

# Runoff Estimation in Steep Slope Forested Dzumah Watershed of Upper Dhansiri, Nagaland Using Standard and Modified Curve Number Method

RIZONGBA KICHU<sup>1</sup>, MANOJ DUTTA<sup>\*1</sup>, A. K. SINGH<sup>2</sup> AND SEWAK RAM<sup>1</sup>

<sup>1</sup>Department of Soil and Water Conservation, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema 797106, Nagaland, India

<sup>2</sup>Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema 797106, Nagaland, India

E-mail: rizong09@gmail.com, manojdutta@nagalanduniversity.ac.in, ak.singh@nagalanduniversity.ac.in, sewakram@nagalanduniversity.ac.in

**\*Corresponding author**

## ABSTRACT

In the present study, an attempt was made to assess the suitability of both the standard and modified NRCS-CN method in determining the amount of runoff in a steep slope watershed. Based on recent findings and improvements, the modification to the standard CN method consisted of integrating slope factor and adjustment of  $\bar{e}$  value in the initial abstraction (Ia) parameter from the traditional constant value of 0.2 to 0.05. The study was carried out in Dzumah watershed of Upper Dhansiri in Nagaland, north-eastern India. Rainfall-runoff events were studied for two years *i.e.*, 2019 to 2020 using both the standard and modified CN method. The runoff depths estimated by the standard CN method for 2019 and 2020 were only 109.95 and 33.25 mm, respectively, representing just 9.49 and 3.78% of total rainfall received in each year. On the other hand, the modified CN method estimated runoff depths of 505.34 and 340.97 mm, which was 43.60 and 38.76 % of the total rainfall received during 2019 and 2020. Rainfall-runoff correlation studies also revealed that the modified CN method showed better correlation with  $R^2$  values of 0.858 and 0.944 as compared to the standard CN method with  $R^2$  values of 0.166 and 0.650 during 2019 and 2020, respectively. The study indicated that standard CN method is inadequate for runoff estimation from steep slope forested watersheds. Integration of slope factor and  $\bar{e}$  value adjustments to standard CN method gave better runoff estimates as well as better rainfall-runoff correlation as compared to the standard CN method.

**Key words:** NRCS-CN, modified CN, initial abstraction, surface runoff, slope adjustment

## INTRODUCTION

Surface runoff is a key hydrologic parameter that needs to be appraised for various ecological and sustainability goals. Understanding the pattern and amount of surface runoff in a watershed is crucial in managing water resources, predicting and preventing floods, designing appropriate land use plans and agricultural management strategies. The Natural Resources Conservation Service Curve Number (NRCS-CN) method is widely used for estimating runoff volume and peak discharge from rainfall events. The method uses a simplified soil-moisture accounting approach, relating the initial abstraction (Ia) and potential maximum retention (P) of a watershed to a curve number (CN), which is a dimensionless parameter with values varying between 0 and 100. The CN is used to calculate direct runoff from a rainfall event, based on the retention

characteristics of the watershed and the antecedent soil moisture conditions. Due to its simplicity and the capacity to generate satisfactory results with minimum data requirements, the CN method has been extensively used for hydrological and environmental studies. Furthermore, the versatility and applicability of the CN method is accentuated by the fact that the method has been integrated into many other hydrologic models and software suites such as CREAMS (Knisel 1980), HEC-HMS (US Army Corps of Engineers), AGNPS (Young et al., 1989), SWAT (Neitsch et al. 2002), PRZM (Carsel et al. 1997) etc. However, despite its popularity and worldwide recognition, the CN method does have its limitations. The SCS-CN method was originally developed for use in agricultural lands having slopes less than 5% and as such, slope was not factored into the equation. However, slope has significant influence on surface runoff generation and therefore,

