Chapter 24
Effect of Land Use on Curve Number in Steep Watersheds

C. B. Singh, S. K. Kumre, S. K. Mishra, and P. K. Singh

Abstract Runoff is an important and valuable variable used in planning of water resources and design of hydraulic structures. A number of models have been developed to calculate runoff from a rainfall event. The Soil Conservation Service Curve Number (SCS-CN) methodology is one of the most widely accepted event-based methods and is extensively used for estimation of surface runoff for a known precipitation event from small un-gauged agricultural watersheds. The model is satisfactorily established in hydrologic engineering. The main cause for its wide applicability lies in the fact that it is easy to use, and it incorporates major runoff generating watershed characteristics: soil type, land use, surface condition, and AMC. The only parameter curve number CN is critical for exact runoff prediction. According to the SCS-CN concept, the runoff quantity agricultural watershed depends on the above four major watershed characteristics. The CN values resulting from exhaustive investigations in the United States for all soil and land uses have been investigated and reported in National Engineering HandbookChapter-4 (NEH-4). Since the inception of SCS-CN method, only a few or no efforts appear to have been made to justify curve number rationality to watersheds in other countries. The slope was excluded in its original development, and it is included as a factor in the recently developed new models. Investigations were carried out on agricultural plot of size (12.0 × 3.0 m^2) located Toda Kalyanpur, Uttarakhand, India to calculate the effect of slope,

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soil type, AMC, and land use on the runoff and runoff curve number in selected three grades of 8, 12, and 16% with same Hydrologic Soil Group (HSG) "A." There were nine0 plots of three land uses, maize, finger millet, and fallow lands for investigation. As expected, the conclusion of land use on runoff curve number was such that the fallow lands showed the largest runoff and the CN values. With the increase of slope, the CN and runoff quantity increased which we got in 16% slope, fallow land. The effect of soil was more prominent than the slope. The soil was, however, the same for all experimental plots, i.e. HSG-A. The SCS-CN parameter potential maximum retention (S) showed an inverse relation with the measured AMC value.

Keywords Curve number · CN-P relationship · NEH-4 · Rainfall-runoff relation · Soil conservation service curve number method · Hydrologic soil groups (HSG)

24.1 Introduction

Hydrology is the science that deals with the occurrence, distribution, and movement of water on the earth surface in space and time. Hydrologists and engineers are much concerned with the calculation of runoff coming out from rainfall event. It requires in all respect whether it is for flood prediction or flood control or water resources assessment or design of hydraulic structures. The surface runoff is an essential parameter for the assessment of water yield potential of a watershed (Swain et al. 2018). The surface runoff is the function of many variables, e.g. rainfall duration and intensity, soil moisture, land use, land cover, soil type, and slope of watershed; i.e. it depends on climatic as well as physiographic condition of watershed (Swain et al. 2017a, b). For runoff computation from a given rainfall, there are so many models available, but probably one of the most widely used methods is SCS-CN method. It is because most of the methods are for gauged watershed, having complex type of approaches and many variables involved in. But SCS-CN method is simple and applicable to un-gauged watershed for which minimum hydrologic information is available. The SCS-CN method was originally developed by Soil Conservation Service (now known as Natural Resources Conservation Service, NRCS) of United States Department of Agriculture (USDA) in 1954, and results were documented in National Engineering Handbook, Hydrology Section-4 in 1956, popularly known as SCS-CN, NEH-4.The current version of NEH-4 is NEH 630 (USDA, NRCS 2003). SCS-CN method is widely accepted for predicting surface runoff in small agricultural watershed because of its simplicity and limited number of parameters required for runoff prediction (Ponce and Hawkins 1996).The SCS-CN method converts the given rainfall into surface runoff by the use of a single parameter CN which represents the runoff potential of watershed characterized by hydrologic soil type, land use and treatment, ground surface condition, and antecedent moisture condition (AMC). The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first proportionality concept of the method relates the two orthogonal hydrological processes of surface water and ground water; the second hypothesis relates to the atmospheric process. Qualitatively, the method broadly integrates all three major processes of the hydrologic cycle, and it can thus form one of the fundamental concepts of hydrology (Mishra et al. 2012). SCS-CN methodology was developed in United States by carrying out exhaustive field investigation for the main purpose of soil conservation which was mandatory to do under the Public law 83–566.CNs were derived which are given in SCS-CN, NEH-4, for different land use, soil type, hydrologic condition in spite of its simplicity; the application of CN procedure leads to a diversity of interpretations and confusions due to ignorance of its limitations (Hawkins 1979b; Hjelmfelt 1991; McCuen 1982). The main difficulties in application are to classify the hydrologic soil group and determination of AMC. Basically, SCS-CN was generated for US condition but is being used worldwide along with many researches for sorting out the limitations. Besides the calculation of runoff, it is used in assessment of soil erosion and sediment yield, environment and water quality, etc. Besides others, CN depends on land use, Hydrologic Soil Group (HSG), and AMC. On the basis of several infiltration tests conducted in USA, soils were divided into four HSGs (A to D) according to their minimum infiltration rates (SCS 1986). Soil type A indicates the highest rate of infiltration and D the lowest. Soil depth and percolation and drainage conditions in the subsoil also influence runoff response. Despite its simplicity, the application of the CN procedure leads to a diversity of interpretations and confusion due to ignorance about its limitations (Hawkins et al. 1985; Hjelmfelt 1980). Difficulties are mainly related with the classification of soil group derived for USA and determination of AMC, which is the index of watershed wetness (Chaudhary et al. 2013). The method has undergone rigorous review and has been recognized to perform well without impairing its simplicity. The works of Ponce and Hawkins (1996), Mishra and Singh (2002b, 2004b, 2013), Mishra et al. (2006c, 2005, 2012), Huang et al. (2006), and Jain et al. (2006) are noteworthy.

