Vol. 47, No. 3, pp 239-243, 2019
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Runoff estimation using SCS-CN method for Bhadokhar watershed, Jhansi district, Uttar Pradesh

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ARTICLE INFO

Article history:
Received : April, 2019
Revised : November, 2019
Accepted : December, 2019

Key words:
Antecedent moisture
Curve number
Potential maximum retention
Runoff
Watershed
Bundelkhand region

ABSTRACT

This study was conducted to determine runoff depth using USDA soil conservation service curve number (SCS-CN) method in Bhadokhar watershed, located in Gursarain block of Jhansi district, Uttar Pradesh. A total of 55 single storm events were selected between the years 1993 and 2012 for estimation. Antecedent moisture content (AMC) of the watershed during the selected period was calculated by taking preceding five days rainfall for three conditions *viz*., AMC-I, AMC-II and AMC-III. Based on the soil cover complex, the hydrological soil group of the watershed falls under group 'B'. It was observed that during the period, 33 rain storms were falling under AMC-I category. Weighted curve number (CN) for entire watershed was calculated based on the watershed information and found to be 83.62 for AMC-II. The CN values corresponding to AMC-I and AMC-III were 69.12 and 92.28, respectively. The runoff for each storm events was estimated and it was found that among the selected storm events, the maximum rainfall was 109.5 mm on 11th September, 1993 at AMC-III. The runoff volume of the watershed for this storm event was calculated as 853117.96 m^3. This value will be useful for designing the soil and water conservation and also rainwater harvesting structures in the watershed.

1. INTRODUCTION

Runoff is one of the most important hydrologic variables in water resources management. The occurrence and quantity of runoff are dependent on rainfall characteristics *viz*., intensity, duration and distribution, and watershed characteristics *viz*., size, shape, infiltration rate, soil texture, topography, soil cover etc. The rainfall runoff behavior of a watershed is complex and non-linear in nature (Sivakumar and Singh, 2012) yet, the linear theory is frequently used because it is mathematically much easier to handle as compared to non-linear regression models.

Direct measurement of runoff in a watershed is a cumber some process because it requires installation and periodical monitoring of various equipments and instruments. Amongst indirect methods, curve number (CN) method can be successfully used to estimate the runoff required for the design of permanent soil conservation and water harvesting structures. The CN method of estimating runoff volumes from rainfall is simple and easy to use (Bansode and Patil, 2014), however, Boughton (1989) reported that major weakness of CN method is the sensitivity of estimated runoff to errors in the selection of the CN. It works well for a wide range of agricultural soil cover complexes. The CN method for estimation of runoff volume is very helpful to engineers and planners. CN is derived from the characteristics of the soil, vegetation (including crops) and land use pattern.

Bhadokhar watershed situated at Gursarain block of Jhansi district, Uttar Pradesh, frequently experiences problems of water scarcity, thereby affecting agriculture production. This watershed has undulating topography with an average slope of 1-5%. Most of the water received does not infiltrate well, and goes waste as runoff. Therefore, it is very essential to take up suitable measures for conservation of runoff generated in the watershed. Keeping above in view the proposed study was undertaken in Bhadokhar watershed with the objective of estimation of runoff using USDA SCS-CN method.

2. MATERIALS AND METHODS

For estimation of runoff potential of Bhadokhar watershed, the CN method developed by Soil Conservation

Service (SCS) of United States Department of Agriculture (USDA) was used. It computes direct runoff through an empirical equation that requires rainfall and a watershed coefficient as inputs. The watershed coefficient is called as the CN, which represents the runoff potential of the land cover soil complex. This method involves relationship between land cover, hydrologic soil class and curve number.