integrating slope factor and adjusting CN values is imperative for runoff estimation. This limitation rendered the standard CN method unsuitable for diverse land use and topographical settings because it was developed for agricultural areas with a relatively homogeneous land use and soil type. In steep sloping forested watersheds, the landscape is much more complex, with a mix of vegetation types, soils, and micro-topography that can greatly affect runoff generation and hydrologic processes. Very few studies are available which account the effect of slope on CN and runoff (Ansari et al. 2020). Significant works on integration of a slope factor for improving runoff estimation from steep slope watersheds were carried out by Sharpley and Williams (1990), Huang et al. (2006), and Ajmal et al. (2016). Meanwhile, the  $\alpha$  value of 0.2 in the initial abstraction (Ia), which is traditionally treated as a constant, is widely debated among researchers because of great variations in the  $\alpha$  value reported across the world (Verma et al. 2018). Several researchers have reported that a  $\alpha$  value of 0.05 gave more appropriate results as compared to the traditional constant  $\alpha$  value of 0.2 (Woodward et al. 2003, Jacobs and Srinivasan 2005, Lim et al. 2006, Beck et al. 2009, Shi et al. 2009). This adjustment of  $\alpha$  value has recently been adopted by the Task Group on Curve Number Hydrology (Hawkins et al. 2019). In recent years, remote sensing (RS) and Geographical Information System (GIS) techniques have been used in runoff estimation by combining information from satellite imagery, aerial photography, and other remote sensing data with GIS databases to map and analyze the physical characteristics of the land surface and to estimate the amount of runoff produced from a particular area (Gajbhiye and Mishra 2012, Dhawale 2013, Topno et al. 2015, Tailor and Shrimali 2016, Al-Ghobari et al. 2020). The integration of the CN model in GIS platform enable researchers and practitioners to spatially analyze and visualize the relationships between land use and runoff, and to develop more accurate runoff models. In view of these recent advances and developments, the present study was conducted to compare and investigate the suitability of the standard as well as the modified CN method in estimating runoff from a steep sloped forested watershed.

## MATERIAL AND METHODS

### Description of the study area

The study was conducted in Dzumah watershed in Medziphema, under Chumukedima district of Nagaland, North Eastern India (Fig. 1). The watershed is located between 93° 51' 33" to 94° 00' 16" E longitude and 25° 40' 45" to 25° 47' 01" N latitude occupying an area of 6555 ha (65.55 km<sup>2</sup>). The elevation of the watershed ranges from 328 to 2345 m above mean sea level and has a humid subtropical climate. More than 70% of the watershed area has slopes varying from 15 to 65% (Kichu and Dutta 2022). The watershed is dominantly under forest with dense and open forest occupying 5552.09 ha, accounting for almost 85% of the total watershed area (Kichu and Dutta 2022). The dominant soil type in the study area was clay loam and silty clay loam (Kichu and Dutta 2022).

### Data collection

Daily rainfall data of two years (2019-2020) was collected from ICAR, Jharnapani, Medziphema, Nagaland for studying the rainfall-runoff relationship of the watershed. Land use land cover (LULC) data, soil data and information regarding slope and topography were sourced in based on the works of Kichu and Dutta (2022). Based on the soil textural data, classification method as described by Ross et al. (2018) was used to derive the hydrological soil group (HSG) of the study area.

### Calculation of runoff depth using standard CN method

Most of the annual rainfall in the study area is received during the month of June to October. Therefore, the rainfall events from the month of June to October were considered for determining the rainfall parameter (P). The rainfall data was used for computing the 5-day antecedent moisture condition (AMC) of the watershed. Three levels of AMC are used in the CN method *i.e.*, AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. The CN values are always documented for the case of AMC-II (USDA 1985). To calculate CN values for AMC-I and AMC-III conditions, the following equations were used (Hawkins et al. 1985):

