Appl Water Sci (2017) 7:1773–1779
DOI 10.1007/s13201-015-0350-7

ORIGINAL ARTICLE

Application of remote sensing and geographical information system for generation of runoff curve number

S. Gajbhiye Meshram[1] · S. K. Sharma[2] · S. Tignath[3]

Received: 22 March 2015 / Accepted: 5 October 2015 / Published online: 17 October 2015

Abstract Watershed is an ideal unit for planning and management of land and water resources (Gajbhiye et al., IEEE international conference on advances in technology and engineering (ICATE), Bombay, vol 1, issue 9, pp 23–25, 2013a; Gajbhiye et al., Appl Water Sci 4(1):51–61, 2014a; Gajbhiye et al., J Geol Soc India (SCI-IF 0.596) 84(2):192–196, 2014b). This study aims to generate the curve number, using remote sensing and geographical information system (GIS) and the effect of slope on curve number values. The study was carried out in Kanhaiya Nala watershed located in Satna district of Madhya Pradesh. Soil map, Land Use/Land cover and slope map were generated in GIS Environment. The CN parameter values corresponding to various soil, land cover, and land management conditions were selected from Natural Resource Conservation Service (NRCS) standard table. Curve number (CN) is an index developed by the NRCS, to represent the potential for storm water runoff within a drainage area. The CN for a drainage basin is estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC). In present study effect of slope on CN values were determined. The result showed that the CN unadjusted value are higher in comparison to CN adjusted with slope. Remote sensing and GIS is very reliable technique for the preparation of most of the input data required by the SCS curve number model.

Keywords SCS-CN · Runoff · Watershed · Remote sensing · Geographical information system

Introduction

Water resources development plays an important role in achieving multifaceted economic and social development of a nation. India is endowed with substantial water resources in accordance with latest estimates of Central Water Commission, annual runoff of its river systems aggregates to 1800 km^3 constituting 4 % of total annual water flows of the world. As the population of India is about 16 % of world's population, there is greater pressure on use of water to meet the demand in this country. A substantial progress has been made in development and management of water resources in the last 50 years. However, the pace of development in the water resources has lead to the exploitation of the water resources in leaps and bounds, resulting in overuse of surface supplies and over exploitation of ground water. Therefore, at this stage one has to realize the need and importance of conservation of water. At the outset water resources planning is a prerequisite for any developmental activities.

As regards planning, watershed development program has become widely accepted concept, which is based on overall exploitation of total resources. Water resources project in general lacks planning in most of the cases due to pressure from various sectors without taking into consideration of developmental possibilities. Therefore, before taking up any water resources development project, the prime necessity is to know the probable quantity of water

✉ S. Gajbhiye Meshram
gajbhiyesarita@gmail.com

1 Department of Water Resources Development and Management, IIT, Roorkee, Uttarakhand, India

2 Department of Soil and Water Engineering, College of Agricultural Engineering, J.N.K.V.V., Jabalpur, MP, India

3 Department of Geology, Government Autonomous Model Science College, Jabalpur, MP, India

available from a watershed. For the estimation of amount of direct runoff that will be produced from a given precipitation from a basin, various hydrologic models are available. Amongst these models, Soil Conservation Services (SCS) model now called as NRCS is most widely used for the direct runoff in the ungauged basins. This model combines watershed parameters and climatic factors in one entity called the Curve Number.

