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Estimation and comparision of curve numbers based on dynamic land use land cover change, observed rainfall-runoff data and land slope

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SUMMARY

The CN represents runoff potential is estimated using three different methods for three watersheds namely Barureva, Sher and Umar watershed located in Narmada basin. Among three watersheds, Sher watershed has gauging site for the runoff measurements. The CN computed from the observed rainfall-runoff events is termed as $CN_{(PQ)}$, land use and land cover (LULC) is termed as $CN_{(LU)}$ and the CN based on land slope is termed as $SACN_2$.

The estimated annual $CN_{(PQ)}$ varies from 69 to 87 over the 26 years data period with median 74 and average 75. The range of $CN_{(PQ)}$ from 70 to 79 are most significant values and these truly represent the AMC II condition for the Sher watershed. The annual $CN_{(LU)}$ was computed for all three watersheds using GIS and the years are 1973, 1989 and 2000. Satellite imagery of MSS, TM and ETM+ sensors are available for these years and obtained from the Global Land Cover Facility Data Center of Maryland University USA. The computed $CN_{(LU)}$ values show rising trend with the time and this trend is attributed to expansion of agriculture area in all watersheds. The predicted values of $CN_{(LU)}$ with time (year) can be used to predict runoff potential under the effect of change in LULC. Comparison of $CN_{(LU)}$ and $CN_{(PQ)}$ values shows close agreement and it also validates the classification of LULC. The estimation of slope adjusted $SA\text{-}CN_2$ shows the significant difference over conventional CN for the hilly forest lands. For the micro watershed planning, SCS-CN method should be modified to incorporate the effect of change in land use and land cover along with effect of land slope.

1. Introduction

Rainfall generated runoff in a watershed is an important input in design of hydraulic structures and erosion control measures. On long term basis, change in runoff volume and its time distribution indicates dynamic changes occurring in a watershed. Poor land use planning and land management practices may adversely impact surface runoff quantities and quality through the reduction of land use and land cover (LULC) and increase in imperviousness of surface areas (Harr et al., 1975; Minner, 1998; Beighley and Moglen, 2002; Tong and Chen, 2002; Booth et al., 2002). Urbanization, deforestation, changes in agricultural practices, open grazing, etc. are part of LULC change. Thus, a hydrologic model that uses LULC as input is useful to quantify the effect of LULC changes on runoff. One such widely used model is the Soil Conservation Service Curve Number (SCS-CN) method. It computes the surface runoff volume for a given rainfall event from small agricultural, forest, and urban watersheds (SCS, 1956 and 1986). The method is simple to use and requires basic descriptive inputs that are converted to numeric values for estimation of direct runoff volume (Bonta, 1997). "Curve number" indicates runoff potential of land area and it is the function of hydrologic soil group, antecedent rainfall, land use pattern, density of plant cover and conservation practices followed in the land area.

The SCS-CN method is widely used by engineers, hydrologists and watershed managers as a simple watershed model, and as the runoff estimating component in more complex watershed models. In words of Ponce and Hawkins (1996) "The SCS-CN method is a conceptual model of hydrologic abstraction of storm rainfall, supported by empirical data. Its objective is to estimate direct runoff volume from storm rainfall depth, based on a curve number CN". Despite widespread use of SCS-CN methodology, realistic estimation of parameter CN has been a topic of discussion among hydrologists and water resources community (Hawkins, 1978; Hjemfelt, 1980; Rallison, 1980; McCuen, 2002; Simanton

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et al., 1996; Steenhuis et al., 1995; Bonta, 1997; Ponce and Hawkins, 1996; Sahu et al., 2007; Mishra and Singh, 2006).

Geographic Information System (GIS), which has been designed to restore, manipulate, retrieve and display spatial and non-spatial data, is an important tool in analysis of parameters such as land use, land cover, soils, topographical and hydrological conditions. Remote sensing along with GIS application help to collect, analyze and interpret the multidisciplinary data rapidly on large scale and is very much helpful for watershed planning. Estimation of runoff potential from ungauged watersheds using conventional methods requires much time and efforts. Conventional methods of runoff measurements are not easy for inaccessible terrain and not economical for a large number of small watersheds. Remote sensing and GIS can augment the conventional method to a great extent in rainfall-runoff modelling (Ragan and Jackson, 1980; Slack and Welch, 1980; Tiwari et al., 1991; Pandey and Sahu, 2002; Patil et al., 2008). They effectively utilized the satellite data to estimate the USDA soil conservation Services (SCS) Runoff Curve Number (CN) for Indian Watersheds.

Recent studies (Sharda et al., 1993; Schumann et al., 2000; Saxena et al., 2000; Shrimali et al., 2001; Reddy et al., 2004; Strager et al., 2010; Makhamreh, 2011; Magesh et al., 2012) illustrate that Remote Sensing (RS) and Geographic Information System (GIS) techniques are of great use in characterization and prioritization of watershed areas. Land use land cover is the category in which RS has made its largest impact and comes closest to maximizing technological capabilities (Garbrecht et al., 2001; Pandey et al., 2002). Keeping in view, RS and GIS can be successfully utilized to improve accuracy in estimation of Curve Number for a watershed from its land use data and digitized soil map (Still and Shih, 1985; White, 1988; Kumar et al., 1997; Melesse and Shih, 2002; Pandey and Sahu, 2002; Cheng et al., 2006).

Thus, the present study deals with the application of SCS-CN method coupled with GIS and Remote Sensing for runoff potential with the following objectives: (i) to develop year wise series of curve numbers (CN_{PQ}) using observed rainfall (P) and runoff (Q) events of period greater than 1-day; (ii) to develop a versatile regression model for estimation of curve numbers (CN_{LU}) using land use land cover and hydrological soil cover data and compare and validate with observed CN_{PQ}; (iii) to predict runoff potential using SCS-CN method based on versatile CN regression model on the basis of LULC changes; and finally (iv) to test the performance of SCS-CN method based on versatile CN regression model for runoff estimation using observed data.

2. SCS-CN method

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of actual amount of direct surface runoff Q to the total rainfall P (or maximum potential surface runoff) to the ratio of actual infiltration (F) to the amount of the potential maximum retention S. The second hypothesis relates the initial abstraction (I_a) to the potential maximum retention (S). The popular form of SCS-CN method is expressed as:

$$\begin{aligned} Q &= \tfrac{(P-Ia)^2}{(P-Ia+S)} \quad \text{for } P \geq Ia \\ &= 0 \quad\quad\quad\quad \text{otherwise} \end{aligned} \tag{1}$$

where P is total rainfall; I_a is initial abstraction; F is cumulative infiltration excluding I_a; Q is direct runoff; and S is potential maximum retention.In general λ is taken as 0.2; the Eq. (1) reduces to

$$\begin{aligned} Q &= \tfrac{(P-0.2S)^2}{(P+0.8S)} \quad \text{for } P \geq 0.2S \\ &= 0, \quad\quad\quad\quad \text{for } P \leqslant 0.2S \end{aligned} \tag{2}$$

The parameter S of the SCS-CN method depends on soil type, land use, hydrologic condition, and antecedent moisture condition (AMC). Analytically, parameter S is obtained from Eq. (2) as (Hawkins, 1993):

$$S = 5[P + 2Q - (4Q^2 + 5PQ)^{1/2}] \tag{3}$$

Since parameter S can vary in the range of $0 \leqslant S \leqslant \infty$, it is mapped onto a dimensionless curve number CN, varying in a more appealing range $0 \leqslant \mathrm{CN} \leqslant 100$, as:

$$\mathrm{CN} = \frac{25400}{(254 + S)} \tag{4}$$

where S is in mm. The difference between S and CN is that the former is a dimensional quantity (L) whereas the later is non-dimensional. CN = 100 represents a condition of zero potential maximum retention ($S = 0$), that is, an impermeable watershed. Conversely, CN = 0 represents a theoretical upper bound to potential maximum retention ($S = \infty$), that is an infinitely abstracting watershed. However, the practical design values validated by experience lie in the range of 40 to 98 (Van Mullem, 1989).

