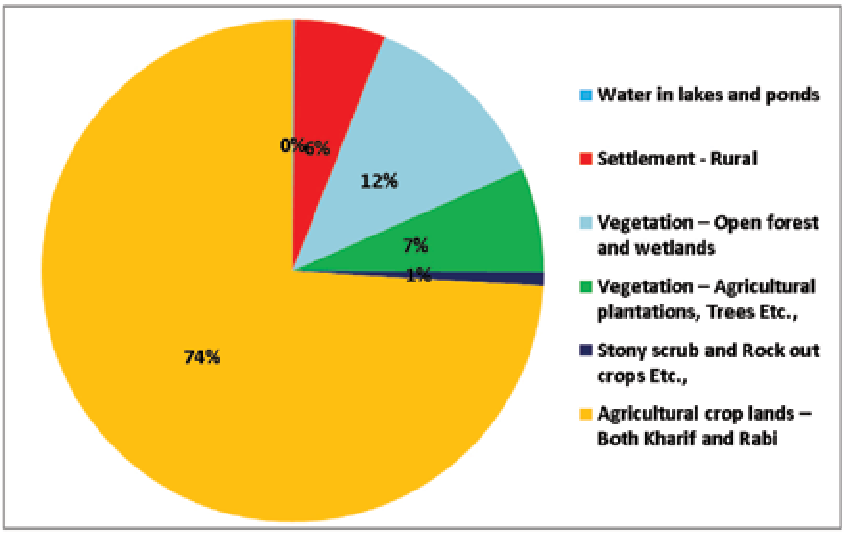

Figure 6. Percentage area distribution of LULC for the year 2004

deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B: Silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists predominantly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist essentially of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

Group D: Soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist mainly of clay soils with high swelling potential, soils with a permanent high water table, soils with a clay layer at or near the surface and shallow soils over nearly impervious material.

In the present study, the soil texture is classified into three hydrological soil groups A, C and D as shown in Figures 8 and 9. It is seen that, 59% of the soil texture falls in the group 'A' indicating low runoff potential and high infiltration rate when thoroughly wetted, and consists of excessively drained sands or gravels. 16% of soil texture fall in 'C' group suggesting low infiltration and moderate rate of water transmission and remaining 25% of the texture indicate group 'D' suggesting low infiltration rates and high runoff potential. The drainage pattern is dendritic in the BKHB catchment, 1^{st} and 2^{nd} order streams dominate the catchment as shown in the Figure 8 and most of them are formed in group 'A' soil signifying that, very high intensity

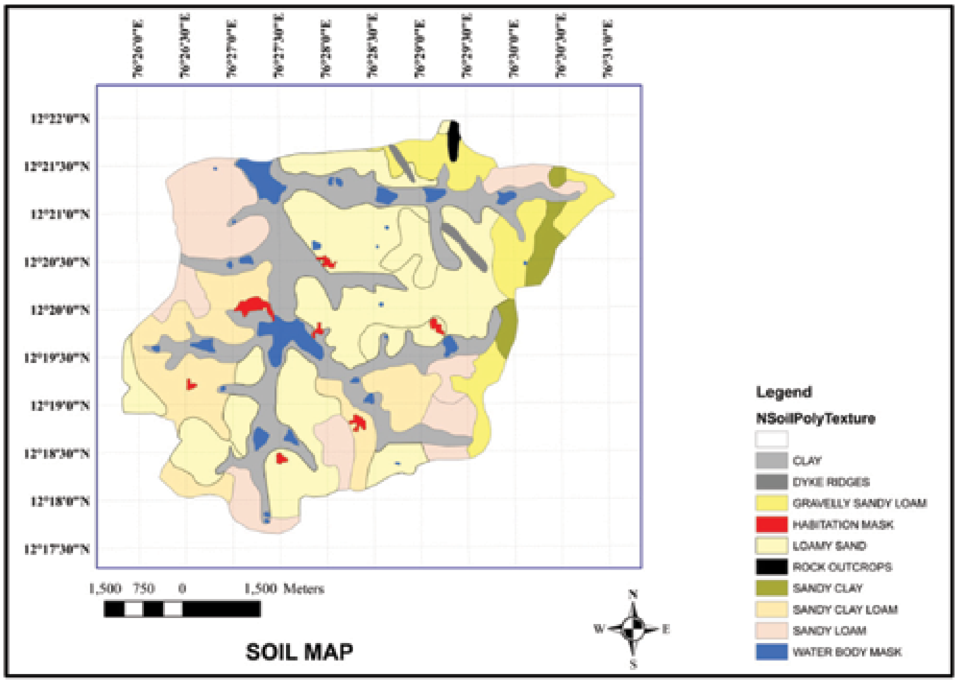

Figure 7. Soil map of the BKHB catchment (Source: NBSS and LUP).

