Vol. 45, No. 2, pp 148-156, 2017

Indian Journal of Soil Conservation

Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Surface water resources assessment in ungauged upper Don river basin of Karnataka by using Remote Sensing and GIS techniques

M.S. Shirahatti[1,3], M.V. Ranghswami[2], M.V. Manjunath[1], R. Sivasamy[2] and S. Santana bosu[2]

[1]*University of Agricultural Sciences, Dharwad-580005, Karnataka;* [2]*Tamilnadu Agricultural University, Coimbatore-641003, Tamil Nadu.*

[3]*E-mail: msshirahatti@gmail.com*

ARTICLE INFO

Article history :

Received : July, 2015
Revised : April, 2017
Accepted : June, 2017

Key words:

GIS,
Modeling,
Probability,
Runoff yield,
SCS curve number,
Surface water resources

ABSTRACT

The information on spatial and temporal availability of runoff, one day maximum runoff and peak runoff rates is helpful for safe and cost effective planning and design of water harvesting and drainage line treatment structures. The present study was taken up in the upper Don river basin of Karnataka, India. The semi-arid climate prevails in the study area. The water resources of the study area were assessed, using SCS curve number method by analyzing daily rainfall data of ten years (1998-2007). The entire watershed (643.5 km^2) was sub-divided into ten sub-watersheds for micro level planning. An attempt was made to use remote sensing (RS) data under the geographic information system (GIS) environment for water resources assessment by adopting lumped curve number technique. Accordingly, loose coupling (linked to GIS) model was used for the assessment of surface water resources. The daily and weekly maximum runoff as well as peak runoff rates were assessed, monthly and annual runoff production at various probability levels were predicted on sub-watershed basis. The annual runoff data analysis revealed that runoff as the percentage of annual rainfall varied from 5.08 to 25.66% with an average of 14.38% (81.6 mm). The runoff was also calculated at various probability levels for the daily and monthly rainfall. The sub watershed wise yearly average annual runoff yield ranged from 121.33 to 927.44 ha-m, with an average of 488.88 ha-m. This information on surface water resources would be helpful for computing the water balance of the watershed as well as hydrologic, hydraulic and structural design of water harvesting and artificial recharge structures, proposed to be constructed in the watersheds.

1. INTRODUCTION

Proper scientific planning and management of water harvesting structures require immense data to make predictions of water availability. The spatial nature of data associated with water resources is the single most factor contributing to the complexity of data management. Advance and rapidly expanding technologies such as remote sensing (RS), geographic information system (GIS) and global positioning system (GPS) hold a great promise to tackle the present challenges faced by hydrologists and hydro geologists.

In hydrologic studies, there are no formulae, which can be universally applied to predict the runoff volume accurately from rainfall for un-gauged watersheds. The relation between rainfall and runoff volumes has been presented by many empirical and semi empirical formulae. Among the different runoff assessing methods, the USDA-Soil Conservation Service (SCS) curve number method is a well accepted tool in applied hydrology. This method is also known as curve number (CN) method. For un-gauged watersheds, the CN method can be used to estimate the depth of direct runoff from the rainfall depth given an index describing runoff response characteristics (Ritzema, 1994). Sarkar *et al.* (2004) used SCS curve number method for estimating runoff from small watersheds and found that the predicted runoff hydrographs were in good agreement with the observed runoff hydrographs. Mohanty *et al.* (2015) found that distributed CN method was better than composite method for assessing the runoff. Singh *et al.* (2011) computed daily one day maximum runoff by using SCS curve number method. Shakir Ali, (2011) developed process based rainfall-runoff model for predicting runoff yield. For the present study, SCS curve number technique was used for measuring the runoff. USDA-SCS Curve Number method was modified for runoff estimation from daily and weekly rainfall data (Rao *et al.,* 2002 and 2003). Runoff was estimated by using SCS curve number method to determine the impact of climate change on design of soil and water conservation (SWC) structures (Rao *et al.,* 2015).

Traditional method for establishing CNs on small watersheds includes field surveys and interpretation of aerial photographs. For large drainage basins, field surveys are expensive and an excessive number of aerial photographs may be required for complete coverage. We can consider the advantages offered by RS images for ground truth data on spatial scale and to integrate them with GIS for analysis purposes, while making use of SCS curve number method for runoff estimation (Gangodamage, 2001). It will be an efficient method in case of surface water resources estimation. One of the options for use of RS and GIS is to improve the estimation of watershed parameter like curve number for a drainage basin with widely used SCS model from its spatially detailed information through land use data and digitized soil map (Sarkar *et al*., 2004 and Ramesh *et al*., 2007). There is an abundant scope and opportunity for harvesting excess runoff in the rainfed region in different states of India. Government of India has introduced several schemes to improve the surface water availability for irrigated and rainfed areas for enhancing the productivity. However, due to unscientific site selection and implementing technology, sufficient dependable runoff data is not available which is one of the major constraints in successful adoption of rain water harvesting projects. The outcome of the present study on spatial and temporal availability of runoff, one day maximum runoff and peak runoff rates would be helpful for safe and cost effective planning and designing of storage and drainage line treatment structures.