24.2 Study Area and Data Collection

The experimental site is located in village Toda Kalyanpur (Latitude: 290 50′9″ N, Longitude: 770 55′ 21″ E) near Roorkee, district Haridwar of Uttarakhand state in India. It is situated about 6 km southeast of IIT Roorkee. Its elevation/altitude is 266 m above mean sea level. The area experiences the sub-tropical climate. Most of the rainfall occurs during the period of June to September. Precipitation varies from 1200 to 1500 mm. Average maximum temperature varies in between 20 and 40 °C, and relative humidity is 35 to 97%. All the data using herein are directly measured in field, and no secondary data were used from outside as it was the experimental work. The required equipment's were established in the farm itself. Rainfall was measured using non-recording type rain gauge; soil moisture was measured by soil moisture meter "Field scout TDR 300″ with probe length of 20 cm. Double-ring infiltrometer was used to compute the infiltration rate of the soil. The runoff generated from each plot can be measured through the collection chamber made at the end of each plot

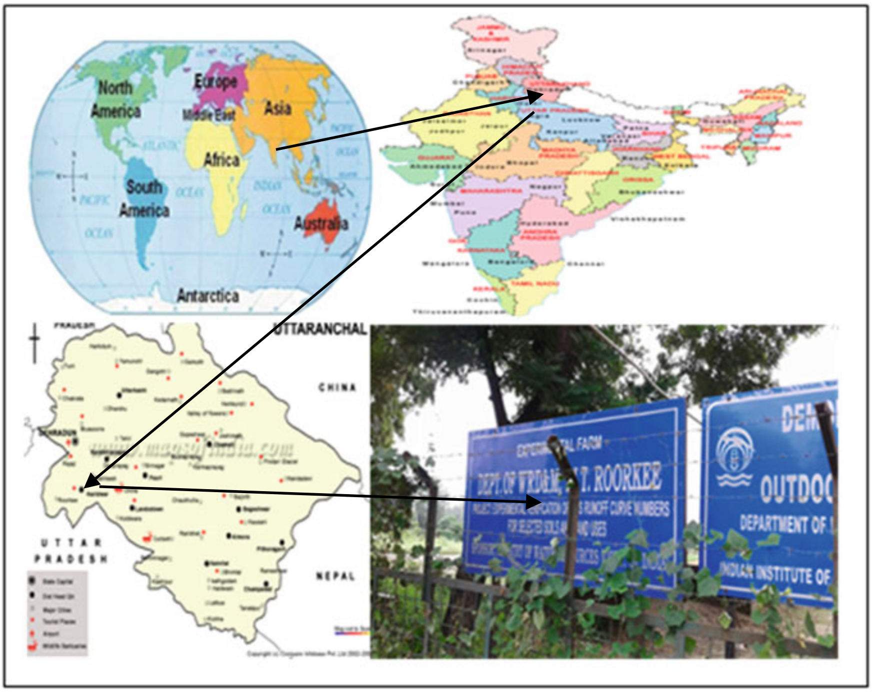

Fig. 24.1 Locations of sampling sites in the study area. (*Source* Google earth)

connected with an approach channel. Soil sample from each plot was collected and analyzed in the laboratory to know the soil type. (Fig. 24.1).