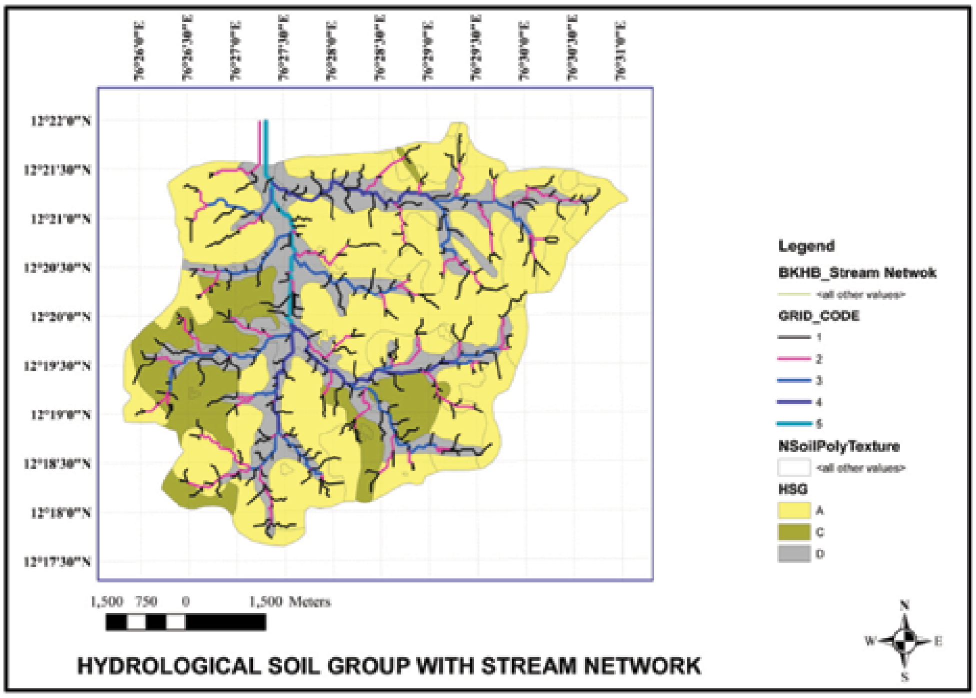

Figure 8. Map of HSG with stream network.

rainfall is required to overcome the rate of infiltration in the catchment and to generate surface runoff.

Curve number (CN) calculation

The CN values for each hydrological soil group and corresponding land use class during years 1994 and 2004 are organized as shown in Table 4. The values are for AMC-II condition. From this CN value, CN-I and CN-III values for AMC-I and AMC-III is calculated using equation (8) and (9). In order to homogenize the curve numbers, weighted curve number is determined for the BKHB catchment. The weighted CN-II values are 77.36 for 1994 and 75.95 for 2004 (Table 5).

