Land Use and Water Resources Research

Impact of watershed management on livelihoods: Quantification and Assessment

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Abstract

Watershed projects in India have grown in recent years from mere technical interventions to restore degraded lands and vegetation to more specific poverty alleviation initiatives. Monitoring of such programmes is critical and existing evaluation techniques do not represent realistic scenarios. In this paper, an effort has been made to quantify the livelihoods of watershed communities by using socio-economic indicators. The analysis was performed for the villages of Dudhi micro-watershed. The socio-economic data from three PRA (participatory rural appraisal) exercises, conducted during 1995, 2002 and 2004, have been processed. The asset portfolio of the individual households has been quantified with the help of proposed indicators and all the indices have been estimated. Various interventions implemented as part of a development programme in the Dudhi micro watershed were simulated using the model ArcSWAT, including structures such as checkdams, ponds and changes in landuse/cover. Factor analysis was performed for the possible linkages between the impacts of watershed management on livelihoods. The results estimate annual watershed growth rate to be 1.2%, which is much lower than the national rural growth rate of India.

Introduction

Integrated watershed management is the process of formulating and implementing a course of action involving natural and human resources in a watershed*, taking into account the social, political, economic and institutional factors operating within the watershed and the surrounding river basin and other relevant regions to achieve specific social objectives (Dixon and Easter, 1986). The prospect of covering all aspects of livelihoods, or even all questions identified as critical for assessing the livelihood impact of watershed development initiatives, can be daunting, especially for econometric analysis; the way in which so many factors are interrelated creates complex problems that would require ever-larger data sets to resolve.

Socio-economic methodologies provide the necessary framework for evaluating and comparing different development options (Calder, 1999). The use of indices is widespread in social and economic sciences for assessment and monitoring purposes. The assessment and monitoring of human development uses the Human Development Index (HDI), the Human Poverty Index (HPI) and the Gender-related Development Index (GDI) (UNDP, 2001); while environmental sustainability and sustainable development at national level employs the Environmental Sustainability Index (ESI) (YCELP 2002) and Indicators of Sustainable Development (Commission on Sustainable Development 2001). Indicators to measure the performance of IWRM (Integrated Water Resources Management) at the river basin scale are found in Hooper and Prato (2004) and indicators of community capacity to achieve sustainability in UWECE (1998). To quantify the livelihoods of rural watersheds, a similar approach has been adopted to that used by the UNDP for capturing the human development. A set of equations is formulated to measure development at different levels within the watershed, namely household, village and watershed. Human Development Reports use three basic indicators, explicitly income, health and literacy, for measuring human development at national level. It is proposed to also use the two additional indicators of cattle-holding and land-holding along with these three HDI indicators to take into account the rural nature of watershed and watershed interventions.

* 'watershed' is an alternative term for catchment or drainage basin. - *Ed.*

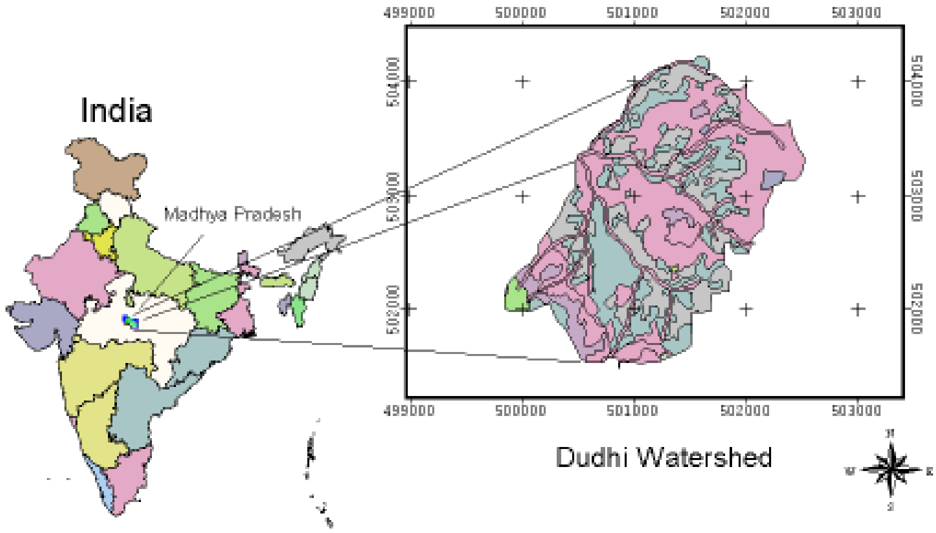

Figure 1 Location map of Dudhi micro-watershed

In this study, the Soil and Water Assessment Tool (SWAT) model is used with an ArcGIS interface to evaluate the impact of interventions on the hydrological parameters for the Dudhi watershed. Among physically based distributed parameter models, SWAT is the most recent one to be used successfully for simulating runoff, sediment yield and water quality of small watersheds (Tripathi *et al*., 2003, 2004; Van Liew and Garbrecht, 2003).

