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ORIGINAL ARTICLE

Impact of landuse/land cover change on run-off in the catchment of a hydro power project

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Abstract The landuse/land cover change and rainfall have a significant influence on the hydrological response of the river basins. The run-off characteristics are changing naturally due to reduction of initial abstraction that increases the run-off volume. Therefore, it is necessary to quantify the changes in the run-off characteristics of a catchment under the influence of changed landuse/land cover. Soil conservation service model has been used in the present study to analyse the impact of various landuse/land cover (past, present and future time period) change in the run-off characteristics of a part of Narmada basin at the gauge discharge site of Mandaleswar in Madhya Pradesh, India. Calculated run-off has been compared with the observed run-off data for the study. The landuse/land cover maps of 1990, 2000 and 2009 have been prepared by digital classification method with proper accuracy using satellite imageries. The impact of the run-off change on hydro power potential has been assessed in the study along with the estimation of the future changes in hydro power potential. Five types of conditions (+10, +5 %, average, −5, −10 % of average rainfall) have been applied with 90 and 75 % dependability status. The generated energy will be less in 90 % dependable flow in respect to the 75 % dependable flow. This work will be helpful for future planning related to establishment of hydropower setup.

Keywords Landuse/land cover change · Run-off · SCS-CN model · Hydro power potential

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Introduction

Impact of landuse/land cover change in the run-off dynamics of a river basin has been an interesting area for hydrologists. Rainfall and landuse/land cover are the important parameter of run-off estimation by hydrological modelling. Different types of land surface parameters have been extracted by many researchers (Mondal et al. 2014a, b; Kundu et al. 2014a, b; Gajbhiye et al. 2014a; Chandniha and Kansal 2014; Palmate et al. 2014) by remote sensing techniques using satellite imagery. Climate change related study has been done using different methods on climatic parameters by researchers (Mondal et al. 2014c, d; Kundu et al. 2014c; Mishra et al. 2014a; Kundu et al. 2014d). Different methodologies have been implemented to get proper knowledge in the subject, but no general 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. Langford (1976) as for example, found out that there is no significant increase in water yield due to burning down of a strand of Eucalyptus. In contrast, after verifying 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 that water yield changed due to variation in the amount of cover of different types of vegetations. After organising a number of studies, Hollis (1975) has concluded that while large rare floods are not significantly affected by urbanisation small frequent floods are increased many times.

In the present years, the hydrological models are used with different approaches to find out the impact of landuse/land cover changes. Lørup et al. (1998), Schreider et al. (2002) and Mondal et al. (2014d) calibrated models for a known period when there is little change in landuse/land cover and applied the calibrated model to a ensuing period in which landuse has changed. They implemented trend analysis between the modelled and the observed run-off to investigate changes in the catchment run-off caused by landuse/land cover change. Fohrer et al. (2001) used a model for the predication of the impact of landuse/land cover changes through sensitivity study of the model. Wooldridge et al. (2001) worked to regionalize the parameters of a simple model for forest and non-forest classification and different climate regions for predicting the impact of landuse/land cover change on the hydrologic response of a catchment. Other attempts have been made for hydrological models to investigate the impact of landuse/land cover change by Bultot et al. (1990), Braud et al. (2001) and De Roo et al. (2001). Parkin et al. (1996) concluded that the results obtained from previous studies to find out the impact of landuse/land cover change on run-off have not been much promising. According to (Beven 2000) model parameters are estimated a priori based on field data or modelling experience. There may still be a need to adjust some of the parameters through model calibration. However, model calibration leads to a non-unique set of parameters and this makes it difficult to associate the parameters estimated through calibration with the land surface characteristics of the catchment. Therefore, the uncertainty associated with the model parameters is important. Application of such an approach to assess the impact of landuse changes in meso-scale catchments has been reported in Bronstert et al. (2002), Ranzi et al. (2002) and Brath et al. (2003). 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, therefore, a different approach should be implemented.

In the 1950s, the soil conservation service (SCS) given by the United States Department of Agriculture (USDA) was given for developing a system to relate the amount of surface run-off from rainfall to soil cover complexes. The theory of the SCS-CN method is 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, 2002; Michel et al. 2005; Mishra et al. 2005; Schneider and McCuen 2005). SCS-CN method is a reliable method and has been used by many researchers. Some of the recent works with the SCS-CN method done by Mishra et al. (2014a), Tessema et al. (2014), Awadallah et al. (2015), Khare et al. (2015), 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, 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 preparation of maximum input data required by SCS-CN model. In recent years, some attempts have been made for finding CN values and for finding a better way to incorporate Antecedent Moisture Content (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; Gajbhiye et al. 2014b). 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). Okonski (2007) examined the impact of landuse/land cover changes from a forest catchment. The use of satellite remote sensing data and Geographic Information system (GIS) along with the SCS-CN model is appropriate to analyse the hydrological response to the effect of landuse/land cover change.

The run-off of a catchment would be affected by the landuse/land cover change of that catchment which would further affect the water yield in the area. As there will be change in run-off, it would affect the hydro power potential in a hydro power project existing in the area. Therefore, for designing a hydro power project this change should be considered for getting optimum power potential in present and future.

EIA (2001), EIA (1999), Voigtlander and Gattinger (1999), European Commission (2000) concluded that hydropower production makes an effective contribution to meet today's increasing world electricity demands. In the mid-1990s hydropower plants portrayed for about 19 % (or approx. 2500TWh) of total electricity production worldwide and reached 22 % (or approx. 700GW) of the total installed capacity for electricity generation. According to European Commission (2000), the hydropower production along with other renewable energy sources, is expected to become increasingly important in future. World production of hydroelectricity has firmly increased by about 2.3 % per year on an average since 1980 but will raise the total electricity production by 3.1 % per year recently. Voigtlander and Gattinger (1999) estimated that worldwide average growth rates of hydroelectricity generation in future will be about 2.4 % per year between 1990 and 2020. (Eurelectric 1997a, b, c) estimated that the worldwide

