

Impact of landuse/land cover change on run-off in a catchment of Narmada river in India

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Received: 12 July 2012 / Accepted: 8 December 2014 / Published online: 24 December 2014
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Abstract The landuse/land cover change has a significant influence on the hydrological response of a river basin. The run-off characteristics are naturally changing due to reduction of initial abstraction that increases run-off volume. Thus, it is necessary to quantify the changes in the run-off characteristics of a catchment that occur due to changes in landuse/land cover. These changes can be sudden or continuous. Physically based conceptual models have developed to find out surface run-off, and one of the models used in the present study is the Soil Conservation Service curve number (SCS-CN) model which has a broad range of applications. The present study is on the application of the SCS-CN model to analyse the impact of various landuse/land cover change in the run-off characteristics of a catchment of Narmada basin in Madhya Pradesh, India. The study includes the preparation of a landuse/land cover map of different years from the satellite imageries, drainage network, and development of a database by using a geographic information system (GIS) and a run-off generation with the model to estimate the impact of landuse change on run-off.

Keywords Landuse/land cover change · SCS-CN model · Narmada · Run-off · GIS

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Introduction

Quantification of the impact of landuse and land cover change in the run-off dynamics of a river basin has been an interesting area for hydrologists in recent years. Little is known till now if there is a well-defined quantitative relationship between the landuse properties and the run-off generation mechanism. Different methodologies have been implemented in an attempt to fill in the deficiency of knowledge in the subject, but no general and credible model has been established yet to predict the effect of landuse/land cover changes (Kokkonen and Jakeman 2002). In the earlier days, assessment of the impact of landuse/land cover changes on the run-off was mainly done through catchment experiments, and different results were obtained, with some even opposing the findings of the others. Langford (1976), as for example, found out that there is no significant increase in water yield as a result of burning down of a stand of eucalyptus. In contrast, after observing results from a number of catchment experiments, Hibbert (1967) concluded that increase in water yield occurs due to reduction of forest cover. Bosch and Hewlett (1982) furnished the changes in water yield due to changes in the amount of cover of different types of vegetations. According to Hollis (1975), urbanization leads to an increase in run-off. He also concluded that while small, frequent floods are increased many times by urbanization, large rare floods are not significantly affected.

Nowadays, the hydrological models are used with various approaches to find out the impact of landuse/land cover changes. Lørup et al. (1998) and Schreider et al. (2002) calibrated models for a reference period when there is little change in landuse/land cover and applied the calibrated model to a subsequent period in which changes in landuse have taken place. They implemented

trend analysis between the modelled and the observed run-off to investigate changes in the catchment run-off that is arising for landuse/land cover changes. Fohrer et al. (2001) used a physically based model for the prediction of the impact of landuse/land cover changes through sensitivity study of the model. Wooldridge et al. (2001) worked on the regionalization of the parameters of a simple model for forest and non-forest classification and several climate regions for predicting the impact of landuse/land cover change on the hydrologic response of a catchment. Another attempt to implement hydrological models to investigate the impact of landuse/land cover change has been furnished in Braud et al. (2001), Bultot et al. (1990), and De Roo et al. (2001). The most rational way to model the impact of landuse/land cover changes on the run-off of a river catchment would be through the implementation of spatially distributed and physically based hydrological models, where the land surface characteristics of the catchment are represented and all the processes influenced by them are modelled using parameters that can be physically estimated. However, such models are highly demanding in terms of their data requirement and computational effort, which increases further as the size of the catchment increases. This limits their applicability to small or mesoscale catchments. Even under such a restriction, results obtained from previous studies done on the application of such approach were not promising (Parkin et al. 1996). Beven (2000) said that a different approach is still to use for rainfall-run-off models which are not entirely physically based. He also concluded that some of the processes required a few data, but more computational effort. Nonetheless, model calibration leads to a nonunique set of parameters, and this makes it difficult to associate the parameters estimated through calibration with the land surface characteristics of the catchment. Therefore, prediction of the effect of landuse change depends on the uncertainty associated with the model parameters. Application of such an approach to assess the impact of landuse changes in mesoscale catchments was reported in Brath et al. (2003), Bronstert et al. (2002), and Ranzi et al. (2002). Modelling large-scale catchments using such kind of models is impractical due to the problem of acquiring the amount of data needed in the models, and thus, a different approach should be implemented.

In the 1950s, the Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA 1972, 1983, 1985) was given the task of developing a system to relate the amount of surface run-off from rainfall to soil cover complexes. The theory of the Soil Conservation Service curve number (SCS-CN) explains that the run-off can be related to soil cover complexes and rainfall through a parameter known as a curve number

(CN). The Soil Conservation Service curve number (now called Natural Resources Conservation Service curve number (NRCS-CN)) method is simple and produces better results (Stuebe and Johnston 1990; Ponce and Hawkins 1996; Mishra and Singh 1999 and 2002; Michel et al. 2005; Mishra et al. 2005; Schneider and McCuen 2005). Many researchers (Pandey and Sahu 2002; Nayak and Jaisawal 2003; Zhan and Huang 2004; Gandini and Usunoff 2004) have used the geographic information system (GIS) technique to estimate run-off curve number values throughout the world. In India, Pandey and Sahu (2002) concluded that the landuse/land cover is an important parameter for the SCS-CN model. Nayak and Jaisawal (2003) developed a good correlation between measured and estimated run-off using GIS and CN. They said that GIS is an efficient tool for the preparation of maximum input data required by SCS-CN model. In recent years, for estimating CN values and for a better way to incorporate antecedent moisture content, some attempts have been made (Mishra and Singh 2006; Jain et al. 2006; Sahu et al. 2007; Brocca et al. 2008; Kannan et al. 2008; Mishra et al. 2008; Soulis et al. 2009). Changes in landuse/land cover have a significant influence on the relations of rainfall run-off (Yang and Yu 1998) and changed run-off and soil cover accordingly (Kim et al. 2002). The impact of landuse/land cover changes from a forest catchment has been analysed by Okoński (2007). For evaluating the hydrological impact, the information on changing landuse/land cover in a watershed is important. The use of satellite remote sensing data and GIS along with the SCS-CN model is appropriate to analyse the hydrological response along with the effect of landuse/land cover change.

In this study, the impact of landuse/land cover change from 1990 to 2009 in a part of the Narmada river basin was analysed to obtain a change in run-off and future run-off due to landuse change. It is necessary to assess the impact of landuse on run-off as the demand of the people increases with the increasing population, which modifies the existing landuse and thus affects natural resources. Thus, to plan for any action, it is necessary to know the run-off or future run-off of a region. The SCS curve number method was used to calculate the run-off, and with the use of satellite images, landuse/land cover maps of 1990, 2000, and 2009 were generated. The results indicate an increase in run-off at the gauge of Mandaleswar with time as the landuse changes.

Study area

Narmada is the largest west flowing river and is the fifth largest river of India as per water availability. It rises from Amarkantak in Madhya Pradesh at an elevation of 1057 m.