2.1. Estimation of CN from observed rainfall (P)-runoff (Q) data: [CN_{PQ}]

The study area consist of three adjacent watersheds namely Barureva, Sher and Umar conjoin together to form an important southern sub-basin of Narmada basin, MP, India. The gauging site at Belkheri (Fig. 1) monitors the discharge of Sher watershed of area 1488 km^2. The daily discharge data for a period of 26 years starting from 1977 to 2002 and corresponding daily rainfall data measured at three major stations, namely Narsinghpur, Harai and Lakhnadon is used in the present analysis. Thiessen polygon method was used for areal averaging of daily rainfall data measured at the three stations. The number of events selected in a year depends upon the amount of rainfall and its daily distribution in watershed. A simple straight line method was adopted for base flow separation (Fig. 2). It was found that the year 1997 observed highest number of flood events (13), while only 2 events were available in year 1989 due to unavailability of daily rainfall data. The duration for the selected events varies from 3 to 13 days as shown in Fig. 2. Same procedure was adopted for the rest of the observed P–Q events used in the estimation of CN analysis.

Procedure adopted for CN_{PQ} estimation for P–Q event occurring from 13th to 21st July, 1986 (Fig. 2) is outlined here as: (i) estimate base flow using Straight Line method (=0.412 mm); (ii) estimate direct runoff depth by deducting base flow from total runoff depth. For the selected event direct runoff depth = 26.61 mm and corresponding rainfall = 84.58 mm; (iii) use Hawkins formula (Eq. (3)) to estimate S = 95.61 mm; and (iv) use (Eq. (4)) to estimate CN_{PQ} for selected event; CN_{PQ} = 72.65.

Same procedure was followed for rest of the observed P–Q events in each year to estimate event based CN_{PQ}. Finally, for AMCII condition, the median value criteria given by Bonta (1993) and Mishra et al. (2005) was applied to get the annual CN_{PQ} values shown in Fig. 3.

2.2. CN from land use and land cover (LULC) and soil cover: [CN_{LU}]

The CN_{LU} is a dimensionless runoff index based on hydrologic soil group (HSG), land use, land treatment, hydrologic conditions and antecedent moisture condition (AMC) which counts on previous 5 days rainfall total. It is termed as 'CN_{LU}' to distinguish from 'CN_{PQ}'. In present study, land use land cover maps of three different years (1972, 1989 and 2000) have been derived from satellite

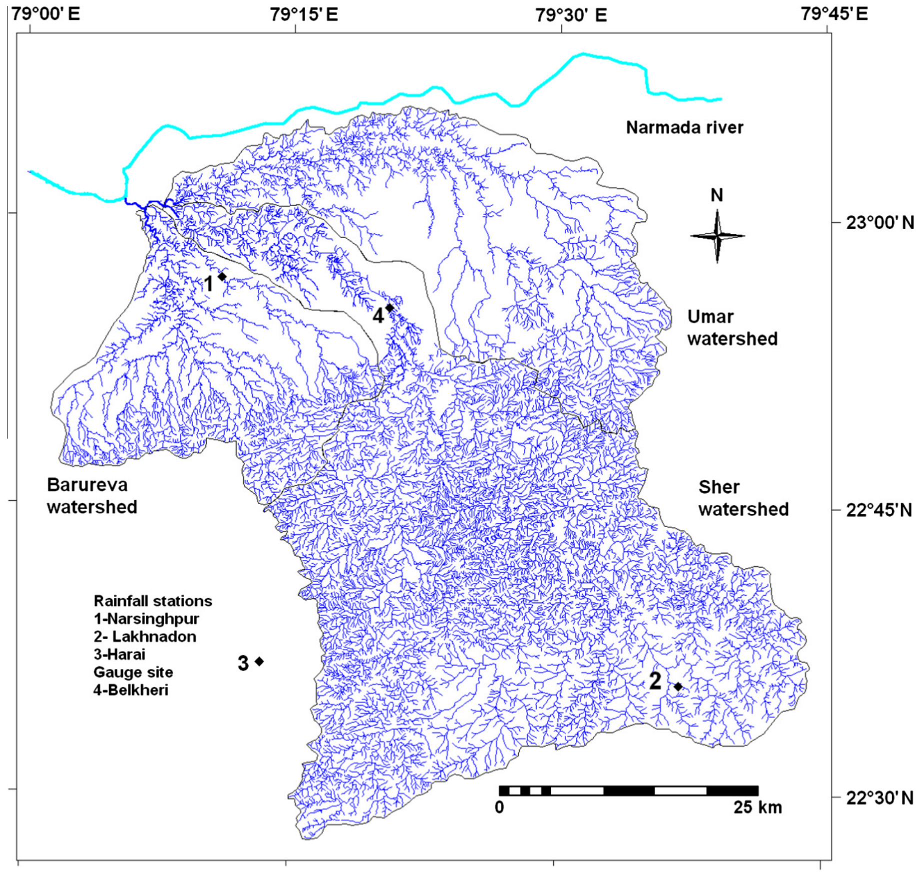


Fig. 1. The study area location showing rainfall stations and gauge site.

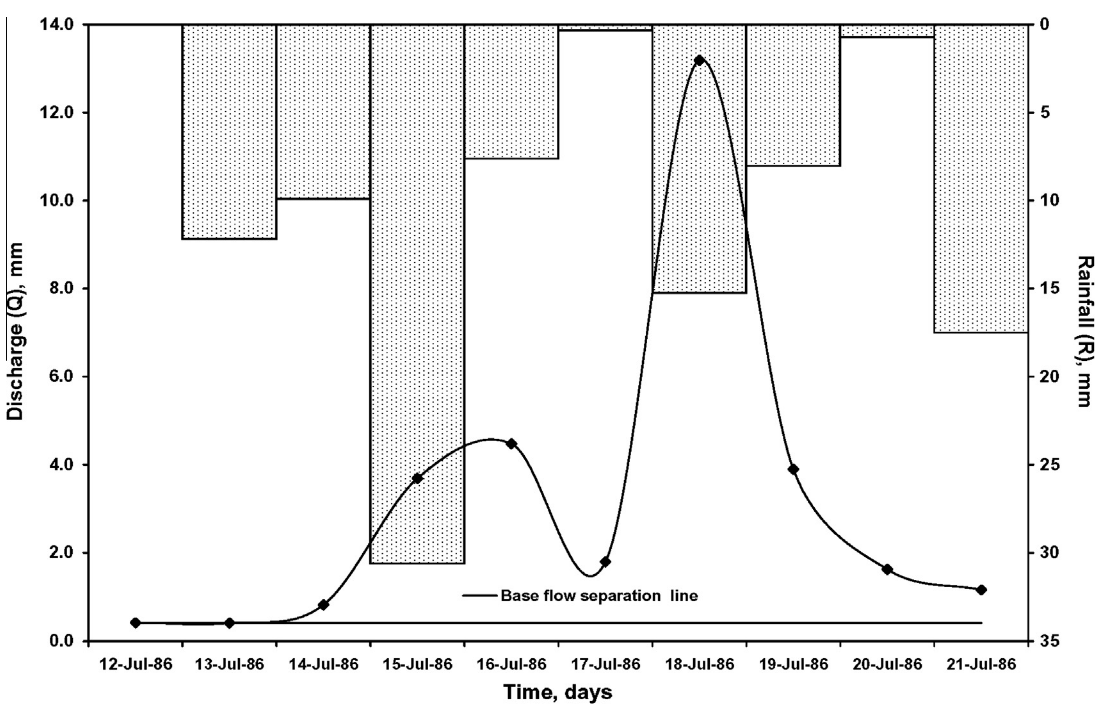


Fig. 2. Base flow separation procedure for the P–Q event, year 1986.