Study Area

General description

The study area (Bhadokhar watershed) is part of Bundelkhand region of Uttar Pradesh which experiences frequent severe droughts (Detailed Project report IWMP Programme 1 Jhansi UP). This watershed is located between 25^{0}33'12.96"-25^0 36'36.72"N latitudes and 79^{0}03' 42.12"- 79^{0}06'15.12"E longitudes in Gursarain block of Jhansi district (Fig. 1). The watershed is situated at an elevation ranging from 169-213 m above mean sea level (AMSL) and has relief of 14-34 m. General relief of the watershed is mild to gentle. The area of watershed under the different slope categories of 0-0.5%, 0.5-1%, 1-3%, 3-5% and >5% is 44.65 ha, 46.13 ha, 574.81 ha, 211.33 ha and 97.23 ha, respectively. The total geographical area (TGA) of the watershed is 974.15 ha, out of which agriculture land is 810.51 ha, fallow/waste land is 94.49 ha, and others land is 69.15 ha, and the river in the watershed is Betwa. The net irrigated area and rainfed area in the watershed is 30.0 ha and 780.5 ha, respectively. The average groundwater table in the watershed during pre-monsoon was 14.8 m and post-monsoon was 11.5 m, More than 85% of open wells get dried up during summer months in the watershed. The length of crop growing season ranges between 90 days to 150 days depending upon rainfall and temperature regimes. Farmers use only field bunds as soil and water conservation structures.

Climatic condition

The climate of this watershed is characterized by hot dry summers and cold winters and is marked for high variability of rainfall (800 mm to 1300 mm) from year to year, about 90% of which is received during south-west monsoon period in the months of July and August. The winter rains are erratic, scanty and uncertain. The total