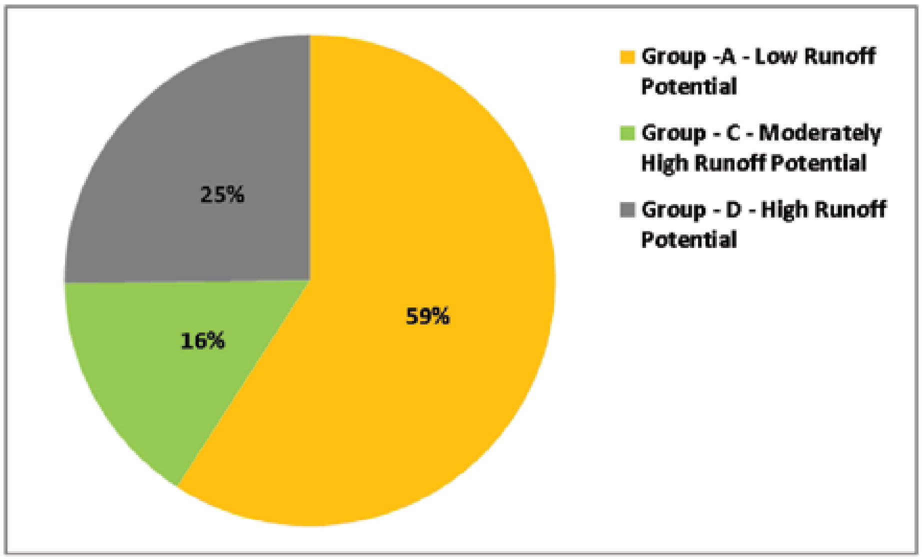

Figure 9. Areal distribution of HSG.

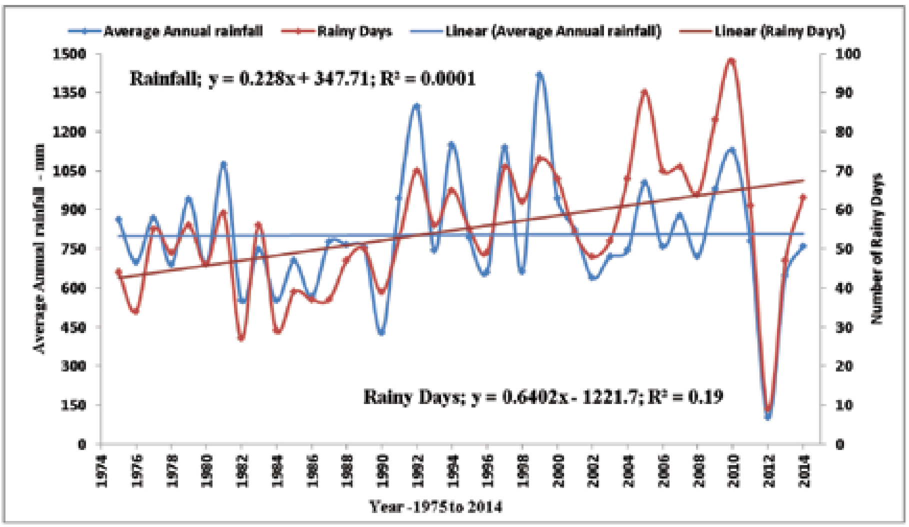

Figure 10. Relationship between rainy days and average annual rainfall.

Rainfall analysis

Average annual rainfall of Hunsur taluk is 802.37 mm, distributed with a coefficient of variation (CV) of 29.34 %, standard variation (SD) of 235.4 mm. The minimum average annual rainfall of 100 mm was in 2012 and a maximum average annual rainfall of 1416 mm in 1999. Excess precipitation (>962.8 mm) occurred in 8 years, Deficient rainfall occurred in 5 years. Scanty rainfall occurred in only one year i.e., in 2012 (-88%) and normal rainfall (range 649.9 mm to 954.82 mm) occurred in 26years among 40 years, indicating that the average annual rainfall is normal in the taluk.

Intensity of rain

The intensity of rainfall is a measure of the amount of rain that falls over time. Forty years daily rainfall data is analyzed and classified as per India Meteorological Department (IMD, 2016); NR: no rain (Intensity of rainfall equal to zero); VLR: very light rain (rainfall between 0.1 mm- 2.4 mm per day); LR: light rain (between 2.5 mm-7.5 mm per day); MR: moderate rain (7.6 mm-35.5 mm per day); RH: rather heavy (35.6 mm-64.4 mm per day); HR: heavy rain (64.5 mm-124.4 mm per day); VHR: very heavy rain (124.5 mm-244.4 mm per day); EHR: extremely heavy rain (greater than 244.5mm per day). Details of various intensities are