24.3 Methodology

The SCS-CN method is mostly used for estimation of runoff from given precipitation event especially in small agricultural watersheds. Its experimental verification for Indian conditions has not been attempted and published in the hydrologic literature, particularly at plot scale. To analyze the effect of soil, land use, AMC, and slope in Indian conditions, an experimental farm has been established by the Department of Water Resources Development and Management, IIT Roorkee in the village Toda Kalyanpur, near Roorkee, district Haridwar, India. The field has been divided into three different slopes at 8, 12, and 16%, and again each slope was arranged into three plots having different land uses. During a precipitation event, the resulting runoff from every plot was passed through a multi-slot divisor connected through a converging channel to tank/chamber of size 1mx1mx1m at the outlet. The runoff was measured in terms of depth of storage water, and multi-slot divisor was used for reducing the frequency of filling up of the chamber. The precipitation was measured by non-recording rain gauge installed at the site. For AMC of the soil, soil moisture was measured daily using TDR 300 during monsoon. In situ double-ring infiltrometer test was carried out for classifying HSG according to minimum infiltration rate.

24.4 Application

This section deals with step-by-step procedure associated with computation of CN from observed precipitation and runoff using the slope-adjusted CN from all the nine experimental plots for assessing the impacts of land use on runoff from steep watersheds.

24.4.1 Preparation of Experimental Plots

Three plots of three different grades were prepared viz. slopes of 8, 12, and 16. Each grade of plots was sub-divided into three small plots of size 12.0×3.0 m^2, leading to nine plots.

24.4.2 Measurement of Rainfall and Runoff

24.4.2.1 Rainfall

Precipitation data were measured from non-recording type rain gauge installed at the site. It was measured at every 8.30 to 9.00 AM from non-recording rain gauge. The rainfall measurement started from June 19, 2017 and it continued till recent rainfall of September 24, 2017. Total 19 rainfall events was observed. It was also found that runoff was generated by rain events of more than 9.6 mm.

24.4.2.2 Runoff

Runoff accumulated for every rainfall event from every plot was obtained in a chamber of size 1mx1mx1 m^3. Multi-slot divisor was established in the approach channel leading from plot to the chamber. Multi-slot divisor had five numbers of slots, and runoff was collected in the chamber coming only from the middle slot and that of other slots was transferred outside the chamber so that dimension of the chamber and the cost of project reduced. The depth of runoff quantity in the tank was measured using a steel tape. Since collecting tank and conveyance passage were open to atmosphere, quantity due to direct precipitation was also deducted to estimate the actual runoff. The water volume thus measured was multiplied five times to compute actual runoff volume, and it was divided by plot area to get the runoff depth.

24.4.3 Measurement of Infiltration Rate and Soil Moisture

24.4.3.1 Infiltration Test

Double-ring infiltrometer tests were carried out in all nine plots to determine the minimum infiltration rate of each of the plots. According to the minimum infiltration rate of the soil, HSG of the plot was decided. Two concentric rings of 30–45 cm^2 Dia. and 30 cm height was inserted into the soil so that about 10 cm was above the ground. Water was poured in both the rings up to a fixed level and drawdown in a certain interval of time was noted for inner ring only. The experiment was continued for at least 3–4 h until two consecutive readings of the same order were obtained, and it took around 9 days to finish these tests in all nine plots.

24.4.3.2 Antecedent Moisture Condition (θ_o)

Daily soil moisture of all plots was collected using field scout TDR 300 with a probe length of 20 cm. Three spot point values were measured in the field, and average of three values was calculated for soil moisture of the plot. It yielded directly the Volumetric Water Content (VWC) in percentage. The soil holding water was preceded for the whole monsoon and remained extended for as and when necessary after the monsoon. It was definitely observed the soil moisture prior to every rain event.