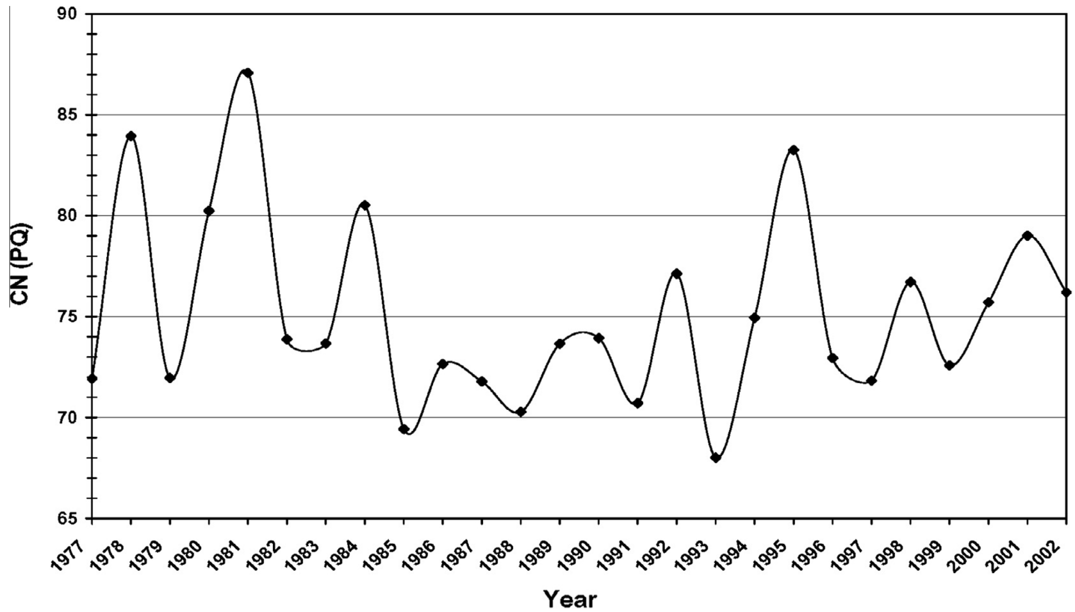


Fig. 3. Annual CN_{PQ} values for AMCII condition for gauged Sher watershed.

Table 1
Type and characteristics of satellite imagery.

Satellite	Corresponding month and year	Sensor	Spectral rage (μm)	Bands used for classification	Pixel size (in meter)
L1–4	November 1972	MSS	0.5–1.1	1, 2, 3	57
L4–5	November 1989	TM	0.45–2.35	3, 4, 5	28.5
L7	December 2000	ETM+	0.45–2.35	3, 4, 5	28.5

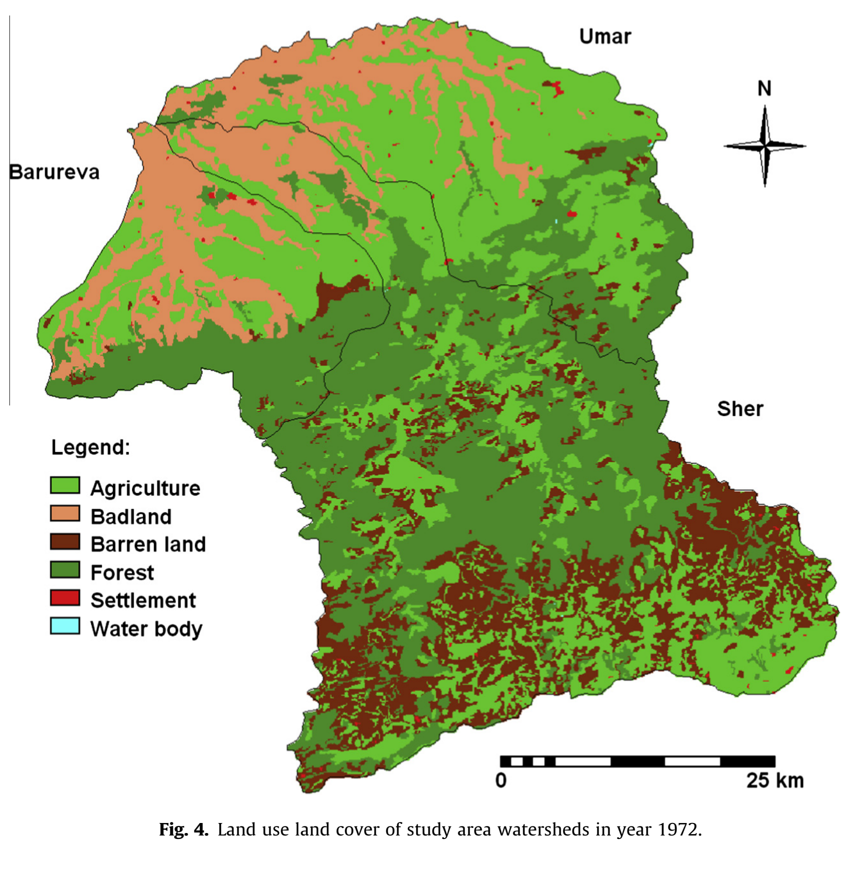


Fig. 4. Land use land cover of study area watersheds in year 1972.

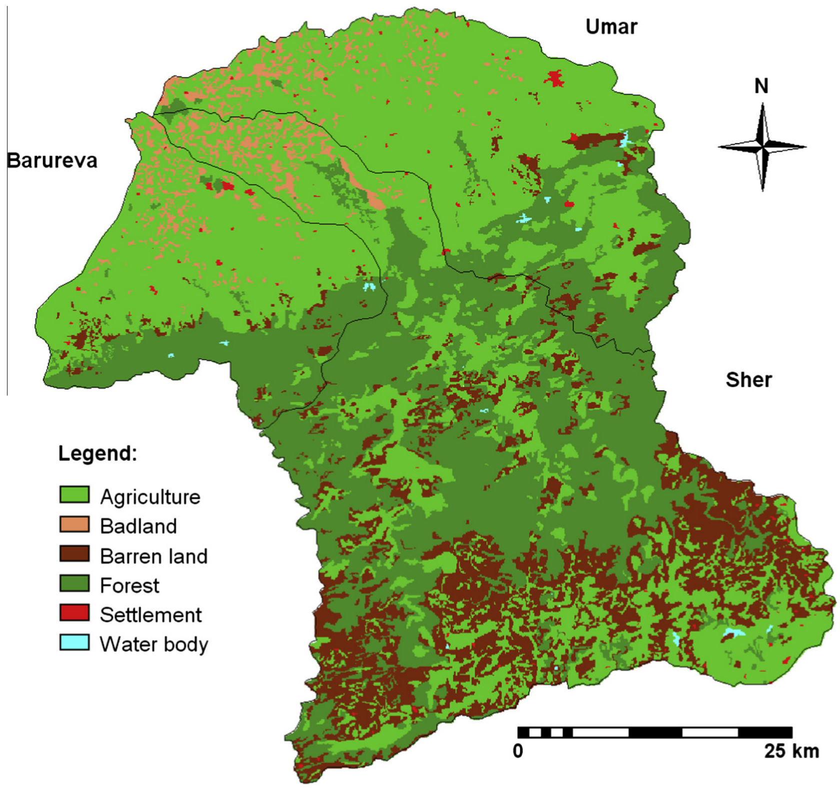


Fig. 5. Land use land cover of study area watersheds in year 1989.