Table 4. Calculation of weighted curve number for BKHB catchment

S. No	LU/LC-1994 Image	HSG	CN	Area-km²	% Area	%Area * CN	Weighted CN
1	Water in Lakes and Ponds	A	90	0.02	0.04	3.85	
		C	98	0.00	0.00	0.19	
		D	100	0.30	0.64	63.91	
		D	100	1.10	2.37	237.18	
2	Settlement - Rural	A	72	0.91	1.96	140.84	
		C	81	0.37	0.80	64.67	
		D	86	0.68	1.46	125.62	
3	Vegetation – Open Forest and Wetlands Etc.,	A	28	1.34	2.89	80.93	
		C	60	0.19	0.40	24.13	
		D	64	1.07	2.30	147.19	77.36
4	Vegetation – Agricultural plantations, Trees Etc.,	A	41	1.22	2.63	107.83	
		C	69	0.14	0.31	21.58	
		D	73	4.54	9.79	714.67	
5	Agricultural Crop Land – Both Kharif and Rabi – Straight row treatment practice.	A	76	23.77	51.29	3898.40	
		C	90	6.49	14.00	1259.92	
		D	93	3.97	8.58	797.57	
6	Stony scrubs and Rock outcrops Etc.,	A	77	0.08	0.16	12.56	
		C	91	0.06	0.12	10.96	
		D	93	0.12	0.25	23.30	
	LU/LC-for 2004 Image						
1	Water in Lakes and Ponds	D	100	0.08	0.18	17.87	
2	Settlement - Rural	A	72	1.43	3.09	222.79	
		C	81	0.61	1.33	107.46	
		D	86	0.59	1.27	109.42	
3	Vegetation – Open Forest and Wetlands Etc.,	A	28	2.52	5.44	152.24	
		C	60	0.44	0.95	56.88	
		D	64	2.81	6.06	388.12	
4	Vegetation – Agricultural plantations, Trees Etc.,	A	41	0.72	1.56	64.03	75.95
		C	69	0.07	0.16	11.12	
		D	73	2.34	5.05	368.68	
5	Agricultural Crop Land – Both Kharif and Rabi – Straight Row treatment practice.	A	76	22.44	48.43	3680.50	
		C	90	6.00	12.95	1165.89	
		D	93	5.84	12.61	1172.96	
6	Stony scrubs and Rock outcrops Etc.,	A	77	0.18	0.38	29.61	
		C	91	0.14	0.30	27.58	
		D	93	0.08	0.16	15.17	

(Source: Govt. of India, 1972)

Table 5. Summaries of CN, S and I_a

S. No	AMC	Weighted - CN values		Maximum soil retention (S) - mm		Initial abstraction – I_a=0.2S	
		1994	2004	1994	2004	1994	2004
1		59.97	58.06	169.54	183.47	33.91	36.70
2		77.36	75.95	74.34	80.43	14.87	16.09
3		88.89	88.09	31.75	34.34	6.35	6.87

presented in Table 6, it is noticed that the intensity of VLR and LR has increased considerably since 2005, MR persists uniformly, RH and HR has decreased significantly.

Mean daily intensity (MDI)

It is the ratio of average rainfall to the number of rainy days (as per IMD- a rainy day is described as a day with a rain amount of 2.5 mm or more). Average annual number of rainy days is 55 and average annual MDI is 14.92 mm per rainy day. Figure 10 displays the variation of average annual rainfall and number of rainy days from 1975 to 2014. It is noticed that the rainfall is relatively uniform and the number of rainy days is increasing. Figure 11 shows the relation between average annual rainfall and MDI.

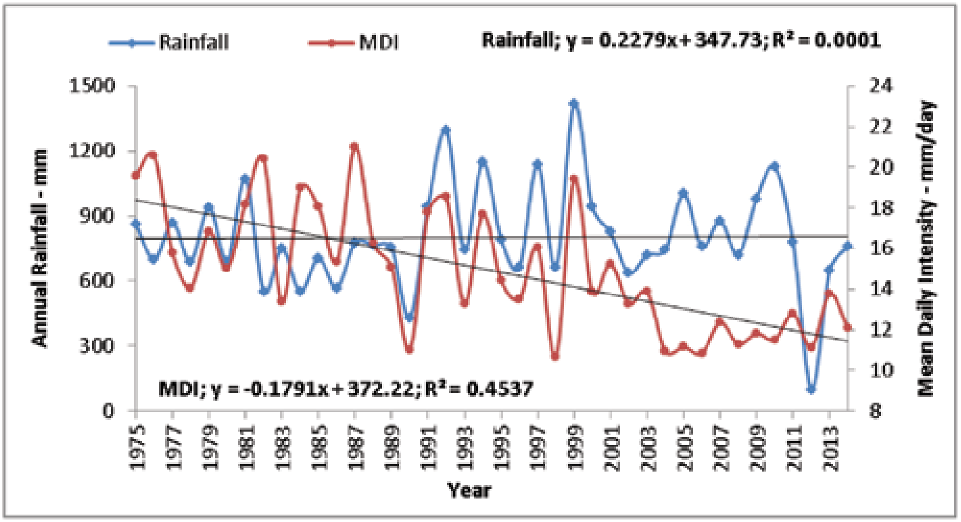

Figure 11. Variation of MDI and annual rainfall (1975 to 2014).

