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Estimation of surface runoff using USDA SCS-CN method

Ajit Kumar Singh and Vikram Singh

Abstract
Since most of the Indian watersheds are ungauged, estimation of runoff depth is one of the key parameter not only for designing engineering structures in watershed but also for prioritization of sub watersheds within the watershed. Present study was undertaken to determine the runoff depth using the USDA Soil Conservation Service curve number (SCS-CN) method in Gandak river basin in 3 stations, namely Gopalganj, Hajipur, Walminagar and Saran. The nearest stations Muzffarpur from study area also take for study. 30 years data were collected from 5 stations nearest study area for runoff calculation from NASA. Soil map were collected from National Bureau of soil Survey (NBSS), Nagpur. Satellite data for Land Use/Land Cover Map was prepared with the assist of ArcGIS. Satellite images for photographs of observed places were used, Landsat 8 data were used. From this study has been found that the maximum rainfall 151.385 mm occurred on 29th July, 1990 giving highest runoff value of 107.43 mm and the peak runoff calculated 1954.66 MCM from Gandak river outlet in year 2008-09 in last 30 years (1987-2017).

Keywords: Surface runoff, soil conservation service (SCS), curve number (CN), Arc GIS

Introduction
Water is one of the most important continuing resources for sustaining life and development in our society. Surface runoff is the major hydrologic variable used in the water resources applications and management planning. Knowing the amount of runoff from a catchment is of vital importance particularly for planning the hydraulic structures and taking necessary erosion control measures. One of the most important objectives of engineering hydrology is to calculate the water yield of the catchments to determine the flood flows for planning the discharge facilities for water storage structures. In situation where there is no sufficient and reliable data, the calculation based on empirical methods lead to mistakes in determining the dimensions of water conservation structures. A good runoff model includes spatially variable parameters such as rainfall, soil types and land use/ land cover etc. (Kumar; 1997). Identification of runoff is also of critical importance where the basic reservoirs support drinking water needs of the people. United States Department of Agriculture Soil Conservation Service (USDA,1964), developed an empirical method for determining approximate amount of direct runoff from small agricultural catchments with different soil groups, vegetation covers and land uses by examining measured precipitation and runoff amounts, and named it as "Soil Conservation Service Curve Number (SCSCN) Method". The SCSCN method (SCS, 1972) also known as hydrologic soil group method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and to get adequate results. It is widely and efficiently used for planning the structures aimed at water storage and erosion and flood control. Generally, the model is well suited for small watersheds of less than 250 km2 and it requires details of soil characteristics, land use and vegetation condition (Sharma *et al.*, 2001) [7].

The runoff for an area is strongly dependent upon rainfall, land use/land cover, antecedent moisture condition, soil types, and topographic characteristics. These characters are found to vary greatly within a watershed. Therefore, a method which takes these factors in to account while estimating runoff is expected to realistically estimate runoff. The Soil Conservation Services (SCS-CN) is one such equation that takes factors such as rainfall, initial abstraction loss, potential maximum retention, soil, and land use/land cover into consideration while assessing runoff.

The runoff curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area.

The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. Gandak is a left bank tributary of the Ganga River. It is meandering in nature and flows in the southeast direction. The BurhiGandak river basin is bounded by Himalaya in the north, by Ganga River in south, by Kosi River in the east, and by Great Gandak River on the west and makes the eastern boundary of the Gandak Megafan. (Singh and Singh 2005)
Realizing the importance of the above mentioned views, the present study was undertaken to Estimation of surface runoff using USDA SCS-CN method.

Materials and Methods

Study area

Present study was undertaken to determine the runoff depth using the USDA Soil Conservation Service curve number (SCS-CN) method in Gandak river basin in 3 stations, namely Gopalganj, Hajipur, Walminagar and Saran. The nearest stations Muzffarpur from study area also take for study. 30 years data were collected from 5 stations nearest study area for runoff calculation from NASA. Soil map were collected from National Bureau of soil Survey (NBSS), Nagpur. Satellite data for Land Use/Land Cover Map was prepared with the assist of ArcGIS.