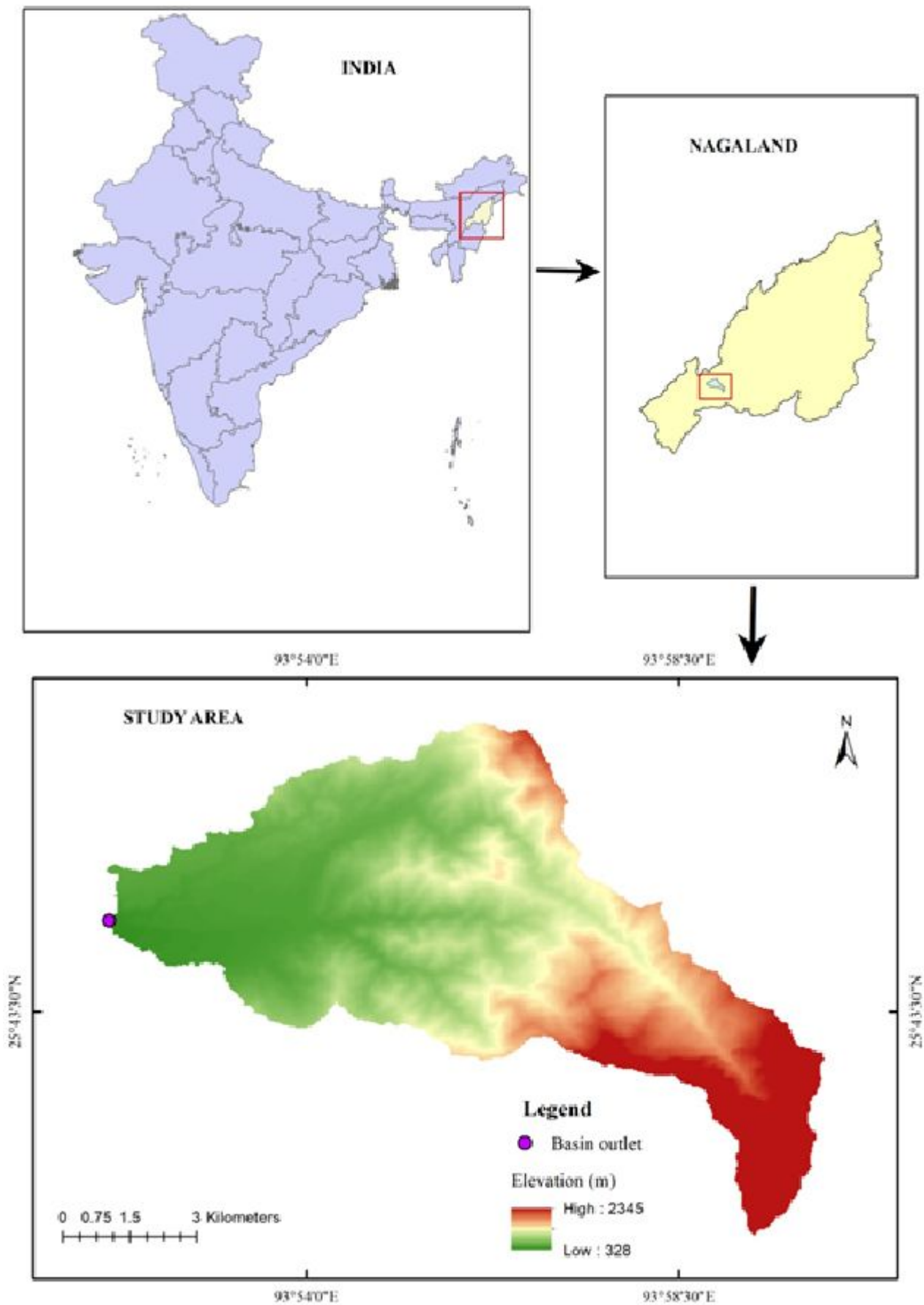


Figure 1. Location and elevation map of Dzumah watershed

$$\text{CN for AMC - I: } CN_I = \frac{CN_{II}}{2.281 - 0.01281 CN_{II}} \quad (1)$$

$$\text{CN for AMC - III: } CN_{III} = \frac{CN_{II}}{0.427 + 0.00573 CN_{II}} \quad (2)$$

Where,  $CN_I$  = curve number for dry condition,  $CN_{II}$  = curve number for normal condition and  $CN_{III}$  = curve number for wet condition.