2. MATERIALS AND METHODS

Study Area

The present study was taken up in the Don river basin, Bijapur district of Karnataka state, India (Fig.1). Its catchment is bounded by 16°42'8" to 16°59'26"N and 75°12'24" to 75°39' 40"E. The major portion of the catchment falls in Bijapur taluk. The area of total upper Don river basin is 643.5 km^2. The physiography is gently sloping (0-3%) and there is a total relief of 143 m, normal rainfall of Bijapur is 590 mm and minimum and maximum temperatures recorded were 9.48 and 41.75°C, respectively while, the monthly reference evapotranspiration (ETo) was in the range of 82.77 to 258.23 mm. The major part of the upper Don watershed is occupied by basalt and other trap intrusions. Black cotton soil (vertisols) is the dominant type of soil and it is followed by mixed loamy soil.

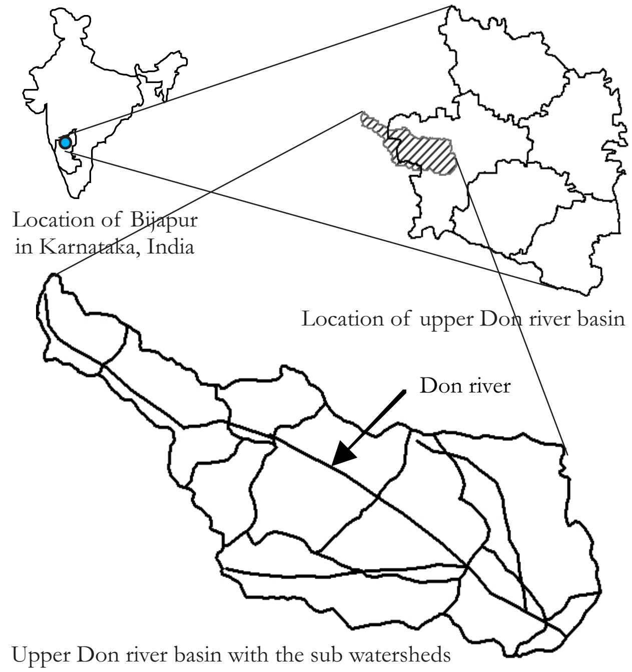

Fig. 1. Location map of the upper Don river basin

SCS-Curve Number

Soil Conservation Department (1972) has modified original SCS formulae and proposed the following equations for different types of soils of India:

$$Q = \frac{(P - 0.1S)^2}{P + 0.9S} \quad \text{(for black cotton soil) - ...(1)}$$

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \quad \text{(for other soils) - ...(2)}$$

Where, P is precipitation and S is recharge capacity of the watershed. For convenience in evaluating antecedent rainfall, soil conditions and land use practices the curve number CN is given by SCD, 1972:

$$CN = \frac{25400}{S + 254} \quad \text{...(3)}$$

Curve numbers for various groups are given by SCD, 1972. These values apply to antecedent moisture condition (AMC) II which is considered as an average condition. In the study area, generally *rabi* crop is sown during the month of September. From June to August months, normally the land is kept fallow, hence, for the dormant season was considered for the AMC calculation.

Data Base for Runoff Calculation

Land use/cover map

For the present study, Indian Remote Sensing 1D LISS-III digital data of May 8, 2003 was obtained from National Remote Sensing Centre (NRSC), Hyderabad, India. The digital land use map was prepared by using the IDRISI software. Eight different land use/cover types were demarcated. The separability analysis and accuracy assessment were also carried out. High transformed divergence (TD) values among the classes were observed and the overall accuracy assessment of about 85% was observed. For the use of same in the curve number calculation method, the land use classes were re-classified into the type of land uses as listed in the runoff curve number Table (SCD, 1972).

Hydrologic soil group map

The soil map prepared by the ICAR-National Bureau of Soil Survey & Land Use Planning (ICAR-NBSS&LUP) in the scale of 1:2,50,000 was used. The major part of the study area is covered by vertisols (black cotton soil) and remaining part is with loamy soils. However, there are sub classes in the particular type of soil *viz.,* very fine montmorillonitic (chromosters), fine montmorillonitic and loamy mixed lithic are existing. Already prepared soil maps were used to generate the hydrologic soil group map. For the various soil classes, appropriate hydrologic soil groups were assigned and the new hydrologic soil group map was generated.

Using both land use and hydrologic soil group maps and CROSS TAB module in the IDIRISI, GIS curve number map was generated.

Theissen polygon map

Rainfall distribution map is one of the important inputs for the runoff calculation. The procedure of preparation of Thiessen polygon is explained in Subramanya (1997). The THIESSEN module of the IDIRISI software was used to generate the Theissen polygon using the five rain gauge stations, situated in and around the study area.

Sub watershed map

The upper Don river basin was sub divided into ten sub-watersheds for systematic micro level planning of water resources, so that the area of each sub-basin is around 100 km^2 or 10,000 ha.

