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Temporal Variability of Runoff on Mutukula Watershed, Prakasam District Using SCS Curve Number and GIS

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ABSTRACT

A watershed is commonly defined as an area in which all water drains to a common point. From a hydrological perspective, a watershed is a useful unit of operation and analysis because it facilitates a systems approach to land and water use in interconnected upstream and downstream areas. Watershed projects aim to maximize the quantity of water available for crops, livestock and human consumption through on-site soil and moisture conservation, infiltration into aquifers, and safe runoff into surface ponds. Remote sensing (RS) and Geographic Information System (GIS) can be effectively used to manage spatial and non-spatial database that represent the hydrologic characteristics of the watershed. Hence, the present study temporal variability of runoff was conducted by using annual, monthly and seasonal rainfall – runoff analysis of 35 years of period (1980-2014) rainfall data of study watershed by using methods like Soil Conservation Service – Curve Number (SCS-CN) and Arc GIS 9.3 tool. Mutukula watershed receives rainfall in almost all the months, the rainfall data of 1980 to 2014 reveals that the watershed received good rain during June to November with a mean monthly rainfall of 51.6, 98.9, 100.4, 87.7, 115.3, 61.9 mm in June, July, August, September, October, November respectively. Watershed generates good runoff during June to November with a total mean monthly runoff of 0.1 mm during January and 1.3 mm rainfall during December. Watershed receives rainfall in all the three season, during Kharif season receives the highest average rainfall amount 402.3 mm, compare to other two seasons, in Rabi season 93.6 mm and Zaid season 104.3 mm. Seasonal runoff in Kharif season the highest amount of average runoff with 21.2 mm throughout the watershed, and fallowed by Rabi with 8.0 mm, Zaid with 4.1 mm.

Keywords

Watershed, Rainfall, Runoff, SCS Curve Number, GIS, RS, DWMA, USSCS

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Introduction

Water, a unique resource on the planet earth, is essential for sustaining all forms of life, food production, economic development, and for general well-being of the life on the planet. Water resources are essential renewable resources that are the basis for existence and development of a society. Proper utilization of

these resources requires assessment and management of the quantity and quality of the water resources both spatially and temporally. Water resources of a country constitute one of its vital assets. India receives annual precipitation of about 4000 km³ and India's average annual surface run-off generated by rainfall and snowmelt is estimated to be about 1869 billion cubic meters (BCM). However, it

is estimated that only about 690 BCM or 37% of the surface water resources can actually be mobilized. The average annual rainfall in India is about 1170 mm. This is considerable variation in rainfall both temporarily and spatially. The total water resources (surface water and groundwater) of Andhra Pradesh are estimated to be about 108 BCM (about 78 BCM from surface water, primarily from the Godavari and Krishna rivers), of which nearly 65 BCM are currently utilized (0.6 BCM for drinking, 64 BCM for irrigation, 0.3 BCM for industry and 0.3 BCM for power generation). Most of the water (about 92%) is currently supplied for irrigation, although other needs are expected to grow in the future. The current trends of increase in water supply from all users will outstrip available supplies significantly by 2025.

Soil and water conservation measures play a vital role for developing a sustainable watershed development programme. Integration of relevant parameters of a watershed, climatological data, soil characteristics, topography, crop management, and supporting conservation practice beneficial in conjunction with social limitations and opportunity involves analysis of huge data. Computer based planning and design tools have been observed to be very much for developing a proper watershed development plan. Remote Sensing (RS) and Geographical Information System (GIS) have been found very much useful for storing, retrieving and analyzing these data efficiently and effectively.

Hence taking the concern of huge investments, Government of India allocating for watershed development programme in the five year plans, it is felt highly essential to work on impact assessment studies on this developed watersheds using advanced tools such as RS and GIS for operational convenience it is proposed to take up studies in nearby

watersheds where such focus is being carried out by District Water Management Agency (DWMA). Prakasam District, Andhra Pradesh is selected for this study. There are two reasons to select the District. Firstly, in most of the areas in the District agriculture is rain-fed and also the rain fall is scarce and erratic. Secondly, it is one of the few Districts not only in Andhra Pradesh, but also in the country where a number of watershed programmes have been launched in the rain-fed areas and a number of NGOs were entrusted with the initiation and management of watershed programme.