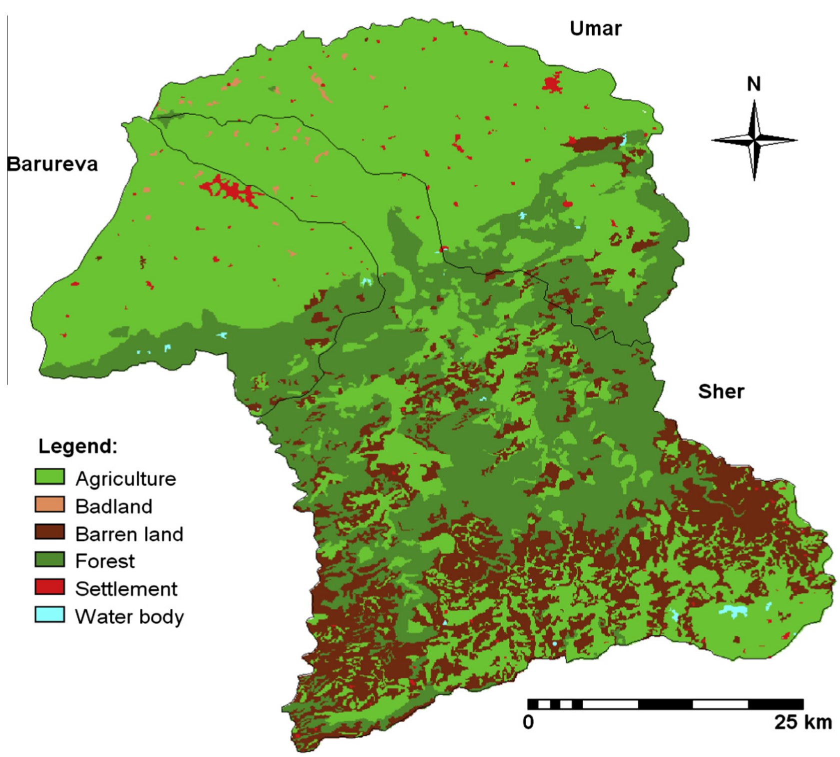


Fig. 6. Land use land cover of study area watersheds in year 2000.

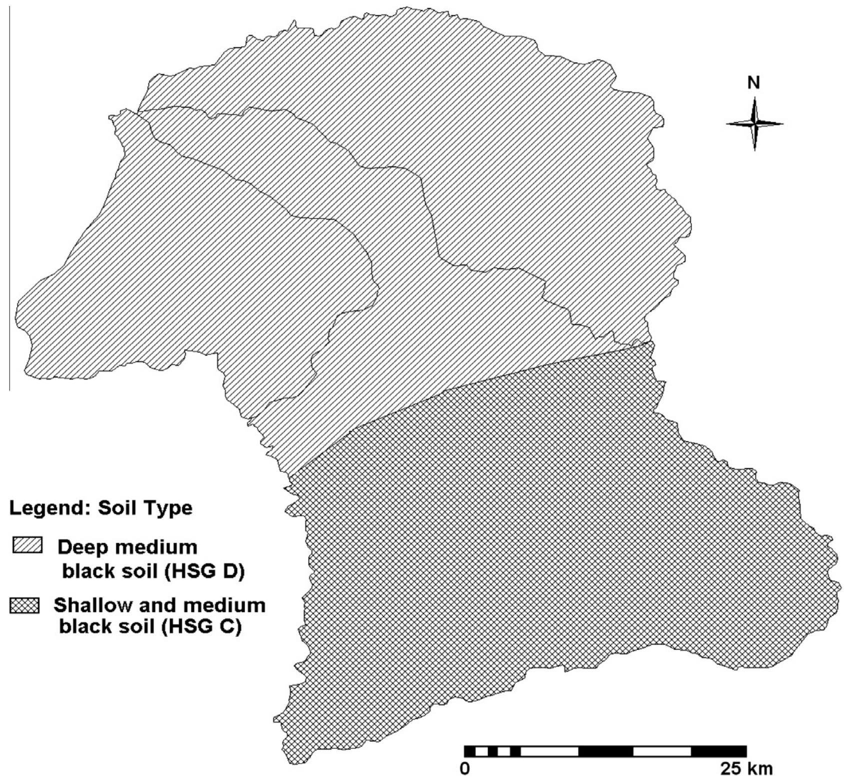


Fig. 7. Soil type in the of study area.

imageries by visual interpretation. The details of satellite imagery used to extract land use and land cover have been given in Table 1.

The classified land use maps showing six major classes such as agriculture, forest, barren land, badland, settlement and water bodies are given in Figs. 4–6 and discussed as given below.

- *Agriculture*: It included distributed patches of standing crop as well as fallow agriculture land which is brought under cultivation immediately.
- *Forest land*: It mainly considers fairly dense to dense forest of evergreen and moist deciduous type and it mainly contains teak.
- *Badland*: It is densely dissected land, which have been severely degraded and where soil has disappeared or lost most of its fertility. It was most dominant class study area near the confluence of rivers.
- *Barren land*: Barren land in the study area mainly defined as land of exposed area which contain small scrubs and very thin tree cover less 1/3 of total area. The very thin covered deforested area also included in this type.
- *Settlement*: The settlement mainly covers large village to urban areas.
- *Water body*: It main includes manmade small water storage structure filled with water.

To identify the soil type and hydrologic soil group (HSG) within the study area, the soil map was prepared using available soil type information and location maps obtained from the published reports (NIH case studies, 1995 and 1997; NBSS-59, 2007), as shown in Fig. 7.

It can be observed from Fig. 7 that lower part of study area has clayey soil with black in color and depth more than 9 m near the confluence of the three rivers. Based on dominance of clay having low value of hydraulic conductivity in lower part of study area it is classified in hydrological soil group D (HSG D) as shown in Fig. 7. On the other hand, the upper part of study area is found to have soils loamy in texture and blended with the clay content. The depth of the soil is very shallow and stony with loam texture on the steep sloping hills and soil is shallow to medium deep clay on medium and gently sloping Deccan plateau (NCA, 1976; Soils of MP, 2005; NBSS-59, 2007). Based on the textural and hydraulic properties, the soil is classified into hydrological soil group C (HSG C) as shown in Fig. 7. Notably, in the present study, the curve numbers (CN_{LU}) were obtained from reference table given by Dhruva Narayana (1993), which is particularly developed for Indian conditions.