Study area and data collection

The Dudhi experimental watershed is a part of the Dudhi river basin which is a tributary of the River Bina and has been part of many previous state and national watershed development programmes, hence data availability was good. The study watershed is situated in the Raisen district of Madhya Pradesh State, India (Fig. 1). It spreads over the two villages Dabri and Bichhua Jagir and covers approximately 500 hectares (see Survey of India topographical sheet no. 55 1/11) and lies between North latitudes 23–24' to 23–27' and East longitudes 78–32' to 78–37'. The area is characterised by undulating topography with steep valleys and flat plateau tops. The altitude ranges from 660 m above MSL to 720 m above MSL. Several streams originate from the hilly region, yielding high runoff which causes erosion on hilly slopes and in adjoining agricultural fields.

The average annual rainfall is 1240 mm, with the monsoon season (June–October) contributing more than 80%. The landuse data have been derived from the satellite imageries, IRS-1B (LISS II) of October 1994 and February 1995. Long range rainfall, temperature, humidity and wind velocity data were available. Socioeconomic surveys at household level were carried out during 1997, 2001 and 2004 to capture the socio-economic details of the population.

Quantification of livelihoods

A set of equations was derived to measure the impacts of the watershed programmes on the livelihoods of the local community. [However, note that due to lack of data related to health parameters, the health indicator could not be calculated in the illustration given herein.]

House-Hold Development Index

HHDI represents the position of a particular household within a given population with respect to the set of five indicators. The HHDI is constructed in two steps. The first step is to define the development indicators — income (X_1), literacy (X_2), land holding (X_3), and livestock holding (X_4) for the households. Maximum and minimum values of the indicators over the region of interest (or project area) are identified for each indicator, given the actual values. The development measure then places a household in the range of zero to one as defined by the difference between the maximum and the minimum.

Thus I_{ij} is the development indicator for the j^{th} household with respect to the i^{th} indicator and it is defined as:

$$I_{ij} = \frac{\left(X_{ij} - \min X_{ij}\right)}{\left(\max X_{ij} - \min X_{ij}\right)} \text{....................(1)}$$

The second step is to measure the HHDI for j^{th} household by taking a simple average of all the development indicators:

$$(HHDI)_j = \sum_{i=1}^{n} I_{ij} / n \text{....................(2)}$$

where n is the number of indicators

HHDI Values

UNDP's Human Development Report (HDR) classifies all countries into three clusters depending upon their Human Development Index (HDI). Countries with an HDI of 0.800 or above are considered high in human development; 0.500–0.799 are medium and less than 0.500 are low in human development (UNDP, 2003). However, the authors have introduced one more category within the low development segment and thus all the households belonging to the study watershed are grouped into four clusters, depending on their HHDI values. The first two groups are similar to the HDR classification but third group has been split into two. The first part is households with low development if the HHDI index is in the range 0.200 to 0.499, and the second

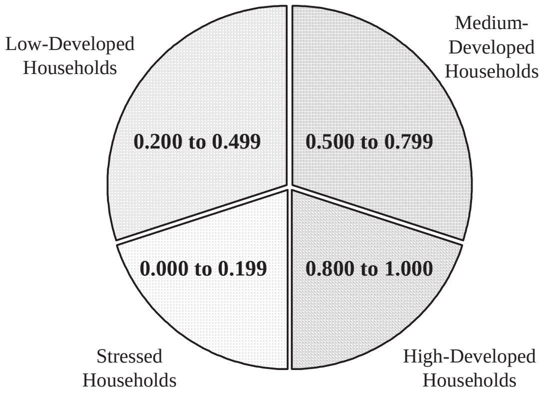

Figure 2 Distribution of households in four groups as per HHDI index

part is stressed households if the HHDI index value is less than 0.200. The classification of households is shown in Fig. 2.