The method was developed in 1954 by the USDA Soil Conservation Service (Rallison 1980), and is described in the Soil Conservation Services (SCS) National Engineering handbook Sect. 4: Hydrology (NEH-4) (SCS 1985). The first version of the handbook was published in 1954. Subsequent revision followed in 1956, 1964, 1965, 1971, 1972, 1985 and 1993. The SCS-CN method has become the focus of much discussion in recent hydrological literature. For example, Ponce and Hawkins (1996) critically examined this method; clarified its conceptual and empirical basis; delineated its capabilities, limitations, and uses; and identified areas of research. Yu (1998) derived the SCS-CN method analytically assuming exponential distribution for the spatial variation of the infiltration capacity and the temporal variation of the rainfall rate. Hjelmfelt (1991), Hawkins (1993) and Bonta (1997) suggested procedures for determining curve numbers using field data of storm rainfall and runoff. Moglen (2000) discussed the effect of spatial variability of CN on the computed runoff. Mishra et al. (2013)modified the SCS-CN method by accounting for the static portion of infiltration and the antecedent moisture. Mishra and Singh (2004) studied the validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates. Mishra et al. (2006) improved the relation between the initial abstraction (I_a) and the potential maximum storage (S) incorporating antecedent moisture in SCS-CN methodology. Many models, such as AGNPS (Young et al. 1989), TR-55, TR-20, HIC-1, WMS, and HIC-HMS adopt SCS-CN method for runoff calculation. Gajbhiye et al. 2014a, b, c, d find relationship between SCS-CN and sediment yield, Gajbhiye et al. 2015a, b simplified sediment yield index model incorporating parameter CN. The SCS-CN method does not take into account the effect of slope on runoff yield because cultivated land in general has slope of less than 5 % and the slope <5 % does not influence the CN value significantly. However, there are few models which incorporate a slope factor to CN method to improve estimation of surface runoff depth and volume (Huang et al. 2006). Those which had taken the slope factor into account are Sharpley and Williams (1990) and Huang et al. (2006). Thus, only a few attempts have been made to include the slope factor into the CN method.

Conventional methods of runoff estimation using SCS model are time consuming and error prone. Thus, Remote Sensing and geographical information system (GIS) techniques are being increasingly used, as all the factors of SCS model are geographic in character. Some of the researcher in India attempted the application of remote sensing (RS) and GIS (Gajbhiye and Sharma 2012, 2015a, b; Gajbhiye et al. 2014a, b, c, d, 2015a, b; Gajbhiye 2015a). Due to geographic nature of these factors of SCS runoff model can easily be modelled into GIS. Some of the research worker in India has attempted to calculate runoff curve number using satellite data. Gajbhiye and Mishra 2012, estimate runoff using SCS-CN method through RS and GIS application in Kanhaiya watershed, Gajbhiye 2015b estimated surface runoff using RS and GIS. Gajbhiye et al. 2013b find a monthly and seasonal variation of runoff curve number of the Narmada watershed. Gajbhiye et al. 2013a, Mishra et al. 2013 design runoff curve number for Narmada Watershed (India). Gajbhiye (2014) estimation of Rainfall generated runoff using RS and GIS. Looking to all these facts a study was undertaken with the objective to generate Curve number using RS and GIS and to see the effect of slope on CN value.

Materials and methods

Study area

The study area Kanhaiya nala watershed which lies within the Tons River catchment is situated between 80°31′ 51.01″ to 80°35′ 17.05E longitude and 24°06′ 29.23″ to 24°11′ 05.03″ latitude with elevation range 480–620 m above Mean Sea Level (MSL) and extends a total area of 2352.65 ha. Kanhaiya nala Watershed situated in Satna District (MP) is shown in Fig. 1. The total area of the watershed is 19.53 km^2. It has a typical subtropical climate with hot dry summers and cool dry winters. Temperature extremes vary between the minimum of 4 °C during December or January months to the maximum of 45 °C in May or June. Average annual precipitation is 1100 mm, which is concentrated mostly between Mid-June and Mid-September with scattered winter rains during late December and January months.