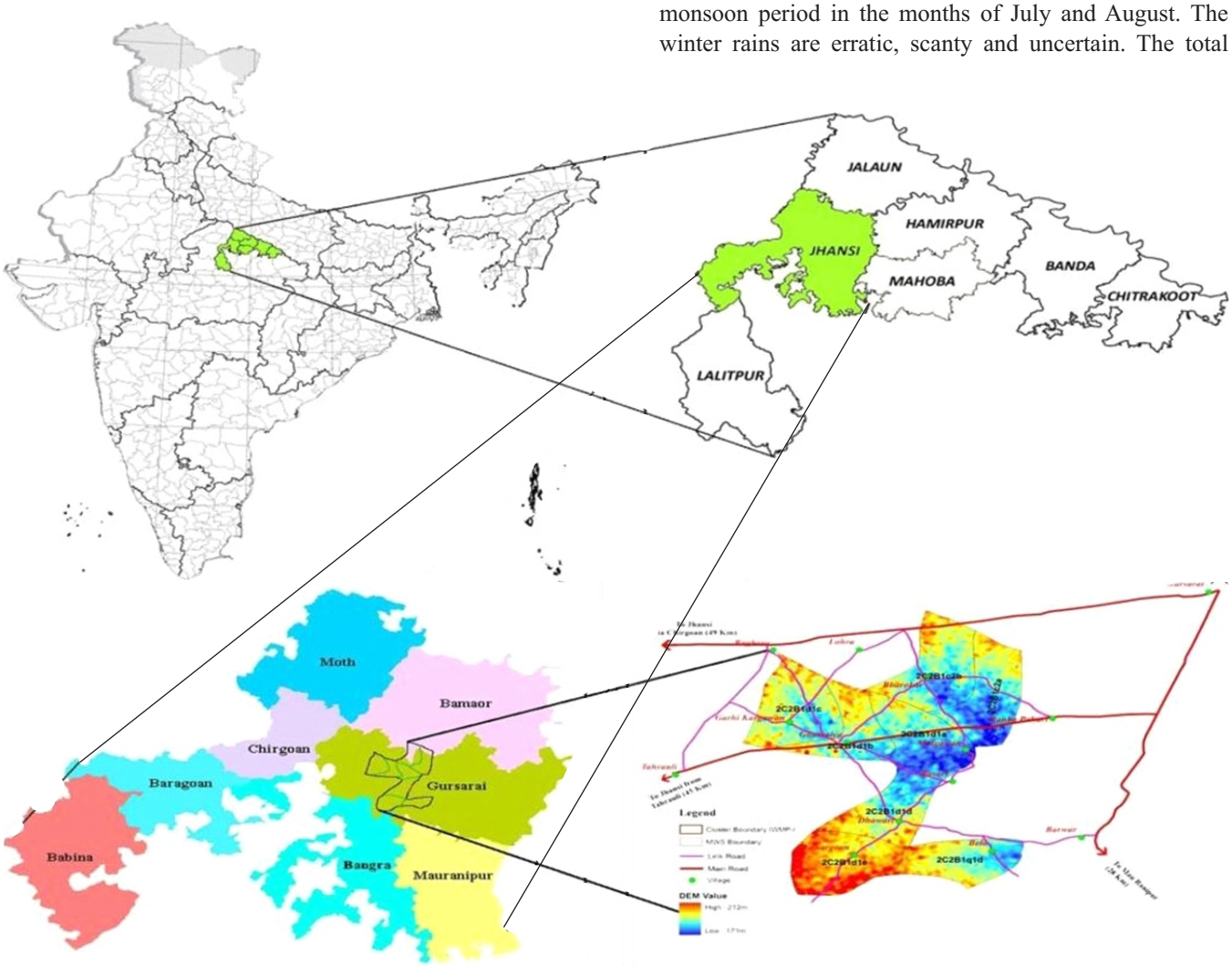

Fig. 1. Location map of Bhadokhar watershed

annual rainy days varies from 30 to 45 with an average of 37. Long dry spells during rainy season are also often experienced, which adversely affect the crops growth. It has been observed that in a cycle of 5 years, 2 are normal years, 2 are drought years and 1 is excessive rainfall year. The open pan evaporation varies from 0.5 mm day^{-1} to 23 mm day^{-1} during the year with an average of about 5 mm day^{-1}. Average relative humidity varied in the range of 25% to 98%; the range of wind speed is 0.9 km hr^{-1} to 16 km hr^{-1}.

Estimation of runoff

Data collection and selection of storm events

Daily rainfall data of the study area for the period from 1993 to 2012 were collected from National Data Centre (NDC), Pune to estimate runoff from the watershed. Storm events of maximum rainfall and corresponding AMC were selected for analysis from the daily rainfall data.

Classification of hydrologic soil groups

For determination of CN, the soils of the watershed were classified in four hydrologic soils groups *viz*., A, B, C and D based upon the infiltration and other characteristics (Musgrave, 1955; Anonymous, 1986).

Determination of CN

CNs for different parts of the watershed were determined based on land use pattern, soil cover type, hydrologic conditions and hydrologic soil group. The weighted CN was then computed with the following relationship:

$$CN = \sum_{i=1}^{n} \frac{CNi \times Ai}{A} \quad ...(1)$$

Where, CN_i = curve number of i^{th} part of watershed; A_i = Area of i^{th} part of watershed (ha); A = total area of watershed (ha).

Determination of AMC

To determine AMC of the watershed soil, total rainfall of preceding 5 days was computed and this total was compared with AMC classes (Subramanya, 2008).

Adjustment of CN for AMC

The CNs were computed using Eq. 1 for AMC-II condition. These CNs were then converted corresponding to the actual AMC of the soil at the time of occurrence of the storm. For conversion the following relationships (Subramanya, 2008) were used:

$$CN\,I = CN\,II / (2.281 - 0.01281\,CN\,II) \quad ...(2)$$

$$CN\,III = CN\,II / (0.427 + 0.00573\,CN\,II) \quad ...(3)$$

Computation of runoff

Runoff is estimated with the following relationship given by USDA-SCS (Anonymous, 1972) which accounts for initial abstraction from interception by surface vegetation, surface depression storage and infiltration before start of runoff. The infiltration losses are combined with surface storage.

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

Where, Q = Direct runoff (mm), P = Total storm precipitation (mm), I_a = Initial abstraction (mm) which is assumed to be equal to 0.2S, S = Potential maximum retention (mm).

The potential maximum retention S was computed by the following relationship:

$$S = \frac{25400}{CN} - 254 \quad ...(5)$$

Where, *CN* is the runoff curve number of hydrologic soil cover complex, which is a function of soil type, land cover and AMC.

3. RESULTS AND DISCUSSION

Hydrological Soil Group

Based on the information collected from the reconnaisance survey about the land use pattern, treatment adopted, cropping pattern and areal extent, the hydrological soil group of the Bhadokhar watershed was considered as 'B' for calculating CN value.