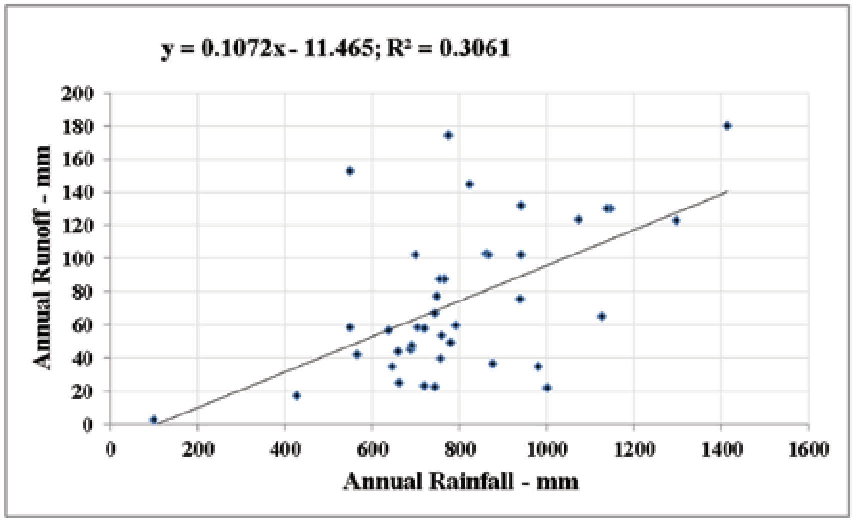

Figure 12. Linear relation between annual rainfall and annual runoff.

Rainfall is more consistent and MDI is in the negative trend. This tendency is due to the increase of more VLR and LR intensities than RH and HR.

Runoff calculation

The daily rainfall data for 40 years from 1975 to 2014 is considered for the runoff calculation. Initial abstraction is calculated at 20% of the maximum potential retention (I_a =0.2S). If the storm event is higher than the initial abstraction, the runoff exists for that rainfall event. From Figures 12 and 13, it is observed that exponential curve fitting is better than linear fit (considering the 'R' Value) between rainfall and runoff. It is seen that a minimum of 508 mm annual rainfall is required to get 43 mm runoff from linear regression and whereas 603 mm is required to get the same runoff in exponential fitting. The equation (10) for linear regression with 'R' value of 0.55 and exponential regression with 'R' equal to 0.74 is given by equation (11).

$$\mathbf{Y = 0.1072x - 11.465} \qquad 10$$

$$\mathbf{Y = 0.0035x^{1.466}} \qquad 11$$

From Table 7, it is observed that a minimum rainfall of 14.87 mm/day to 16.09 mm/day is required to start the runoff process in the BKHB catchment for average AMC conditions. Table 6 shows the annual runoff and MDI from 1975 to 2014. From the observation of satellite images from 1975-2014, it is established that both the tanks were getting filled till 2003, except for the years 1990 and 1998. It is also seen that the lakes/tanks are dry since 2004; therefore a scatter plot between MDI and runoff is drawn

Table 6. Intensity of Rainfall, Rainy days and Mean Daily Intensity (MDI)