Data source

Topographic map at the scale of 1:50,000 prepared by Survey of India (SOI) was used for delineation of the watershed. SOI toposheet no. 63 D/12 was used for the delineation of watershed boundary. The Landsat ETM satellite data, with 30 m resolution procured from Global Land Cover Facility (GLCF), Maryland, with the date of pass 11 Oct 2006 were used to prepare the LULC map of watershed. Soil map prepared by National Bureau of Soil

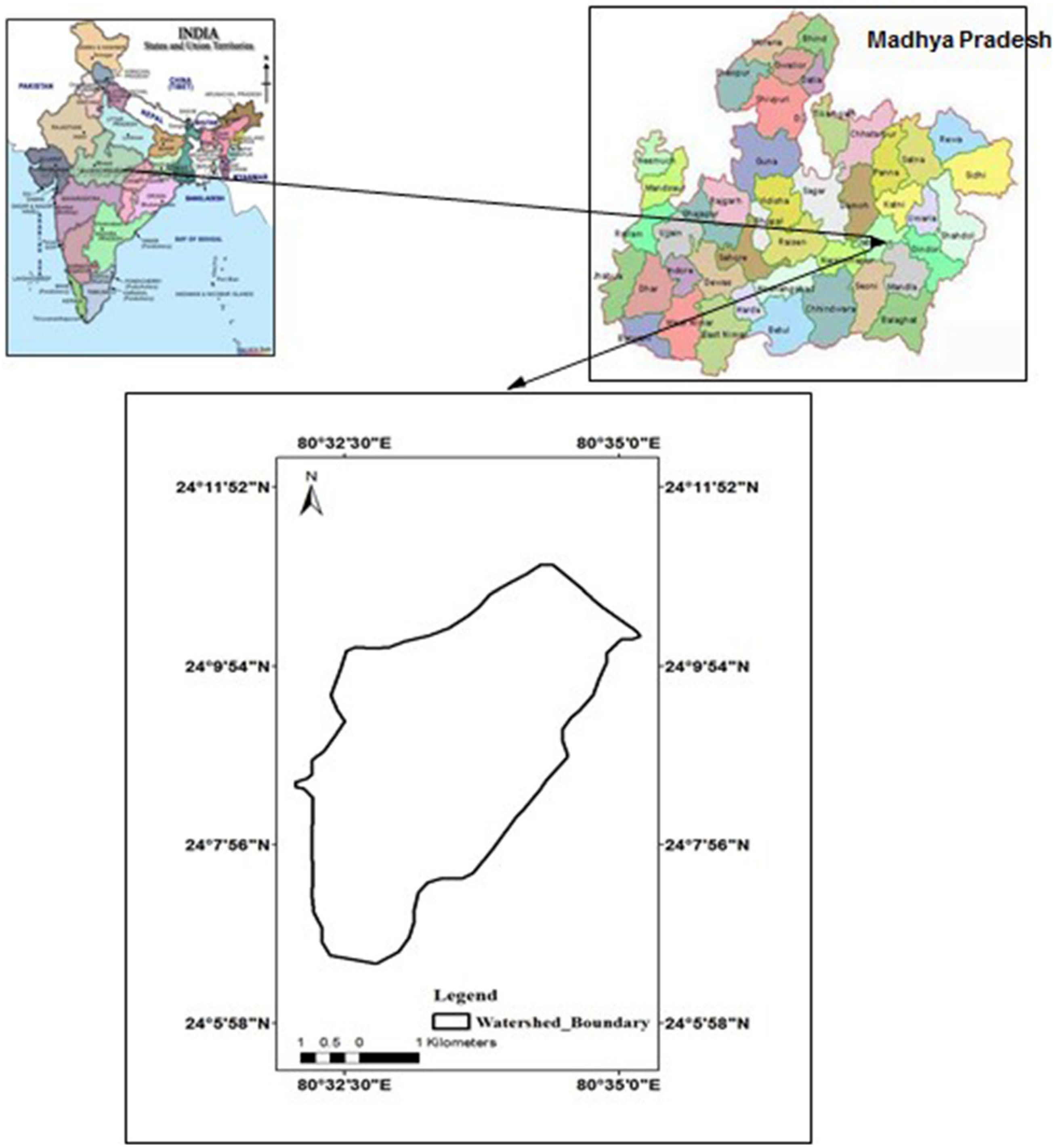

Fig. 1 Location map of the study area

Survey on 1:250,000 and printed on 1:500,000 was used to prepare soil map of study area.