Loose Coupling Model for Runoff Computation

To date, most GIS's can easily accomplish overlay and index operations, but cannot perform process based modeling functions (Jha and Peiffer, 2006). As a result, the process based simulation models and GIS need to be coupled, which provides an efficient tool for processing, storing, manipulating and displaying hydro-geological data (Crowin *et al*., 1997). In loose coupling model (Fig. 2), the GIS and simulation model represent two distinct software packages and the data transfer from one model to another is made by storage of data in one system and subsequent reading of the data by the other. The GIS software is used to pre process and post process the spatial data (Watkins *et al*., 1996). Accordingly, loose coupling (linked to GIS) model was used, after developing the curve number in the GIS environment. All the basic data which is required for runoff calculation *viz.,* curve number, soil unit and rainfall were taken out from the GIS environment and used the same for the input for runoff calculation program, which was coded in the BASIC language. Further, the program read the ten years rainfall data of five rain gauge stations from the external data base. The output (runoff values) from the program was once again transformed pixel by pixel to the GIS environment, and further analysis and display was carried out in the GIS. The program flow diagram is presented in Fig. 3.

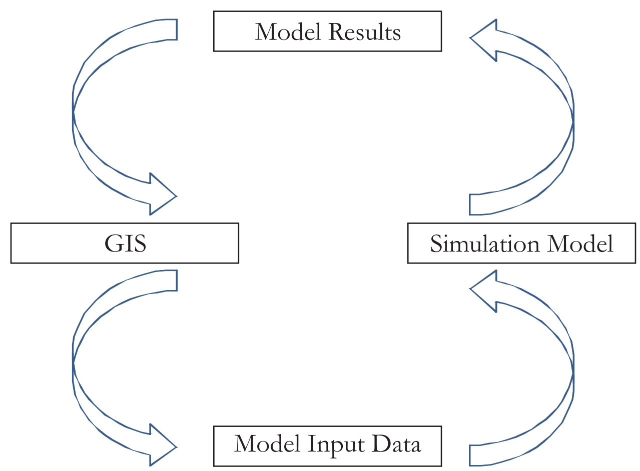

Fig. 2. Loose coupling model

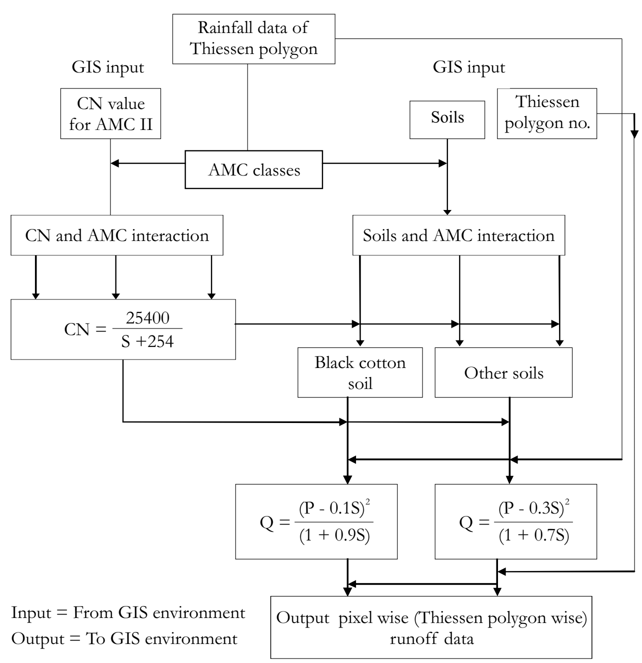

Fig. 3. Flow diagram used for developing program for calculating runoff from GIS input data

The various operations involved for calculating runoff through RS and GIS in the IDIRISI software is explained through the flow diagram presented in Fig. 4.

Peak Runoff Rates Assessment

For hydrologic design of any structure is concerned, the analysis of the peak design runoff rate and flood volume, which the structures are to handle this quantity of water safely is essential. For the calculation of peak discharge, the rational formula was used. Sub watershed wise, for the prevailing land use, topography and soil type, the appropriate runoff coefficient values were assigned. For the rainfall intensity calculation, the methodology developed for the flood estimation for Krishna and Pennar sub zone-3 (h) by Central Water Commission (CWC) was used (Anon., 2000). The CWC followed the hydro meteorological approach, they carried out analysis of collected concurrent rainfall and flow data for the gauged catchment to derive unit hydrographs of mostly one hour duration, such representative unit hydrographs were prepared for each of the gauged catchment from the selected flood events. From this information, they developed sub-zone wise graphs by converting 24 hr point rainfall to short duration rainfall. The same was used for calculating the rainfall intensity.

3. RESULTS AND DISCUSSION

Input Maps for the Runoff Estimation

Land use/Land cover map

The various land use/land cover classes considered for the curve number assessment are given in Fig. 5. There were totally four land use classes identified *viz.,* cultivable land (90.1%) followed by waste land (5.34%), orchard (4.48%) and water bodies (0.08%). Among the land use classes, the cultivable land was found to be dominant land use class. It is distributed all over the study area. The straight row cultivation practice was considered for the curve number assessment. Sub watershed wise areal extents of different land use/land cover classes were also calculated. Further, in the study area, *rabi* is the major cropping season and the crop is grown from the residual moisture. During *kharif*, the land is kept fallow till mid of the September.