The present study proposed to with an objective to evaluate temporal variability on runoff using runoff model was conducted for Mutukula watershed, Pullalachruvu Mandal, Prakasam (District) in Andhra Pradesh

Materials and Methods

Study area

The Mutukula watershed with an extent of 51 km² lies in Prakasam District in Andhra Pradesh. This area was located between 16°10'45.4" to 16°16'52.9" Northern latitude and 79°20'53.5" to 79°33'28.2" Eastern longitude, with average elevation ranging 620 m above MSL (Mean Sea Level). The watershed receives average annual rainfall of 600.2 mm, the minimum and maximum temperature is in range of 25°C to 45°C. The study area and its location map were shown in Figure 1. The watersheds of the Eastern range of hills forms the boundary between Giddalur and Kanigiri Mandals. The water from these hills drains towards direction and joins in Gundlakamma river.

Land use / Land cover map

The conventional land use/ land cover map of the watershed was obtained from the National

Remote Sensing Agency, Department of Space, Hyderabad. Boundaries of different land use were digitized in Arc INFO and the attributes were given. Four land use/ land covers were presented in Table 1.

As the cropping pattern and vegetation influences as part of the runoff pattern, it is classified into *Kharif*, *Kharif + Rabi*, degraded forest / scrub land and deciduous forest. It is evident from the above table that about 62.98% of land is under deciduous forest and followed by *Kharif*, 19.70%. The land use/land cover pattern procured from NRSA (National Remote Sensing Agency). After digitization with false colour complex and process through Arc INFO the final map is presented in (Figure 2) with all the land uses for further better planning and monitoring.

Soil textural status of the study area

The soil map of the watershed was obtained from the National Remote Sensing Agency, Department of Space, Hyderabad. Boundaries of different soil textures were representing various soils classes were assigned with different colours for recognition and Hydrologic soil groups *i.e.* A, B, C, and D were considered for the classification of the watershed, and were enlisted in Table 2.

Hydrological Soil Group (HSG) classification

SCS developed soil classification system that consists of four groups, which are identified as A, B, C, and D according to their minimum infiltration rate. The hydrological soil group classification, by US Soil Conservation Service (USSCS) is given in Table 3. CN values were determined from hydrological soil group and antecedent moisture conditions of the watershed. Runoff curve numbers (AMC II) for hydrologic soil cover complex are in appendix I and appendix II. The Curve

Number values for AMC-I and AMC-III were obtained from AMC-II by the method of conservation.

Antecedent Moisture Condition (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is determined by total rainfall in 5 day period preceding a storm. The AMC value is intended to reflect the effect of infiltration on both the volume and rate of runoff according to the infiltration curve. An increase in index means an increase in the runoff potential. Three antecedent soil-moisture conditions and labeled them as I, II, III, according to soil conditions and rainfall limits for dormant and growing seasons. Classification of Antecedent Moisture Condition is shown in Table 4.

SCS curve number method

Runoff is one of the important hydrologic variables used in the water resources applications and management planning. Estimation of surface runoff is essential for the assessment of water yield potential of the watershed, planning of water conservation measures, recharging the ground water zones and reducing the sedimentation and flooding hazards downstream.

The curve number method (Soil Conservation Services, SCS, 1972) also known as the hydrologic soil cover complex method, is a versatile and widely used procedure for runoff estimation. This method includes several important properties of the watershed namely soil permeability, land use and antecedent soil water conditions which are taken into consideration.

Surface runoff is mainly controlled by the amount of rainfall, initial abstraction and moisture retention of the soil. The SCS curve

number method is based on the water balance equation and two fundamental hypotheses which are stated as, ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration, and the amount of initial abstraction is some fraction of the potential infiltration.

Mathematically this can be represented as

$$\frac{Q}{(P-I_a)} = \frac{F}{S} \quad (1)$$

$$F = (P - I_a) - Q \quad (2)$$

F= Cumulative infiltration (mm),

Substituting eq. (2) in eq. (1) and by solving

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad (3)$$

Where,

Q = actual runoff (mm),

P = rainfall (mm),

I_a = initial abstraction,

Which represents all the losses before the runoff begins and is given by the empirical equation.

$$I_a = 0.2 S \quad (4)$$

Substituting eq. (4) in eq. (3). Then the eq. (2) becomes

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad (5)$$

S= the potential maximum infiltration after the runoff begins given by following equation

$$S = \frac{25400}{CN} - 254$$

Where CN is Curve Number and is estimated using antecedent moisture condition and hydrological soil group of the area.