The Narmada river makes the traditional boundary between north India and south India and flows westwards over a length of 1312 km and then falls into the Arabian Sea through the Gulf of Cambay. It flows through the states of Madhya Pradesh (1079 km), Maharashtra (74 km), and Gujarat (159 km).

The study area is the sub-catchment of a part of the Narmada river basin. The study area lies within 21° 23' 7.7" N to 22° 55' 8" N and 75° 21' 7" E to 77° 21' 17" E and covers an area of 20,561 km². The outlet of the study area is Mandaleswar. In Fig. 1, the location map and drainage map of the study area are shown along with the gauge site of Mandaleswar.

The climate of this basin is humid and tropical, although at places, extremes of heat and cold are often encountered. In a year, four distinct seasons occur in the basin. They are

- (i) The winter ranges from November to February.
- (ii) The summer ranges from March to mid-June.
- (iii) The southwest monsoon ranges from mid-June to mid-September.
- (iv) Post monsoon ranges from mid-September to October.

Here, the mean annual temperature varies from 7.5 °C to 42.5 °C. The annual rainfall in the hilly and upper plain areas of the basin is around 1400 mm, but in lower plains, the annual rainfall decreases rapidly and comes to around 650 mm. The soils in the upper hilly regions of the basin are mostly shallow red and yellow with low fertility. The upper Narmada plains are broad and fertile areas well suited for cultivation with deep black soils up to the East Nimar district. These soils are highly water retentive in nature. Thereafter,

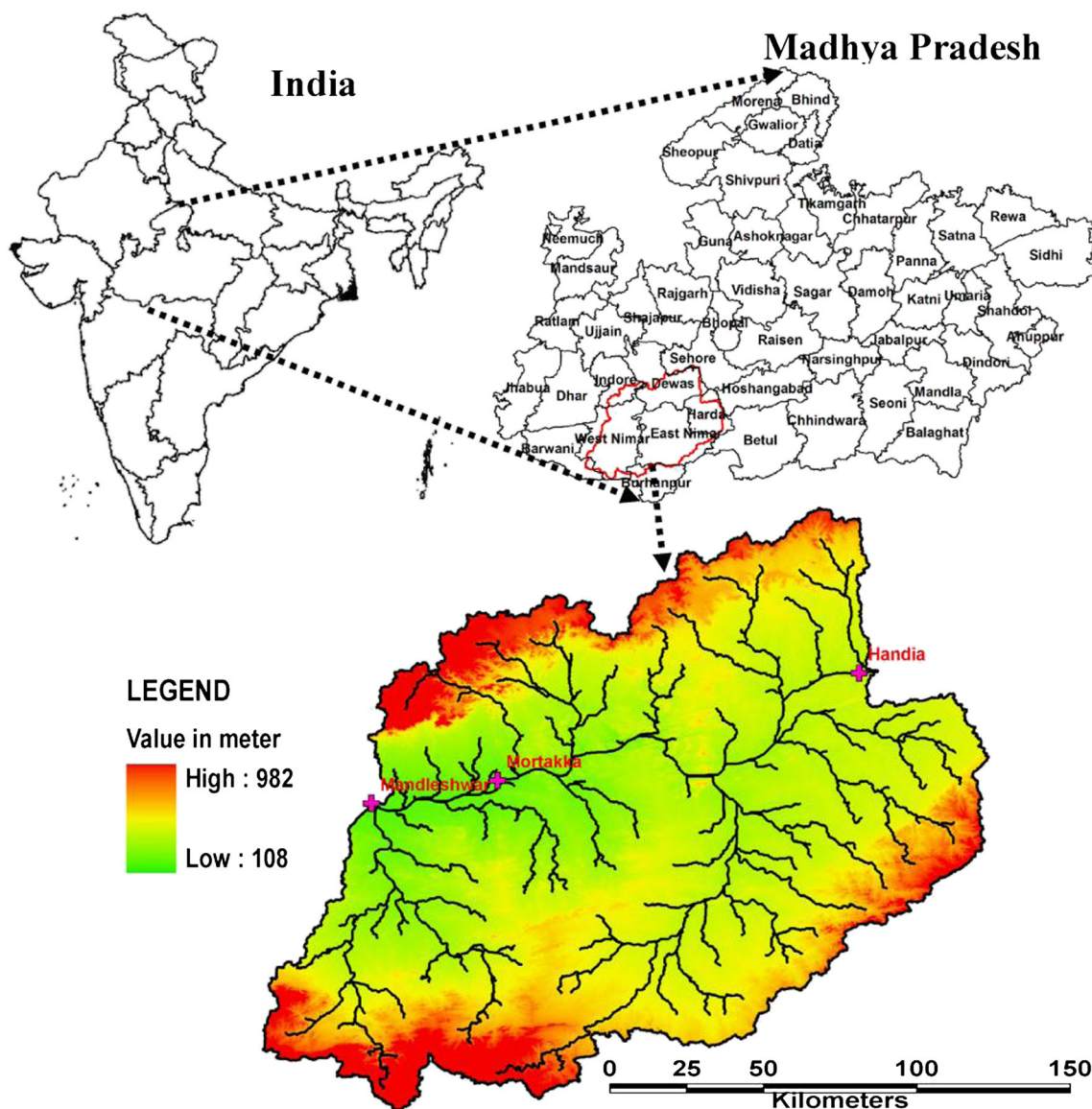


Fig. 1 Location map of study area

there are medium black soils in the West Nimar, and in Barwani district, it is mixed with skeletal red and yellow soils. The lower hilly portions in the study area have mostly shallow red and yellow and skeletal soils of low fertility (National Bureau of Soil Survey and Landuse Planning 1996).

Data set

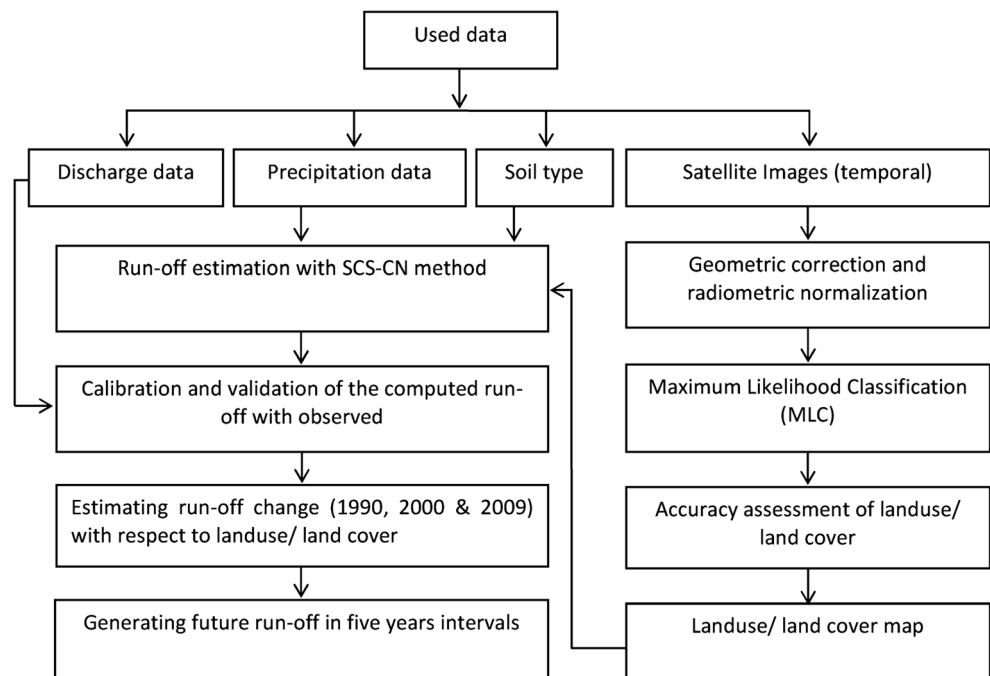
In the present study, following data are acquired:

- Spatial data collected are topographic maps from Survey of India (SOI) and satellite images from the United States Geological Survey (USGS).
- Hydrological data of 20 years of river flow data at the gauging station of Mandaleswar.
- Rainfall data from three rain gauge stations within the study area for 40 years.

Methodology

Landsat TM data sets were acquired from USGS [website <http://glovis.usgs.gov>]. Data sets were projected in UTM projection zone 44 and WGS 84 datum. The 1990 image was considered as base data, and the 2000 and 2009 images were co-registered by a first-order polynomial model with 0.5-pixel root-mean-square error (RMSE) accuracy. After geometric correction and radiometric normalization, the images of 1990, 2000, and 2009 were classified using the Maximum Likelihood Classification technique into five landuse classes.

Fig. 2 Flow chart of methodology



The accuracy assessment was then performed with the classified images.

The image of the year 2000 had some portion under cloud cover. But all the images of the same year do not have equal cloud cover. Covered areas were replaced from 3 June 2000 of 145/45 path-row, 25 May 2000 of 146/44 path-row, and 9 May 2000 of 146/45 path/row which were not under cloud in these images. Then, the image correlation was performed between these images which resulted in a high correlation. Then, the clouded areas were digitized to demarcate them and were replaced by cloud free areas from other images of the same year.

The surface run-off data series of 1990, 2000, and 2009 were analysed with the help of the SCS-CN model, and the stream flow of these years were calculated. All these data were calibrated and validated with the observed flow of the river at the gauging site. The values of the SCS-CN were taken from the range of CN values for different landuse types, and calibrated values were compared with the observed values to get the minimum error between the calculated and observed run-off. Validation was done with the observed data. Finally, the effect of landuse/land cover change on the run-off was analysed from 1990 to 2009 in this study area. The future run-off was estimated by taking rainfall as a constant of the year 1990 and taking linear regression of the run-off of 19 years for future projection. Thus, the impact of landuse change is evident over the study area. The general methodology is given in Fig. 2.

Data for landuse/land cover map preparation

The remote-sensing technique was used to prepare the landuse/land cover map of the study area. Properties of satellite images

Table 1 Properties of satellite data, landuse/land cover map of 1990

Sl. no.	Path/row	Acquisition date	Pixel size	Sensor	Source
1	146/44	6th January, 1990	30	Landsat TM	USGS
2	146/45	6th January, 1990	30	Landsat TM	USGS
3	145/45	15th January, 1990	30	Landsat TM	USGS
4	146/44	3rd February, 2000	30	Landsat TM	USGS
5	146/45	3rd February, 2000	30	Landsat TM	USGS
6	145/45	3rd June, 2000	30	Landsat TM	USGS
7	146/44	December 12, 2009	30	Landsat TM	USGS
8	146/45	December 12, 2009	30	Landsat TM	USGS
9	145/45	3rd November, 2009	30	Landsat TM	USGS

for preparing landuse/land cover map of 1990, 2000, and 2009 are tabulated in Table 1. The area was covered by three images. The image which covers the largest part of the study area was considered as the mother or base image, and the common area was taken from this image only. The rest of the areas not covered by this image was only taken from the other two images, and all three were mosaiced. After mosaicing, histogram matching was done.

Accuracy assessment

A variety of approaches have been developed to assess the accuracy of thematic maps (Congalton 1991; Stehman and

Czaplewski 1998; Smits et al. 1999). The ‘error matrix’ (also called confusion matrix, confusion table, and contingency table) is central to most measures of thematic map accuracy (Story and Congalton 1986; Smits et al. 1999; Foody 2002). A sample error matrix is generally a square array of numbers set out in rows and columns which express the number of sampling units assigned to a particular category relative to the actual category as verified on the ground (Congalton 1991).

In this study, the error matrix has been prepared for a total of 130 sample points taken from the whole area randomly. Although a rule of thumb says that 50 samples for each landuse should be taken in the error matrix (Congalton 1991), but due to lack of time and accessibility in this case,

Table 2 Accuracy assessment for the years 1990, 2000, and 2009

Class name	Reference totals	Classified totals	Number of correct points	Producer’s accuracy (%)	User’s accuracy (%)
1990					
Water body	2	2	2	100	100
Built-up	2	2	1	50	50
Dense vegetation	36	36	27	75	75
Light vegetation	55	56	46	83.64	82.14
Fallow land	35	34	26	74.29	76.47
Total	130	130	102
2000					
Water body	1	1	1	100	100
Built-up	9	9	7	77.78	77.78
Dense vegetation	37	37	28	75.68	75.68
Light vegetation	45	47	36	80	76.60
Fallow land	38	36	28	73.68	77.78
Total	130	130	100
2009					
Water body	3	3	3	100	100
Built-up	9	8	6	66.67	75
Dense vegetation	40	40	30	75	75
Light vegetation	23	22	17	73.91	77.27
Fallow land	55	57	45	81.82	78.95
Total	130	130	101

Table 3 Kappa statistics in different landuse conditions in different years

Class name	Kappa statistics (1990)	Kappa statistics (2000)	Kappa statistics (2009)
Water body	1	1	1
Built-up	0.49	0.76	0.73
Dense vegetation	0.65	0.66	0.64
Light vegetation	0.69	0.64	0.72
Fallow land	0.68	0.69	0.64

it was limited to 130 samples. The overall accuracy explains the total accuracy, where the number of sampling points obtained from the field match with the samples of the digital classification.

Hydrological method-SCS-CN approach for run-off calculations

The Soil Conservation System curve number model was used for run-off simulation in the Narmada river catchment at the gauging site of Mandaleswar. The impacts of landuse/land cover on the surface run-off were observed, which have a direct effect on the stream flow. The parameter CN is a transformation of *S* (potential maximum soil moisture retention), and it is used to make interpolating, averaging, and weighting operations more linear (Eqs. 1–5, source: Chow et al. 1988).

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

But, $I_a = 0.2 \times S$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{2}$$

When $P > 0.2S$, otherwise $Q = 0$

$$S = \frac{25400}{CN} - 254 \tag{3}$$

where *Q* is the run-off (mm), *P* is rainfall (mm), *S* is the potential maximum soil moisture retention (mm) after run-off begins, and *I_a* is the initial abstraction (mm) (due to infiltration, evaporation, interception) losses before run-off begins, and *CN* is the curve number value.