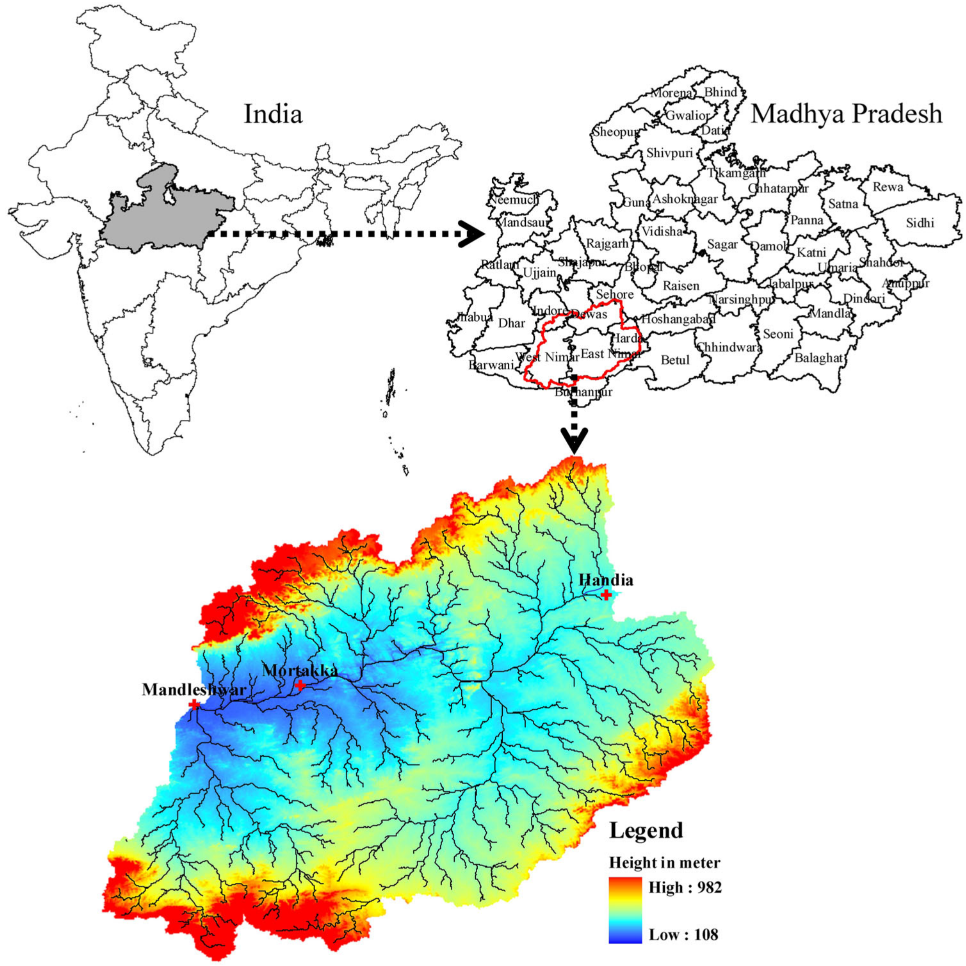


Fig. 1 Location map of study area

average growth rates of hydroelectricity generation in the future will be about 3.6 % per year between 1990 and 2020. Henrichs et al. (2002) elaborated the scope of water resource-related climate impact studies by examining the impact of general circulation model (GCM)-derived climate change scenarios on the financial performance of a proposed hydro scheme.

In this study, impact of landuse/land cover change on run-off has been assessed from 1990 to 2009 in the Narmada river basin at the gauge of Mandaleswar in central India. Variation in rainfall run-off relationship using SCS-CN model has also been analysed. Finally, the impact of run-off change in the future hydro power potential of the area has been computed and analysed.

Study area

Narmada River is the fifth largest river of India with respect to the available quantity of water. The basin of Narmada extends over an area of 98,796 km^2 between the Vindhya and Satpura ranges. The study area is a part of a sub-basin of the Narmada River, which lies in between the area of Handia and Mandaleswar gauging station. It is extending from 21°23′7.7″N to 22°55′8″N and 75°21′7″E to 77°21′17″E covering 20,561 km^2 area (Fig. 1). The study area includes the districts of Harda, Dewas, Khargone and Khandwa in Madhya Pradesh state, India. It is under the subtropical type of climate, and average annual rainfall is 1370 mm. The mean annual temperature varies between 7.5 to 42.5 °C for the entire year. The Narmada plains area is fertile for cultivation with deep black soil. Red and yellow types of soil with low fertility are found in the lower hilly region.

Used data and methodology

In the present study, the following data are acquired.

- Spatial data collected are topographic maps from survey of India, satellite images (1990, 2000 and 2009), digital elevation model (DEM) with 30 m resolution from the United States Geological Survey (USGS). The elevation of the study area is taken from the advanced spaceborne thermal emission and

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	06/01/1990	30	Landsat TM	USGS
2	146/45	06/01/1990	30	Landsat TM	USGS
3	145/45	10/01/1990	30	Landsat TM	USGS
4	146/44	03/02/2000	30	Landsat TM	USGS
5	146/45	03/02/2000	30	Landsat TM	USGS
6	145/45	03/06/2000	30	Landsat TM	USGS
7	146/44	12/12/2009	30	Landsat TM	USGS
8	146/45	12/12/2009	30	Landsat TM	USGS
9	145/45	03/11/2009	30	Landsat TM	USGS

reflection radiometer-global digital elevation map (ASTER-GDEM) (METI and NASA).

- 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.

Data for landuse/land cover map preparation

Using remote sensing technique, the landuse/land cover map of this study area has been prepared. Property of landuse/land cover map of 1990, 2000 and 2009 are tabulated in the Table 1.

Methodology

Satellite Images 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. Maximum likelihood classification (MLC) technique is used to classify the satellite images after geometric correction and radiometric normalisation. Assessment of landuse/land cover change has been assessed from 1990 to 2009 and its impact on run-off has been assessed. The general methodology has been given by the flow chart in the Fig. 2.

Landuse/land cover map preparation of the study area for the years 1990, 2000 and 2009 has been done with the help of remote sensing technique. Different classes are forest and dense vegetation, light vegetation, fallow land, built-up area and water body, and accuracy assessment of the classified images has been done after the classification. Curve number of every class has been assigned from the table of the National Engineering Handbook: "Results and discussion" (NEH-4). Surface run-off data series of these 3 years has been analysed with the help of SCS-CN model and by considering the base flow of the River Narmada at the gauging station of Mandaleswar, the stream flow of the year 1990, 2000 and 2009 have been calculated. These data have also been calibrated and validated with the observed flow of the river at the gauging site of Mandaleswar. Further, the effect of landuse/land cover change on the run-off has been analysed for this period and future run-off data series has been computed considering the average rainfall and +10, +5 %, −5, −10 % of the average rainfall of 40 years. The impact of run-off change in the future hydro power potential in the year 2011 and 2021 has been assessed with the help of calculation of the run-off data series. From these results it is possible to conclude whether there is any provision for extra unit to be incorporated or not.