Results and Discussion

Temporal variability of runoff was carried out based on the SCS-CN method for all 35 years.

The different layers of soil, Hydrologic soil group and land use/land cover were overlaid one by one and the new PAT (Polygon Attribute Table) was obtained using Arc GIS 9.3. The result obtained from this PAT was used to compute the total area weighted curve number of the study area to calculate the AMC-II refer Table 5. For the weighted curve numbers of AMC-I and AMC-III conversion factors are given in appendix III.

Using the land use and soil maps the weighted curve number values obtained are 40.73, 56.65, and 71.42 for AMC-I, AMC-II and AMC-III respectively.

Analysis of Monthly Rainfall and Runoff Data

Mutukula watershed receives rainfall in almost all the months, the rainfall data of 1980 to 2014 reveals that the watershed received good rain during June to November with a mean monthly rainfall of 51.6, 98.9, 100.4, 87.7, 115.3, 61.9 mm in June, July, August, September, October, November respectively. The month wise rainfall pattern of watershed enlisted in Table 6. The maximum average rainfall occurred during the October of 115.3 mm and minimum of rainfall occurred during the January of 7.7 mm (Figure 3).

The estimated runoff for the years 1980 to 2014 reveals that the watershed generates good runoff during June to November. The month wise runoff pattern of watershed enlisted in Table 7.

Fig.1 Index map of the study area, Mutukula watershed

Fig.2 Digitized land use/ land cover map of Mutukula watershed

Fig.3 Monthly rainfall (mm) pattern of Mutukula watershed

Fig.4 Monthly runoff (mm) pattern of Mutukula watershed

Fig.5 Seasonal rainfall (mm) pattern of Mutukula watershed

Fig.6 Temporal variation of annual and seasonal rainfall distribution during period (1980 to 2014) of Mutukula watershed

Fig.7 Seasonal runoff (mm) pattern of Mutukula watershed

Fig.8 Rainfall - runoff relationship of Mutukula watershed

Fig.9 Rainfall - runoff as percentage of rainfall relationship of Mutukula watershed

Fig.10 Annual rainfall during period (1980 to 2014) of Mutukula watershed

Fig.11 Annual runoff during period (1980 to 2014) of Mutukula watershed

Table.1 Land use/land cover classes present in the study area

S.No.	Land use/ Land cover	Area (ha)	Area (%)
1	<i>Kharif</i>	1005	19.70
2	Double crop (<i>Kharif</i> + <i>Rabi</i>)	803	15.79
3	Degraded forest / Scrub land	80	1.56
4	Deciduous forest without scrub	3212	62.98
	Total Area	5100	100

Table.2 Soil texture and hydrological soil groups of watershed

S. No.	Land use/ Land cover	Soil Texture	Hydrologic Group
1	<i>Kharif</i>	Sandy Clay Loam	C
2	Double crop (<i>Kharif</i> + <i>Rabi</i>)	Sandy Loam	A
3	Degraded forest / Scrub land	Sandy Clay Loam	C
4	Deciduous forest without scrub	Loamy Sand	A

Table.3 Hydrological soil group classification given by USSCS

S. No.	Hydrologic Soil Group	Type of Soil	Runoff potential	Final infiltration rate (mm/hr)
1	Group A	Deep, well drained sands and gravels	Low	>7.5
2	Group B	Moderately deep, well drained with moderately fine to coarse textures	Moderate	3.8 – 7.5
3	Group C	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderate	1.3 – 3.8
4	Group D	Clay soils that swell significantly when wet, heavy plastic and soils with a permanent high water table	High	< 1.3

Table.4 Classification of Antecedent Moisture Conditions (AMC)

S. No.	AMC Class	Description of soil condition	Total five day antecedent rainfall (mm)	
			Dormant season	Growing season
1	I	Soils are dry but not to the wilting point, satisfactory cultivation has taken place	< 12.7 mm	< 35.56 mm
2	II	Average conditions.	12.7-27.94 mm	35.56-52.34 mm
3	III	Heavy rainfall or light rainfall and low temperatures have occurred within last 5 days, Saturated soils.	> 27.94 mm	52.34 mm