The overall curve number was obtained by individual landuse/land cover curve number. This curve number is then used to determine the run-off in the catchment for the years 1990, 2000, and 2009.

$$CN = \frac{(A_1CN_1 + A_2CN_2 + A_3CN_3 + \dots + A_nCN_n)}{(A_1 + A_2 + A_3 + \dots + A_n)} \tag{4}$$

Here, *CN* is the overall curve number ($A_1 + A_2 + A_3 + \dots + A_n$) is the overall area of all landuse/land cover. *A₁* to *A_n* are the areas of different landuse/land cover classes, and *CN₁* to *CN_n* are the corresponding curve numbers of the landuse/land cover classes.

Generation of run-off from rainfall using SCS-CN method

Surface run-off was estimated with the average rainfall data of three rain gauge station, which are Mortakka (latitude—22° 13' 30" N, longitude—76° 2' 20" E), Mandaleswar (latitude—22° 10' 48" N, longitude—75° 40' 12" E), and Khandwa (latitude—21° 50' N, longitude—76° 20' E) for the years 1990, 2000, and 2009. The study area is a sub-catchment of Narmada river near Mandaleswar which covers 20,561 km². Mandaleswar is the outlet of this catchment. River run-off of Narmada river at Mandaleswar was estimated using surface run-off, total catchment area of Narmada river at Mandaleswar, and base flow. The total catchment area was subdivided into five landuse classes which are dense vegetation, light vegetation, fallow land, built-up area, and water body. From these five landuse classes, surface run-off by SCS-CN method was computed and finally, future flow was observed.

Calculation of run-off change due to landuse/land cover change

The rainfall data and landuse/land cover data of 1990 were used to get the run-off of the year for the study area. Run-off (*R₁*) is a function of rainfall (*P₁*) of 1990 and landuse/land cover (*LU₁*) of 1990 or $R_1 = f(P_1, LU_1)$. The rainfall (*R₁*) of 1990 and landuse/land cover (*LU₂*) of 2000 were used to calculate run-off for the year

Table 4 Overall kappa statistics and overall accuracy in different years

Category	1990	2000	2009
Overall kappa statistics	0.68	0.67	0.67
Overall accuracy (%)	78.46	76.92	77.69

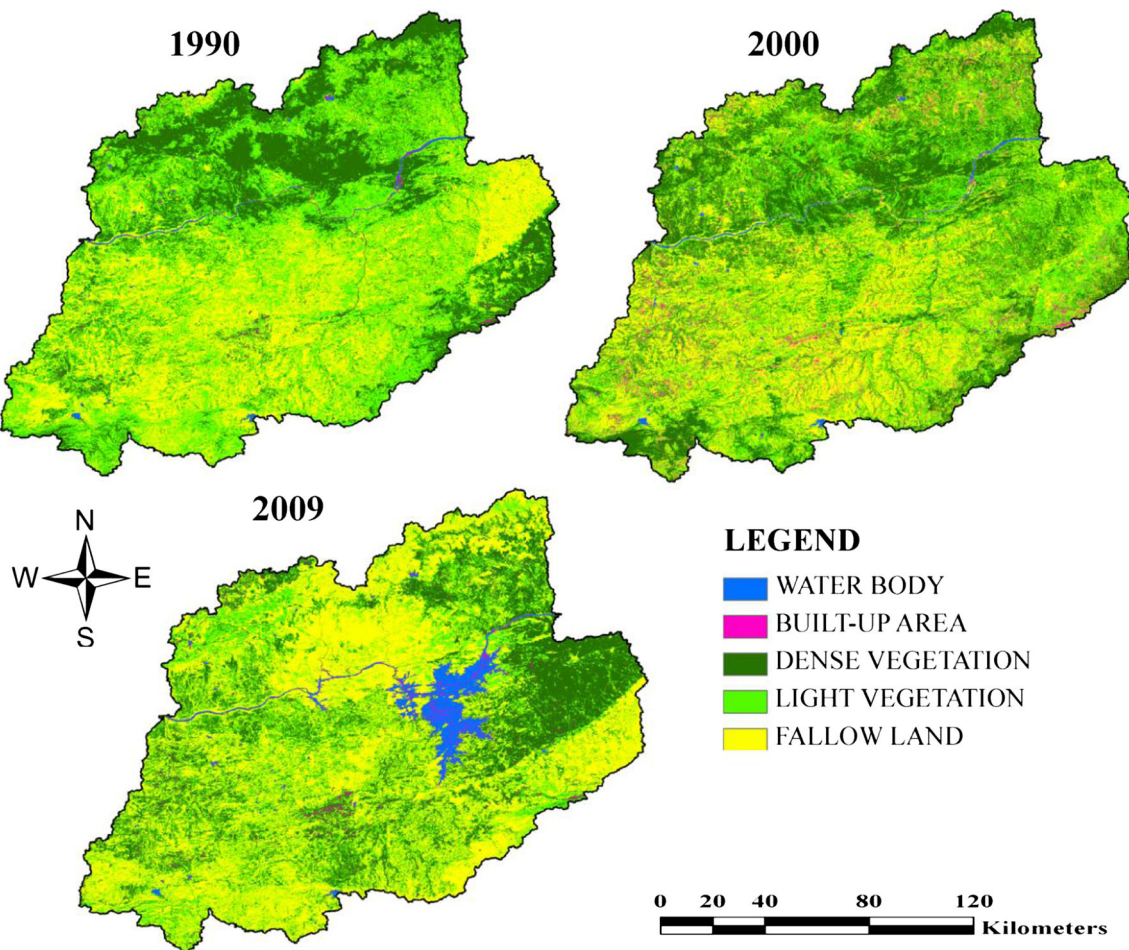


Fig. 3 Landuse/land cover maps of 1990, 2000, and 2009

2000. Here, run-off of 2000 (R_2) is a function of rainfall (P_1) of 1990 and landuse/land cover of 2000 (LU_2) or $R_2=f(P_1, LU_2)$. The factor having an impact on run-off due to landuse/land cover change is calculated by the given equation,

$$F = \frac{\sum R_2}{\sum R_1} \tag{5}$$

Here, F is the factor that has been utilized for generating future run-off. $\sum R_2$ is the total run-off of 2000 and $\sum R_1$ is the total run-off of 1990.

Results and analysis

This section presents the results of landuse/land cover classification of the years 1990, 2000, and 2009 and run-off estimation using existing landuse/land cover, calibration, and

Table 5 Area and percentage of landuse/land covers of 1990, 2000, and 2009

Sl. no.	Landuse/land cover type	1990		2000		Difference from 1990 to 2000 (%)	2009		Difference from 2000 to 2009 (%)
		Area (km ²)	Percentage	Area (km ²)	Percentage		Area (km ²)	Percentage	
1	Forest and dense v egetation	6239	30.34	5892	28.65	-1.69	4863	23.65	-5.00
2	Light vegetation	7187	34.94	7380	35.86	+0.92	4302	20.92	-14.94
3	Fallow land	6236	30.33	5776	28.09	-2.24	8703	42.33	+14.24
4	Built-up area	770	3.74	1359	6.61	+2.87	1971	9.59	+2.98
5	Water body	129	0.65	154	0.79	+0.14	722	3.51	+2.72
	Total	20,561	100	20,561	100	0	20,561	100	0

Table 6 Curve number values

Year	1990	2000	2009
Weighted average CN	83.26	83.78	86.22

estimating future run-off at the gauging station of Mandaleswar of the river Narmada.