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

Soil conservation system curve number model has been used for run-off simulation at Narmada river catchment at the gauging site of Mandaleswar and to estimate the impact of landuse/land covers on the surface run-off which have a direct effect on the stream flow. The parameter CN is a transformation of S, and it is used to make interpolating, averaging and weighting operations more linear (Eqs. 1–5, Chow et al. 1988).

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

But, $I_a = 0.2 \times S$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, \text{ when } P > 0.2\text{S}, \text{ otherwise } Q \quad (2)$$

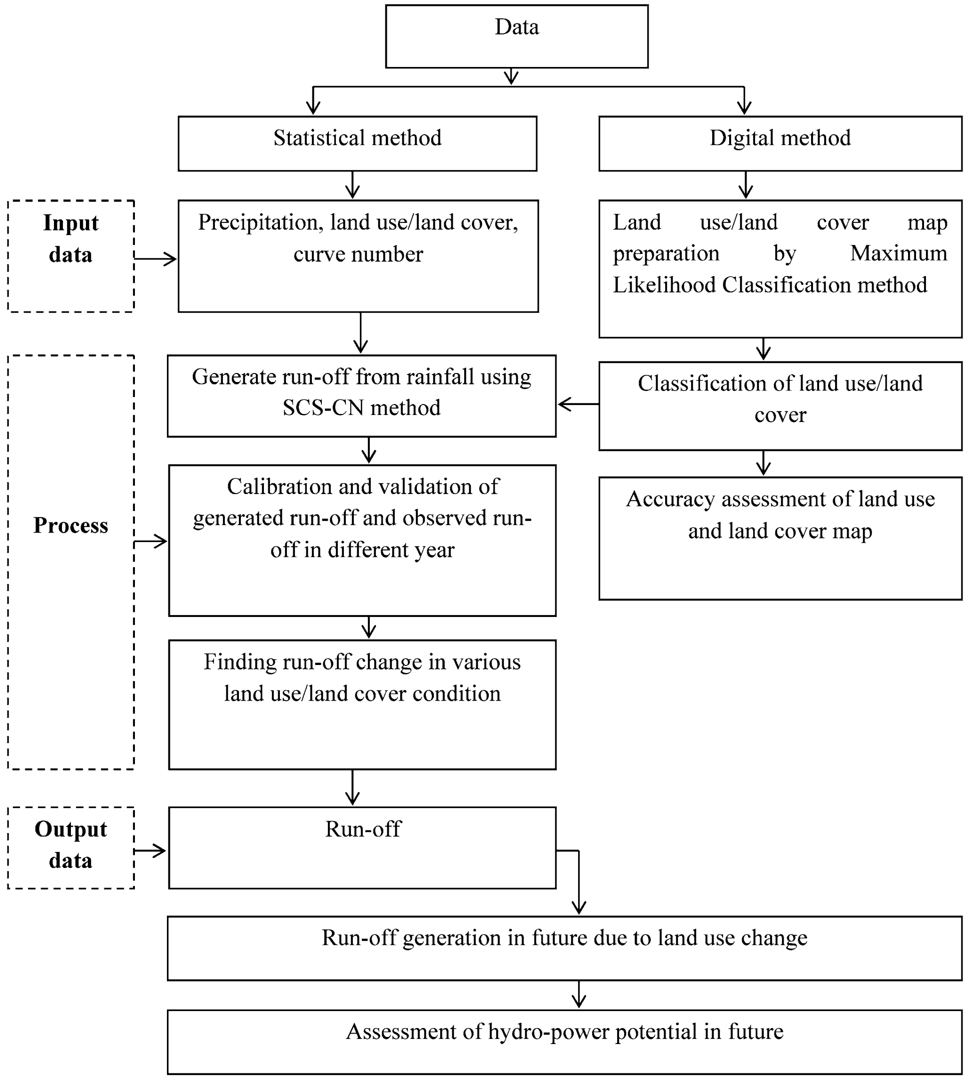
$$S = \frac{25{,}400}{\text{CN}} - 254, \quad (3)$$

where Q represents the run-off (mm), P stands for rainfall (mm), S stands for potential maximum retention (mm) and I_a denotes the initial abstractions (due to infiltration, evaporation, interception). Here CN is the curve number value. The overall curve number has been attained by individual landuse/land cover curve number. This CN is then used for the determination of run-off in the catchment for the years 1990, 2000 and 2009.

$$\text{CN} = \frac{(A_1\text{CN}_1 + A_2\text{CN}_2 + A_3\text{CN}_3 + \cdots + A_n\text{CN}_n)}{(A_1 + A_2 + A_3 + \cdots + A_n)}. \quad (4)$$

Here CN represents the overall curve number, $(A_1 + A_2 + A_3 + \cdots + A_n)$ signifies the overall area of all landuse/land cover. A_1 to A_n symbolises the area of different landuse/land cover classes and CN_1 to CN_n represents the corresponding curve number of landuse/land cover classes.

Fig. 2 Flow chart of Methodology



Run-off generation from rainfall using SCS-CN method

Surface run-off has been computed by using 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 sub-catchment which has been the study area of Narmada river near Mandaleswar covers an area of 20,561 km^2. Mandaleswar represents the outlet of this study area. Run-off of Narmada River at Mandaleswar has been generated by considering the surface run-off, total catchment area of Narmada River at Mandaleswar and base flow. The total catchment area has been subdivided into five landuse categories that stand for dense vegetation, light vegetation, fallow land, built-up area and water body. From these five landuse classes surface run-off has been computed by SCS-CN method and finally the computation of river run-off has been done.

Run-off change calculation for various landuse/land cover

Using the existing rainfall data and landuse/land cover data of 1990, run-off of the year has been calculated for the point at Mandaleswar on Narmada River. Run-off (R_1) constitutes the function of rainfall (P_1) of 1990 and landuse/land cover (LU_1) of 1990 or $R_1 = f\ (P_1, LU_1)$. With the rainfall (R_1) of 1990 and from the existing landuse/land cover (LU_2) of 2000, run-off for the year 2000 has been calculated for the area. 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 that has an impact on run-off due to change in landuse/land cover has been calculated by the given equation,

$$F = \frac{\sum R_2}{\sum R_1}. \quad (5)$$

Here F represents the factor that has been utilised 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.