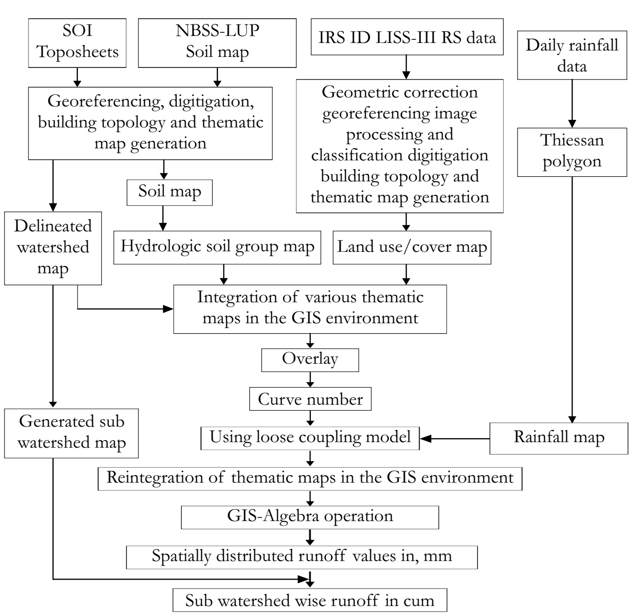

Fig. 4. Flow chart depicting the detailed procedure of calculating runoff under GIS environment

Hydrologic soil group map

The map depicting the original soil groups was procured and their corresponding hydrologic soil groups were assigned. The map revealed that all the montmorillonitic groups fall in hydrologic soil group "D", while loamy mixed lithic group falls in hydrologic soil group "C". From Fig. 6, it reveals that hydrologic soil group "D" is dominant one (77.98%), which occupies major portion of the watershed and the remaining area on southern and western side is covered by hydrologic soil group "C".

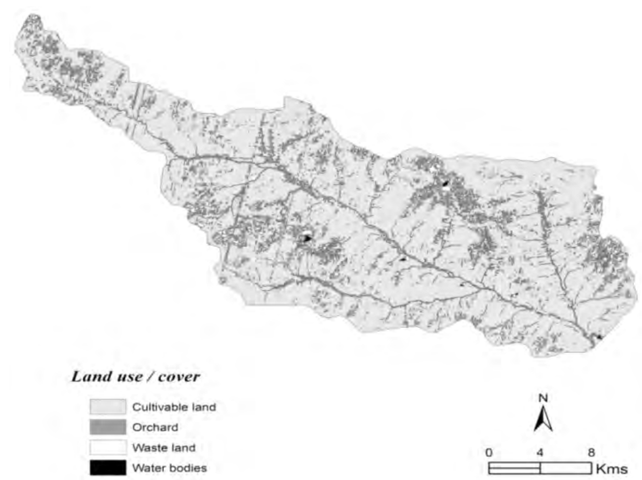

Fig. 5. Land use/cover map of the upper Don river basin

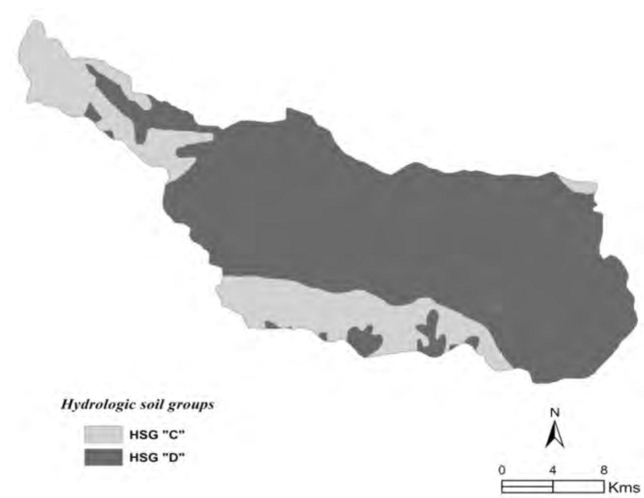

Fig. 6. Hydrologic soil group map of the upper Don river basin

Thiessen polygon map

Thiessen polygon map of the study area was prepared. The rain gauge stations of Tikota, Bijapur, Jath, Bableshware and Telsang covered 37.68, 8.29, 16.38, 11.74 and 25.90% of the total area, respectively. The Tikota rain gauge station encompasses the maximum area, while Bijapur covers the minimum area. The sub watershed wise distribution of different Thiessen polygon areas was also calculated.

Sub watershed map

The sub watershed map is depicted in Fig. 1. The areas of different sub watersheds range from 13 to 116.58 km^2. The sub watershed 9 covers the highest area (18.12%), while the sub watershed 10 covers the lowest area (2.02%).

Curve Number Map

Land use/cover and hydrologic soil group maps were used to develop the curve number map and the same is presented in the Fig. 7. The curve number values varied from 69 to 93 over the watershed for AMC-II condition. Further, it shows that in most of the areas, the curve number value was more than 88, while in some pockets, it ranged between 69 to 88.

The high values of CN are attributed to the presence of hydrologic soil groups C and D, which are considered as the high runoff producing soil groups. Under GIS environment, Durbude and Chandramohan (2000), Sarkar *et al*. (2004) used similar procedure to generate the curve number map. Further, for runoff calculation, the in- built programming in SCS-loose coupling model was used to adjust the curve numbers according to AMC-I and III conditions.