Village Development Index

The average of all HHDI values at village level will provide an index representing average development of the community at village level. This index is termed the Village Development Index or VDI. Mathematically, it can be expressed as:

$$VDI = \sum_{i=1}^{x} (HHDI)_i \,/\, x\text{....................}(3)$$

where x is the number of households in the village

Watershed Development Index

An integration of all the village development indices at the watershed level would represent the general well-being of the community inhabiting the entire watershed in a holistic manner and such an integrated index is described as Watershed Development Index or WDI. A watershed may consist of several villages. VDI is calculated for each village in the watershed. The arithmetic mean of VDI values will provide the desired index WDI.

$$WDI = \sum_{i=1}^{y} (VDI)_i \,/\, y\text{....................}(4)$$

where y is the number of villages in the watershed.

The WDI is calculated using the village development indices based on the household data. Thus, the index is a realistic representation of the livelihood situation in the watershed area. The WDI can be observed during the implementation of the watershed development programme and hence the changes in livelihoods of the community can be evaluated.

Stressed Community Index

The Stressed Community Index (SCI) is an index of stressed households with an HHDI index value of less than 0.20 at the beginning of the watershed development programmes. They are the most vulnerable group and have the fewest livelihood options. The average value of HHDI for such households will form the SCI. The numerical value of SCI can be traced throughout the implementation of the watershed program and is of great help in the evaluation of integrated watershed programmes or other such projects.

$$SCI = \sum_{i=1}^{z} (HHLZ)_i \,/\, z\text{....................}(5)$$

HHLZ denotes households having an HHDI value less than 0.200 and z is the number of such stressed households.

Livelihood analysis for study area

Livelihood analysis was performed for the villages of the Dudhi micro-watershed, using the socio-economic data from three PRA exercises conducted during 1997, 2002 and 2004. The asset portfolio of individual households has been quantified with the help of proposed indicators and all the indices have been estimated using their definitions.

The required minimum and maximum values for calculation of the proposed indicators have been identified from the socio-economic data pertaining to the Dabri and Bichhua Jagir villages of Dudhi micro-watershed. Out of a total of 115 households many are completely illiterate, have no land or livestock and thus get minimum values of associated zero. The income disparity among households is high and calculated *per capita* annual income at household level ranges from Indian Rupees (INR) 833 to 24667. Apart from income disparity, approximately 95% of households fall below the criteria set by UNDP as Millennium Development Goals for extreme poverty and hunger. The maximum and minimum values of the indicators for the Dudhi micro-watershed are given in Table 1.

Table 1. Maximum and minimum values of various indicators in Dudhi micro-watershed

Indicators	*Maximum Value*	*Minimum Value*
Income per capita (INR per annum)	24667.0	833.0
Literacy (%)	100.0	0.0
Land holding per capita (acre)	10.0	0.0
Livestock holding per capita (no.)	5.5	0.0

Equations (1) and (2) have been used to calculate the values of various indicators, i.e. income, literacy, land holding and livestock holding, for the Dabri and Bichhua Jagir households for the three survey years. The maximum and minimum values identified for the Dudhi watershed have been used, along with the status of a particular household, to arrive at the final values for indicators. These are shown in Tables 2 and 3.

Table 2. Developmental indices for Dabri village

Indices / Years	*1997*	*2001*	*2004*
Village Development Index	0.267	0.290	0.294
Stressed Community Index	0.113	0.153	0.216

Table 3. Developmental indices for Bichhua Jagir village

Indices / Years	*1997*	*2001*	*2004*
Village Development Index	0.325	0.328	0.332
Stressed Community Index	0.175	0.196	0.195

The watershed development index, which represents overall development in the watershed, has been calculated by taking the simple arithmetic means of the village development indices of the villages in the Dudhi micro-watershed. The improvement in the watershed development index is 4% and 6% from the base year 1997 to 2001 and 2004 respectively (Table 4). The impact of the watershed programme is visible in the development of the poorest people; the Stressed Community Index — an index of the bottom 20% of households from the base year — has shown improvement and equates to around 21% and 43% from the base year 1997, to 2001 and 2004 respectively (Table 4).

Table 4. Developmental indices for Dudhi micro-watershed

Indices / Years	*1997*	*2001*	*2004*
Watershed Development Index	0.296	0.309	0.313
Stressed Community Index	0.144	0.175	0.206

Hydrological simulation of watershed interventions

Several physically based distributed parameter models such as ANSWERS, AGNPS, SHE, SWRRB and SWAT have been developed to predict runoff, erosion, sediment and nutrient transport from rural and agricultural watersheds under various management regimes. Among these models, the Soil and Water Assessment Tool (SWAT) is the most recent to be used successfully for simulating runoff, sediment yield and water quality of small watersheds. The SWAT model is a distributed parameter, continuous model developed by the USDA-ARS (Arnold *et al*., 1996, 1998). The SWAT model was tested mainly on a monthly and annual basis for predicting runoff and sediment yield (Bingner *et al*., 1997; Peterson and Hamlett, 1998; Rosenthal *et al*., 1995; Srinivasan and Arnold, 1994; Srinivasan *et al*., 1997).The SWAT model has, however, also been validated on the basis of daily runoff and sediment yield (Tripathi *et al*., 2003, 2004).