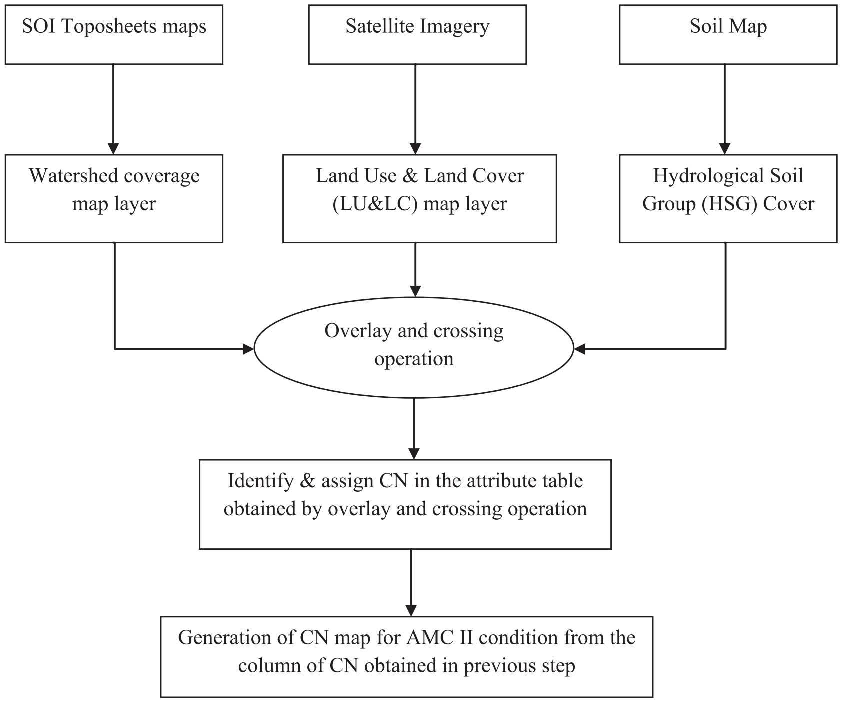
2.3. Spatial distribution of CN_{LU}

Based on the CN_{LU} values obtained from Land Use, Land Cover, Soil type and hydrologic soil group, spatially distributed CN_{LU} maps were prepared in GIS environment (ILWIS 3.0, 2001)as per the procedure given in Flow Diagram 1. The collective layers with their assigned CN values were used to generate distributed CN map of three different years 1972, 1989 and 2000 as shown in Figs. 8–10.

The weighted CN values for three study watersheds were computed using the formula

$$CN_{LU} = \frac{\sum (CN_i X\ A_i)}{A} \tag{5}$$

where CN_{LU} is weighted curve number; CN_i is curve number of area i assigned on the basis of land use and land cover and hydrologic soil group conditions; varies from 0 to 100; A_i is area having CN_i; A is total area of watershed.



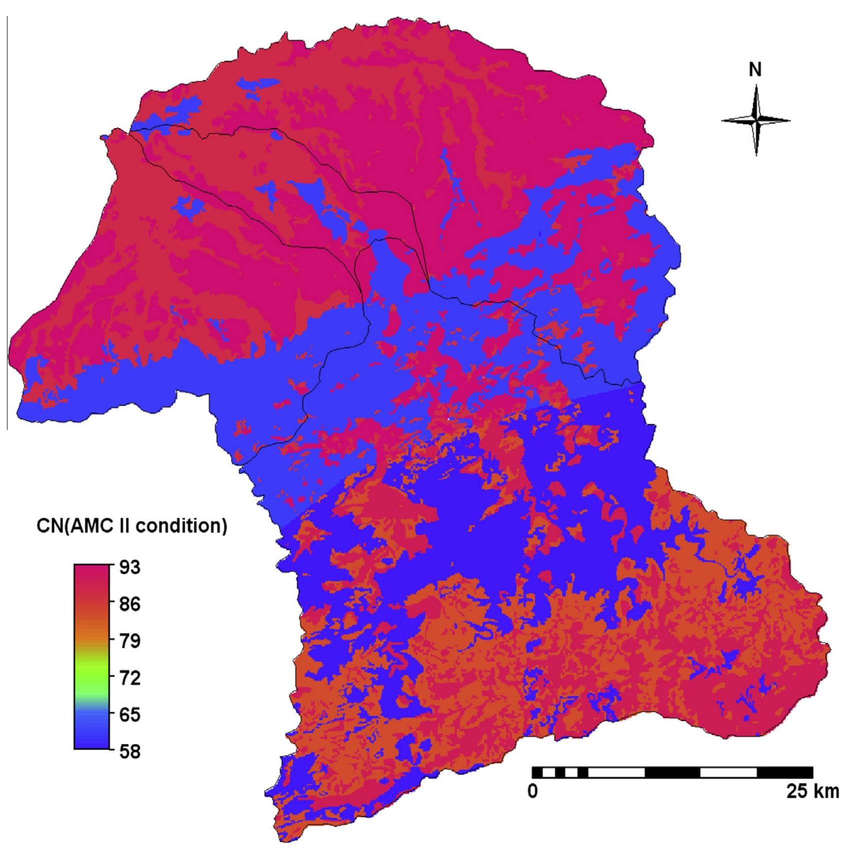


Fig. 8. Spatial distribution of CN_{LU} (runoff potential) in the year 1972.

Flow diagram 1. Procedure for determination of CN_{LU} map for AMC II.The GIS generated CN maps were further crossed with watershed boundaries of Sher (up to gauge site), Barureva, and Umar watersheds to get their respective weighted CN values of the watersheds for the considered years. The computed weighted CN_{LU} values for three watersheds are given in Table 2.

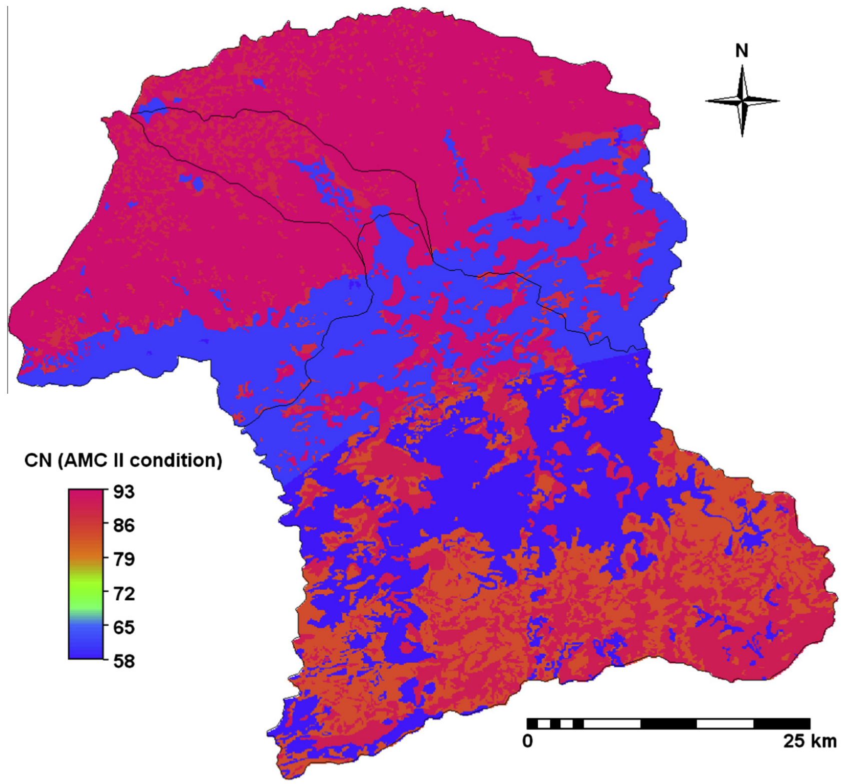


Fig. 9. Spatial distribution of $CN_{(LU)}$ (runoff potential) in the year 1989.