Software used

Arc view 3.1 power GIS software was used for creating, managing and generation of different layer and maps. ERDAS 9.1 was used for generation of LULC map. The Microsoft excel was used for mathematical calculation.

LULC map

The LULC map was generated with the help of satellite data using unsupervised classification. In Kanhaiya Nala

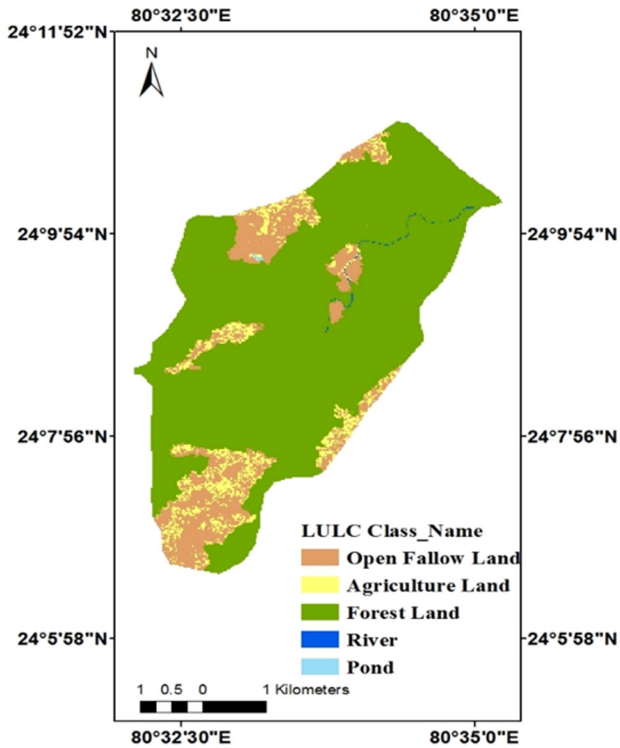

Fig. 2 LULC map of the watershed

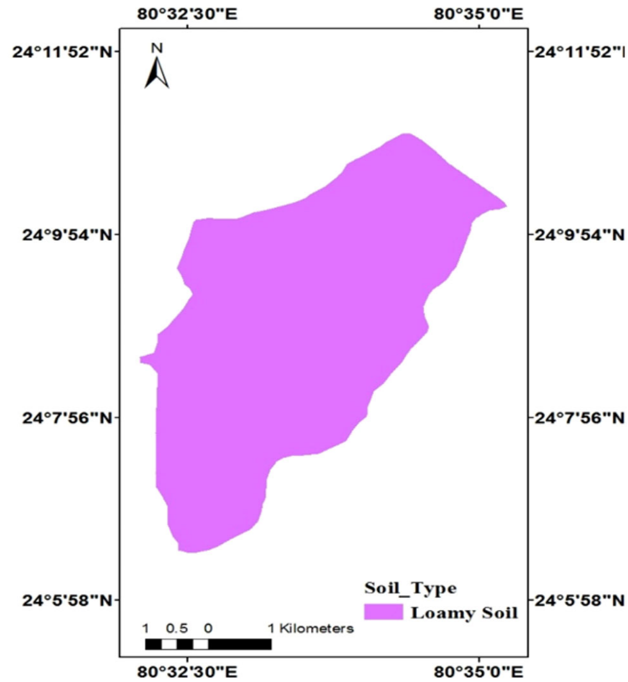

Fig. 3 Soil map of the watershed

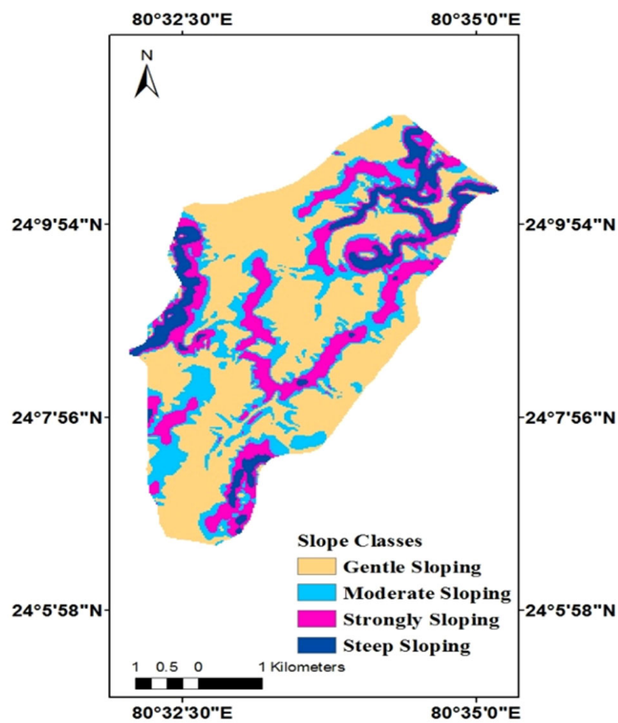

Fig. 4 Slope (%) map of the watershed

watershed five land use/land cover classes were identified, i.e., river, pond, open land, agriculture and forest (Fig. 2; Table 2).

Soil map

Soil map of Madhya Pradesh has been prepared by NBSS and LUP and it published on 1:500,000 scale in nine sheets. Sheet no. 4 has the soil map of study area. So, the same has been scanned and further GIS operation has been made in Arc Info. In present study only one type of soil (loamy) was present (Fig. 3) which comes under the hydrologic soil group B.

Slope map