Runoff Analysis

Daily and weekly runoff analysis

Daily maximum runoff values of the five rain gauge stations for a period of 10 years (1998-2007) were analysed and presented in Table 1. Most of the times, the daily maximum runoff events were recorded in the month of September, followed by October and June. The data revealed that the maximum one day runoff was in the range of 0 to 181.7 mm. The year 2003 witnessed the severe drought year in the past 50 years, the average annual rainfall recorded was in the range of 150 to 300 mm only. During 2003, in the Telsang rain gauge station, no runoff events were recorded, while 3.2 to 32 mm runoff was recorded in other stations. The highest one day maximum daily runoff was recorded in the year 2007. In four, out of five rain gauge stations, the maximum one day runoff recorded was more than 120 mm. It is attributed to the one day maximum rainfall burst of 160 to 200 mm recorded in the second fortnight during the month of June.

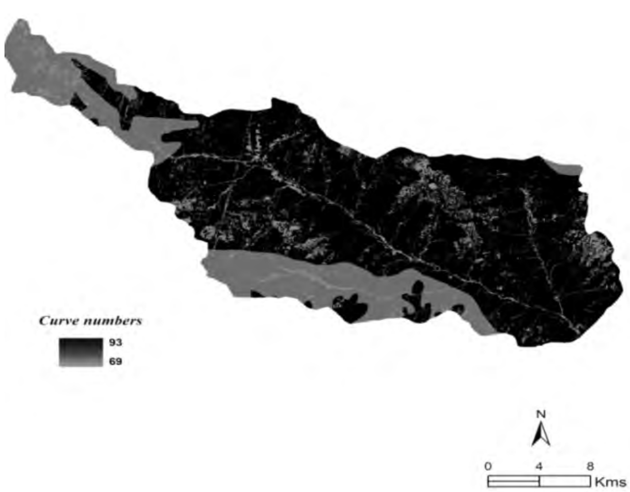

Fig. 7. Curve number map of the upper Don river basin

The weekly maximum runoff values also followed the same trend as daily maximum runoff. During the study period (1998-2007), the maximum weekly runoff was in the range of 0 to 226.39 mm. The minimum was recorded during the year 2003, while maximum was recorded in the year 2007. The maximum weekly runoff analysis revealed that more than 70% of the times it occurred during 39-42nd standard meteorological weeks (September-October months), followed by 23-25th standard meteorological weeks (June month).

Peak runoff rates

For the individual sub watersheds, the peak runoff rate was assessed from the highest one day maximum rainfall recorded during the study period (1998-2007) and the output of the analysis is presented in Table 2. Peak runoff rate observed was in the range of 101.11 to 469.26 cumec. The highest peak runoff rate was attributed to the one day maximum rainfall of 200 mm recorded in the month of June during the year 2007.

Monthly runoff analysis

Monthwise average runoff values of all the 10 sub watersheds for a period of 10 years (1998-2007) are presented in Table 3. The spatial distribution of a monthly runoff for September 2007 is depicted in Fig. 8. Runoff occurred only during the months of May to October in almost all years. Further, maximum runoff occurred during the months of June, September and October. It is attributed to the occurrence of the high monthly rainfall during these months. The results are in agreement with the findings of Anon. (2000). Average monthly runoff varied from 5.21 to 23.54 mm. The results of the monthly runoff of all the 10 years revealed that more than 100 mm of runoff was observed in three sub watersheds (1, 2 and 4) during September, 2001. It could be due to the high maximum monthly rainfall during that month. The Jath rain gauge station which influences the above sub watersheds

Table: 1
Daily and weekly maximum rainfall and runoff at different rain gauge stations of upper Don river basin

Year	Tikota				Vijayapura				Jatt			
	Max. daily 'P',mm	Max. daily 'Q',mm	Max. weekly 'P',mm	Max. weekly 'Q',mm	Max. daily 'P',mm	Max. daily 'Q',mm	Max. weekly 'P',mm	Max. weekly 'Q',mm	Max. daily 'P',mm	Max. daily 'Q',mm	Max. weekly 'P',mm	Max. weekly 'Q',mm
1998	50.50	35.19	96.00	65.73	93.00	76.03	194.20	123.34	65.00	48.92	65	48.90
1999	38.60	24.24	78.60	30.47	48.6	33.41	152.40	73.11	71.20	54.87	71.2	54.90
2000	36.20	21.47	78.60	30.47	52.4	36.97	74.00	45.73	90.00	73.10	181	134.54
2001	62.20	46.24	80.30	53.35	110	92.68	100.00	92.70	108.00	90.72	169	122.45
2002	45.20	30.26	45.20	30.26	66.6	50.45	111.80	80.71	42.50	27.78	42.5	27.80
2003	20.20	3.79	20.20	2.67	48	32.86	60.80	36.40	32.20	18.56	32.2	18.60
2004	75.50	59.02	75.50	59.02	49.8	34.53	95.40	47.02	57.00	41.30	125.6	82.12
2005	32.20	18.56	32.20	18.56	53.2	37.72	78.40	50.35	63.80	47.77	136.4	85.82
2006	40.20	25.69	111.2	68.7	81.4	64.73	110.00	67.57	70.00	53.71	216.2	138.35
2007	55.60	39.98	136.0	81.6	180.8	162.70	273.40	226.39	156.00	138.10	174.6	145.57