Hydropower generation

Hydropower is produced from a generator driven by water turbines that convert the energy of fast-flowing water into mechanical energy. Water at a higher elevation flows downward through large pipes or tunnels (penstocks). The falling water rotates turbines, which drive the generators. The generator in turn converts the turbines mechanical energy into electricity. The quantity of water as well as the available head determines the production of the hydropower. Therefore, the amount of power generated when Q cumecs of water is allowed to fall through a head of H metres is given by the following equation (Paish, 2002),

$$P = \eta \times \rho \times g \times Q \times H, \quad (6)$$

where, P is the power in watt, g is the acceleration due to gravity (m/s^2), η is the overall efficiency of the hydro mechanical equipment. ρ is the density of water (kg/m^3).

Here the efficiency of turbine and generator is considered to be 90 and 95 %, respectively. After considering the total efficiency of electromechanical equipment the final equation comes to,

$$P = 8.57 \times Q \times H \times \eta. \quad (7)$$

This given equation has been used to find out hydro power potential.

Estimation of hydropower potential using flow duration curve (FDC)

The available discharge at the project site can be estimated with the help of flow duration curves. The flow duration curve of a stream is a plot of discharge against the percent of time the flow is equalled or exceeded. A flow duration curve provides the percentage of time the stream flow is exceeded over a historical period for a particular river basin (Vogel and Fennessey 1994). Construction of FDC is a prerequisite for hydropower planning besides other uses (Castellarin et al. 2004).

The 90 % dependable year has been found by arranging the available annual run-offs in descending order, using Weibull's formula,

$$P_p = (m/N + 1) \times 100\ \% \quad (8)$$

where, m is the order number of the discharge (or class value), P_p is the percentage probability of the flow magnitude being exceeded.

The plot of the discharge Q against P_p is the flow duration curve. This gives the percentage of time a discharge is available for power production (MNRE 2008).

Normally for run-off river plant, power estimation of 75 and 90 % dependability discharge values is considered and for this study these two levels of flow dependability have been considered. Only the possible run-off of the river sites, where power could be generated without constructing any reservoir, has been identified. After deciding the head, which is 35 m, after a site visit and considering the minimum effect of eco-system and maximum stability of that area and discharge available at the selected site, the available hydropower potential at the identified sites have been estimated using established power equation (CEA 1997).

Result and discussion

The major finding apart from the landuse/land cover classification, accuracy check and assessment of the variation in run-off due to landuse and land cover change is to estimate the future river run-off of the year 2011 and 2021 and to calculate the hydro power potential for these years with the help of run-off data series.

Accuracy assessment

The overall accuracy of the landuse/land cover map for the year 1990, 2000 and 2009 are 78.46, 76.92 and 77.69 %, respectively. The calculated overall kappa statistics of the year 1990, 2000 and 2009 are 0.68, 0.67 and 0.67, respectively.

Landuse/land cover change from 1990 to 2009

Figure 3 describes the landuse/land cover maps of 1990, 2000 and 2009.

The landuse/land cover change of the study area has been extracted from the images of the year 1990 to 2009 by digital classification technique. The results are shown in Table 2.

In the given study, the results have shown that there has been a significant decrease in the area of forest and dense vegetation from the year 1990 to 2000 by 1.69 % and from 2000 to 2009 by 5 % of the total area. The decrease of dense vegetation from the year 1990 to 2009 is 6.69 % of the total area. Similarly the area of light vegetation has increased from the year 1990 to 2000 by 0.92 %, but has decreased from 2000 to 2009 by 14.94 % of the total area. The decrease of the light vegetation area from the year 1990 to 2009 is 14.02 % and this is mainly due to the expansion of built-up areas in place of light