Potential maximum retention ( $S$ ) was calculated for all land use classes in the study area using the equation as follows:

$$S = \frac{25400}{CN} - 254 \quad (3)$$

The amount of initial abstraction ( $I_a$ ) is some fraction of the potential maximum retention and it is expressed as:

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

Where,  $\lambda$  = initial abstraction ratio and  $S$  = potential maximum retention

Thereafter, the runoff ( $Q$ ) was estimated using the following equation:

$$Q = \frac{(P - 0.25)^2}{P + 0.85} \quad \text{when } P > I_a \quad (5)$$

Where,  $Q$  is runoff depth (mm);  $P$  is rainfall (mm) and  $S$  is potential maximum retention (mm).

### Calculation of runoff depth using modified CN method

In this study, modifications to the standard CN method were done based on the works and recommendations of other researchers. The adjustment of  $\lambda$  value to 0.05 has recently been adopted by the Task Group on Curve Number Hydrology (Hawkins et al. 2019), which recommends a new relation as follows:

$$S_{0.05} = 1.42S_{0.2} \quad (6)$$

This modification in the  $\lambda$  value and the resultant change in the  $CN_{II}$  value is calculated using the following equation:

$$CN_{II0.05} = \frac{100}{1.42 - 0.0042 CN_{0.2}} \quad (7)$$

This modified  $CN_{II}$  value is further subjected to slope adjustment. The Huang et al. (2006) approach was used to integrate the slope factor into the investigation and is given as follows:

$$CN_{II\alpha} = CN_{II} \left( \frac{322.79 + 15.63\alpha}{\alpha + 323.52} \right) \quad (8)$$

Where,  $CN_{II\alpha}$  = Slope adjusted  $CN_{II}$  and  $\alpha$  = slope ( $m \cdot m^{-1}$ )

Weighted slope was computed as follows:

$$\text{Weighted slope} = \frac{\sum_{i=1}^n a_i X s_i}{A} \quad (9)$$

Where,  $a_i$  = area of slope (ha),  $s_i$  = slope (%) and  $A$  = polygon area (ha)

Weighted slope was applied in equation (8) to compute slope-adjusted  $CN_{II}$  values.

## RESULTS AND DISCUSSION

### Hydrologic soil group

The soil in the watershed was predominantly clay loam with medium to fine in texture. With the exception of Sample no. 15, which showed a clay content of 42.60%, all samples showed clay contents ranging from 20-40%. The sand and silt content among the samples varied from 19.0 to 35.80% and 28.00 to 47.7%, respectively (Kichu and Dutta 2022). These findings led to the conclusion that the entire watershed belonged to hydrologic soil group C and has a moderately high runoff potential (Table 1).

### CN values

The standard and modified CN values for different land use classes in the watershed are presented in Table 2. The standard CN-II values were assigned based on the standard TR-55 table (USDA-NRCS 1986) and the values varied from 70 to 100. Since the entire watershed falls under HSG-C, the CN values were greatly influenced by land use and land cover pattern. Excluding the water bodies, the highest and the lowest standard CN values were recorded in buildup area and dense forest land use, respectively. Similarly, the resultant changes for  $\lambda$ -adjusted ( $CN_{II0.05}$ ) and slope-adjusted ( $CN_{II\alpha}$ ) values ranged from 88.81 to 94.45 and 91.02 to 96.8, respectively. Higher the CN value higher will be the runoff potential.