Table.5 Weighted curve numbers for Mutukula watershed

S.No.	Land use/ Land cover	Soil Group	Area (ha)	CN	Weighted curve Number
1	<i>Kharif</i>	C	1005	88	AMC-I = 40.73 AMC-II = 56.65 AMC-III = 71.42
2	Double crop (<i>Kharif</i> + <i>Rabi</i>)	A	803	62	
3	Degraded forest / Scrub land	C	80	77	
4	Deciduous forest without scrub	A	3212	45	

Table.6 Monthly rainfall (mm) values for Mutukula watershed

S. No.	Year/ Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual rainfall (mm)
1	1980	0.7	0	1.6	1.3	24	120.2	89.4	84.3	62.9	68.5	57.4	1.2	511.5
2	1981	4.4	0.7	12.6	31.8	9.1	56.2	54.8	75.7	66.1	88.8	19.5	4.5	424.2
3	1982	2.6	0	0	5.4	17.7	48.9	73.4	42.5	66.5	115.7	84.5	0	457.2
4	1983	0	1	0.1	27.4	14.5	37.1	202.7	128	205	145.8	8.7	3.2	773.5
5	1984	2.5	5.5	0.6	1.5	0.1	23.4	114.2	35.1	50	74.8	13	2.2	322.9
6	1985	34.9	0	12.3	2.4	22.7	41.1	163.2	73	67.4	161.8	21.7	54.2	654.7
7	1986	43.1	6.8	0	5.9	29.9	60.1	69.1	107.8	70.5	116.8	57.6	4.3	571.9
8	1987	23.5	0.1	31.9	2.3	17.6	42.4	54.6	117.1	50.6	193.8	147.8	30.4	712.1
9	1988	0	2.4	9.3	17.5	24.7	43.8	141.5	159.5	124.5	27.1	3.8	52.5	606.6
10	1989	0	0	42.7	0.2	5.9	38.8	207.3	82.3	156.6	30.9	44.1	15.4	624.2
11	1990	5.4	8	28.7	10	188.3	76.6	45.3	124.8	96	83	125.3	1.7	793.1
12	1991	7.8	0	0.8	3.6	18.9	150.2	54.4	71.9	146.8	92.2	165.5	9.1	721.2
13	1992	13.4	0.5	0	1.2	28.8	27.1	54.5	156.2	76.3	77.7	125.8	1.6	563.1
14	1993	0	0	5.2	3.1	34.8	35.7	94.6	59.5	76.7	144.5	58.6	17.3	530.0
15	1994	10.5	18.6	0.1	14	46.8	25.4	81	106.5	13.9	265.9	137.2	3.1	723.0
16	1995	21.9	0	8.8	0.9	64.5	41.2	117.2	106.7	99.4	201.1	9.8	0.5	672.0
17	1996	0	0.2	0	18.9	15.9	109.4	76	153.8	129.1	196.6	32.2	9.9	742.0
18	1997	41.7	0	2.4	41	3.4	10.1	62	55.1	284.1	118.4	89.2	160.2	867.6
19	1998	0.2	3.2	0.2	15.7	31.2	53	104.5	114.4	102.9	215.5	52.1	0	692.9
20	1999	0.1	6.6	0	0	20.5	37.5	112.3	117.5	89.9	67.3	1.7	0.5	453.9
21	2000	0	113	0.4	1.8	26.3	114.9	110.4	302.5	29.3	51	15.6	9.8	775.0
22	2001	13.2	0	4.3	23.7	4.3	50.6	34.3	84.4	71.5	150.6	31.5	3.4	471.8
23	2002	14.3	0.1	0.7	1	27.1	32.2	34.8	76.4	21	122.4	27.7	0	357.7
24	2003	2.4	0.3	15.4	1	0.3	49.5	100.1	80	66.7	106.1	4.7	35	461.5
25	2004	21.4	0.1	1.7	4.9	88.4	21.2	191.2	35.8	112.6	62.5	16.7	0	556.5
26	2005	4.3	7.6	3.2	4.8	14.2	17.5	105.9	50.2	102.6	176.5	18.1	1.5	506.4
27	2006	0	0	22.1	24.2	43.2	47.1	70.4	47.6	88.6	81	114.5	1.2	539.9
28	2007	0	1	0	5.9	10.9	110.2	52.5	97	124.7	60.8	18.1	1.3	482.4
29	2008	0	0	198	0	25	0	72	189	0	69	153	0	706.0
30	2009	0	0	5	0	7	75	0	112.8	85	74.4	49.4	0	408.6
31	2010	0	0	0	14	62	45.4	200	87.2	45.8	39	150.6	64.9	708.9
32	2011	0	0	0	2.6	94.6	45.4	200	87.2	54.8	39	150.6	65	739.2
33	2012	0	0	0	4.8	44.8	0	81	34.6	50.2	134.8	2.4	0	352.6
34	2013	0	100.6	0	12.2	51	40.6	84.2	103.4	86	164.8	100.8	0	743.6
35	2014	0	10.8	0	0	12	77.6	151.8	155.4	96	216.4	57.8	0	777.8
Avg.		7.7	8.2	11.7	8.7	32.3	51.6	98.9	100.4	87.7	115.3	61.9	15.8	600.2