Data collection

The data related to the characteristics of Gandak river basin were collected from 5 stations nearest study area for runoff calculation from NASA. Soil map were collected from National Bureau of soil Survey (NBSS), Nagpur. Satellite data for Land Use/Land Cover Map was prepared with the assist of ArcGIS.

SCS-CN method

Mathematical description of the SCS-CN model is based on three equations (water balance and two concepts).The water balance equation equates the total rainfall (P) to sum of initial abstraction (I_a), actual infiltration (F) and direct runoff (Q).
The first concept assumes that the ratio of actual infiltration(F) to potential maximum retention (S) equals the ratio of actual effective rainfall (direct runoff) (Q) to the total rainfall (P) less initial abstraction (I_a).In addition, the amount of potential maximum retention(S) is related to initial abstraction (Ia) by linear dependence. The measure of the dependence is the coefficient (λ).
Thus, 1)

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

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

$$I_a = \lambda \cdot S \quad (3)$$

The formula of effective rainfall is derived as a result of transformation of equations (1), (2), (3):

$$Q = \frac{(P - \lambda \cdot S)^2}{P + (1 - \lambda) S} \quad (4)$$

In the SCS method it is assumed that the value of λ coefficient equals 0.2, although for Indian context pertaining to the black soil region the values are taken as follows (NIH, 98).
For black soil region

$$Ia = 0.3S \quad (5)$$

For black soil region

$$Ia = 0.1S \quad (6)$$

Eq 6 is used with the assumption that the cracks which are typical of black soil when in dry conditions get vanished due to the expansive characteristics of the black soils.
The potential maximum retention by the soil is given by relating it to a dimensionless parameter known as the curve number (CN) that depends upon the hydrologic soil groups, antecedent moisture conditions as well as land use land cover factors in the catchment area.

$$S = \frac{25400}{CN} - 254 \quad (7)$$

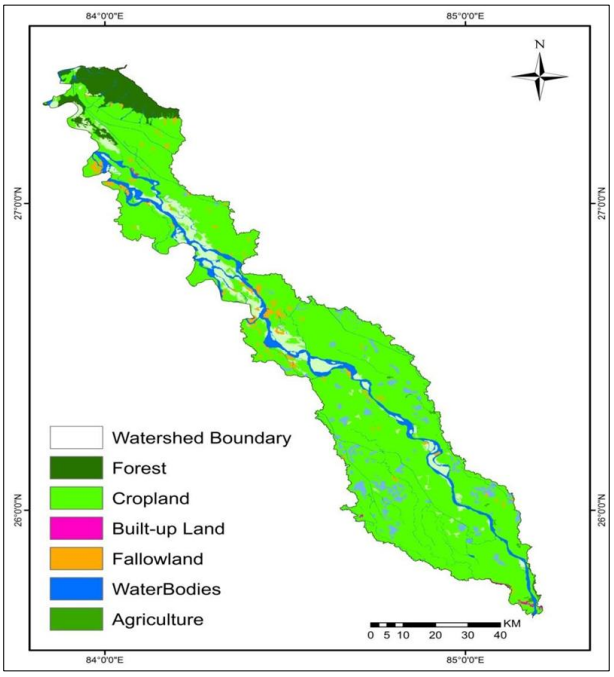

Fig 1: Land Use/ Land Cover Map (2005) of the Gandak River Catchment

Results & Discussion

Table 1: Weights for Average Rainfall Computation

S. No.	Stations	Weightage
1.	Hajipur	0.5
2.	Gopalganj	0.35
3.	Saran	0.60
Total		1.0

Table 2: SCS-CN model parameter

Moisture	AMC I	AMC II	AMC III
Condition	DRY	NORMAL	WET
CN	51	70	85
S	248	108	46
Ia=0.2S	49.6	21.6	9.2
Ia=0.8S	77.4	32.4	13.8

Computation of estimated runoff and runoff volume

Direct runoff value (Q) of each year was calculated by SCS-CN method, and the values are presented. The estimated runoff was depicted in the form of graph as shown in fig., it is noted that among the selected storm event maximum rainfall of 151.385 mm occurred on 29th, July, 1990 giving highest runoff value of 107.43 mm.