24.4.3.3 Soil Grain Size Analysis

Soil collected from every plot was carried to the laboratory in plastic bags. The soil was dried in an oven and mixed clearly such that structure of the soil was become disturbed. Then, it was passed through the sequence of sieves for 20 min. The retained soil on various sieves was weighed. It was compared with the previously weighed soil sample whether the loss of weight was more than 2%. The output was tabulated and analyzed to get the part of sand, silt, and clay which was the prime concern of the experiment. It was then used to differentiate HSG obtained from the infiltrometer test.

24.4.4 Estimation of Curve Number for Experimental Plots

In this research work, CNs were estimated using (i) NEH-4 table based on HSG and land use for all the three land use and 5% land slope, (ii) observed rainfall and runoff data from all the nine experimental plots, and finally (iii) the slope-adjusted CNs based on steps (i) and (ii). The estimated CNs were finally used for runoff estimation from all nine experimental plots.

24.5 Results and Discussion

The SCS-CN method is one of the simplest and most popular methods to compute runoff from given rainfall events. It was developed for the un-gauged small agricultural watershed. As there were twenty-one rainfall events that were able to generate runoff from all nine plots of different three grades, the effect of land use and slope of watershed was analyzed. From the observed rainfall and runoff pair, the potential maximum retention (S) and corresponding runoff curve number value were derived for all slopes and crops. CN values were derived for each storm event. In this study, all nine plots were agricultural lands. It was cultivated with row crops like maize, finger millet, and one plot in each slope was kept uncultivated as a fallow. Fallow lands were believed to generate more runoff than others, and to some extent, it was true. In this study, for slope of 12%, fallow land had the highest runoff and largest CN (Figs. 24.2–24.4). The effect of slope on runoff and CN is analyzed between 8 and 16% plot. It is seen that the runoff and CN values are lower for 8% plot than for 16% plot. Larger the slope and, in turn, the velocity generated, the shorter will be the opportunity time for infiltration to occur, and therefore, higher will be the runoff (or

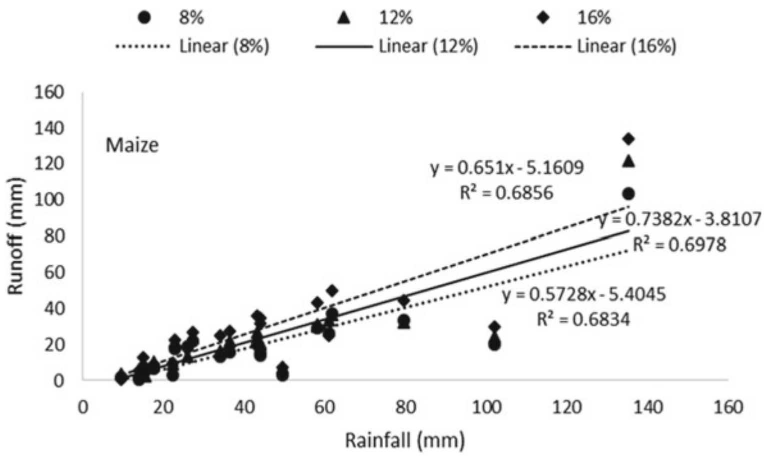

Fig. 24.2 Relationship between rainfall and runoff in maize crop

CN) generated. Thus, the larger slope is to produce larger runoff (or CN), and vice versa, which is in contrast with the observations for highest rain event. Table 24.1 shows the observed runoff and curve number corresponding to the observed rainfall. (Figs. 24.5–24.7).