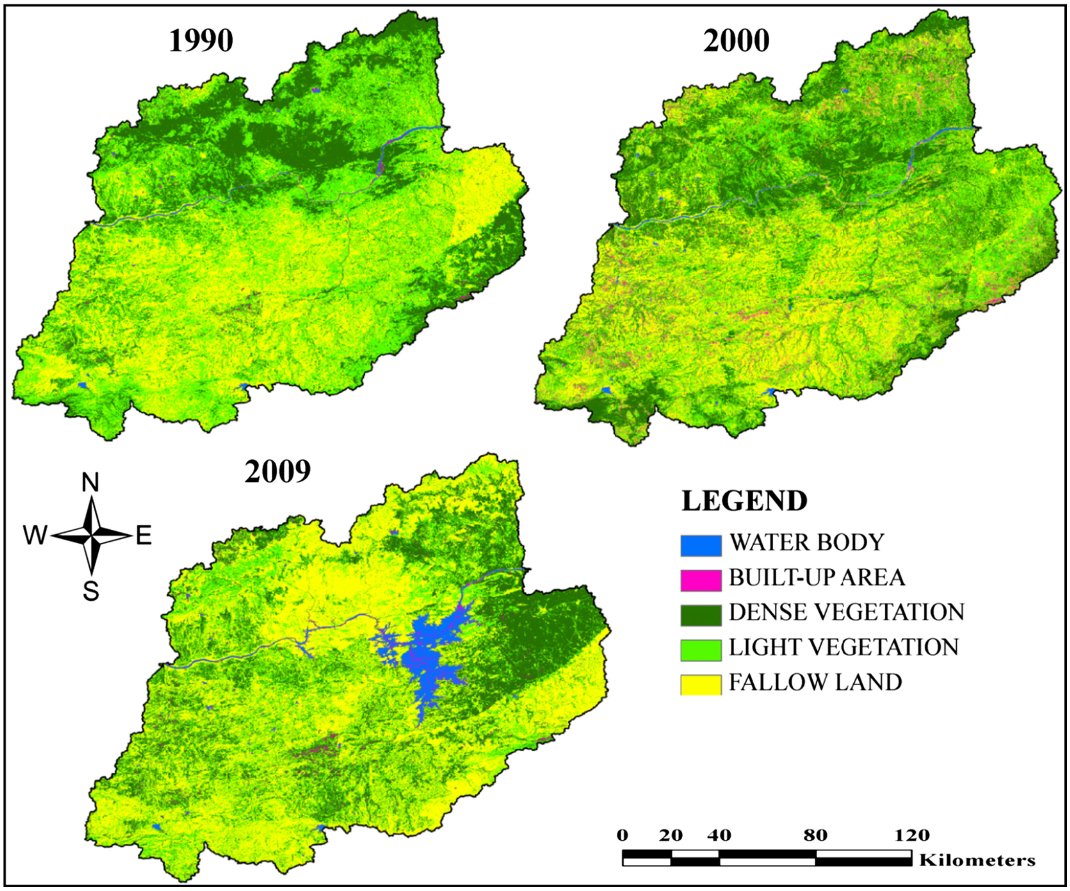


Fig. 3 Landuse/land cover maps

Table 2 Area and percentage of landuse/land covers of 1990, 2000 and 2009

Sl. no.	Landuse/land cover type	1990		2000		2009	
		Area (km^2)	Percentage	Area (km^2)	Percentage	Area (km^2)	Percentage
1	Forest and dense vegetation	6239	30.34	5892	28.65	4863	23.65
2	Light vegetation	7187	34.94	7380	35.86	4302	20.92
3	Fallow land	6236	30.33	5776	28.09	8703	42.33
4	Built-up area	770	3.74	1359	6.61	1971	9.59
5	Water body	129	0.65	154	0.79	722	3.51
	Total	20561	100	20561	100	20561	100

vegetation. Decline in the area of fallow land has occurred since the year 1990 to 2000 which is 2.24 % of the total area and abruptly in the next decade from 2000 to 2009 the area has increased by 14.24 %. This happened because of the high rate of deforestation. Henceforth, there has been an increase in fallow land from the year 1990 to 2009 which is 12 % of the total area. Growth in built-up area has been obvious, from 1990 to 2000 it is 2.87 % and the rise from 2000 to 2009 is 2.98 %. The increase in built-up from the year 1990 to 2009 is 5.85 % of the total area. Area of water body has increased slightly from 1990 to 2000 by 0.14 % and quite notably from 2000 to 2009 by 2.72 %, mainly because of the construction of the IndiraSagar dam in this decade. Thus,

Table 3 curve number values

Year	1990	2000	2009
Weighted average CN	83.26	83.78	86.22

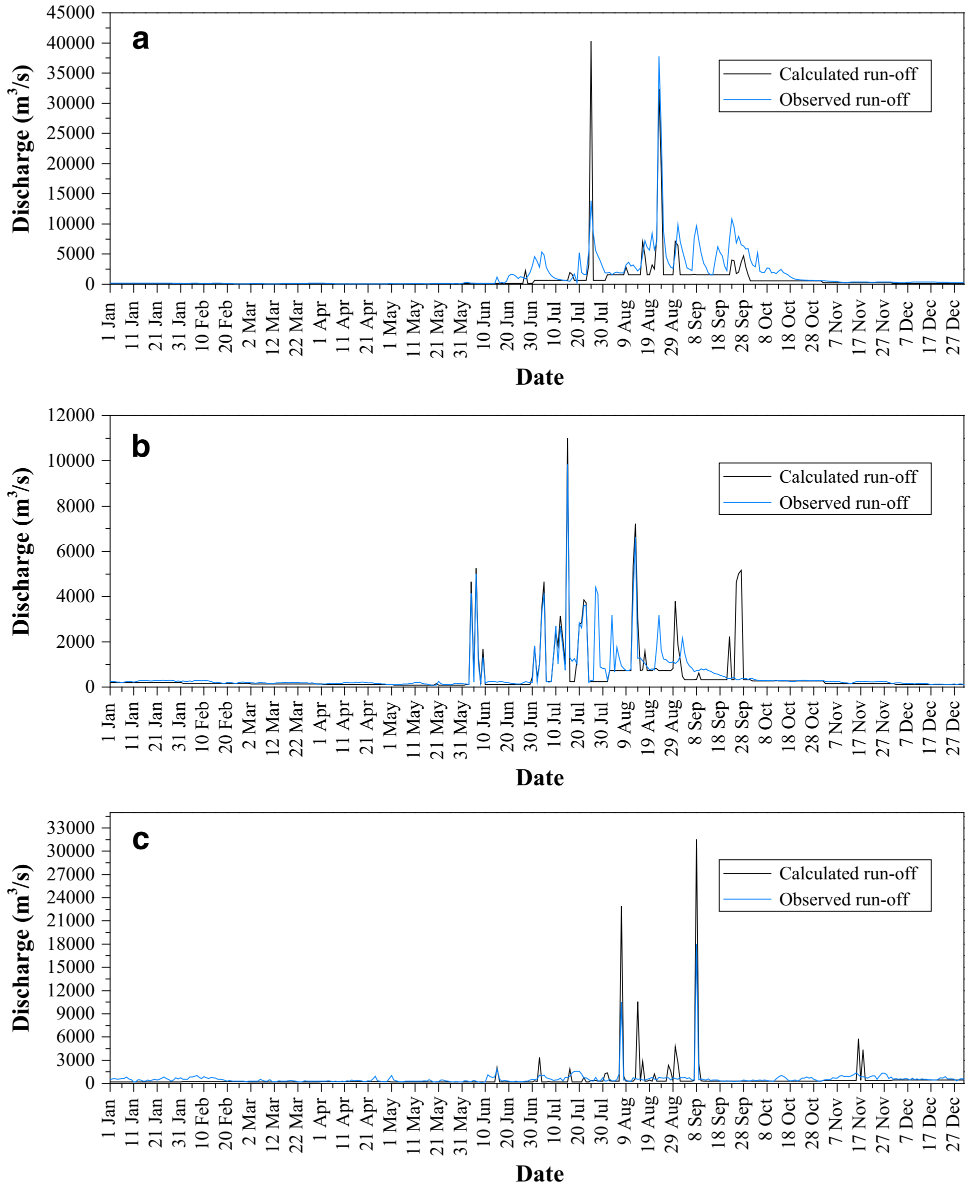


Fig. 4 Simulation and observed river run-off at gauge **a** 1990, **b** 2000 and **c** 2009

there is an increase of water body area from 1990 to 2009 which is 2.86 % of the total area.