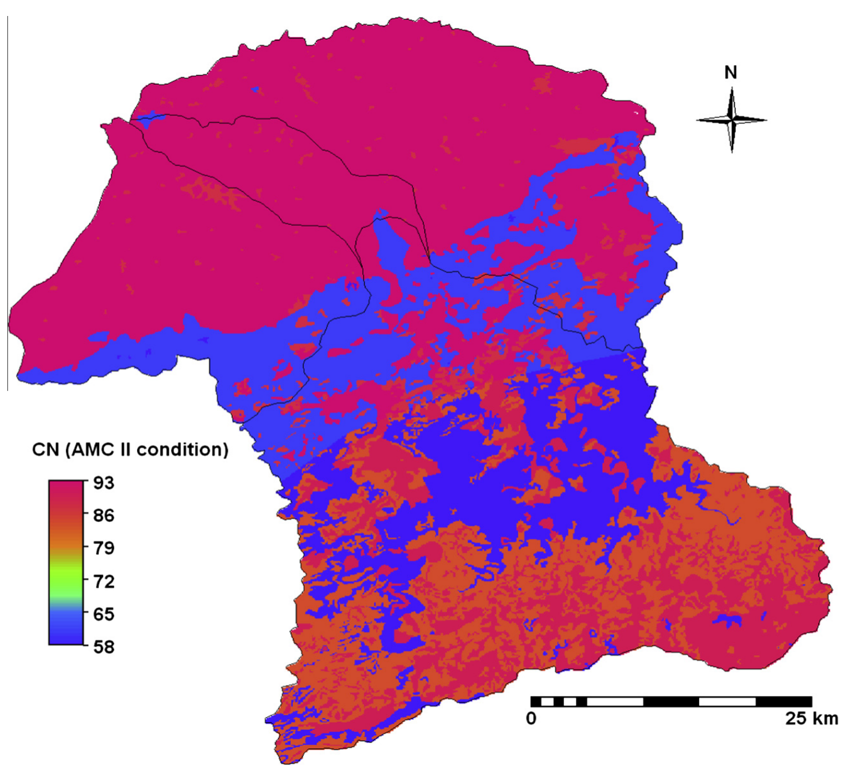


Fig. 10. Spatial distribution of $CN_{(LU)}$ (runoff potential) in the year 2000.

2.4. Development of versatile CN regression model based on LULC change

In general, the LULC in a watershed is assumed to be static in nature. However, due to increased human activities these are being changed dynamically. So, it is necessary to study changes in LULC in a watershed for its effective management plans over long periods of time say annually. Since, the conventional methods of runoff measurements are not easy for inaccessible terrains and not economical for a large number of small watersheds and at the same

Table 2
CN_{LU} for AMCII condition for three watersheds in study area.

Watershed name	Area (km^2)	$CN_{(LU)}$ for following years		
		1972	1989	2000
Barureva	488	81.24	82.98	84.86
Umar	699	84.79	85.8	86.77
Sher (u/s gauge site)	1488	75.31	75.28	77.06
Sher (d/s gauge site)	147	87.37	89.88	92.48
Sher	1635	76.40	76.60	78.46

Table 3
Predicted CN_{LU} values using versatile CN regression models.

Watershed name	Predicted CN_{LU} for following selected future years				Predicted year for CN_{LU} = 100
	2025	2050	2075	2100	
Barureva	87.88	91.06	94.23	97.41	2120
Umar	88.95	90.70	92.45	94.20	2183
Sher (u/s gauge site)	84.10	85.60	87.10	88.60	2290
Sher	83.21	84.96	88.46	89.16	2265

time, for ungauged watersheds accurate prediction of runoff requires much efforts and time. Hence, remote sensing and GIS techniques can be utilized successfully to facilitate estimation of watershed parameters such as Curve Number to estimate runoff potential using SCS-CN method in order to assess effects of changes in LULC.

Hence, the computed CN_{LU} values based on LULC, and hydrologic soil group were regressed with time 't' (numeric value of years in present case) to develop a simple but versatile model for each of the study watersheds as:

$$\text{For Barureva watershed}: \quad CN_{(LU)} = 0.127(t) - 169.29; \quad r^2 = 0.98 \tag{6}$$

$$\text{For Umar watershed}: \quad CN_{(LU)} = 0.07(t) - 52.80; \quad r^2 = 0.99 \tag{7}$$

$$\text{Sher watershed}: \quad CN_{(LU)} = 0.057(t) - 37.40; \quad r^2 = 0.62 \tag{8}$$

(upstream gauge site)

$$\text{Sher watershed}: \quad CN_{(LU)} = 0.07(t) - 58.54; \quad R^2 = 0.72 \tag{9}$$

Eqs. (6)–(9) were used to predict CN_{LU} (runoff potential) values for desired span of time to plan effective watershed planning & management approach as illustrated in Figs. 8–10 (CN_{LU} distribution maps) for three different years. These figures depict gradual increase in CN values from 1972 to 1989 and from 1989 to 2000. Notably, the increase in CN values is more apparent in lower part of the three watersheds where badland (CN = 89) and forest land (CN = 61) has been significantly converted into the agriculture land (CN = 93). The change in CN values in Barureva and Umar watersheds are caused by reclamation of badland for agriculture purpose. Isolated patches of forest which existed near the confluence of three rivers in year 1972 and 1989 have been completely replaced by agriculture area in year 2000 (Figs. 4, 6 and 7). The changes in $CN_{(LU)}$ gauged Sher watershed are not as remarkable as observed in Barureva and Umar watersheds and also in the downstream of gauge site of Sher watershed. Conversion of forest cover (CN = 58) into the barren land (CN = 89) in the middle part of gauged Sher watershed caused increase in CN values with the successive time period. Deforestation has lead to emergence of barren land along the boundaries of forest and agriculture land and result the increase in CN values.

Among three watersheds, Umar watershed shows highest $CN_{(LU)}$ value for AMC II condition, while Sher watershed shows the lowest $CN_{(LU)}$ for selected years. Consequently, Umar watershed has highest runoff potential under the same magnitude of received rainfall in comparison to other watersheds. Further, it can be observed that $CN_{(LU)}$ values particularly for Sher watershed do not show significant increase despite the spatial changes in LULC with time. The agriculture area in Barureva, Umar and part of Sher watershed downstream of gauge site have almost become stabilized and further increase is not expected as agriculture area has almost replaced previous existed land classes such as badland area and forest cover area. On the other hand, agriculture area in Sher watershed upstream of the gauge site is expected to increase in place of barren land, though the rate of increase is slow. This could be mainly due to inadequate water availability.

2.5. Future prediction of CN_{LU} for study watersheds

The developed relationship of CN_{LU} with historical years of 1972, 1989 and 2000 (Eqs. (6)–(8)) can be used for prediction of CN_{LU} in future, if the ongoing rate of changes in LULC persists in the watersheds. CN_{LU} values for each watershed have been predicted for time period up to 2100 as shown in Table 3.