Model validation

An initial validation exercise was performed for the study watershed to ensure that SWAT could produce reasonable flow estimates using land use and soil data for the relatively small watershed. The validation was performed for the monsoon season of 2000 using daily precipitation and temperature data obtained by the Dudhi weather station located within the watershed. The watershed was divided into 33 subwatersheds, as shown in Figure 3, for the validation simulation.

Figure 4 shows average daily measured and simulated flows for the monsoon season of the year 2000. In general, the predicted flows compared well with the measured values but it is important for simulation models to produce frequency distributions that are similar to measured frequency distributions. Close agreement between means and standard deviations (Table 5) indicated that the frequency distributions were similar. Regression line slope and coefficient of determination (R^2, Figure 5) values near unity also indicate a close relationship between measured and predicted yields. The American Society for Civil Engineers Task Committee on Evaluation Criteria for Watershed Models (1993) recommends the Nash-Sutcliffe coefficient as a goodness-of-fit criterion (Nash and Sutcliffe, 1970) for watershed models. This coefficient measures the goodness-of-fit to the line-of-perfect-fit (the 1:1 line) and

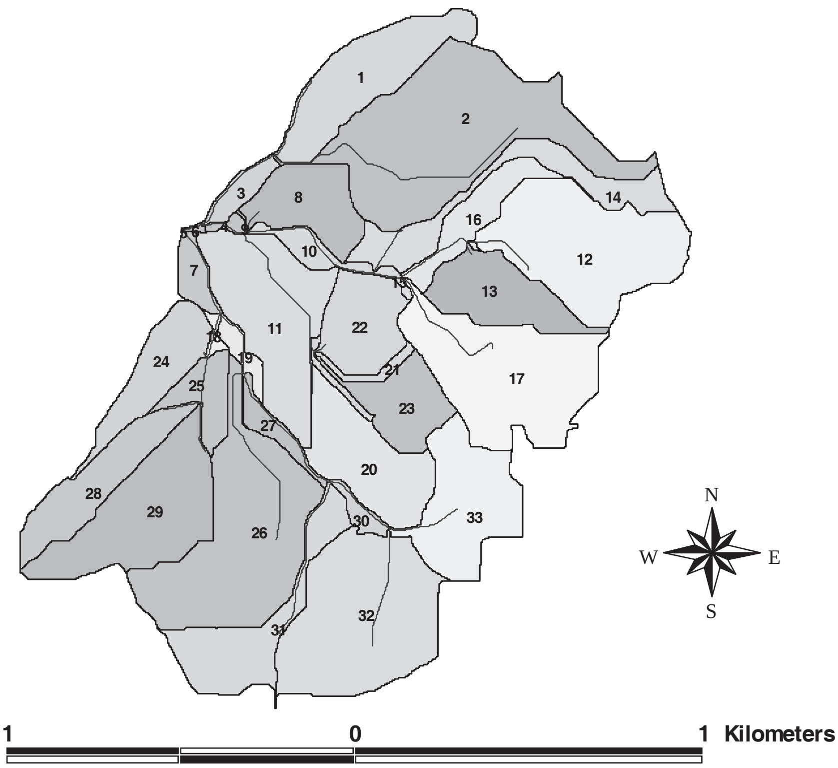

Figure 3. Automatically delineated watershed and subwatersheds

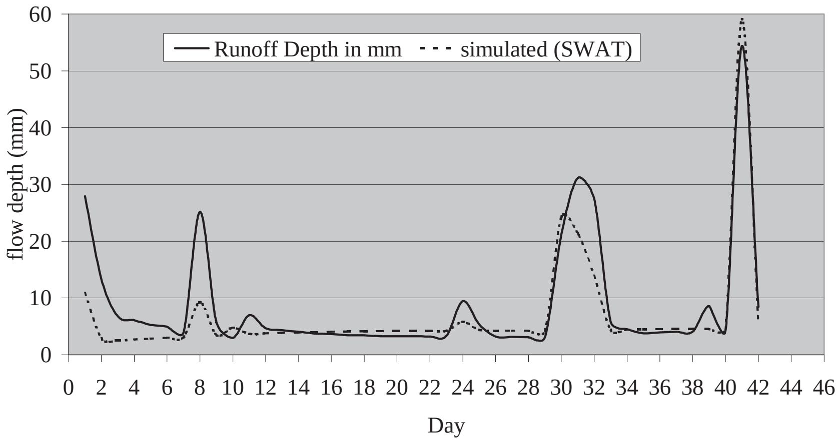

Figure 4 Measured versus simulated average daily water depth values (Monsoon season of the year 2000)