Table.7 Monthly runoff (mm) values for Mutukula watershed

S. No.	Year/ Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual runoff (mm)
1	1980	0.0	0.0	0.0	0.0	0.0	3.5	0.7	2.4	0.0	5.4	1.0	0.0	13.1
2	1981	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	1.0
3	1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.9	2.6	0.0	20.5
4	1983	0.0	0.0	0.0	0.0	0.0	0.0	11.2	5.0	7.0	4.4	0.0	0.0	27.6
5	1984	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.4	0.5	0.3	0.0	0.0	2.3
6	1985	0.2	0.0	0.0	0.0	0.0	0.0	18.3	0.0	0.0	7.6	0.0	2.8	28.9
7	1986	1.0	0.0	0.0	0.0	0.2	0.1	1.9	5.7	0.0	3.7	0.7	0.0	13.3
8	1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.1	22.7	19.9	0.1	45.9
9	1988	0.0	0.0	0.0	0.0	0.0	0.0	2.9	2.4	11.4	0.0	0.0	2.4	19.1
10	1989	0.0	0.0	3.0	0.0	0.0	0.0	33.3	0.0	4.9	0.1	0.0	0.0	41.2
11	1990	0.0	0.0	0.0	0.0	21.4	1.9	0.0	2.6	0.0	2.3	19.6	0.0	47.7
12	1991	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.8	18.5	3.8	16.5	0.0	50.8
13	1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	3.0	8.5	0.0	23.1
14	1993	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	8.6	0.0	0.0	9.8
15	1994	0.0	0.0	0.0	0.0	1.0	0.0	0.1	3.1	0.0	27.3	21.3	0.0	52.7
16	1995	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.4	20.2	0.0	0.0	21.3
17	1996	0.0	0.0	0.0	0.0	0.0	4.6	0.0	3.5	0.1	18.0	0.0	0.0	26.2
18	1997	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.9	6.0	0.0	20.3	68.6
19	1998	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	12.1	0.0	0.0	12.4
20	1999	0.0	0.0	0.0	0.0	0.0	0.0	0.2	5.5	0.1	0.5	0.0	0.0	6.2
21	2000	0.0	16.3	0.0	0.0	0.0	0.7	8.4	55.3	0.0	0.0	0.0	0.0	80.8
22	2001	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	8.3	0.0	0.0	8.6
23	2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	5.3
24	2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	2.2
25	2004	0.0	0.0	0.0	0.0	1.4	0.0	3.8	0.1	1.3	0.0	0.0	0.0	6.7
26	2005	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	1.8	6.7	0.0	0.0	13.1
27	2006	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.4	7.5	18.1	0.0	33.6
28	2007	0.0	0.0	0.0	0.0	0.0	9.2	0.0	2.6	0.8	0.0	0.5	0.0	13.1
29	2008	0.0	0.0	46.1	0.0	0.2	0.0	10.3	59.3	0.0	4.8	20.6	0.0	141.2
30	2009	0.0	0.0	0.0	0.0	0.0	14.8	0.0	4.7	0.0	9.4	0.1	0.0	28.9
31	2010	0.0	0.0	0.0	0.0	2.9	3.1	20.5	3.6	0.0	0.0	22.2	9.5	61.8
32	2011	0.0	0.0	0.0	0.0	4.9	3.1	20.5	3.6	0.0	0.0	22.2	9.5	63.8
33	2012	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	5.2	12.2	0.0	0.0	17.6
34	2013	0.0	30.6	0.0	0.0	0.5	0.5	5.6	3.5	0.4	44.2	13.1	0.0	98.4
35	2014	0.0	0.0	0.0	0.0	0.0	8.7	12.6	14.7	0.7	23.1	0.4	0.0	60.2
Avg.		0.1	1.3	1.4	0.0	0.9	1.8	4.7	5.6	2.7	8.2	5.3	1.3	33.4