Rainfall Analysis

It was observed that during the period of study (1993 to 2012), the total number of rainy days per year were 35-40 with an average of 37 rainy days per year. For the estimation of direct runoff, fifty-five rain storm events which were expected to yield runoff were selected. The recorded rainfall data and corresponding AMC condition of each storm event are presented in Table 1.

Effect of AMC on CN and Surface Retention

The weighted CN for entire watershed corresponding to AMC II was found to be 83.62 for hydrologic soil group of B. CN of the watershed were 69.12 and 92.28 for AMC-I and AMC-III conditions, respectively.

Potential Maximum Retention (S) and Initial Abstraction (Ia)

Potential maximum retention S for each storm was estimated based on AMC condition of the soil. The data indicates that potential maximum retention S for the watershed was 113.5 mm, 49.8 mm and 21.2 mm for AMC-I, AMC-II and AMC-III conditions, respectively. The S value for AMC-I condition is much higher than that of AMC-II and AMC-III conditions, which indicates that soil will absorb more amount of rainwater and thus generate less runoff. Similarly, the initial abstraction for AMC-I, AMC-II and AMC-III conditions came out to be 22.7 mm, 10.0 mm and 4.3 mm, respectively.

Table: 1
Estimation of runoff depth and volume for selected storms

Date of storm event	Rainfall (mm)	AMC	Runoff depth (mm)	Runoff volume (m^3)
15/07/1993	20.6	I	0.0	383.63
11/09/1993	109.5	III	87.6	853117.96
03/08/1995	55.8	III	36.5	355636.68
22/08/1995	27.6	I	0.2	1980.42
04/09/1995	9.5	I	1.7	16912.07
26/06/1996	14.2	I	0.7	6695.56
27/07/1996	56.8	III	37.4	364559.82
02/08/1996	59.0	III	39.4	384266.53
19/08/1996	32.0	I	0.7	6870.77
05/07/1997	10.6	I	1.4	14055.54
15/07/1997	77.7	III	57.0	555009.00
22/07/1997	28.6	I	0.3	2846.07
23/08/1997	15.5	I	0.5	4744.21
10/07/1998	78.3	III	57.5	560561.61
15/08/1998	39.5	II	11.0	107272.90
13/09/1998	18.8	I	0.1	1348.24
22/07/1999	25.3	I	0.1	569.80
04/08/1999	3.01	I	0.6	5518.38
17/08/1999	64.4	III	44.5	433032.82
05/09/1999	74.3	III	53.8	523616.83
17/09/1999	55.0	III	35.8	348514.53
19/07/2000	163.6	III	140.6	1369722.19
20/08/2000	29.0	I	0.3	3233.83
04/09/2000	20.2	I	0.1	546.12
30/06/2001	43.5	II	13.5	131639.52
07/14/2001	29.6	I	0.4	3859.19
15/08/2002	91.1	III	69.8	679790.12
13/07/2003	17.2	I	0.3	2723.45
19/07/2003	73.4	III	52.9	515328.91
05/09/2003	91.7	III	70.4	685410.52
05/08/2004	11.4	I	1.2	12161.61
17/08/2004	50.1	II	17.9	174684.80
03/03/2005	1.9	I	4.7	45450.82
06/07/2005	38.6	II	10.5	101995.72
17/08/2005	61.6	III	41.8	407639.05
15/09/2005	27.9	I	0.2	2224.41
11/07/2006	13.6	I	0.8	7718.97
21/07/2006	34.0	I	1.0	9978.95
15/08/2006	5.8	I	3.0	28789.35
29/08/2007	51.2	II	18.7	182158.68
15/08/2009	24.1	I	0.0	167.56
29/08/2009	18.6	I	0.2	1493.00
07/10/2009	82.0	III	61.1	594880.94
13/11/2009	5.0	I	3.3	31844.23
08/01/2010	16.8	I	0.3	3146.09
19/08/2010	19.6	I	0.1	845.03
09/03/2010	77.8	III	57.1	555934.18
19/06/2011	58.4	III	38.9	378881.99
13/07/2011	36.6	II	9.3	90563.05
08/04/2011	48.0	II	16.5	160642.05
08/06/2012	26.2	I	0.1	1023.46
25/07/2012	30.1	I	0.5	4419.90
06/08/2012	44.2	II	14.0	136046.63
22/08/2012	26.3	I	0.1	1081.76
12/09/2012	34.2	I	1.1	10318.59