The slope has major influence on the soil and water of the watershed and thereby influences the land use capability. The percentage slope determines the erosion susceptibility of the soil depending on its nature. The slope map (Fig. 4) was generated from the contour of survey of India toposheet at 1:50,000 scale following 20 m contour interval. The contour was digitized using ARC GIS 9.3.

Preparation of CN map

To prepare CN map, the soil map and land use map were uploaded to the arc view. The soil map and land use map were selected for intersection, after intersection a map with new polygon representing the merged soil-land map. The appropriate CN value for each polygon of the soil-land map was assigned (see Fig. 5; Table 1).

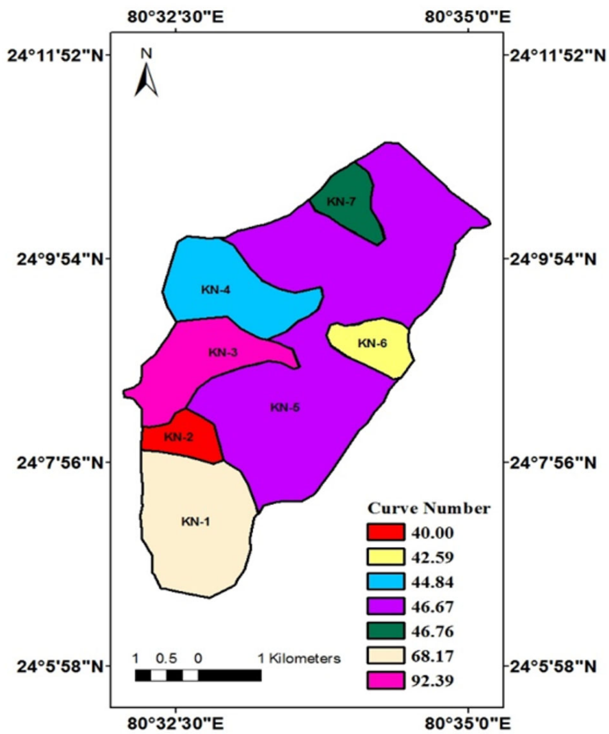

Fig. 5 CN map of the watershed

$$\mathrm{CN} = \left(\sum (\mathrm{CN}_i \times A_i)\right)/A$$

where CN = weighted curve number. CN_i = curve number from 1 to any no. N. A_i = area with curve number $\mathrm{CN}_i A$ = the total area of the watershed.

Calculating slope adjusted CN

The NRCS-CN method does not take into account the effect of slope on runoff

$$\mathrm{CN2}\ \alpha = \mathrm{CN2} \times K$$

$$K = \frac{322.79 + 15.63\alpha}{\alpha + 323.52}$$

where K = CN constant and CN2 α = value of CN2 for a given slope.