Table.8 Seasonal rainfall (mm) pattern and seasonal rainfall distribution (%) of Mutukula watershed

		Seasonal rainfall (mm)			Seasonal rainfall distribution (%)			
S. No.	Year	<i>Kharif</i>	<i>Rabi</i>	<i>Zaid</i>	<i>Kharif</i>	<i>Rabi</i>	<i>Zaid</i>	Annual rainfall (mm)
1	1980	305.1	59.3	147.1	59.6	11.6	28.8	511.5
2	1981	285.4	29.1	109.7	67.3	6.9	25.9	424.2
3	1982	298.1	87.1	72	65.2	19.1	15.7	457.2
4	1983	681.5	12.9	79.1	88.1	1.7	10.2	773.5
5	1984	274.1	23.2	25.6	84.9	7.2	7.9	322.9
6	1985	465.4	110.8	78.5	71.1	16.9	12.0	654.7
7	1986	364.2	111.8	95.9	63.7	19.5	16.8	571.9
8	1987	416.1	201.8	94.2	58.4	28.3	13.2	712.1
9	1988	452.6	58.7	95.3	74.6	9.7	15.7	606.6
10	1989	477.1	59.5	87.6	76.4	9.5	14.0	624.2
11	1990	349.1	140.4	303.6	44.0	17.7	38.3	793.1
12	1991	365.3	182.4	173.5	50.7	25.3	24.1	721.2
13	1992	364.7	141.3	57.1	64.8	25.1	10.1	563.1
14	1993	375.3	75.9	78.8	70.8	14.3	14.9	530.0
15	1994	467.3	169.4	86.3	64.6	23.4	11.9	723.0
16	1995	524.4	32.2	115.4	78.0	4.8	17.2	672.0
17	1996	555.5	42.3	144.2	74.9	5.7	19.4	742.0
18	1997	519.6	291.1	56.9	59.9	33.6	6.6	867.6
19	1998	537.3	55.5	100.1	77.5	8.0	14.4	692.9
20	1999	387	8.9	58	85.3	2.0	12.8	453.9
21	2000	493.2	138.4	143.4	63.6	17.9	18.5	775.0
22	2001	340.8	48.1	82.9	72.2	10.2	17.6	471.8
23	2002	254.6	42.1	61	71.2	11.8	17.1	357.7
24	2003	352.9	42.4	66.2	76.5	9.2	14.3	461.5
25	2004	402.1	38.2	116.2	72.3	6.9	20.9	556.5
26	2005	435.2	31.5	39.7	85.9	6.2	7.8	506.4
27	2006	287.6	115.7	136.6	53.3	21.4	25.3	539.9
28	2007	335	20.4	127	69.4	4.2	26.3	482.4
29	2008	330	153	223	46.7	21.7	31.6	706.0
30	2009	272.2	49.4	87	66.6	12.1	21.3	408.6
31	2010	372	215.5	121.4	52.5	30.4	17.1	708.9
32	2011	381	215.6	142.6	51.5	29.2	19.3	739.2
33	2012	300.6	2.4	49.6	85.3	0.7	14.1	352.6
34	2013	438.4	201.4	103.8	59.0	27.1	14.0	743.6
35	2014	619.6	68.6	89.6	79.7	8.8	11.5	777.8
Mean		402.3	93.6	104.3	68.2	14.5	17.3	600.2
S _d		103.0	73.1	52.9	11.7	9.2	7.0	146.4
C _v (%)		25.6	78.1	50.8	17.2	63.4	40.3	24.4