Accuracy assessment

validation. The major finding is to assess run-off change due to the landuse/land cover change of the catchment area and

The accuracy assessment of the years 1990, 2000, and 2009 is furnished in Table 2.

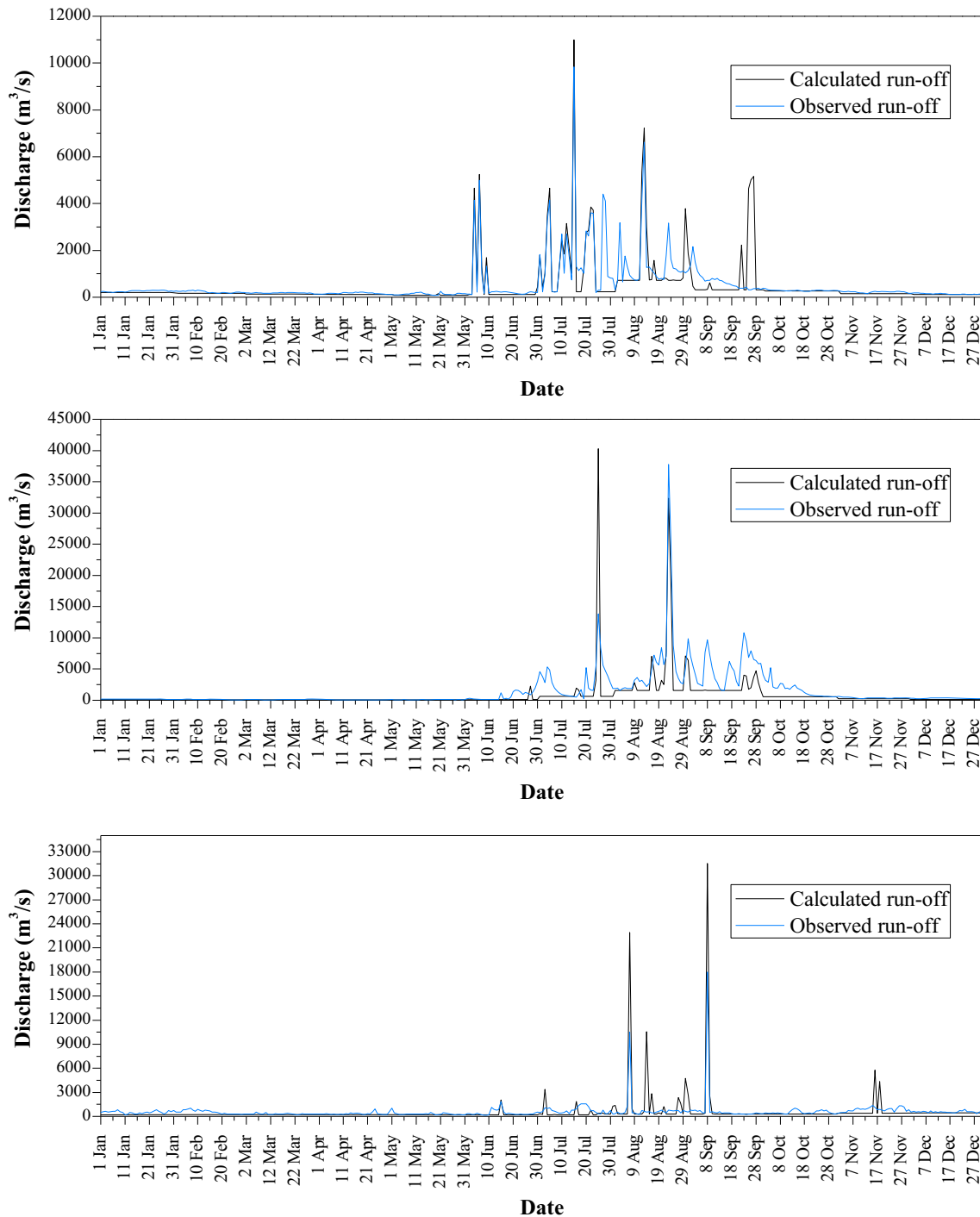


Fig. 4 a–c Simulation of calculated and observed river run-off at Mandaleswar gauge in the years 1990, 2000, and 2009