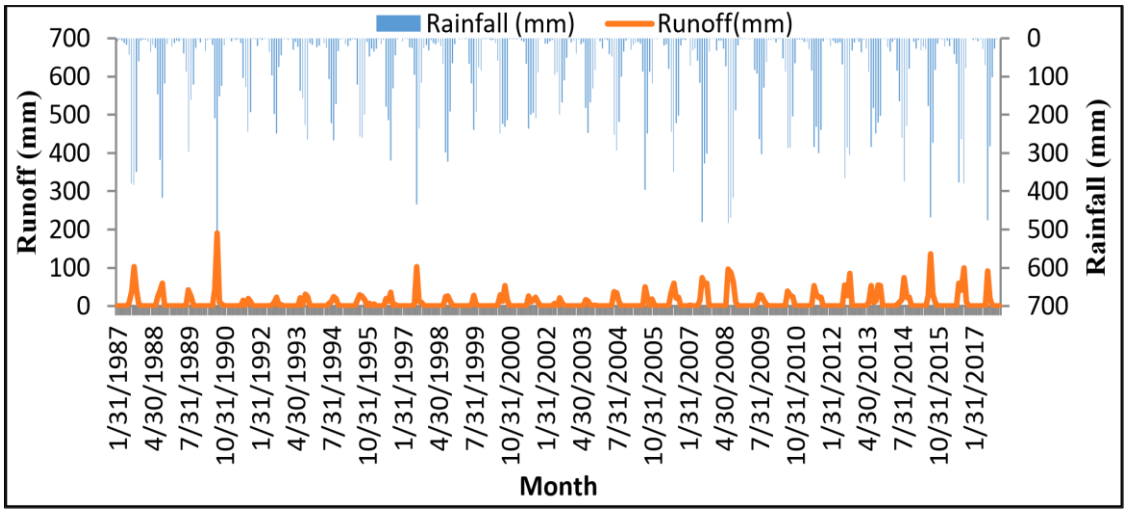

Fig 2: Monthly Runoff Simulations from SCS-CN (1987-2017)

From year 1987 to 2017 in July, 1990 the highest rainfall occurs 578 mm which is highest rainfall and almost 50% of total annual rainfall of year 1990.