S.No	Period	Average annual rainfall	NR	VLR	LR	MR	RH	HR	VHR	RND	MDI
1	1975	862.30	320	1	14	25	4	1	0	44	19.60
2	1976	699.20	330	2	7	20	6	1	0	34	20.56
3	1977	868.30	309	1	22	28	3	2	0	55	15.79
4	1978	689.10	316	0	14	32	2	1	0	49	14.06
5	1979	940.90	309	0	16	34	6	0	0	56	16.80
6	1980	691.00	320	0	12	31	2	1	0	46	15.02
7	1981	1073.00	306	0	9	43	4	3	0	59	18.19
8	1982	550.40	333	5	10	14	2	0	1	27	20.39
9	1983	748.50	277	32	32	18	5	1	0	56	13.37
10	1984	550.00	337	0	5	19	4	1	0	29	18.97
11	1985	703.90	325	1	11	25	3	0	0	39	18.05
12	1986	566.90	328	0	8	26	3	0	0	37	15.32
13	1987	776.50	327	1	14	16	5	1	1	37	20.99
14	1988	766.00	292	27	17	26	3	1	0	47	16.30
15	1989	754.90	281	34	22	24	3	1	0	50	15.10
16	1990	428.60	283	43	24	14	1	0	0	39	10.99
17	1991	942.40	291	21	24	20	8	1	0	53	17.78
18	1992	1297.20	275	21	27	30	12	1	0	70	18.53
19	1993	743.00	290	19	28	24	3	1	0	56	13.27
20	1994	1148.20	275	25	25	33	5	2	0	65	17.66
21	1995	792.90	297	13	18	33	3	1	0	55	14.42
22	1996	661.00	311	6	22	25	2	0	0	49	13.49
23	1997	1139.20	259	35	28	36	5	2	0	71	16.05
24	1998	662.00	287	16	33	27	2	0	0	62	10.68
25	1999	1416.00	275	17	20	44	6	3	0	73	19.40
26	2000	942.80	278	20	37	26	2	3	0	68	13.86
27	2001	823.90	281	30	33	14	4	3	0	54	15.26
28	2002	637.40	290	27	28	18	1	1	0	48	13.28
29	2003	720.60	291	22	23	23	6	0	0	52	13.86
30	2004	742.90	282	16	33	34	1	0	0	68	10.93
31	2005	1003.20	238	37	43	45	2	0	0	90	11.15
32	2006	758.20	259	36	40	28	1	1	0	70	10.83
33	2007	877.90	262	32	33	35	3	0	0	71	12.36
34	2008	721.20	265	37	37	25	2	0	0	64	11.27
35	2009	980.50	180	102	47	33	3	0	0	83	11.81
36	2010	1126.40	182	85	52	42	3	1	0	98	11.49
37	2011	780.87	250	54	34	23	4	0	0	61	12.80
38	2012	100.00	354	3	4	5	0	0	0	9	11.11
39	2013	647.50	277	41	21	24	2	0	0	47	13.78
40	2014	760.00	261	41	39	18	6	0	0	63	12.06
	Avg	802.37	288	23	24	27	4	1	0	55	14.92

(Rainfall in mm, NR-No rain, VLR-Very light rain, LR-Light rain, MR-Moderate rain, RH-Rather heavy rain, HR-Heavy rain, VHR-Very heavy rain)

as shown in Figure 14. The equation for linear trend with 'R' value of 0.8 is given by

$$\mathbf{Y = 11.703x - 100.04} \tag{12}$$

where Y= runoff and x = mean daily intensity.

From the equation (12) it is consequent that a least MDI value of 8.6 mm/day is required to have the surface runoff. Assessment of runoff data reveals that, when the runoff is higher than 43 mm (AMC-II) both the lakes/tanks were full with a corresponding MDI value greater than 12.3 mm/rainy day and average annual rainfall greater than 603 mm. Looking at the Table 6 and Figure 15, it is observed that the runoff is significantly in the decreasing trend since 2004 even though the rainfall is more consistent. This is because of the decreasing MDI. Though the value of runoff is greater than 43 mm in the years 2010 and 2014, the tanks are not getting filled due to the lower value of MDI. Whereas in the year 2011, both runoff and MDI are higher than the specified values; smaller ponds and ditches were filled but not Bilikere and Halebidu lakes. This may be due to the increased wetland vegetation cover in the catchment and clogging of stream channels.