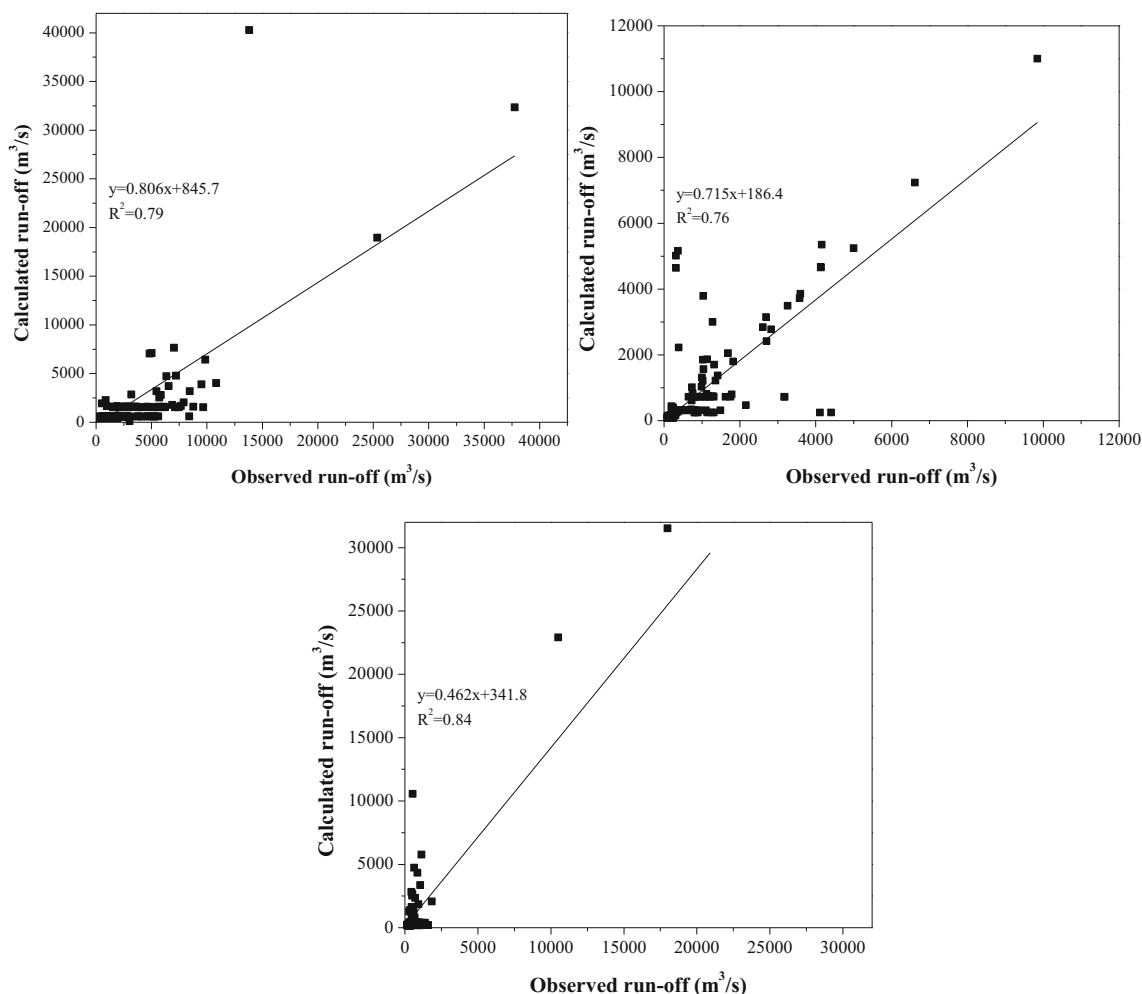


Fig. 5 a–c Scatter plot of calculated and observed river run-off at Mandaleswar gauge in the year 1990, 2000, and 2009

In 1990, the producer’s accuracy for water body, built-up area, dense vegetation, light vegetation, and fallow land are 100, 50, 75, 83.64, and 74.29 %, respectively. And the user’s accuracy for these classes are 100, 50, 75, 82.14, and 76.47 %, respectively.

In 2000, the producer’s accuracy for water body, built-up area, dense vegetation, light vegetation, and fallow lands are 100, 77.78, 75.68, 80, and 73.68 %, respectively. And the user’s accuracy for these classes are 100, 77.78, 75.68, 76.60, and 77.78 %, respectively.

Similarly, in 2009, the producer’s accuracy in the year 2009 for water body, built-up area, dense vegetation, light vegetation, and fallow lands are 100, 66.67, 75, 73.91, and 81.82 %, respectively. And the user’s accuracy for these classes are 100, 75, 75, 77.27, and 78.95 %, respectively. The kappa statistics of different landuse/land cover condition in different years are given in Table 3.

Table 4 gives kappa for water body, built-up area, dense vegetation, light vegetation, and fallow land in the year 1990, which are 1, 0.49, 0.65, 0.69, and 0.68, respectively. The

kappa statistics for these classes in the year 2000 and 2009 are 1, 0.76, 0.66, 0.64, and 0.69 and 1, 0.73, 0.64, 0.72, and 0.64, respectively.

The overall kappa statistics for the years 1990, 2000, and 2009 are 0.68, 0.67, and 0.67, respectively, and overall accuracy for the years 1990, 2000, and 2009 are 78.46, 76.92, and 77.69 %, respectively (Table 4). According to Landis and Koch (1977), the kappa value of the classified result is within the range of 0.61 to 0.80 which means the strength of agreement is substantial.

Landuse/land cover change from 1990 to 2009

Landuse/land cover maps of 1990, 2000, and 2009 are shown in Fig. 3.

Here, it is described how the landuse/land cover change from the year 1990 to 2009 has occurred by using the remote sensing technique. Landuse maps of the study area were extracted for the years 1990, 2000, and 2009. The results are shown in Table 5.

Table 7 Total run-off in the year 1990, 2000, 2009 and future projection

Year	Annual total run-off (mm)	Difference (mm)	Percentage
1990	161.6	0	0
2000	170.24	8.64	5.35
2009	188.91	18.67	10.97
2014	192.96	4.05	2.15
2019	200.09	7.13	3.69
2024	207.22	7.13	3.56

The results revealed that there is a significant decrease in the area of forest and dense vegetation from the year 1990 to 2000 by 1.69 % of the total area and from 2000 to 2009 by 5 %. The decrease from the year 1990 to 2009 was 6.69 % of the total area. Similarly, the area of light vegetation increased from the year 1990 to 2000 by 0.92 % of the total area, but decreased from 2000 to 2009 by 14.94 %. The decrease of light vegetation area from the year 1990 to 2009 was 14.02 %, and this is mainly because of the growth of built-up areas in place of light vegetation. Declination in the area of fallow land has occurred from the year 1990 to 2000 which is 2.24 % of the total area, and suddenly in the next decade from 2000 to 2009, it has increased by 14.24 %. This result is due to a high rate of deforestation. Thus, on average, there was an increase in fallow land from the year 1990 to 2009 which was 12 % of the total area. Rise in built-up area is obvious, from 1990 to 2000, it was 2.87 % and the increase from 2000 to 2009 was 2.98 %. The increase from the year 1990 to 2009 was 5.85 % of the total area. The area of water body increased insignificantly from 1990 to 2000 by 0.14 % and quite significantly from 2000 to 2009 by 2.72 % because of the construction of

the Indira Sagar dam within this decade. Therefore, an increase of water body area from 1990 to 2009 became 2.86 % of the total area.

Curve number values

The run-off calculation was made from the rainfall data by SCS-CN curve number method for 1990, 2000, and 2009. The results were calibrated and validated with the observed river flow. The weighted average CN value and the different values of curve number are tabulated in Table 6.

Here, it is observed that the weighted average of CN is increasing, and the graphs are indicating increasing run-off from 1990 to 2009.

Run-off values

The rainfall of three rain gauge stations within the study area was taken, and surface run-off was calculated with the SCS-CN curve number method. Base flow was used for estimating river run-off on a daily basis. The results were validated with the observed run-off data series for the years 1990, 2000, and 2009.

Comparison between calculated and observed run-off for the year 1990 is shown in Figs. 4a and 5a, the 2000 run-off is given in Figs. 4b and 5b, and 2009 is presented in Figs. 4c and 5c.

From all of these results, linear regression calculation was done. In the year 1990, the R^2 value is 0.791 that is quite good. In the year 2000, the value of R^2 is 0.758 which is also good. And in the year 2009, the R^2 value is 0.836 which is impressive. From these graphs, it is concluded that the relation between observed run-off and calculated run-off was best for the year 2009.