Year	Bableshwar				Telsang			
	Max. daily 'P',mm	Max. daily 'Q',mm	Max. weekly 'P',mm	Max. weekly 'Q',mm	Max. daily 'P',mm	Max. daily 'Q',mm	Max. weekly 'P',mm	Max. weekly 'Q',mm
1998	74.20	57.76	131.80	77.15	100.40	83.26	153	109.77
1999	44.60	29.71	77.60	35.15	55.40	39.79	126.6	66.28
2000	45.20	30.26	45.20	30.30	58.20	42.44	83.4	55.07
2001	98.00	80.91	141.40	99.40	84.20	67.45	164.4	131.02
2002	50.80	35.47	115.70	73.39	40.40	25.87	109.2	51.70
2003	19.20	7.92	19.20	7.92	0.00	0.00	0.00	0.00
2004	51.00	35.65	51.00	35.70	39.20	24.78	101.6	49.32
2005	65.00	48.92	105.00	74.42	30.20	16.83	50.40	25.50
2006	46.60	31.56	81.60	46.26	43.00	28.24	79.50	42.20
2007	200.00	181.78	200.00	181.80	140.80	123.05	140.8	123.10

P - Precipitation; Q - Runoff

Table: 2
Sub watershed wise highest maximum daily runoff and peak runoff rate recorded during 1998-2007

Sub watershed No	Sub watershed area (sq km)	Max. Daily Rainfall (mm)	Max. Daily Runoff (mm)	Peak discharge (cumec)
1	36.9	156	138.10	223.86
2	68.27	140.8	123.05	373.82
3	35.2	140.8	123.05	192.74
4	36.15	156	138.10	219.31
5	85.7	140.8	123.05	469.26
6	104.67	75.5	59.02	307.32
7	101.84	75.5	59.02	299.01
8	45.2	200	181.78	351.56
9	116.58	75.5	59.02	342.29
10	13	200	181.78	101.11

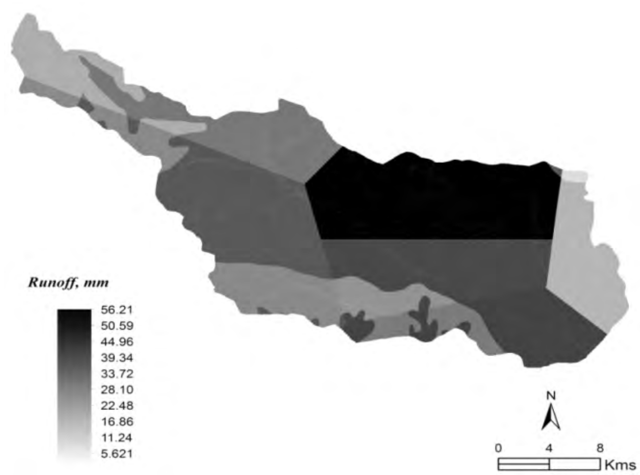

Fig. 8. Spatial distribution of monthly runoff for study area (September, 2007)

Table: 3
Sub watershed wise average monthly runoff yield (in mm) for the period of 1998-2007

Month	Sub watershed No.										Average (mm)
	1	2	3	4	5	6	7	8	9	10	
May	3.37	5.20	6.93	5.29	3.97	5.09	3.72	5.43	6.14	6.93	5.21
June	18.09	21.48	23.12	24.30	16.25	14.79	6.85	20.20	16.64	24.43	18.62
July	9.16	9.64	8.59	14.02	5.83	7.70	5.54	7.41	7.50	8.64	8.40
August	12.95	10.23	5.27	20.07	2.67	5.85	2.87	3.86	7.46	6.77	7.80
September	23.38	26.88	28.38	32.90	17.75	24.91	19.42	19.03	21.65	21.11	23.54
October	11.75	18.19	23.79	16.34	15.91	16.44	11.68	21.37	19.68	25.48	18.06

received 382 mm rainfall during September, 2001. Further, in most of the years, May month did not receive any runoff in most of the watersheds. On the contrary, September month received the runoff regularly and it is in agreement with the rainfall distribution. May and September months received minimum and maximum rainfall, respectively. The runoff process is not consistent and is variable during different months depending on the rainfall pattern.

Annual runoff analysis

The sub watershed wise annual rainfall, annual runoff and runoff percentage were analysed for the period of 1998-2007. The annual runoff varied from 1.54 (during 1998, watershed 3) to 29.49% (during 2007, watershed 10) of the annual rainfall. Year wise average runoff yield of all the watersheds is presented in Table 4. Annual runoff depth was in proportion to the annual rainfall. It was in the range of 5.08 to 25.66% of the annual rainfall (Shirahatti, 2009). Further, runoff has no consistent trend over the years. It is obvious that the years that received higher rainfall produced higher amount of runoff and *vice-versa*. During the years 2001 and 2007, the annual rainfall of 525 and 649.02 mm yielded 137.03 (25.66%) and 158.26 mm (24.24%) of the runoff, respectively. Though, annual rainfall of only 525.60 mm was received during the year 2001, but maximum runoff was observed (25.66%). This could be due to the heavy intensity of rainfall *i.e.,* more than 200 and 300 mm during the months of September and October in all the five rain gauge stations.

Further, the lowest runoff yield (5.08%) was recorded during the year 2003. During the study period, in the year 2003, lowest rainfall of 177.82 mm was received. The detailed analysis of the runoff data of all the watersheds over a period of 10 years period revealed that on an average, annual runoff yield (81.6 mm) of the watershed is equal to the 14.38% of the annual rainfall. It is near to the annual runoff yield of 11.97% estimated by Anon., (2000) in one of the sub watersheds of the study area.