Calculation of curve number values

Run-off calculation has been done from the rainfall data and SCS-CN curve number method for the years 1990, 2000 and 2009. The results have been calibrated and validated with the observed river flow. The weighted average CN value and the different values of curve number are tabulated in Table 3.

Here it has been observed that the weighted average of CN is increasing, and from graph also it is observed that the run-off is increasing from 1990 to 2009. So it has been concluded that the run-off will increase if the CN increases.

Run-off calculation in different years

The rainfall of three rain gauge stations within the study area and SCS-CN curve number method have been considered to calculate the surface run-off. Again by using this computed surface run-off and base flow, the river run-off has been generated on a daily basis. Then the results have been simulated and validated with the observed run-off data series. The run-off calculation has been done for the years 1990, 2000 and 2009 that are discussed below.

The comparison between the calculated and observed run-off for the year 1990 is shown in Figs. 4a and 5a where the difference between the calculated and observed run-off is around 6.66 %. The comparison between calculated and observed run-off for the year 2000 is presented in Figs. 4b

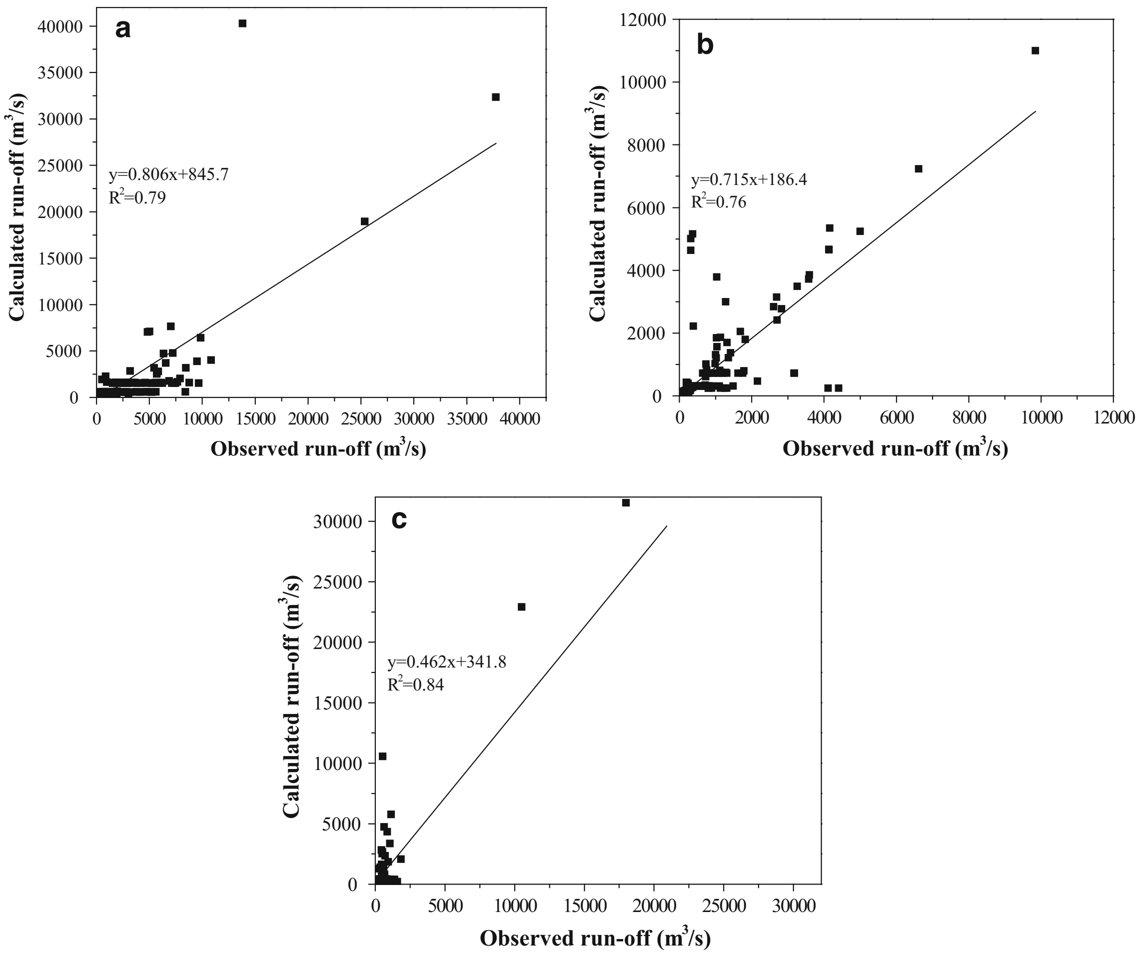


Fig. 5 Scatter plot of simulation and observed river run-off at gauge **a** 1990, **b** 2000 and **c** 2009

and 5b where the difference between calculated and observed run-off is around 11.73 %. Similarly the comparison between the calculated and observed run-off of the year 2009 has been presented in Figs. 4c and 5c where the difference between calculated and observed run-off is around 75 %.

From all of these three results linear regression has been calculated. In the year 1990 the R^2 value is 0.791 that is good, for the year 2000 the value of R^2 is 0.758, where also the relation is quite good and lastly for the year 2009, the R^2 value is 0.836 that is quite impressive.

Run-off calculation using landuse changed condition

The result of the impact of landuse/land cover change on run-off is tabulated in the Table 4.

From the given table it has been observed that the total run-off of the year 1990 $= \sum R_1 = 161.6$ mm and total run-off of the year 2000 $= \sum R_2 = 170.24$ mm. Therefore the impact factor of landuse/land cover on run-off of this study area is 1.053. This factor has been used for computing the daily run-off of river for the year of 2021 which has the influence of changed landuse/land cover. Here in the Fig. 6, the impact of landuse change on run-off in the study area has been illustrated.

Table 4 Total run-off in the year 1990 and 2000

Year	1990	2000
Total run-off (mm)	161.6	170.24

From this result, it is clear that the peak run-off is 48.3 mm and if landuse change is considered the peak run-off becomes 49.7 mm. So the effect on run-off due to landuse change has been 3 % in 10 years of this study area on a daily basis.