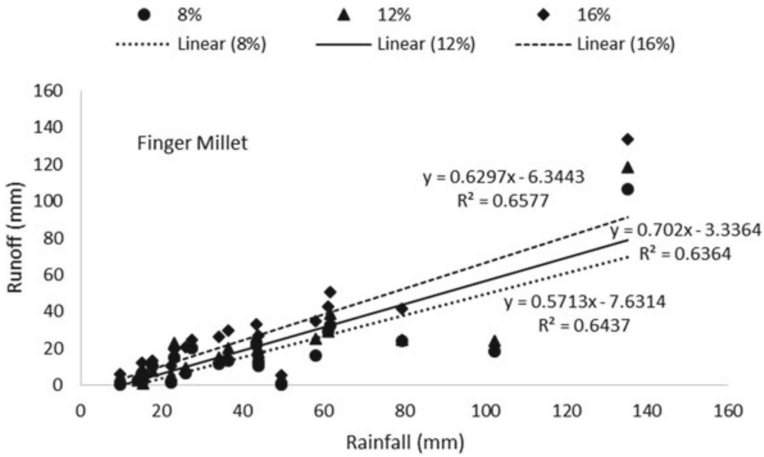

Fig. 24.3 Relationship between rainfall and runoff in finger millet

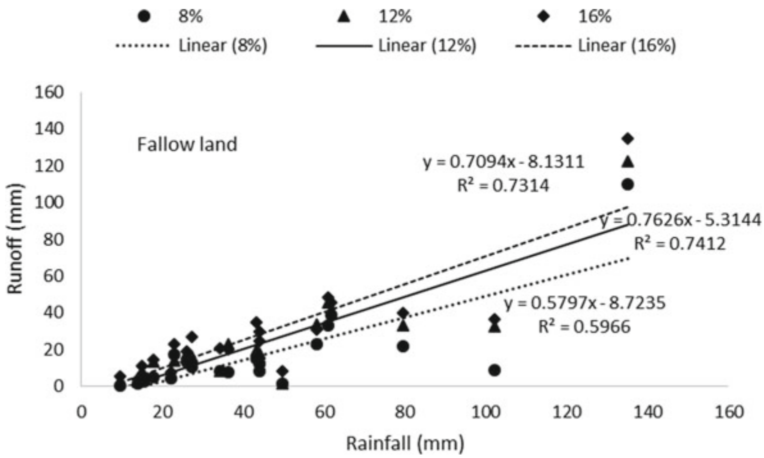

Fig. 24.4 Relationship between rainfall and runoff in fallow land

Table 24.1 Direct runoff and runoff curve numbers for different watersheds

Event no	Date	Rainfall (P) mm	Runoff (Q) (mm) for different watershed slopes								
			8%			12%			16%		
			Maize	Finger millet	Fallow	Maize	Finger millet	Fallow	Maize	Finger millet	Fallow
1	6/19/17	44.0	14.2	13.0	8.3	20.1	17.8	15.4	31.9	27.2	29.6
2	6/26/17	34.2	13.4	11.6	8.1	16.5	15.1	8.1	24.8	26.2	20.6
3	6/28/17	135.2	103.6	106.8	109.9	121.8	118.5	122.5	134.0	133.5	134.80
4	6/29/17	17.7	6.4	10.6	5.0	10.6	7.8	13.3	9.2	13.3	14.7
5	6/30/17	15.0	7.1	6.8	5.4	9.8	9.1	8.2	13.0	12.3	10.9
6	7/6/17	36.4	16.1	13.3	7.8	21.7	20.3	23.1	27.2	30.0	20.3
7	7/24/17	14.0	0.7	2.8	1.4	4.1	2.8	2.8	5.5	2.8	4.1
for8	8/2/17	79.5	33.2	24.2	22.1	32.5	24.9	33.2	44.3	41.5	40.1
9	8/3/17	9.6	2.0	0.6	0.6	3.4	4.7	3.4	0.6	6.1	5.7
10	8/7/17	27.4	21.6	20.2	10.5	23.7	23.0	16.1	26.5	24.8	27.00
11	8/10/17	43.4	19.9	22.0	15.1	26.9	26.2	19.9	35.9	33.1	34.7
12	8/19/17	22.3	2.9	1.6	4.6	9.2	5.7	6.4	9.9	10.4	7.9
13	8/22/17	58.1	29.0	16.3	23.3	30.9	25.3	33.7	43.4	35.1	30.9
14	8/23/17	15.5	5.3	2.5	2.5	2.5	1.2	5.3	6.7	3.9	2.5
15	8/25/17	61.8	37.3	32.4	38.7	36.6	38.7	41.4	49.8	50.5	45.6
16	9/1/17	44.0	15.0	10.8	12.2	20.5	15.0	17.8	34.4	17.8	24.7
17	9/1/17	23.0	17.4	15.3	17.4	21.6	23.0	13.8	22.5	19.5	23.0
18	9/2/17	61.1	26.3	29.1	33.2	33.2	29.1	45.7	24.9	42.9	48.5
19	9/3/17	26.0	19.1	6.6	13.5	13.5	9.3	17.7	17.7	20.5	19.1

(continued)

Table 24.1 (continued)