### Runoff depth

Runoff depth estimated by both standard and modified CN method aggregated on monthly basis for the year 2019 and 2020 are presented in Tables 3 and 4, respectively. The total rainfall received in the watershed from June to October during 2019 and 2020 were 1159 and 879.70 mm, respectively. The standard CN-estimated runoff depths for 2019 and 2020 were only 109.95 mm and 33.25 mm, representing just 9.49% and 3.78% of total rainfall

Table 1. Soil texture and resultant hydrologic soil group of Dzumah watershed (adopted from Kichu and Dutta 2022)

Sample Number	Sand (%)	Silt (%)	Clay (%)	Textural Class	HSG
1	35.80	42.50	20.10	Loam	C
2	19.70	46.20	32.50	Silty Clay Loam	C
3	27.70	38.80	32.50	Clay Loam	C
4	33.80	41.20	22.70	Loam	C
5	18.80	46.70	33.30	Silty Clay Loam	C
6	19.00	51.40	28.30	Silty Clay Loam	C
7	34.70	29.80	34.10	Clay Loam	C
8	35.50	33.40	28.60	Clay Loam	C
9	30.00	34.50	32.80	Clay Loam	C
10	32.40	34.20	29.40	Clay Loam	C
11	20.00	44.30	33.80	Silty Clay Loam	C
12	21.00	52.30	24.20	Silt Loam	C/D
13	35.00	28.00	35.20	Clay Loam	C
14	35.80	28.40	33.50	Clay Loam	C
15	19.40	36.50	42.60	Silty Clay Loam	C
16	27.30	33.10	38.20	Clay Loam	C
17	19.30	47.70	31.80	Silty Clay Loam	C
18	24.60	38.50	35.50	Clay Loam	C
19	27.10	33.50	37.80	Clay Loam	C

of each year, respectively. Whereas, the runoff estimated using the modified CN method showed runoff depths of 505.34 and 340.97 mm, indicating that 43.60 and 38.76% of the total rainfall received during 2019 and 2020 were converted to surface runoff. Rainfall-runoff correlation for the years 2019 and 2020 using both standard and modified CN method are given in Figure 2 (a, b) and Figure 3 (a, b), respectively. The R<sup>2</sup> values of runoff estimated using standard CN method for 2019 and 2020 were 0.166 and 0.650, respectively. Better rainfall-runoff correlation was observed in both the years by using modified CN method with R<sup>2</sup> values 0.858 and 0.944, respectively. The results of the current study

Table 2. CN value modification

Sl.No.	LULC	CN-II	CN-II <sub>0.05</sub>	CN-II <sub>a</sub>
1	Cultivated area	84	93.70	95.61
2	Dense forest	70	88.81	91.02
3	Open forest	73	89.81	92.04
4	Buildup area	86	94.45	96.8
5	Water body	100	100	100

Table 3. Rainfall and runoff depth for the year 2019

Month	Total Rainfall (mm)	Std. CN Runoff (mm)	Mod. CN Runoff (mm)	Std. CN Runoff %	Mod. CN Runoff %
June	195.0	5.57	69.56	2.85	35.67
July	271.3	8.40	124.40	3.10	45.85
August	274.5	27.72	120.76	10.10	43.99
September	173.4	4.61	57.64	2.66	33.24
October	244.8	63.66	132.98	26.01	54.32
<b>Total</b>	<b>1159.0</b>	<b>109.95</b>	<b>505.34</b>	<b>9.49</b>	<b>43.60</b>

Table 4. Rainfall and runoff depth for the year 2020

Month	Total Rainfall (mm)	Std. CN Runoff (mm)	Mod. CN Runoff (mm)	Std. CN Runoff %	Mod. CN Runoff %
June	266.2	25.35	124.89	9.52	46.92
July	199.9	1.88	69.67	0.94	34.85
August	80.3	0.00	13.97	0.00	17.40
September	157.6	0.48	51.87	0.30	32.91
October	175.7	5.54	80.57	3.15	45.86
<b>Total</b>	<b>879.7</b>	<b>33.25</b>	<b>340.97</b>	<b>3.78</b>	<b>38.76</b>