Run-off calculation for the year 2011 using landuse/land cover change condition

The run-off has been calculated considering the average of 40 years of daily rainfall data of Mandaleswar and landuse/land cover change condition of the study area. The

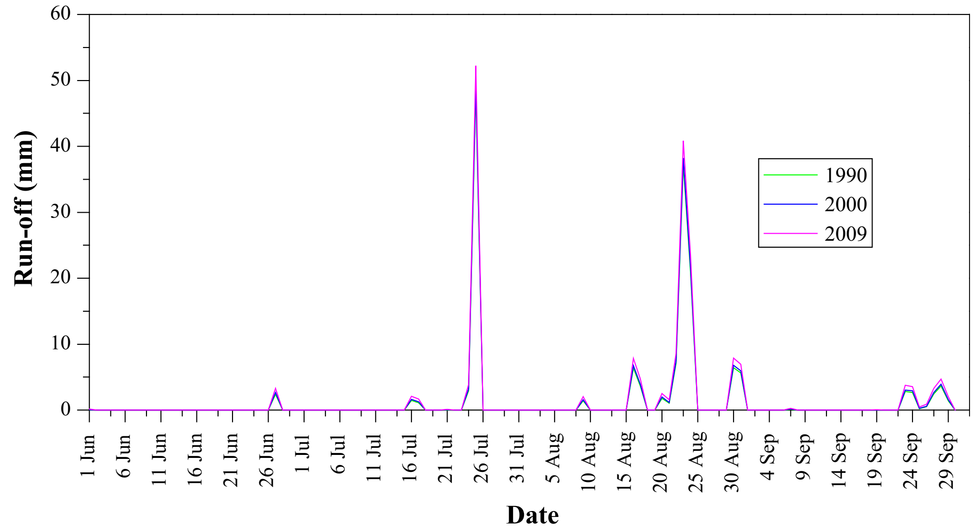


Fig. 6 Run-off change due to landuse change in the year 2000 and 2009

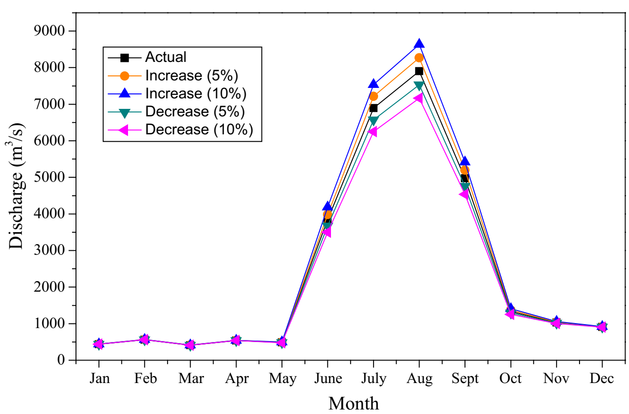


Fig. 7 Run-off variation due in different conditions considering average daily rainfall

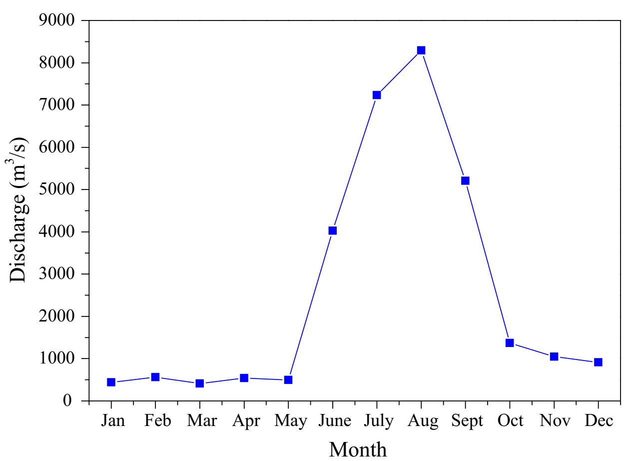


Fig. 8 Run-off of the year 2021 due to landuse change in the year 2021

average daily rainfall has also been calculated by considering +10, +5 %, average, −5 and −10 % of the daily rainfall data and from these five conditions the run-off has been calculated (Fig. 7).

Calculation of run-off at 2021

Here the run-off of 2021 for the study area has been analysed with respect to average rainfall of 40 years of Mandaleswar and considering the landuse/land cover change condition. From this calculated run-off, the flow duration curve has been prepared considering the average rainfall condition and with the help of this flow duration curve the dependable flow of 90 and 75 % has been analysed. Again from 90 and 75 % dependable flow, the Hydro power Potential has been computed. The run-off pattern of 2021 has been furnished in the Fig. 8.

Calculation of hydropower potential

The hydro power potential has been analysed considering all five conditions of rainfall that is +10, +5 %, average, −5 and −10 % of the average daily rainfall data. The flow duration curve has been prepared for all these five conditions of 2011 and by considering 90 and 75 % dependability of flow, the Hydro Power Potential has been analysed.

Flow duration curve of Narmada River considering five different conditions

The flow duration curve has been prepared for five different conditions from daily run-off data of 2011with the help of average monthly flow on account of finding the