Event no	Date	Rainfall (P) mm	Runoff (Q) (mm) for different watershed slopes								
			8%			12%			16%		
			Maize	Finger millet	Fallow	Maize	Finger millet	Fallow	Maize	Finger millet	Fallow
Event no	Date	Rainfall (P) mm	Runoff curve numbers (CN) for different watershed slopes								
			8%			12%			16%		
			Maize	Finger millet	Fallow	Maize	Finger millet	Fallow	Maize	Finger millet	Fallow
1	6/19/17	44.0	84.0	82.9	77.5	88.7	86.9	85.0	95.3	93.0	94.2
2	6/26/17	34.2	89.2	87.6	83.8	91.6	90.5	83.8	96.3	96.9	94.2
3	6/28/17	135.2	89.0	90.1	91.3	95.5	94.3	95.7	99.6	99.4	99.9
4	6/29/17	17.7	93.6	96.8	92.0	96.8	94.9	98.3	95.9	98.3	98.9
5	6/30/17	15.0	96.0	95.8	94.5	97.8	97.4	96.8	99.3	99.0	98.4
6	7/6/17	36.4	90.1	87.8	81.9	93.7	92.9	94.4	96.5	97.7	92.9
7	7/24/17	14.0	85.9	91.7	88.5	93.8	91.7	91.7	95.3	91.7	93.8
8	8/2/17	79.5	79.4	73.3	71.7	78.9	73.8	79.4	85.6	84.2	83.4
9	8/3/17	9.6	94.3	90.4	90.4	96.3	97.6	96.3	90.4	98.5	98.2
10	8/7/17	27.4	97.8	97.2	91.0	98.7	98.4	95.0	99.7	99.1	99.9
11	8/10/17	43.4	88.9	90.3	85.1	93.1	92.7	88.9	97.3	96.1	96.8
12	8/19/17	22.3	84.8	81.0	87.8	93.1	89.4	90.3	93.7	94.1	91.9
13	8/22/17	58.1	87.1	77.7	83.3	88.2	84.8	89.8	94.5	90.5	88.2
14	8/23/17	15.5	94.0	90.0	90.0	90.0	86.3	94.0	95.4	92.3	90.0

(continued)

Table 24.1 (continued)

Event no	Date	Rainfall (P) mm	Runoff (Q) (mm) for different watershed slopes								
			8%			12%			16%		
			Maize	Finger millet	Fallow	Maize	Finger millet	Fallow	Maize	Finger millet	Fallow
15	8/25/17	61.8	90.0	87.3	90.7	89.6	90.7	92.0	95.6	95.9	93.9
16	9/1/17	44.0	84.7	80.5	82.0	89.0	84.7	86.9	96.4	86.9	91.6
17	9/1/17	23.0	97.8	96.8	97.8	99.5	100.0	96.0	99.8	98.7	100.0
18	9/2/17	61.1	83.9	85.6	88.1	88.1	85.6	94.2	82.9	93.0	95.4
19	9/3/17	26.0	97.3	87.7	94.1	94.1	90.8	96.6	96.6	97.9	97.3

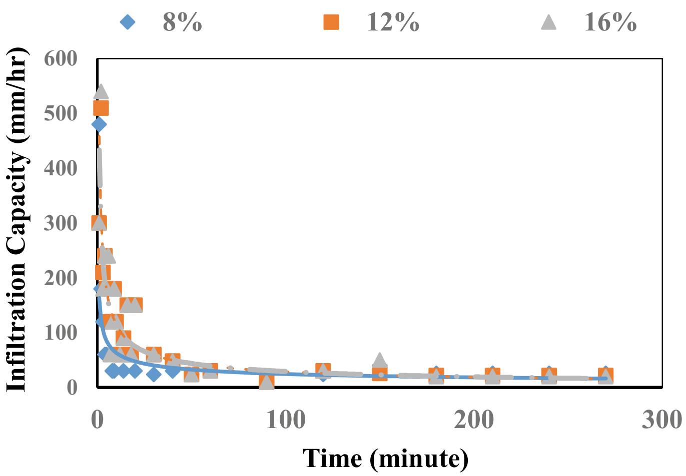

Fig. 24.5 Infiltration curve (Maize)