Slope and CN map were intersected to get slope of each polygon, since each polygon has different slope, then calculation of weighted slope is need for each polygon. Weighted slope of polygon was computed using formula

$$\text{Weighted slope} = \frac{\sum(\mathrm{Ai} \times \mathrm{Si})}{A}$$

where Ai = area of slope (ha), Si = slope (%) and A = polygon area (ha).

Table 1 Runoff curve numbers for (AMC II) for the Indian conditions

SI no.	Landuse	Treatment/practice	Hydrologic condition	Hydrologic soil group			
				A	B	C	D
1	Cultivated	Straight row	–	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			Good	62	71	77	81
		Bunded	Poor	67	75	81	83
			Good	59	69	76	79
		Paddy (rice)	–	95	95	95	95
2	Orchards	With under stony cover	–	39	53	67	71
		Without under stony cover		41	55	69	73
3	Forest	Dense	–	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	61
4	Pasture	–	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5	Wasted land	–	–	71	80	85	88
6	Hard surface	–	–	77	86	91	93

Table 2 Land use/land cover classification of the Kanhaiya Nala watershed

S. no.	Classes	Area (km^2)	Percentage
1	Open land	2.79	14.28
2	Agriculture	1.11	5.68
3	Forest	15.56	79.67
4	River	0.04	0.20
5	Pond	0.03	0.15
Total		19.53	100

Table 3 Curve number for Kanhaiya Nala watershed

S. no	Sub-watershed	CN (AMCII)	Slope adjusted CN (AMCII)	Weighted slope (%)
1	KN_1	68.17	68.10	3.96
2	KN_2	40.00	39.96	4.39
3	KN_3	92.39	92.29	4.33
4	KN_4	44.84	44.79	3.09
5	KN_5	46.76	46.66	2.23
6	KN_6	42.59	42.50	1.96
7	KN_7	46.76	46.71	3.56

Result and discussion

The soil of the Kanhaiya Nala watershed is loamy, which comes under the hydrologic soil group 'B' (Fig. 3). The study watershed was delineated into seven subwatersheds. The land use/land cover classification of the watershed is presented in Table 2. On the basis of unsupervised classification the classes namely River (0.20 %), Pond (0.03 %), Open/fallow land (14.28 %), Agriculture land (5.68 %) and Forest (79.67 %) were identified. Further land use/land cover digital data was used for generation of CN.

Curve number

The USDA curve number table modified for Indian conditions was used for the determination of the curve number for individual sub watersheds based on the hydrological soil groups and land use classes of respective areas. The weighted CN (AMCII) and slope adjusted CN (AMCII) values are given in Table 3.

The weighted CN value of sub watershed 1, 2, 3, 4, 5, 6, and 7 comes to be 68.17, 40.00, 92.39, 44.84, 46.76, 42.59 and 46.76, respectively. And slope adjusted CN value for sub watershed 1, 2, 3, 4, 5, 6, and 7 to be 68.10, 39.96, 92.29, 44.79, 46.66, 42.50 and 46.71, respectively. It can be inferred from Table 3 that the CN unadjusted value are higher in comparison to CN adjusted with slope.

There is no provision for runoff monitoring in Kanhaiya Nala watershed, therefore this method could be used to find out the runoff. Thus, the generated curve numbers may be used for prediction of runoff from an ungauged watershed.

Conclusion

The synoptic concept of satellite image in remote sensing and GIS application is fairly easy for identification of the broad physical features such as stream network, land use/land cover, soils surface, water bodies, etc. which are necessary input parameters for estimation of runoff using NRCS model. In the present study the CN unadjusted value are higher in comparison to CN adjusted with slope. Although curve number method is empirical approach to determine the runoff depth from watersheds, it can be useful for estimating the runoff for places which do not have runoff record. Moreover, study on the curve number behavior of watersheds can be carried out to distinguish watershed behavior for soil and water conservation planning.

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