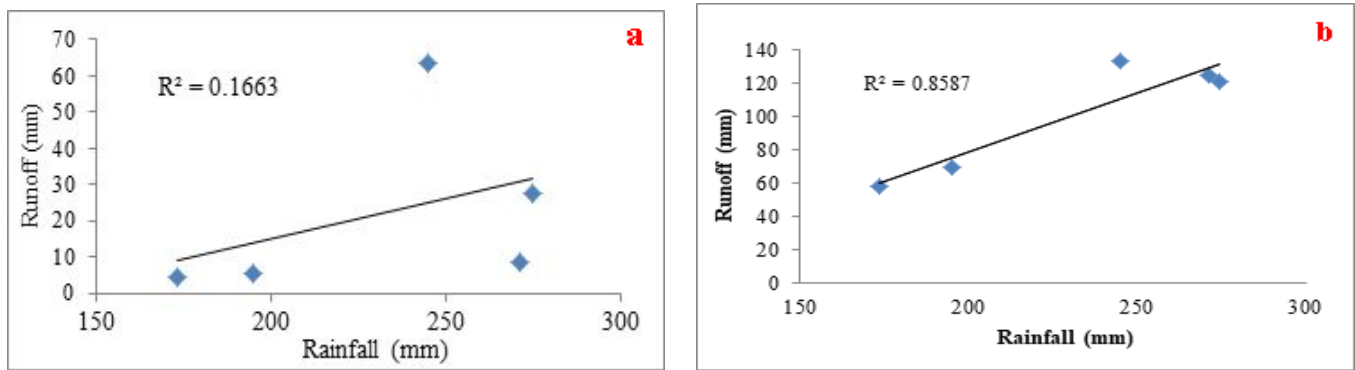


Figure 2. (a) Rainfall - runoff correlation using standard CN method (Year – 2019), (b): using modified CN method (Year - 2019)

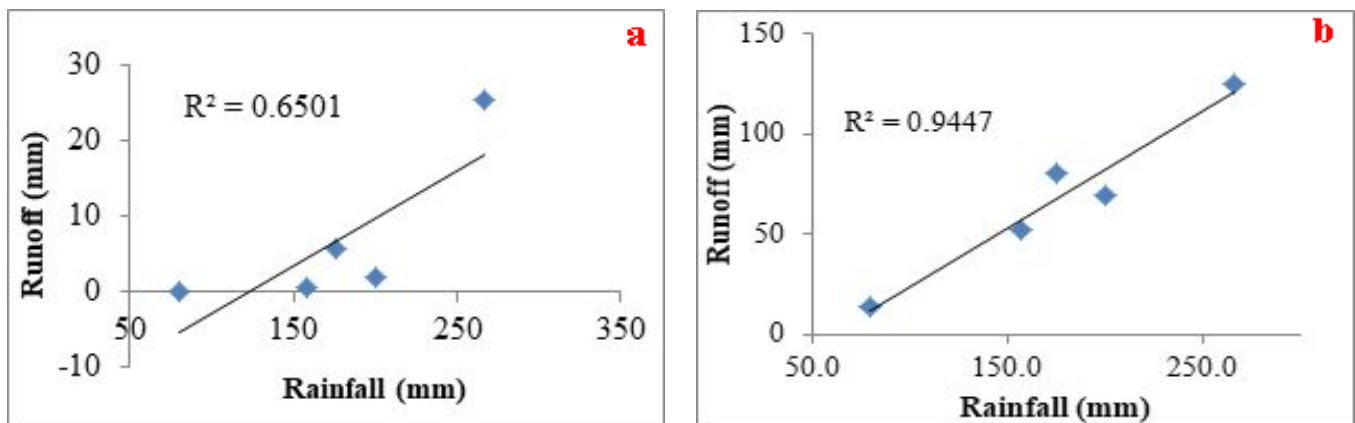


Figure 3. (a): Rainfall - runoff correlation using standard CN method (Year - 2020), (b): using modified CN method (Year - 2020)

indicated that the conventional CN method is inadequate for determining runoff from forested watersheds. Modification of the CN method with integrated slope factor and  $\lambda$  value adjustments gave better runoff estimates as well as better rainfall-runoff correlation as compared to the standard CN method. Similar results have been reported by Jacobs and Srinivasan (2005), Lim et al. (2006), Shi et al. (2009), Ebrahimian et al. (2012) and Ajmal et al. (2020).