Table: 4
Year wise average annual rainfall and corresponding runoff from the average of the sub-watersheds

Year	Annual rainfall 'P' (mm)	Annual runoff 'Q'(mm)	% of 'P'
1998	777.80	134.56	17.10
1999	539.28	79.48	14.20
2000	566.05	79.22	13.62
2001	525.60	137.03	25.66
2002	297.27	31.12	10.00
2003	177.82	9.84	5.08
2004	516.33	57.95	11.09
2005	389.22	38.42	9.29
2006	662.919	91.70	13.58
2007	649.021	158.26	24.24

P=Precipitation, Q= Runoff

Further, during the year 2000, annual rainfall recorded was 566.05 mm and corresponding runoff yield was 79.22 mm (13.62% of rainfall). This annual rainfall of 566.05 mm is very near to the normal annual rainfall of Bijapur *i.e.* 590 mm.

Yearly average (1998-2007) sub watershed wise runoff yield is presented in Table 5. The data revealed that availability of annual runoff yield was in the range of 121.33 ha-m (watershed 10) to 921.74 ha-m (watershed 9) with an average of 488.88 ha-m. In terms of the runoff as the percentage of rainfall, it was in the range of 12.9 (watershed 5) to 18.99% (watershed 4). The contents of this Table would be made use for prioritizing watershed for development on the basis of water availability and also for water harvesting and artificial recharge planning.

Model run for computing runoff at various probability levels of rainfall

The runoff yield at various probability levels of monthly rainfall is presented in Table 6. The data revealed that at 50% probability of rainfall, the runoff yield varied from 1.20 to 10.90 mm with an average of 4.48 mm, whereas at 75% of

Table: 5
Sub watershed wise availability of annual runoff

SW No	Avg. 'P' (mm)	Avg. 'Q' (mm)	% of 'P'	Sub watershed area (sq km)	Annual runoff (ha-m)
1	591.61	78.71	13.30	36.9	290.44
2	550.27	91.62	16.65	68.27	625.48
3	508.32	96.11	18.91	35.2	338.31
4	601.34	114.19	18.99	36.15	412.78
5	483.43	62.38	12.90	85.7	534.58
6	445.94	74.78	16.77	104.67	782.76
7	363.88	50.08	13.76	101.84	509.98
8	502.15	77.30	15.39	45.2	349.38
9	494.99	79.06	15.97	116.58	921.74
10	559.38	93.37	16.69	13	121.38

SW = Sub watershed; P = Precipitation; Q = Runoff

Table: 6
Occurrence of monthly rainfall at various probability level and their corresponding runoff, (mm)

Sub watershed No	'P' monthly prob. of occur. 50% (mm)	Runoff (mm)	'P' monthly prob. of occur. 75% (mm)	Runoff (mm)
1	74.19	2.11	28.78	0.04
2	69.40	4.10	27.38	0.47
3	65.01	5.25	26.12	0.93
4	74.70	5.99	28.86	0.53
5	62.07	1.54	27.55	0.25
6	57.06	3.20	24.59	0.77
7	47.10	1.12	22.42	0.67
8	64.71	2.27	32.86	1.05
9	70.75	10.90	31.11	0.82
10	75.60	8.36	36.10	1.19

P = Precipitation

probability level, the runoff yield ranged from 0.04 to 1.19 mm with an average of 0.67 mm. Analysis of results clearly revealed that at 75% probability of monthly rainfall, the runoff yield was very less, while at 50% probability level, it was relatively better. Hence, rainfall at 50 or less than 50% of probability level yields the moderate to good runoff.

Similarly, the runoff yield at various probability levels of daily rainfall was also calculated. The analysis revealed that at 10, 20 and 30% probability levels of rainfall, on an average the runoff yield recorded was 8.81, 3.06 and 1.19 mm, respectively. From the daily rainfall probability results, it was found that runoff occurred only at the probability levels of 20 or less than 20% *i.e.* equivalent to one in five rainfall events cause runoff.

Runoff based planning of SWC structures

In the design of SWC structures, the most important factors used are (i) peak runoff rates, (ii) runoff volume, and (iii) temporal distribution of runoff rates and volumes. In the present study, all these factors have been assessed for the upper Don river basin. The estimation of one day maximum runoff and peak runoff rates is essential for safe and cost effective planning and design of storage and drainage line treatment structures especially in arid and semi-arid regions. The identification of appropriate types of SWC structures should be taken into account by considering the need to retain runoff in areas where water is short or discharge runoff where it is in excess, they can also be designed so that part of the runoff is retained, but the excess, during heavy storms, is discharged. The design of any structure to retain or discharge runoff should be based on a reasonable estimate of the volume of runoff (m^3) to be retained or the peak rate of runoff ($m^3 s^{-1}$) to be discharged. In the higher rainfall areas (*e.g.* more than 1200 mm annum^{-1}), where crops are rarely shortage of water, it is necessary to design structures to discharge runoff , while in the drier areas (*e.g.* less than 750 mm annum^{-1}), it is desirable to harvest rainwater *in-situ* and to prevent runoff. The assessment of the runoff volume is useful for designing the short term rain water harvesting structures like contour as well as graded bunds and Zingg conservation terraces. The runoff volume information is also useful for designing the long term water harvesting structures like farm pond, earthen bund, tanks and percolation pond, while, the peak runoff rate information would be helpful in designing the bund surplussing structures, tank spillways, water ways, diversion drains and drainage line treatments. The design of a structure to discharge runoff can rarely be based on the heaviest storm possible. Usually, it is based on the heaviest storm that can be expected in a given return period (*e.g.* 10 or 20 years).