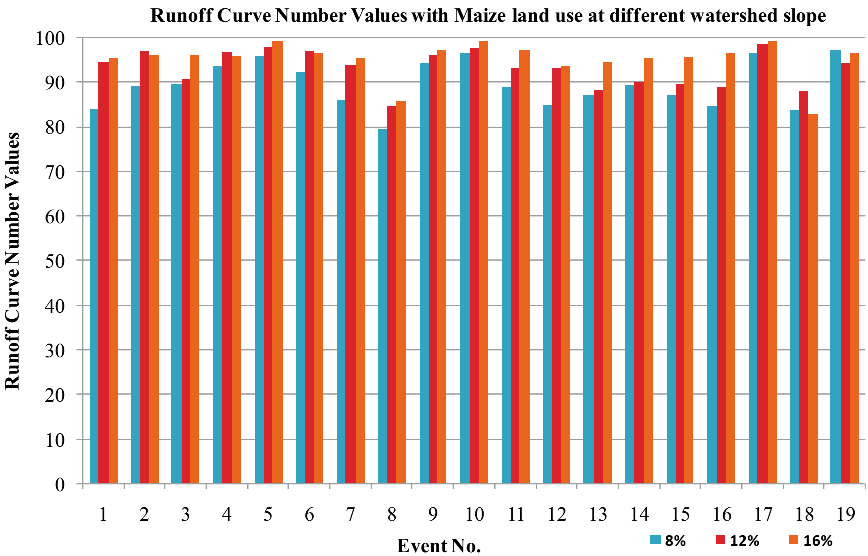

Fig. 24.6 Effect of maize on CN in different slope

24.6 Conclusions

The plot experiments were conducted to investigate the effects of land use on watershed runoff for steep slopes, effects of watershed slope on CN and runoff and to test the performance of the slope-adjusted SCS-CN method in predicting runoff from

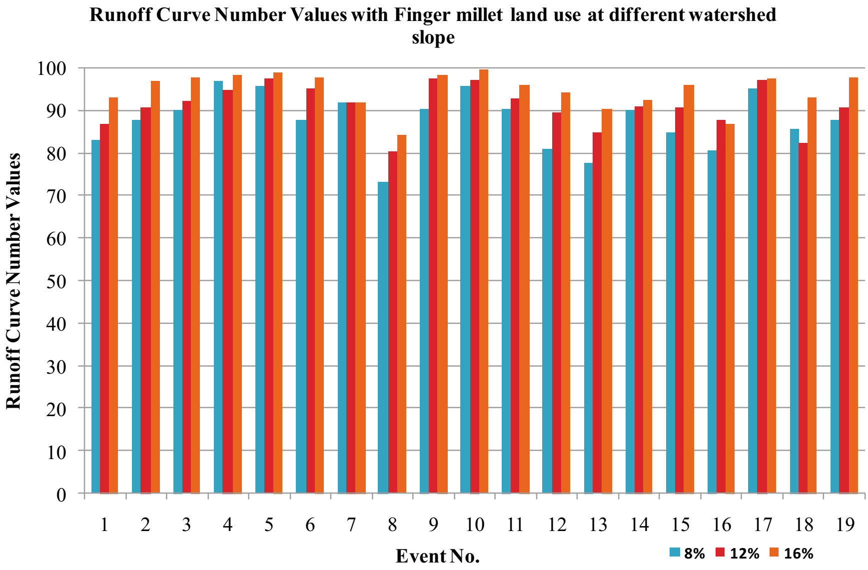

Fig. 24.7 Effect of finger millet on CN in different slope

different land uses and slopes using SCS-CN model from natural rainfall, consequent observed runoff, and other experimental works. The field had three slopes of 8, 12, and 16%, and each slope had three plots of size 12 m x 3 m. HSG of all the fields was the same as "A," and initial hydrologic condition of all the fields was poor (with no grass/vegetal cover). The land use of the field was agricultural and cultivated with maize, finger millet, and one plot from each slope was left fallow. The following conclusions are derived from the study:

The outputs of the study of the effects of soil, land use, slope, and AMC on runoff and CN are homogenous with the usual expectations. The SCS-CN parameter S shows a well-known inverse relation with measured AMC.

The effect of slope is not as important as that of soil on both runoff and CN; and thus, it is viable that a plot of higher grade may give lesser runoff depends on soil type. But in our case, the plot with the highest slope generated the highest runoff as well as CN because of same soil group in all experimental plots. Therefore, the fallow land produces the highest runoff and CN from all the slopes.

For more accurate runoff prediction, the effect of slope adjustment was investigated significant for slopes more than5%. In calculating the computed potential maximum retention and computed runoff, the slope adjustment formula was employed.

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