## CONCLUSION

For steep sloping forested watersheds, the conventional CN method was unable to accurately estimate surface runoff in a manner that reflects real-world conditions. The present study revealed that the standard CN method could lead to significant errors in runoff estimation in steep sloped forested watersheds due to complex and heterogeneous nature of the landscape. The validation of the model's

prediction accuracy was not possible due to the lack of hydrologic gauging stations and daily flow records. Nevertheless, the model provided a reasonable representation of the watershed's hydrologic response to rainfall events, and its results can be utilized for conservation and management purposes.

**Authors' contributions:** All authors contributed equally

**Conflict of interest:** The authors declare no conflict of interest

## REFERENCES

- Ajmal, M., Waseem, M., Kim, D. and Kim, T.W. 2020. A pragmatic slope-adjusted curve number model to reduce uncertainty in predicting flood runoff from steep watersheds. *Water*, 12, 1469.

- Ajmal, M., Waseem, M., Kim, H.S. and Kim, T.W. 2016. Runoff estimation using the NRCS slope-adjusted curve number in mountainous watersheds. *Journal of Irrigation Drainage and Engineering*, 142, 1-12.
- Al-Ghobari, H., Dewidar, A. and Alataway, A. 2020. Estimation of surface water runoff for a semi-arid area using RS and GIS-based SCS-CN method. *Water*, 12, 1924.
- Ansari, T.A., Katpatal, Y.B. and Rishma, C. 2020. A Historical Review of Slope Based SCS Method and its Effect on CN and Runoff Potential Globally. Preprints, 2020100024. doi: 10.20944/preprints202010.0024.v1
- Beck, H.E., de Jeu, R.A.M., Schellekens, J., van Dijk, A.I.J.M. and Bruijnzeel, L.A. 2009. Improving curve number based storm runoff estimates using soil moisture proxies. *Journal of Selected Topics in Applied Earth Observation*, 2(4), 250-259.
- Carsel, R., Imhoff, J., Hummel, P., Cheplick, J. and Doniga, A. 1997. PRZM 3.1 Users Manual, National Exposure Research Lab, Office of Research and Development, US Environmental Protection Agency, Athens, Georgia.
- Dhawale, A.W. 2013. Runoff estimation for Darewadi watershed using RS and GIS. *International Journal of Recent Technology and Engineering*, 1(6), 46-50.
- Ebrahimian, M., Nurrudin, A.A.B., Soom, M.A.B., Sood, A.B. and Neng, L.G. 2012. Runoff estimation in steep slope watershed with standard and slope-adjusted curve number methods. *Polish Journal Environmental Studies*, 21(5), 1191-1202.
- Feldman, A. 2000. Hydrologic Modeling System (HEC-HMS): Technical Reference Manual, U.S. Army Corps of Engineers: Washington DC.
- Gajbhiye, S. and Mishra, S.K. 2012. Application of NRSC-SCS curve number model in runoff estimation using RS & GIS. PP. 346-352, In: IEEE-International conference on advances in engineering, science and management (ICAESM-2012).
- Hawkins, R.H., Hjelmfelt, A.T. and Zevenbergen, A.W. 1985. Runoff probability, storm depth, and curve numbers. *Journal of Irrigation and Drainage Engineering*, 111(4), 330-340.
- Hawkins, R.H., Theurer, F.D. and Rezaeianzadeh, M. 2019. Understanding the basis of the curve number method for watershed models and TMDLs. *Journal of Hydrologic Engineering*, 24(7), 06019003. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001755](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001755)