4. CONCLUSIONS

The information on spatial and temporal availability of runoff, one day maximum runoff and peak runoff rates is helpful for safe and cost effective planning and designing of storage and drainage line treatment structures. The runoff data analysis revealed that the runoff as the percentage of annual rainfall varied from 5.08 to 25.66% with average of 14.38% (81.6 mm) of annual rainfall. This information on surface water resources would be helpful for computing the water balance of the watershed as well as hydrologic, hydraulic and structural design of water harvesting and artificial recharge structures, which are proposed to be constructed in the watersheds. The GIS and RS technologies could be successfully used for assessing the surface water resources on spatial and temporal basis at ungauged watersheds.

ACKNOWLEDGEMENTS

The authors are grateful to the All India Coordinated Research Project on Dry Land Agriculture, CRIDA Hyderabad for providing necessary facilities to carry out the work and providing the funds.

REFERENCES

Anonymous. 2000. Water conservation measures in the arid and semi arid area of hard rock region. *Technical bulletin* No. CS/AR -32/99-2000. National Institute of Hydrology, Roorkee, 39 p.

Anonymous, 2000. Estimation report for Krishna and Pennar sub zone-(3h). Central Water Commission, Ministry of Water Resources, Government of India.

Crowin, D.L., Vaughan, D.J. and Loague, K. 1997. Modelling non-point source pollutants in the Vadoze zone with GIS. *Environ. Sci. Tech.*, 31(8): 2157-2175.

Durbude, D.G. and Chandramohan, T. 2000. Application of remote sensing technique for estimation of surface runoff from an unguaged watershed using SCS curve number method, *J. Appli. Hydrol.*, XIII(1&2): 1-9.

Gangodamage, C. 2001. Hydrological Modeling Using Remote Sensing and GIS. In: *22nd Asian Conference on Remote Sensing*, Singapore.

Jha, M.K. and Peiffer Stefan. 2006. *Applications of Remote Sensing and GIS Technologies in Groundwater Hydrology: Past, Present and Future*. University of Bayreuth, Germany, pp. 130-131.

Mohanty, S., Jena, S.K., Jha, M.K., Dash, S.S.J. and Kumar, Ashwani. 2015. Runoff estimation by composite and distributed curve number methods using remote sensing data. *Ind. J. Soil Cons.*, 43(2):120-124.

Ramesh, H., Pradeep, M.P. and Putti, M.R.Y. 2007. Evaluating and mapping of SCS-curve number for Lokapavani catchement using remote sensing and GIS. In: *3rd International Ground Water Conference*, Coimbatore, TS-1-15, pp. 1-8.

Rao, B.K., Singh, D.K. and Bhattacharya, A.K. 2002 Applicability of Curve Number method for Runoff estimation from extended duration of rainfall. *J. Soil Water Cons.*, 1(2&3): 163-170.

Rao, B.K., Singh, D.K. and Bhattacharya, A.K. 2003. Derivation of Curve Numbers from the Observed Rainfall and Runoff Data for Banha and Karso watersheds of Upper Damodar Valley. *J. Soil Water Cons.*, 2 (3&4): 136-145.

Rao, B.K., Kurothe, R.S., Mishra, P.K., Kumar, Gopal and Pande, V.C. 2015. Climate change impact on design & costing of soil & water conservation structures in watersheds, *Curr. Sci.,* 108(5): 960-966.

Ritzema, H.P. (ed.). 1994. *Drainage principles and applications*. ILRI Publication, No 16, Wagingen, pp. 604-607.

Sarkar, M.K., Behera, S., Panda, R.K. and Chowdary, U.M. 2004. Evaluation of suitability of composite and distributed curve number techniques using remote sensing and GIS. In: *Proc. International Conference on Emerging Technologies in Agricultural and Food Engineering,* IIT, Kargpur, pp. 73-77.

Ali, Shakir, 2011. A mathematical model for estimating surface runoff from small watersheds. *Ind. J. Soil Cons.*, 39(3):188-194.

Shirahatti, M.S. 2009. Development of an artificial recharge model using GIS and Remote Sensing for hard rock area. *Un-published Ph.D thesis* submitted to TNAU, Coimbatore.

Singh, P.K., Machiwal, D. and Roy, M.K. 2011. Modelling daily runoff and probabilistic estimation of design maximum daily runoff from selected watersheds of Udaipur, Rajasthan. *Ind. J. Soil Cons.*, 39(3):176-182.

Soil Conservation Department (SCD). 1972. *Hand book of Hydrology*. Ministry of Agriculture, New Delhi.

Subramanya, K. 1997. *Engineering Hydrology*, Tata McGraw Hill Publications, New Delhi, pp. 41- 44.

Watkins, D.W., Mckinney, D.C. Maidment, D.R. and Lin, M.D. 1996. Use of geographic information systems in groundwater flow modeling. *J. Water Resour. Planning Manage., ASCE,* 122(2): 88-96.