It is observed from Table 3 that the predicted CN_{LU} values for Sher watershed has much lower CN increments due to slow rate of agriculture expansion. The Sher watershed (upstream gauge site) have the adequate scope for further increase in agricultural area by replacing barren land in future which is possible by introducing surface water storage structures and by improving irrigation schemes. Therefore, CN_{LU} prediction for Sher watershed may follow the current trend of CN_{LU} values in future year as shown in Table 3. If the predicted trend of CN_{LU} continues, CN_{LU} for all watersheds will attain the theoretically ultimate values of 100 sometime in future. The Barureva and Umar may attain CN_{LU} at 100 much earlier because these watersheds are under highly agricultural expansion due to increased population pressure. Comparatively, Sher watershed has lower human interference in terms of agricultural area expansion which has partly kept control on CN_{LU} of watershed. The value of CN_{LU} = 100 represents completely impermeable state of watershed which is practically not possible. Therefore, possible upper limit of CN_{LU} for all watersheds is 90 to 93 which is representative of CN_{LU} of agriculture for hydrological soil group of C and D, respectively. This situation expected to be reached around year 2075.

3. Validation of $CN_{(LU)}$ using $CN_{(PQ)}$

$CN_{(LU)}$ values derived from LULC and hydrologic soil group were compared with observed $CN_{(PQ)}$ for the gauged Sher watershed. The agreement between $CN_{(LU)}$ and $CN_{(PQ)}$ is depicted in Fig. 11. It is to mention here that the $CN_{(PQ)}$ for year 1972 was not available, and therefore $CN_{(PQ)}$ for year 1977 was been taken for analysis and its corresponding $CN_{(LU)}$ was computed from Eq. (8). From Fig. 11, it can be concluded that $CN_{(LU)}$ values have close association with the observed CN_{PQ}. In addition, the comparison of computed CN_{LU} and observed CN_{PQ} also validates the derived land use land cover classification from satellite imageries for years 1972, 1989 and 2000.

4. Daily simulation of runoff based on predicted annual $CN_{(LU)}$

The CN_{LU} estimated for each year from the proposed Versatile CN Regression model (Eq. (8)) were used for the using existing SCS-CN method (Eq. (2)). The agreement between computed and

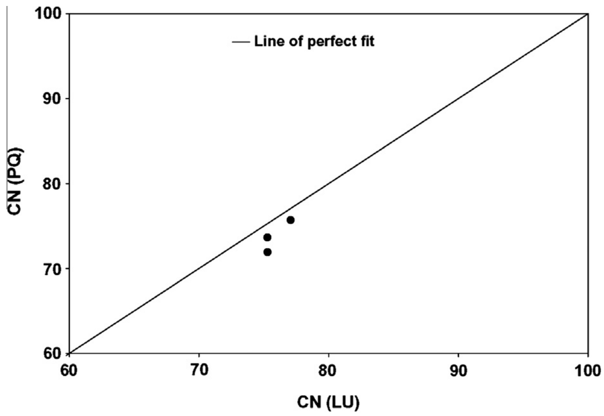


Fig. 11. Comparison of $CN_{(LU)}$ and $CN_{(PQ)}$ for gauged Sher watershed.

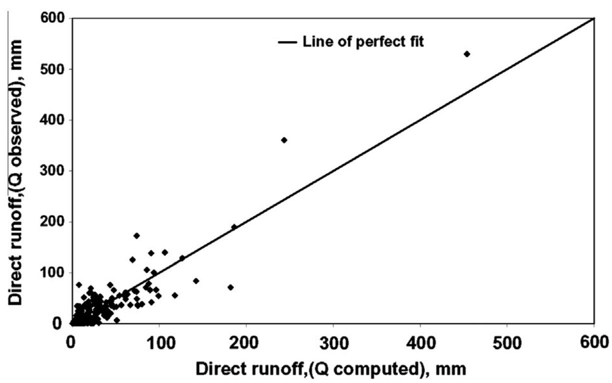


Fig. 12. Observed and computed event runoff values for gauged Sher.

observed event runoff values for gauged Sher watershed is shown in Fig. 12. It is observed that paired data sets of observed and computed values have closeness with line of perfect fit. The performance of the model was further evaluated in terms of Nash–Sutcliffe (NS) efficiency (Nash and Sutcliffe, 1970) and root mean square error (RMSE) as discussed below: .

4.1. Nash–Sutcliffe (NS) efficiency

Based on computed and observed data sets of direct runoff of selected long term events, NS efficiency is as:

$$NS = 1 - \frac{\sum (Q_{obs} - Q_{comp})^2}{\sum \left(Q_{obs} - \bar{Q}_{obs}\right)^2} \times 100 \tag{10}$$

where Q_{obs} is the observed runoff, Q_{comp} and $\bar{Q}_{obs}$ stand for computed and the mean of the observed runoff, respectively. The efficiency varies on the scale of 0–100. It can also assume a negative value if $\sum (Q_{obs} - Q_{comp})^2 > \sum \left(Q_{obs} - \bar{Q}_{comp}\right)^2$, implying that the variance in the observed and computed runoff values is greater than the model variance. In such a case, the mean of the observed data fits better than does the proposed model. The efficiency of 100 implies that the computed values are in perfect agreement with the observed data.

4.2. Root mean square error (RMSE)

The RMSE is computed for observed and computed data sets using following formula as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (Q_{obs} - Q_{comp})_i^2} \tag{11}$$

where Q_{obs} and Q_{comp} are observed and computed values and N is the data sample size. Higher the value of RMSE, poorer is the performance of the model, and vice versa. The values of RMSE = 0 indicate a perfect fit.

NS efficiency values were found to vary from 19.55 to 96.29, however high negative values were also observed for years 1987, 1992, 1995,1996,1997,1998 and 2001 due to underestimates of model output values against observed direct runoff. The SCS model simulates well for years 1977, 1978, 1982, 1984, 1999, 2000 and 2002 with NS efficiency values in the range of 70–97%. The NS efficiencies values are found in the range of 40–70% for years 1980, 1983, 1985, 1988, 1989, 1991 and 1993. In this case for some events predicted value of direct runoff are less than 50% of observed direct runoff values, however other events of these years show good agreement between computed and observed direct runoff values. Years such as 1979, 1981, 1986 and 1990 show poor performance of model in prediction of direct runoff values with NS efficiency value in the range of 19 to 40% due to either lack of sufficient events or due to one or two redundant event predictions. Therefore, it is necessary to consider overall efficiency for all data sets for model performance. The NS efficiency for entire data set (events for all years) is observed to be around 75% which is quite satisfactory. The RMSE values for all years of data set were found to vary in the range of 5–48 mm with an average of 21 mm.

On the basis of the above results it can be concluded that the SCS model under dynamic annual CN_{LU} is capable to predict direct runoff satisfactory for low as well as high rainfall events in the gauged Sher watershed. Therefore, the CN_{LU} computed for ungauged Barureva and Umar watersheds can be satisfactorily used for runoff prediction as well.

5. Estimation of slope adjusted CN for AMC II: SACN2

Due to increase in population, land availability per capita is decreasing. Increase in food production is being brought about by increasing the agriculture area through deforestation and cultivation of hill slope areas. The SCS-CN method for estimation of runoff was originally developed for agricultural watersheds with land slope near about 5%. However, over the years its application has been extended to watersheds having multiple land use without considering effect of topography. Huang et al. (2005) has reviewed various studies on the effect of soil slope on the runoff. An increase in surface runoff due to steeper slopes is due to (i) reduction of initial abstraction (Chaplot and Bissonnais, 2003), (ii) decrease in infiltration (Philip, 1991) and (iii) reduction of the recession time of overland flow (Evett and Dutt, 1985). The reduced recession time results in less opportunity for infiltration and consequently more runoff.