Effect of Rainfall on Runoff

Direct runoff of selected fifty-five rain storm events was calculated by SCS-CN method (Table 1). Runoff depth is linearly related to rainfall depth (Fig. 2). The following linear relationship between rainfall-runoff was observed in the watershed.

$$\text{Runoff} = 0.93 \times \text{Rainfall} - 18.68 \quad (R^2 = 0.93) \qquad ...(6)$$

It is evident from the graph that runoff is generated only when rainfall is more than 20 mm. It was observed that AMC played an important role in generation of runoff volume.

4. CONCLUSIONS

Bhadokhar watershed, which is characterised by frequent droughts, was selected for estimation of runoff by using SCS-CN method. Fifty-five rain storm events spread over a period of 20 years (1993 to 2012) were analysed. Based on the soil conditions, the hydrologic soil group of the watershed was classified as B. AMC condition of each storm event were calculated and it was observed that out of 55 storm events, 33 events were of AMC-I, 8 events were of AMC-II, and 14 events were of AMC-III. The estimated potential maximum retention value S varied from 21.24 mm to 113.47 mm, and S value for AMC-II was found to be 49.75 mm. It was also noted that for the storm events which were of AMC-I and AMC-II, the S values were much higher. Weighted CN value of entire watershed was found to be 83.62 for AMC-II. This indicates that the runoff potential of the area is high. CN II value was converted to CN I and CN III based on AMC condition of the watershed and found to be 69.12 and 92.28, respectively. Runoff corresponding to each storm event was estimated and it was noted that among the selected storm events, the maximum rainfall of

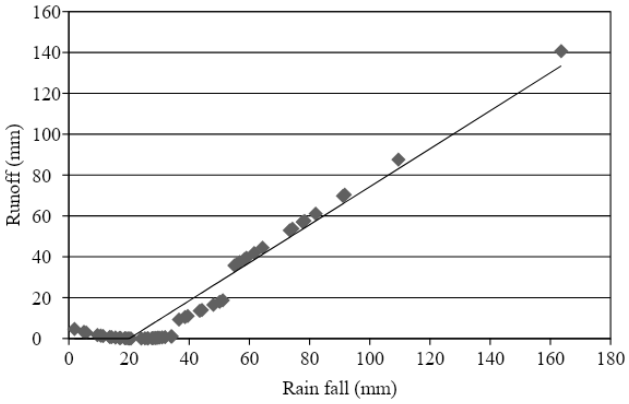

Fig. 2. Rainfall-runoff relationship of the watershed

109.5 mm occurred on 11th September 1993 at AMC III giving highest runoff depth of 87.60 mm, and minimum rainfall of 24.1 mm occurred in 15th August 2009 at AMC-I with runoff depth of 0.02 mm.

REFERENCES

Anonymous. 1972. Handbook of Hydrology. Central Unit for Soil Conservation (Hydrology and Sedimentation), Soil Conservation Division, Ministry of Agriculture, Government of India.

Anonymous.1986. Urban Hydrology for Small Watersheds. Technical Release 55.U.S. Department of Agriculture.

Bansode, A. and Patil, K.A. 2014. Estimation of runoff by using SCS curve number method and Arc-GIS. *Int. J. Scien. Eng. Res.,* 5(7): 1283-1287.

Boughton, W.C. 1989. A review of the USDA SCS curve number method. *Aus. J. Soil Res.,* 27(3): 511-523.

Musgrave, G.W. 1955. How much of the rain enters the Soil? In the yearbook of agriculture, Water USDA Washington DC.

Sivakumar, B. and Singh, V.P. 2012. Hydrologic system complexity and nonlinear dynamic concepts for a catchment classification framework. *Hydrol. Earth Syst. Sci.,* 16: 4119-4131.

Subramanya, K. 2008. Engineering Hydrology. Tata McGrew Hill Publishing Company Limited, New Delhi, 157p.