Table 7. Annual runoff values with Mean Daily Intensity

Year	Annual-Rainfall (mm)	Annual Runoff (mm)			MDI (mm/rainy day)
		AMC-I	AMC-II	AMC-III	
1975	862.30	15.23	102.85	280.09	19.60
1976	699.20	16.69	101.79	246.64	20.56
1977	868.30	20.49	102.11	255.71	15.79
1978	689.10	6.91	44.68	147.64	14.06
1979	940.90	6.22	74.98	247.66	16.80
1980	691.00	5.06	46.97	160.39	15.02
1981	1073.00	24.11	123.51	316.31	18.19
1982	550.40	83.28	152.72	241.28	20.39
1983	748.50	11.37	77.22	197.37	13.37
1984	550.00	6.95	58.27	164.47	18.97
1985	703.90	3.07	58.14	191.02	18.05
1986	566.90	4.15	41.50	133.08	15.32
1987	776.50	66.77	174.56	321.69	20.99
1988	766.00	17.80	87.19	213.11	16.30
1989	754.90	26.72	87.31	202.88	15.10
1990	428.60	0.42	16.74	67.04	10.99
1991	942.40	20.64	131.96	315.73	17.78
1992	1297.20	14.14	122.53	331.45	18.53
1993	743.00	10.49	66.79	184.16	13.27
1994	1148.20	22.33	129.90	348.05	17.66
1995	792.90	9.60	59.11	178.59	14.42
1996	661.00	2.76	43.59	147.41	13.49
1997	1139.20	26.24	129.86	325.65	16.05
1998	662.00	1.66	24.77	108.39	10.68
1999	1416.00	34.73	179.94	457.35	19.40
2000	942.80	19.79	102.04	260.96	13.86
2001	823.90	44.98	144.40	284.94	15.26
2002	637.40	7.46	56.52	164.04	13.28
2003	720.60	4.59	57.40	170.29	13.86
2004	742.90	0.81	22.14	106.94	10.93
2005	1003.20	0.02	21.97	130.73	11.15
2006	758.20	5.83	39.29	127.39	10.83
2007	877.90	3.41	36.50	147.85	12.36
2008	721.20	0.04	22.77	106.11	11.27
2009	980.50	0.70	34.40	156.35	11.81
2010	1126.40	12.37	65.00	197.41	11.49
2011	780.87	5.08	49.18	155.60	12.80
2012	100.00	0.00	2.33	13.26	11.11
2013	647.50	1.59	34.36	129.23	13.78
2014	760.00	3.86	53.47	171.50	12.06
Average	802.37	14.21	74.52	202.64	14.92

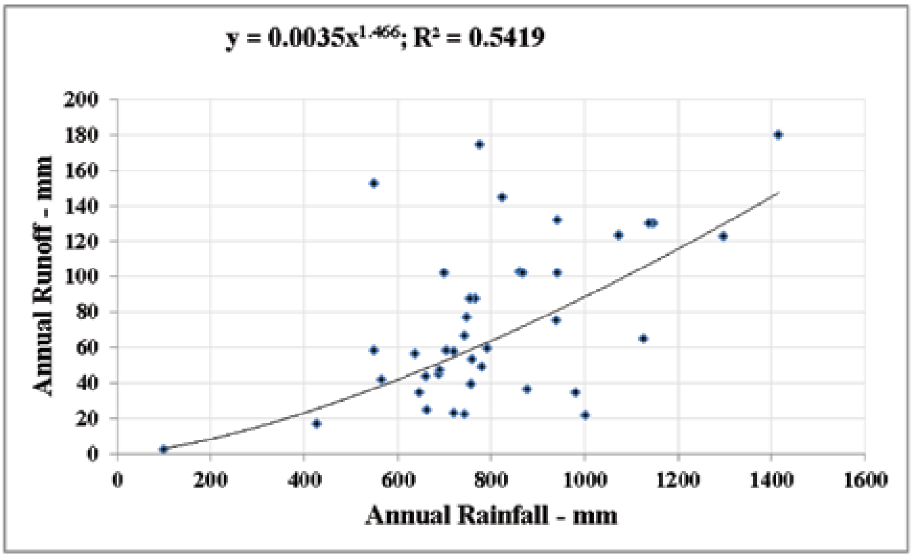

Figure 13. Exponential relationship between annual rainfall and annual runoff.

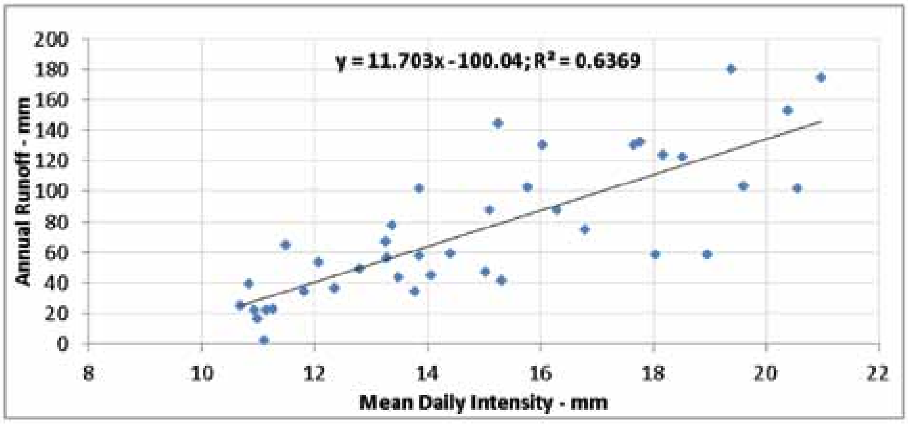

Figure 14. Linear relationship between MDI and annual runoff.