- Huang, M., Jagues, G., Wang, Z. and Monique, G. 2006. A modification to the soil conservation service curve number method for steep slopes in the Loess plateau of China. *Hydrological Processes*, 20(3), 579-589.
- Jacobs, J.H. and Srinivasan, R. 2005. Effects of curve number modification on runoff estimation using WSR-88D rainfall data in Texas watersheds. *Journal of Soil and Water Conservation*, 60(5), 274-279.
- Kichu, R. and Dutta, M. 2022. Assessment of soil erosion using GIS and remote sensing techniques in Dzumah watershed of upper Dhansiri, Nagaland. *The Pharma Innovation Journal*, 11(9), 2266-2273.
- Kichu, R., Dutta, M., Nayak, R.C. and Hangshing, L. 2022. Quantitative morphometric analysis of Dzumah watershed of Upper Dhansiri, Nagaland, India. *Indian Journal of Ecology*, 49(3), 837-842.
- Knisel, W.G. 1980. CREAMS: a field-scale model for chemical, runoff and erosion from agricultural management systems. Conservation Research Report No. 26, South East Area, US Department of Agriculture, Washington, DC.
- Lim, K.J., Engel, B.A., Muthukrishnan, S. and Harbor, J. 2006. Effects of initial abstraction and urbanization on estimated runoff using CN technology. *Journal of the American Water Resources Association*, 42, 629-643.
- Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. and King, K.W. 2002. Soil and Water Assessment Tool (SWAT): Theoretical Documentation, Version 2000, Texas Water Resources Institute, College Station, Texas, TWRI Report TR-191.
- Ross, C.W., Prihodko, L., Anchang, J., Kumar, S., Ji, W. and Hanan, N.P. 2018. HYSOGs250m, global gridded hydrologic soil groups for curve-number-based runoff modeling. *Scientific Data*, 5, 180091. <https://doi.org/10.1038/sdata.2018.91>
- Sharpley, A.N. and Williams, J.R. 1990. EPIC- Erosion/Productivity Impact Calculator: 1. Model Documentation, US Department of Agriculture Technical Bulletin No. 1768. US Government Printing Office, Washington, DC.
- Shi, Z.H., Chen, L.D., Fang, N.F., Qin, D.F. and Cai, C.F. 2009. Research on the SCS-CN initial abstraction ratio using rainfall-runoff event analysis in the Three Gorges Area, China. *Catena*, 77, 1-7.
- Taylor, D. and Shrimali, N.J. 2016. Surface runoff estimation by SCS curve number method using GIS for Rupen-Khan watershed, Mehsana district, Gujarat. *Journal of Indian Water Resources Society*, 36(4), 1-5.
- Topno, A.; Singh, A.K. and Vaishya, R.C. 2015. SCS-CN runoff estimation for Vindhyaachal region using remote sensing and GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1): 1214-1223.
- USDA-NRCS. 1986. Urban hydrology for small watersheds, Technical Release 55, Springfield, VA: National Technical Information Service.
- Verma, S., Singh, A., Mishra, S.K., Singh, P.K. and Verma, R.K. 2018. Efficacy of slope-adjusted curve number models with varying initial abstraction coefficient for runoff estimation. *International Journal of Hydrology Science and Technology*, 8(4), 317-338.
- Woodward, D.E., Hawkins, R.H., Jiang, R., Hjelmfelt, A.T. Jr., Van Mullem, J.A. and Quan, Q.D. 2003. Runoff curve number method: Examination of the initial abstraction ratio. *World Water & Environment Resources*, in: Congress 2003 and Related Symposia, EWRI, ASCE, Philadelphia, Pennsylvania, USA.
- Young, R.A., Onstad, C.A., Bosch, D.D. and Anderson, W.P. 1989. AGNPS: a nonpoint-source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation*, 44(2), 168-173.

*Received: 30th March 2023*

*Accepted: 14th July 2023*