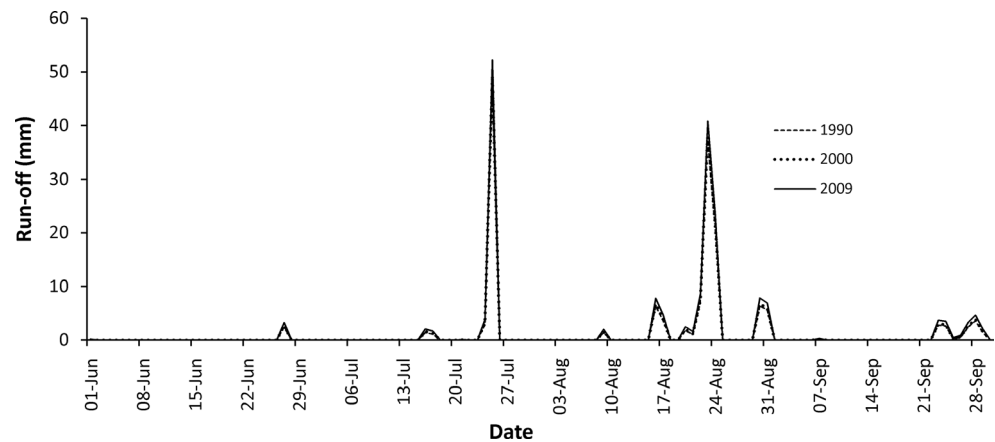
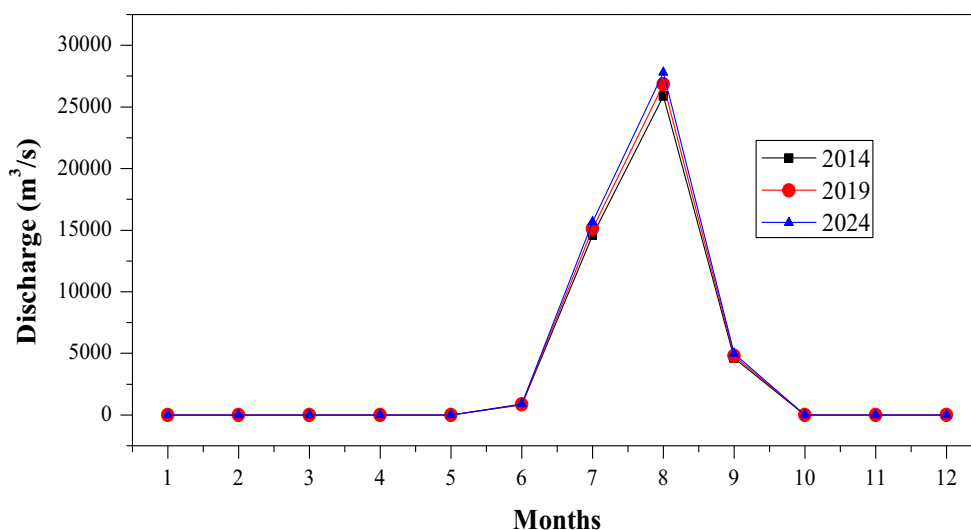
Fig. 6 Run-off change due to change in landuse in 1990, 2000, and 2009

Fig. 7 Run-off in a 5 year intervals due to landuse change considering average daily rainfall



Run-off values for landuse/land cover changed condition

The result of the impact of landuse/land cover change on run-off is tabulated in Table 7.

From the table, it is observed that annual total run-off of the year 1990 was 161.6 mm, and total run-off of the year 2000 was 170.24 mm. So the difference is 8.64, and the percentage of run-off difference from 1990 to 2000 was 5.35. Similarly, from 2000 to 2009, the run-off increased by 10.97 %. In 2014, the annual total run-off is estimated to be 192.96 mm which will be an increase of 2.15 %; in 2019, it will be 200.09 mm with an increase of 3.69 %; and in 2024, the run-off will be 207.22 mm with an increase of 3.56 %. In case of future run-off estimation, a linear trend of the previous years of 1990 to 2000 and 2000 to 2009 was followed (Fig. 6).

Future run-off calculation in a 5-year interval for 2014, 2019, and 2024 using landuse/land cover change condition

Three processes were adopted for generating future run-off. In the first process, the future run-off in a 5-year interval from 2009 was calculated by considering the linear trend of run-off from the initial 3 years. Rainfall of 1990 was taken as constant, and run-off of 1990, 2000, and 2009 were calculated with the changing landuse of different years. Prediction of run-off in the years 2014, 2019, and 2024 due to changing landuse was computed by taking the 1990 rainfall as constant and considering the linear trend of run-off from 1990 to 2000 and 2000 to 2009. Thus, the impact of change in landuse/land cover on run-off was emphasized and estimated for the future, if the rainfall remains constant. The rainfall used was average daily rainfall (Fig. 7 and Table 7).

Two other methods adopted for estimating future run-off are by observing the rate of change/year of run-off from 1990 to 2009 (19 years) and from 2000 to 2009 (9 years). For the 19 years rate of change/year, there is an increase in run-off of

3.81 % from 2009 to 2014, 7.33 % from 2014 to 2019, and 10.24 % from 2019 to 2024. For the 9 years (2000 to 2009) rate of change/year, an increase of 5.49 % is found from 2009 to 2014, 10.41 % from 2014 to 2019, and 14.14 % from 2019 to 2024.

Conclusion

Results from the curve number model developed by the Soil Conservation Service have shown that the overall weighted curve number has increased from 83.26 in 1990 to 83.78 in 2000 and to 86.22 in 2009. This implies that the surface run-off increases with time while infiltration decreases. This analysis shows that the estimated surface run-off increased by 5 % in 10 years from 1990 to 2000 due to changes in landuse, in case the rainfall remains the same and increases to almost double from 2000 to 2009. The future river run-off data series was calculated with the help of the SCS-CN model by considering the average rainfall data of the study area.

There is a continuous process of increase in population, which results in an increasing demand leading to drastic changes in landuse. There have been alterations and changes in natural resources and environment with variations in vegetation, agricultural land, settlement, etc. Change in landuse has an impact on the surface run-off causing change in flow. This study has helped in assessing the future run-off change due to changing landuse, on the basis of which various measures and plans can be taken such as conjunctive use of water, developing irrigation projects, etc. which largely depends on the landuse pattern. This study with the SCS-CN model can be extended to any other watershed for assessing the impact of landuse/land cover changes on run-off in the future.

Acknowledgments The authors acknowledge the United States Geographical Survey (USGS) and Survey of India (SOI) for providing the Landsat satellite imagery and topographical map of the selected study area. The authors are also thankful to the Indian Meteorological Department for providing rainfall and run-off data.