Table 5. Measured and Predicted Water Yield Statistics for Dudhi Watershed, Madhya Pradesh

Water Yield	*Mean*	*Standard Deviation*	*Regression Slope*	*R^2*	*Nash-Sutcliffe*
Measured	8.595	10.387			
Simulated	6.762	9.387	0.801	0.790	0.758

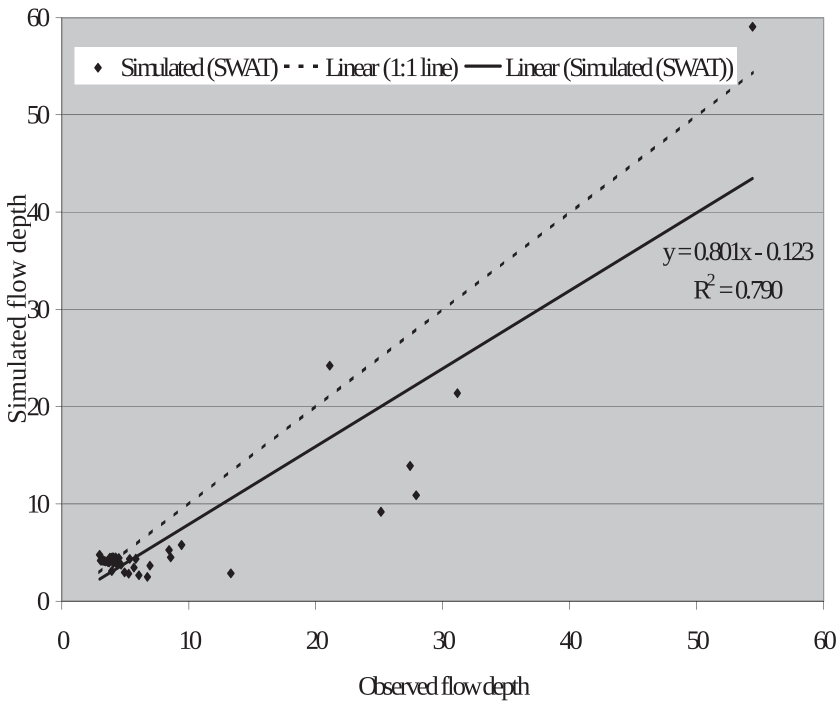

Figure 5 Comparison between observed and simulated average daily flow depths for model validation

measures how well the simulated and measured flows correspond. The Nash-Sutcliffe coefficient value is 0.758 for the study watershed which indicates a reasonable goodness-of-fit.

Watershed simulation

The SWAT model was run to assess the impact on hydrological components of interventions carried out in the watershed such as land use change, ponds and checkdams using data for 2004. The results of this simulation are compared with the base year 1997 in Table 6.

Linkages between watershed development and dydrological components

It is well-established that improvements in watershed conditions bring positive changes in the livelihoods of the community inhabiting it (Jones *et al*., 2002; Biltonen and

Table 6. Impact of watershed management activities on hydrological components

Components	*Av annual outputs for the base year*	*Av annual outputs with landuse + ponds + CDs*	*% Change in components*
Surface runoff (mm)	325.01	288.54	–11.22
Shallow aq recharge (mm)	567.44	645.51	13.76
Deep aquifer recharge (mm)	29.06	32.12	10.54
Evapotranspiration (mm)	338.70	348.11	2.78
Sediment loading (t/ha)	51.10	13.02	–74.52

Note: CDs = checkdams

Dalton, 2003). The rate at which these changes occur varies, depending upon many political, geographical, socio-economic and technological factors. To explore the possible linkages between the impacts of watershed management on socio-economic development and hydrological components, a multiple regression analysis has been carried out using the SPSS package (SPSS Inc., 1999) with WDI as the dependent variable and SWAT outputs in the form of surface runoff, shallow aquifer recharge, deep aquifer recharge, evapotranspiration and total sediment loading, as independent variables. The analysis showed that the problem of multi-collinearity exists in the predictor variables of the watersheds. The value of the variance inflation factor (VIF) is more than its acceptable limit, i.e. more than 10 (Bowerman and O'Connell, 1990) and hence multiple regression analysis cannot be used directly in this instance.