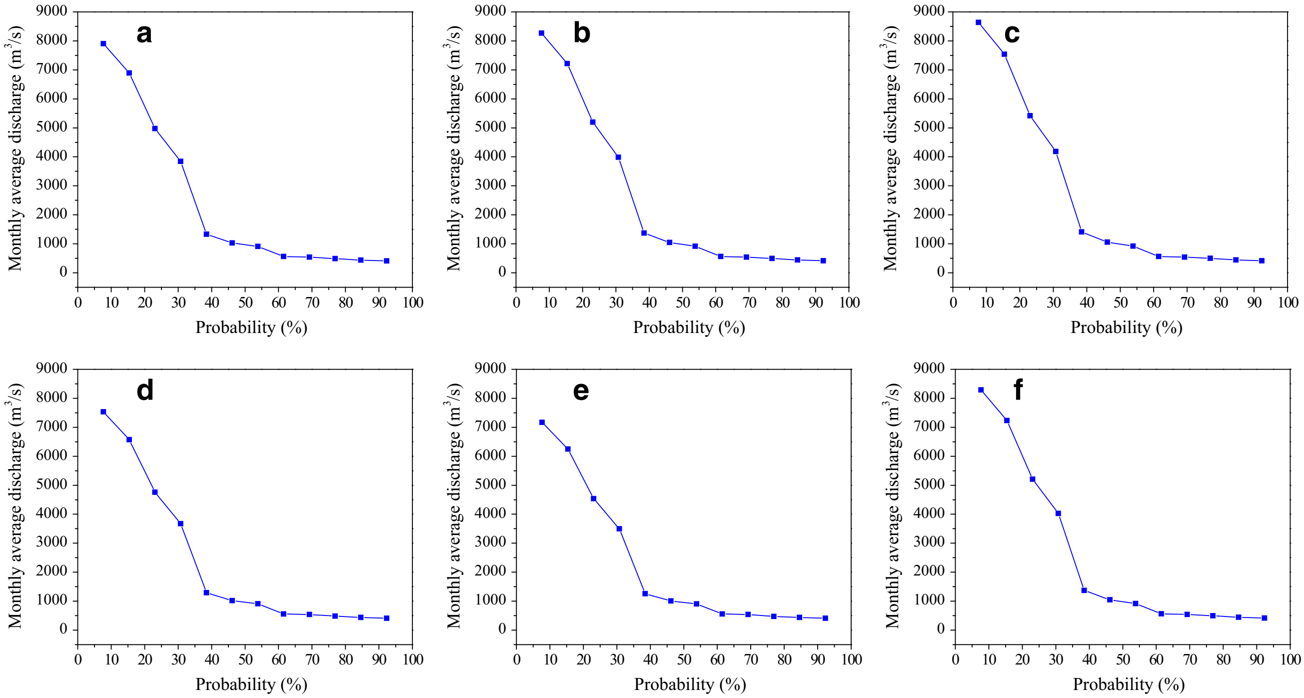


Fig. 9 Flow duration curve in different conditions: **a** rainfall 2011, **b** 5 % increase, **c** 10 % increase, **d** 5 % decrease, **e** 10 % decrease and **f** 2021 landuse in 2011 rainfall

hydro power potential for all the five conditions. In Fig. 9a–e, the flow duration curve of Narmada river flow has been furnished considering +10 , + 5 %, average, −5,−10 % of average rainfall, respectively.

From the given curve, it has been observed that if average rainfall is considered, then for 90 and 75 % dependable flow it will be 416.56 and 490 cumec, respectively, for landuse/land cover change in this study area. Similarly, if +10 % of average rainfall is considered then 90 and 75 % dependable flow will give 435.63 and 530.4 cumec, respectively. If +5 % of average rainfall is considered then for 90 and 75 % dependable flow it will be 433.75 and 528 cumec and if −5 % of average rainfall is considered then it will be 413.96 and 486.69 cumec, respectively. Further, if −10 % of average rainfall is considered then 90 and 75 % dependable flow will give 411.21 cumec and 482.63 cumec, correspondingly. River run-off can be assessed with the help of all these data.

Flow duration curve considering average rainfall condition of 2021

Considering the average rainfall of 40 years and landuse/land cover change of the study area the run-off of 2021 has been analysed in the Fig. 8. From this run-off data series, the flow duration curve has been prepared and shown in the Fig. 9f. From the graph it has been found out that the 90 and 75 % dependable flow for the year 2021 will be 422.33 and 506.1 cumec, respectively. Here from the graph it is observed that if 90 % dependability of flow is taken in 2011 then discharge will be 416.56 cumec and in case of 90 % dependable flow in 2021, it will be 422.33 cumec. The percentage change of 90 % dependable flow due to landuse/land cover change has been 1.38 % and if 75 % dependability is taken, then for 2011 it will be 490 and for 75 % dependable flow in 2021 it will be 506.1 cumec. Thereby the change is 3.3 %.

Hydro power potential at different conditions

As the 90 and 75 % dependable flow is changing in different conditions, the hydro power potential will also change. The results of these hydro power potentials are furnished as follows:

Hydro power potential for 2011 has been calculated as 124.2 MW (mega watt) and 146.1 MW for 90 and 75 % dependable flow, respectively, by considering average rainfall condition. For 2011, hydro power potential is 130.67 and 159.1 MW for 90 and 75 % dependable flow, respectively, considering 10 % increased average rainfall condition. For 5 % increased average rainfall condition, the hydro power potential is 130.10 and 158.37 MW, respectively, for 90 and 75 % dependable flow. For 5 % decreased average rainfall condition, hydro power potential by considering 90 % and 75 % dependable flow is 124 and

Table 5 Comparison of Hydro Power Potential for landuse/land covers change condition

Year	90 % Dependable flow (MW)	75 % Dependable flow (MW)
2011	124.2	146.1
2021	126.7	151.81

145 MW, correspondingly. Similarly hydro power potential for 10 % decreased average rainfall condition, is 123 and 144 MW for 90 and 75 % dependable flow, respectively. Finally, hydro power potential prediction for the year 2021 is 126.7 and 151.81 MW, respectively, for 90 and 75 % dependable flow considering average rainfall. The variation of hydro power potential between 2011 and 2021 for 90 and 75 % dependable flow is furnished in the Table 5.

From these analyses, it is clear that the hydropower potential has not changed significantly within 10 year interval due to landuse/land cover change in this study area. The increase of Hydro Power Potential for 90 % dependable flow is 2.5 MW, which is 2.02 %. Again, if 75 % of dependable flow is considered then the increase of hydro power potential is 5.71 MW, which is 4 %. So it is concluded that in this study at the point of Mandaleswar the run-off will not change significantly. So provision for another unit of Hydro Power generation may not be required. But provision for extra 2.5 and 5 MW units can be installed if 90 % dependable flow and 75 % dependable flow is considered respectively, for 2021, but in the long run the Hydro Power Potential will increase as per the present trend of landuse/land cover change condition.

Conclusion

Results from curve number model developed by the Soil Conservation Service have shown that the overall weighted curve number has been increasing from 83.26 in 1990 to 83.78 in 2000 to 86.22 in 2009. This implies that the surface run-off increases, and at the same time it renders the amount of infiltration water to decrease. This analysis shows that the estimated surface run-off increased by 3 % in 10 years from 1990 to 2000 if the rainfall is same considering the normal landuse/land cover change condition. The future river run-off data series has also been computed with the help of SCS-CN model and average rainfall data of the study area.

It is concluded from the above study that by acquiring the rainfall, run-off data and SCS-CN curve number method, the future run-off of the river and the future hydro power potential of that gauge discharge station can be obtained. If a hydro power plant already exists in the area, then in future how much power or energy will be obtained or how much power will decrease can be decided with this method. Future run-off of the river can also be attained by observing the different landuse/land cover of this catchment area so that hydropower potential situated at that site may be optimised.

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