Table.9 Seasonal runoff (mm) values of Mutukula watershed

		Runoff (mm)			
S. No.	Year	<i>Kharif</i>	<i>Rabi</i>	<i>Zaid</i>	Annual
1	1980	8.5	1.0	3.5	13.1
2	1981	0.5	0.0	0.5	1.0
3	1982	17.9	2.6	0.0	20.5
4	1983	27.6	0.0	0.0	27.6
5	1984	2.3	0.0	0.0	2.3
6	1985	25.9	3.0	0.0	28.9
7	1986	11.3	1.7	0.3	13.3
8	1987	25.9	20.0	0.0	45.9
9	1988	16.7	2.4	0.0	19.1
10	1989	38.3	0.0	3.0	41.2
11	1990	4.9	19.6	23.3	47.7
12	1991	23.2	16.5	11.2	50.8
13	1992	14.6	8.5	0.0	23.1
14	1993	9.7	0.0	0.0	9.8
15	1994	30.5	21.3	1.0	52.7
16	1995	21.3	0.0	0.0	21.3
17	1996	21.6	0.0	4.6	26.2
18	1997	46.9	21.7	0.0	68.6
19	1998	12.4	0.0	0.1	12.4
20	1999	6.2	0.0	0.0	6.2
21	2000	63.7	16.3	0.7	80.8
22	2001	8.5	0.0	0.1	8.6
23	2002	5.3	0.0	0.0	5.3
24	2003	2.2	0.0	0.0	2.2
25	2004	5.3	0.0	1.4	6.7
26	2005	13.1	0.0	0.0	13.1
27	2006	15.5	18.1	0.0	33.6
28	2007	3.4	0.5	9.2	13.1
29	2008	74.3	20.6	46.3	141.2
30	2009	14.1	0.1	14.8	28.9
31	2010	24.1	31.7	6.0	61.8
32	2011	24.2	31.7	8.0	63.8
33	2012	17.5	0.0	0.1	17.6
34	2013	53.6	43.8	1.1	98.4
35	2014	51.1	0.4	8.7	60.2
Avg.		21.2	8.0	4.1	33.4

Table.10 Annual rainfall (mm), runoff (mm) and runoff as percentage of rainfall (%) for watershed

S. No.	Year	Annual rainfall (mm)	Annual runoff (mm)	Runoff as percentage (%) of rainfall
1	1980	511.5	13.1	2.6
2	1981	424.2	1.0	0.2
3	1982	457.2	20.5	4.5
4	1983	773.5	27.6	3.6
5	1984	322.9	2.3	0.7
6	1985	654.7	28.9	4.4
7	1986	571.9	13.3	2.3
8	1987	712.1	45.9	6.5
9	1988	606.6	19.1	3.2
10	1989	624.2	41.2	6.6
11	1990	793.1	47.7	6.0
12	1991	721.2	50.8	7.0
13	1992	563.1	23.1	4.1
14	1993	530	9.8	1.8
15	1994	723	52.7	7.3
16	1995	672	21.3	3.2
17	1996	742	26.2	3.5
18	1997	867.6	68.6	7.9
19	1998	692.9	12.4	1.8
20	1999	453.9	6.2	1.4
21	2000	775	80.8	10.4
22	2001	471.9	8.6	1.8
23	2002	357.7	5.3	1.5
24	2003	461.5	2.2	0.5
25	2004	556.5	6.7	1.2
26	2005	506.4	13.1	2.6
27	2006	539.9	33.6	6.2
28	2007	482.4	13.1	2.7
29	2008	706	141.2	20.0
30	2009	408.6	28.9	7.1
31	2010	708.9	61.8	8.7
32	2011	739.2	63.8	8.6
33	2012	352.6	17.6	5.0
34	2013	743.6	98.4	13.2
35	2014	777.8	60.2	7.7
Avg.		600.2	33.4	5.0

The maximum average runoff occurred during the month October of 8.2 mm and there is less runoff during December to May, because there is less rainfall during the respective months (Figure 4).

Analysis of seasonal rainfall and runoff data

Seasonal rainfall and runoff of watershed area can be classified into *Kharif* season (July to October), *Rabi* season (November to February) and in Zaid (March to June) season. Watershed receives rainfall in all the three season, during *Kharif* season receives the highest average rainfall amount 402.3 mm, compare to other two seasons shows in the Figure 5. In *Rabi* season 93.6 mm, and Zaid season 104.3 mm. In *Kharif* season maximum rainfall receives during 1983 of 681.5 mm, and minimum amount during 2002 of 254.6 mm. In *Rabi* season maximum rainfall during the 1997 amount of 291.1 mm. and minimum in the year 2012 amount of 2.4 mm. In the Zaid season the maximum amount receives during period 1990 of 303.6 mm. and minimum during 1984 amount of 25.6 mm. are presented in Table 8.