Field (2000) describes the use of factor scores in overcoming collinearity problems in regression. If, following a multiple regression analysis, sources of multi-collinearity are identified then the interpretation of the analysis is questioned. In this situation, factor analysis can be performed on the predictor variables to reduce them down to a subset of uncorrelated factors. The variables causing the multi-collinearity will combine to form a factor. If the regression is then re-run, but using the factor scores as predictor variables, then the problem of multi-collinearity should vanish.

Following Field's (2000) method, factor analysis has been performed on the predictor variables to overcome the problem of multi-collinearity in the data set. The factors have been extracted using principal components analysis (PCA). Based on the scree plot (plot between eigen value and factors), only one factor could be extracted. The one-factor model results reveal that the first component's eigen value extracted from the matrix accounts for more than 98% of total variance. Varimax rotated component matrix with Kaiser Normalization was used for the PCA. The calculated factor scores were defined using the hydrological components index (HCI) and have been used for the further regression analysis (see Table 7).

The SWAT model output has been used for future forestry policy scenarios and for the existing forest landuse scenarios. The national forest policy targets are to bring 25% and 33% of the geographical area of India under forest cover by the end of tenth (year 2007) and eleventh (year 2012) development plans, respectively (Planning Commission 2002). The data have been linearly interpolated for the missing years. The computed watershed development indices for the Dudhi micro-watershed have been used to develop the following regression model which predicts moderate development in the area for the above future forestry scenarios. The projected values of the watershed development index compare well with the computed values, with little deviation. The rate of growth for the year 2012 is observed to be about 18% on the base year of 1997. The annual growth rate is about 1.2%, which does not compare well with the national (India) rural growth rate of approximately 2% (Indiresan, 2001).

It is the authors' opinion that the poor rural growth scenario in the Dudhi watershed may be linked to the geographical position of the watershed. The study area forms part of the headwaters of the Dudhi river basin which is characterised by undulating topography with steep valley sides and flat plateau tops. Several high yielding streams originate from the hilly region, which cause erosion in the hilly slopes and adjoining agricultural fields. The SWAT model predicts that none of the HRUs (hydrologic response units) come under the moderate erosion class. Most of the HRUs fall under very the severe soil erosion class to more than the average for India which is 16.35 tons per hectare per year.

$$WDI_{Dudhi} = -0.014 * HCI + 0.317$$

Table 7. Projected values of watershed development index for Dudhi micro-watershed

Year	*HCI*	*Projected WDI*	*Year*	*HCI*	*Projected WDI*
1997	–1.394	0.296	2005	-0.109	0.318
1998	–1.217	0.299	2006	0.155	0.323
1999	–1.040	0.302	2007	0.420	0.327
2000	–0.864	0.305	2008	0.691	0.332
2001	–0.687	0.308	2009	0.963	0.336
2002	–0.583	0.310	2010	1.234	0.341
2003	–0.478	0.312	2011	1.506	0.345
2004	–0.374	0.314	2012	1.777	0.350

Conclusions

The paper demonstrates a methodology for the quantification of socio-economic data for watershed analysis. The methodology can be replicated for any other watershed for the given parameters. The livelihood indices are useful in addressing the issues of sustainability and policy making. For the Dudhi study watershed, the VDI index shows 8.7% and 10.1% improvement for the years 2001 and 2004 respectively from the base year 1997. The SCI improves by 41.7% by the year 2001 and 95.6% in 2004 from the base year 1997.

The SWAT model was effective in simulating the various interventions in the watershed. The simulation for the checkdams, ponds and changes in landuse/cover was done with ArcGIS and SWAT, and the results are comparable with the observed data.

The study recognises potential linkages between the impacts of watershed management on socio-economic development and hydrological components. The potential linkages have been established using statistical analysis such as factor and regression modelling. The factor analysis was useful in reducing the SWAT model outputs and in generating a new index, which has been labelled the Hydrological Components Index or HCI. The regression model developed for Dudhi micro-watershed predicts moderate development in the area. The rate of growth for the year 2012 is observed to be about 18% from the base year 1997. The annual growth rate is around 1.2%, which is lower than the average national rural growth rate of approximately 2% for India.

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