References

- Beven KJ (2000) Rainfall-runoff modelling: the primer. Wiley, New York
- Bosch JM, Hewlett JD (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *J Hydrol* 55:3–23
- Brath A, Montanari A, Moretti G (2003) Assessing the effects on flood risk of the land-use changes in the last five decades: an Italian case study. *IAHS Publ* 278:435–441
- Braud I, Vich AII, Zuluaga J, Fornero L, Pedrani A (2001) Vegetation influence on runoff and sediment yield in the Andes region: observation and modelling. *J Hydrol* 254:124–144
- Brocca L, Melone F, Moramarco T (2008) On the estimation of antecedent wetness conditions in rainfall-runoff modelling. *Hydrol Process* 22:629–642
- Bronstert A, Niehoff D, Burger G (2002) Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrol Process* 16:509–529
- Bultot F, Dupriez GL, Gellens G (1990) Simulation of landuse changes and impacts on the water balance—a case study for Belgium. *J Hydrol* 114:327–348
- Chow VT, Maidment DR, Mays LW (1988) Applied hydrology. McGraw-Hill International Editions, Singapore
- Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens Environ* 37:35–46
- De Roo A, Odijk M, Schmuck G, Koster E, Lucieer A (2001) Assessing the effects of landuse changes in the Meuse and Oder catchment. *Phys Chem Earth B* 26:593–599
- Fohrer N, Haverkamp S, Eckhardt K, Frede HG (2001) Hydrologic response to landuse changes on the catchment scale. *Phys Chem Earth B* 26:577–582
- Foody GM (2002) Status of land cover classification accuracy assessment. *Remote Sens Environ* 80:185–201
- Gandini ML, Usunoff EJ (2004) SCS Curve Number estimation using remote sensing NDVI in a GIS environment. *J Environ Hydrol* 12 (Paper no. 16)
- Hibbert AR (1967) Forest treatment effects on water yield. In: Sopper WE, Lull HW (eds) International symposium on forest hydrology. Pergamon, Oxford, p 813
- Hollis GE (1975) The effect of urbanization on flood of different recurrence interval. *Water Resour Res* 11:431–435
- Jain MK, Mishra SK, Sureshbabu P, Venugopal K, Singh VP (2006) Enhanced run-off curve number model incorporating storm duration and a nonlinear ia-S relation. *J Hydrol Eng ASCE* 11:631–635
- Kannan N, Santhi C, Williams JR, Arnold JG (2008) Development of a continuous soil moisture accounting procedure for curve number methodology and its behaviour with different evapotranspiration methods. *Hydrol Process* 22:2114–2121
- Kim Y, Engel BA, Lim KJ (2002) Runoff impacts of landuse change in Indian river Lagoon watershed. *J Hydrol Eng* 7:245–251
- Kokkonen TS, Jakeman AJ (2002) Structural effects of landscape and landuse on streamflow response. In: Beck MB (ed) Environmental foresight and models: a manifesto. Elsevier, Oxford, pp 303–321
- Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. *Biometrics* 33:159–174
- Langford KJ (1976) Change in yield of water following a bush fire in a forest of Eucalyptus regnans. *J Hydrol* 29:87–114
- Lørup JK, Refsgaard JC, Mazvimavi D (1998) Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modeling: case studies from Zimbabwe. *J Hydrol* 205:147–163
- Michel C, Vazken A, Perrin C (2005) Soil conservation service curve number method: how to mend a wrong soil moisture accounting procedure. *Water Resour Res* 41:1–6
- Mishra SK, Singh VP (1999) Another look at the SCS-CN method. *J Hydrol Eng ASCE* 4:257–264
- Mishra SK, Singh VP (2002) SCS-CN based hydrological simulation package. In: Singh VP, Frevert D (eds) Mathematical models in small watershed hydrology and applications. Water Resources Publications, Littleton, pp 391–464
- Mishra SK, Singh VP (2006) A relook at NEH-4 curve number data and antecedent moisture condition criteria. *Hydrol Process* 20:2755–2768
- Mishra SK, Jain MK, Pandey RP, Singh VP (2005) Catchment area-based evaluation of the AMC-dependent SCS-CN-based rainfall-runoff models. *Hydrol Process* 19:2701–2718
- Mishra SK, Pandey RP, Jain MK, Singh VP (2008) A rain duration and modified AMC SCS-CN procedure for long duration rainfall-runoff events. *Water Resour Manag* 22:861–876
- National Bureau of Soil Survey & Landuse Planning (NBSS) (1996) Soils series of Madhya Pradesh. Indian Council, Indian Council of Agricultural Research, Nagpur
- Nayak TR, Jaisawal RK (2003) Rainfall-runoff modelling using satellite data and GIS for Bebas river in Madhya Pradesh. *Inst Eng (IEI)* 84: 47–50
- Okoński B (2007) Hydrological response to land use change in central European lowland forest catchment. *J Environ Eng Landsc Manag* 15:3–13
- Pandey A, Sahu AK (2002) Generation of curve number using remote sensing and geographic information system. (Link: <http://www.gisdevelopment.net/application/nrm/water/watershed/watws0015pf.htm>)
- Parkin G, O'Donnell G, Ewen J, Bathurst JC, O'Connell PE, Lavabre J (1996) Validation of catchment models for predicting land-use and climate change impacts. 1. Case study for a Mediterranean catchment. *J Hydrol* 175:595–613
- Ponce VM, Hawkins RH (1996) Runoff curve number: has it reached maturity? *J Hydrol Eng ASCE* 1:11–19
- Ranzi R, Bochicchio M, Bacchi B (2002) Effects on floods of recent afforestation and urbanisation in the Mella River (Italian Alps). *Hydrol Earth Syst Sci* 6:239–253
- Sahu RK, Mishra SK, Eldho TI, Jain MK (2007) An advanced soil moisture accounting procedure for SCS curve number method. *Hydrol Process* 21:2872–2881
- Schneider LE, McCuen RH (2005) Statistical guidelines for curve number generation. *J Irrig Drain Eng ASCE* 131:282–290
- Schreider SY, Jakeman AJ, Letcher RA, Nathan RJ, Neal BP, Beavis SG (2002) Detecting changes in streamflow response to changes in non-climatic catchment conditions: farm dam development in the Murray–Darling basin. *Aust J Hydrol* 262:84–98
- Smits PC, Dellepiane SG, Schowengerdt RA (1999) Quality assessment of image classification algorithms for land-cover mapping: a review and a proposal for a cost-based approach. *Int J Remote Sens* 20:1461–1486
- USDA Soil Conservation Service (1972) National engineering handbook section 4 hydrology. Chapters 4–10
- USDA Soil Conservation Service (1983) National engineering handbook section 4 hydrology. Chapter 19
- Soulis KX, Valiantzas JD, Dercas N, Londra PA (2009) Investigation of the direct runoff generation mechanism for the analysis of the SCS-

- CN method applicability to a partial area experimental watershed. *Hydrol Earth Syst Sci* 13:605–615
- Stehman SV, Czaplewski RL (1998) Design and analysis for thematic map accuracy assessment: fundamental principles. *Remote Sens Environ* 64:331–344
- Story M, Congalton RG (1986) Accuracy assessment: a user's perspective. *Photogramm Eng Remote Sens* 52:397–399
- Stuebe MM, Johnston DM (1990) Run-off volume estimation using GIS techniques. *J Am Water Resour Assoc* 26:611–620
- USDA-SCS (1985) National engineering handbook, section 4 hydrology. USDA-SCS, Washington, D.C
- Wooldridge S, Kalma J, Kuczera G (2001) Parameterisation of a simple semi-distributed model for assessing the impact of landuse on hydrologic response. *J Hydrol* 254:16–32
- Yang TC, Yu PS (1998) The effect of land-use change on the design hydrograph. *J Hydrol Chang Environ* 3:207–216
- Zhan X, Huang M (2004) Arc CN-runoff: an arc GIS tool for generating curve number and run-off maps. *Environ Model Softw* 19:875–879