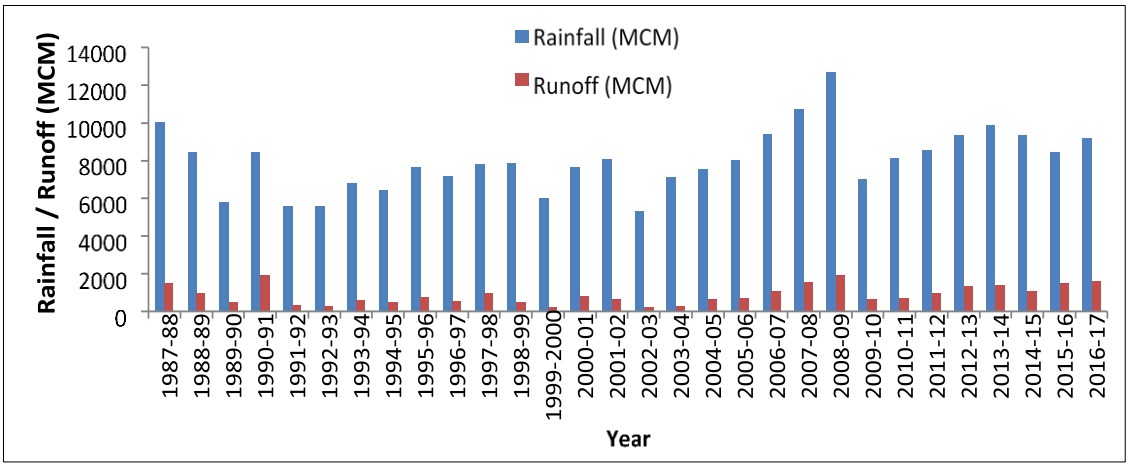

Fig 3: Yearly (Water year) Runoff Simulation from SCS-CN (1987-2017)

The lowest runoff calculated 229.35 MCM in 2002-03 and the highest runoff calculated 1954.66 from Gandak river outlet in year 2008-09.

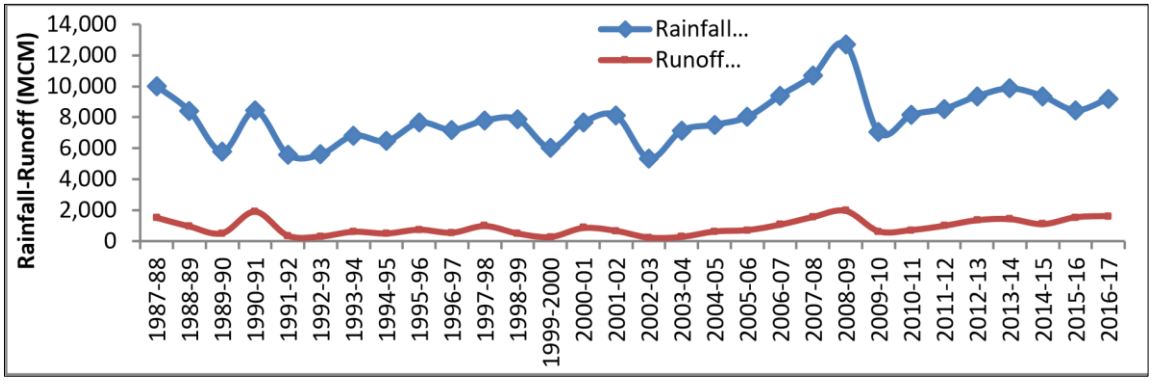

Fig 4: Graphically representation of Yearly (Water year) Runoff Simulation from SCS-CN (1987-2017)

Table 3: Runoff from outlet Simulated value from SCN-CN (1987-2017)

Year	Runoff SCS-CN method (MCM)
1987-88	1510.6
1988-89	951.1
1989-90	510
1990-91	1908.5
1991-92	354.1
1992-93	298.1
1993-94	608.1
1994-95	495.8
1995-96	739.4
1996-97	546.4
1997-98	977
1998-99	493.85
1999-2000	267.92
2000-01	847.18
2001-02	665.19
2002-03	229.35
2003-04	274.70
2004-05	625.47
2005-06	710.24
2006-07	1062.01
2007-08	1560
2008-09	1954.66
2009-10	635.63
2010-11	717.54
2011-12	990.95
2012-13	1353.01
2013-14	1424.27
2014-15	1097.67
2015-16	1543.20
2016-17	1624.95

Conclusion

Rainfall-Runoff modeling is one of the important tool in hydrologic analysis for the purpose of water resource planning, flood forecasting and in many other application. In the present study rainfall-runoff modeling was carried SCS-CN method. The SCS-CN method in GIS platform coupled with remote sensing data is found to be effective, since the spatial distribution of soils and land use of the watershed are addressed. From this study has been found that the maximum rainfall 151.385 mm occurred on 29th July, 1990 giving highest runoff value of 107.43 mm and the peak runoff calculated 1954.66MCM from Gandak river outlet in year 2008-09 in last 30 years (1987, 2017)

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