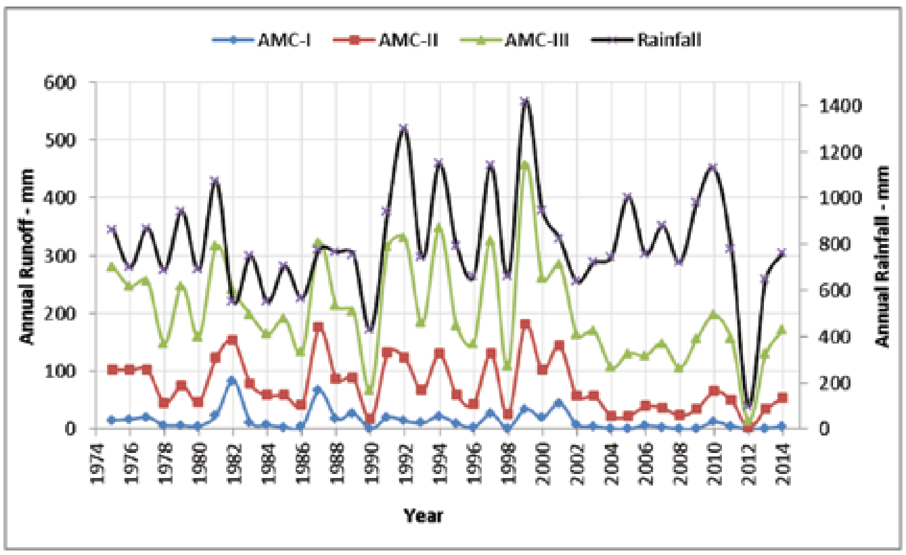

Figure 15. Annual rainfall and annual runoff for all 3-AMC conditions (1975-2014).

CONCLUSIONS

SCS-CN model combined with RS and GIS is used to calculate the surface runoff from BKHB catchment. The following observations are made from the present study

i. Daily rainfall data from 1975 to 2014 reveals that, the Antecedent Moisture Condition (AMC) in the catchment for the Kharif and Rabi season belongs to average conditions, i.e., AMC-II.
ii. Land use/land cover classification of 1994 and 2004 image discloses that, the water bodies have dried up from 3% to 0.1%, vegetation cover in and around the wetlands has increased significantly from 6% to 12%, rural settlement also has increased from 4% to 6%.
iii. Almost sixty percent of the catchment area is occupied under the category of 'A' group of HSG, indicating higher permeable soil texture and low runoff potential. Hence, necessitates a minimum of 15 mm rainfall per day to have the surface runoff.
iv. BKHB Catchment is dominated by first and second order streams and majority of them are formed in group-A soil which leads to higher rate of infiltration.
v. Weighted curve number values of 77.36 and 75.95 suggest that the basin is having low to moderate runoff capability.
vi. Potential maximum retention of soil varies from 75 to 80 mm for the BKHB catchment.
vii. Rainfall analysis shows that, the average annual rainfall is uniform in the region, however intensity of rainfall is decreasing gradually.
viii. Mean Daily intensity is also in the negative drift from the average value.
ix. Number of rainy days is in the positive movement but with low intensity rainfall.
x. Direct runoff has lowered from 2004. This may be due to increase in vegetation cover surrounding the lake and stream bed.
xi. A runoff value higher than 43 mm is essential for both the tanks to get water upto the maximum level.
xii. A minimum of 603 mm average annual rainfall required to have 43mm annual runoff.
xiii. A least MDI value of 12.3 mm/per rainy day is necessary to have minimum runoff.
xiv. Thus, it may be concluded that the surface runoff in the BKHB catchment has decreased since 2004 and hence the lakes/tanks in the catchment have dried up completely.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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