Average annual rainfall distribution (%) during the last three decades (1980 to 2014) was 600.2 mm (ranged as 511.5 mm in 1980 and 777.8 mm in 2014) and 68.2% of which occurred during *Kharif* season, and 14.5% in *Rabi* season and 17.3% in Zaid season (Table 8). Coefficient of variation in seasonal rainfall was 25.6% for *Kharif* season, 78.1% for *Rabi* and 50.8% for Zaid season. Therefore, cultivation in the *Kharif* season required assured irrigation. However, *Rabi* and Zaid season cultivation may be carried out under rain fed condition depending upon the water requirement of crops to be cultivated. Marked variation of annual rainfall was observed during the last three decades, (Figure 6).

In seasonal runoff analysis, the amount of runoff generated in the watershed was estimated during the period of seasons. The highest amount of average runoff with 21.2 mm from the watershed in *Kharif* season is followed by *Rabi* with 8.0 mm, Zaid with 4.1 mm (Figure 7). In *Kharif* season, highest runoff was recorded during the period 2008 with 74.3 mm, and minimum runoff was recorded in the year 1981 with 0.5 mm. During the *Rabi* season, maximum runoff was recorded in the year 2013 with runoff of 43.8 mm, minimum runoff in watershed having the 0 mm, in the fifteen years. In Zaid season maximum runoff during the period of 2008 amount of 46.3 mm as like *Rabi* season Zaid season also having fifteen years of 0 mm (Table 9).

Analysis of annual rainfall and runoff data

The mean average annual rainfall of the study area for the period between 1980 and 2014 is 600.2 mm with a maximum rainfall of 867.6 mm during the year 1997 and a minimum rainfall of 322.9 mm during the year 1984. From SCS Curve number, estimate the maximum runoff for the watershed was estimated to be 141.2 mm in the year 2008 and minimum runoff of 1 mm in the year 1981. The annual rainfall and annual runoff and also runoff as percentage of rainfall for Mutukula watershed for the period of 1980 to 2014 (Table 10). The rainfall and runoff relationship for Mutukula watershed represented in Figure 8. The rainfall and runoff are strongly correlated with Regression coefficient (R^2) value being 0.642.

The relationship between annual rainfall and runoff as percentage of rainfall, the maximum runoff was 20% during the year 2008 and minimum runoff percentage 0.2% during the year 1981 (Figure 9). The rainfall and percentage of runoff are strongly correlated with Regression coefficient (R^2) value being

0.422. The runoff percentage of rainfall sharply increases with significant increase in rainfall. This is reflected in Regression coefficient (R^2) value being 0.642 between runoff and rainfall.

However, trend analysis of annual rainfall during the years 1980 to 2014 revealed that annual rainfall increased over the past three decades at the rate of 0.696 mm per annum (Figure 10). Analysis of total annual runoff as increased over the past three decades at the rate of 1.106 mm per annum as (Figure 11). In the timeline, it could be observed that the runoff increased due to various reasons like deforestation, overgrazing and bare soil exposure etc. However the impact of watershed works could be witnessed only gradually because they are ongoing still in the Mutukula watershed. Hence the study is required to be continued to exactly assess the impact of watershed works.

The present study concluded that the PAT (polygon attribute table) was used to compute the total area weighted curve number of the study area by using the land use and soil maps the weighted curve number values obtained are 40.73, 56.65, and 71.42 for AMC –I, AMC –II and AMC –III respectively. Mutukula watershed receives rainfall in almost all the months, the rainfall data of 1980 to 2014 reveals that the watershed received good rain during June to November with a mean monthly rainfall of 51.6, 98.9, 100.4, 87.7, 115.3, 61.9 mm in June, July, August, September, October, November respectively. Watershed generates good runoff during June to November with a total mean monthly runoff of 0.1 mm during January and 1.3 mm rainfall during December. Watershed receives rainfall in all the three season, during Kharif season receives the highest average rainfall amount 402.3 mm, compare to other two seasons, in Rabi season 93.6 mm and Zaid season 104.3

mm. Seasonal runoff in Kharif season the highest amount of average runoff with 21.2 mm throughout the watershed, and followed by Rabi with 8.0 mm, Zaid with 4.1 mm. The mean average annual rainfall of the study area for the period between 1980 and 2014 is 600.2 mm with a maximum rainfall of 867.6 mm during the year 1997 and a minimum rainfall of 322.9 mm during the year 1984. From SCS Curve number, estimate the maximum runoff for the watershed was estimated to be 141.2 mm in the year 2008 and minimum runoff of 1 mm in the year 1981.

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