Although the effect of the slope on runoff volume has been clearly established by research studies, few attempts have been made to study effect of topography in the SCS-CN method. Sharpley and Williams (1990) has proposed the following equation to obtain slope adjusted CN value but it does not appear to have been verified in field (Huang et al., 2005).

$$SACN_2 = \frac{1}{3}(CN_3 - CN_2) - \left(1 - 2e^{-13.86\alpha}\right) + CN_2 \tag{12}$$

where $SACN_2$: slope adjusted CN for antecedent soil moisture condition II; CN_2: CN for antecedent soil moisture condition II; CN_3: CN for antecedent soil moisture condition III; α: soil slope (m/m); CN_2 and CN_3 correspond to a soil slope of 5%.

In the present study, Eq. (12) has been used to study the spatial effect of slope on runoff potential at watershed and sub watershed

Table 4
CN_{slope} (LU) for AMCII condition for different watersheds in study area.

Watershed name	Area (km^2)	Year		
		1972	1989	2000
Barureva	488	80.22	82.19	84.23
Umar	699	83.61	84.75	85.79
Sher (gauge)	1488	75.29	75.26	77.04
Sher (d/s gauge)	147	86.14	88.84	91.58
Sher	1635	76.28	76.51	78.37

level in Barureva, Umar and Sher watersheds. This exercise was performed for three different years of land use and land cover i.e. year 1972, 1989 and 2000. SCS-CN value have been compared with slope adjusted CN (SA-CN_2) in Table 4. It is seen that the difference between SCS-CN and SA-CN_2 values is insignificant at watershed level suggesting negligible effect of slope. However, since slope may vary significantly within a watershed. The effect of slope may have pronounce effect if study is conducted at sub-watershed level.

Fig. 13 shows spatial distribution of difference in $SACN_2$ and SCS-CN corresponding to land use and land cover in the year 2000. Effect of slope on CN in areas under different land use and land cover is shown in Table 5.

Following inferences can be drawn from the table.

(i) SA-CN_2 is less than the SCS-CN over land with slope less than 5% and it is more than SCS-CN with slopes more than 5%. Higher the deviation from 5% slope more is the difference.
(ii) Significant difference in CN is observed in the forest lands which are usually located on slopes. Therefore, land slope should be considered in SCS-CN method for evaluating runoff potential especially for hilly area watersheds.
(iii) Effect of slope on CN is relatively less significant in watersheds having agriculture and other land use and land covers.
(iv) For micro watershed planning, SCS-CN method can be modified to incorporate effect of change in land use also in addition to effect of slope.

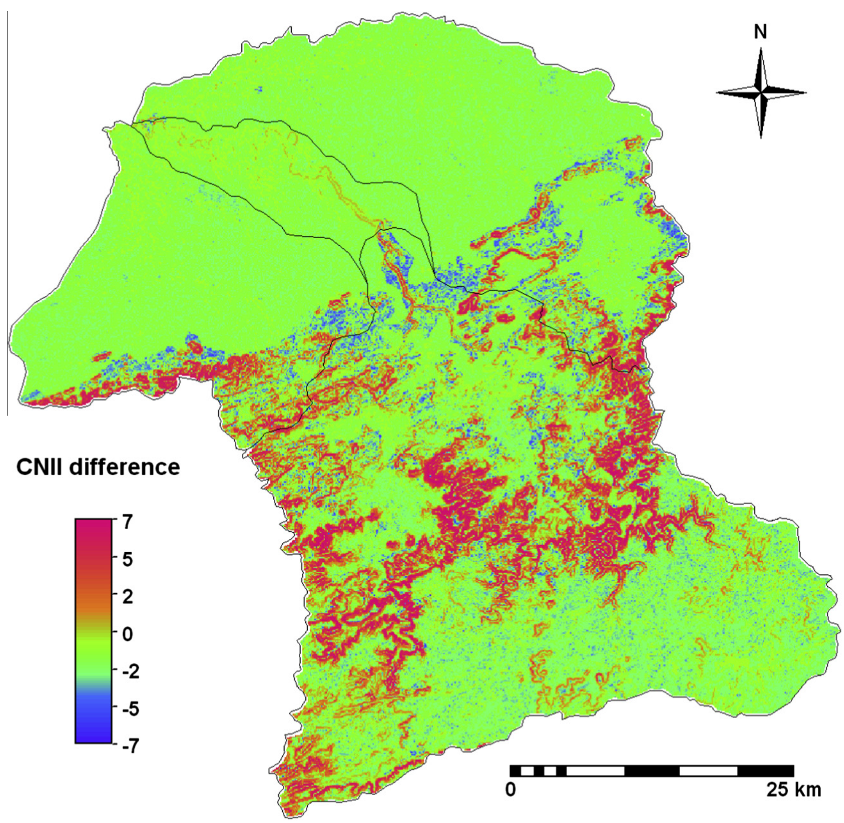


Fig. 13. Spatial distribution of difference in SA-CN_2 and SCS-CN.

Table 5
Estimation of difference between SA-CN_2 and CN_{LU} for the study area.

Land use and land cover	Slope (%)						
	0–1	1–3	3–5	5–10	10–15	15–30	>30
Agriculture	−3 to −1	− 1 to −2	−1 to 0	0–1	1–2	1–3	2–3
Forest	−7 to −5	−5 to −2	−2 to 0	0–3	3–5	5–7	6–7
Barren land	−4 to −2	−3 to −1	−1 to 0	0–2	2–3	2–4	3–4
Badland	−3 to −2	−2 to −1	−1 to 0	0–1	–	–	–
Settlement	−4 to −2	−3 to −1	−1 to 0	0–2	–	–	–
Water body	0	0	0	0	–	–	–

6. Conclusions

- The spatial and temporal changes in land use and land cover significantly affect the surface runoff potential from a watershed. Such changes in runoff potential will have influence on sustainable utilization of water resource for the watershed development and management.
- The developed relationship of $CN_{(LU)}$ with historical year can be used for prediction of $CN_{(LU)}$ in future if the ongoing changes persist in the watersheds.
- $CN_{(LU)}$ distribution maps depict gradual increase in CN values from 1972 to 1989 and from 1989 to 2000. The increase in CN values is more apparent in lower part of three watersheds where badland (CN = 89) and forest land (CN = 61) has been significantly converted into the agriculture land (CN = 93).
- Conversion of forest cover (58) into the barren land (89) in the middle part of gauged Sher watershed caused increase in CN values in the successive time period.
- Among three watersheds, Umar watershed has higher $CN_{(LU)}$ value for AMC II condition indicating higher runoff potential under the same magnitude of received rainfall in comparison to other watersheds.
- Three paired data sets of $CN_{(LU)}$ and $CN_{(PQ)}$ values for year 1977, 1989 and 2000 have been validated though their closeness with the line of perfect fit.
- Model performance is again checked by plotting computed and observed direct runoff values with the line of perfect fit. It is observed that paired data sets of observed and computed values have closeness with line of perfect fit. It is concluded that the SCS model under dynamic annual $CN_{(LU)}$ can be used to predict direct runoff potential in ungaged watersheds.
- Although the effect of the slope on runoff volume has been clearly established by research studies, few attempts have been made to study effect of topography in the SCS-CN method. The present study shows that slope adjusted CN is less than conventional CN over areas with slope less than 5% and more than conventional CN for areas with slope more than 5%. Higher the deviation from 5% slope more is the difference. Significant difference in CN is observed in the forest lands which are usually located on slopes. For micro watershed planning, SCS-CN method should be modified to incorporate effect of change in land use also in addition to effect of slope. Further research is needed to study effect of morphological parameters on the curve number.

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