Changes in Water Resources Systems: Methodologies to Maintain Water Security and Ensure Integrated Management (Proceedings of Symposium HS3006 at IUGG2007, Perugia, July 2007). IAHS Publ. 315, 2007.

Externalities in watershed management

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Abstract The term "externality" is used to describe the indirect or accidental consequences of actions associated with watershed activities. Building new structures, afforestation and soil/land treatments are a few such watershed activities. The present paper demonstrates the measurement of externalities in an experimental watershed through GIS-based watershed modelling and using livelihood indices. The simulated results show that the surface runoff has reduced by 11.22% and 22.56% for the 2007 and 2012 futuristic forest policy scenarios, respectively. Heavy losses in surface runoff may reduce the water availability to downstream areas, stressing water demands, especially during the water stressed months. This has also been reported in the primary survey conducted during 2004. An analysis shows that for a downstream village, Amoli, the average time spent in water collection for domestic uses has increased by about 4%. The experimental micro-watershed Dudhi is located in the Raisen district of Madhya Pradesh State, India.

Key words externalities; forest policy; GIS; India; watershed management; watershed modelling

INTRODUCTION

In watershed programmes all attempts are made to effectively store rainfall in the soil profile, between the bunds and check dams, and in water storage reservoirs, so that the rainfall is more effectively utilized within the watershed. Negative externalities may be generated when such watershed activities cause increased loss of water in the form of evapotranspiration, and excessive detention of water in newly created water structures. This results in less surface runoff to downstream areas, and thus stresses the downstream community in fetching water for drinking, livestock and other uses. Watershed management activities have also resulted in massive land-use changes in India. Forest policy in India targets increasing forest cover from the present 19% to 33% by the end of the 11th development plan, i.e. 2012. Such management scenarios affect the total water quantity available at the downstream watersheds and are the cause of negative externalities.

The hydrological model used in the present study is the Soil and Water Assessment Tool (SWAT) (Arnold *et al.*, 1998) with an ArcView GIS interface (Srinivasan *et al.*, 1998). SWAT is a river basin or watershed scale model, developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions, over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts.

A primary socio-economic survey was conducted in 2004 in order to ascertain the consequences of the watershed programme on the downstream community. The indicators chosen were primarily dependent on the watershed activities in the study area. Data for two previous surveys was available for 1997 and 2001. The livelihood evaluation and monitoring indices developed by Lodha & Gosain (2005) have been used to process the socio-economic data and to measure the impacts in quantitative terms.

STUDY AREA

The Dudhi experimental watershed is a part of the Dudhi River basin, which is a tributary of the River Bina. The study watershed is situated in the Raisen district of Madhya Pradesh State, in the central part of India (Fig. 1). It has a spread of two villages, namely Dabri and Bichhua Jagir, covering approximately 500 ha of land.

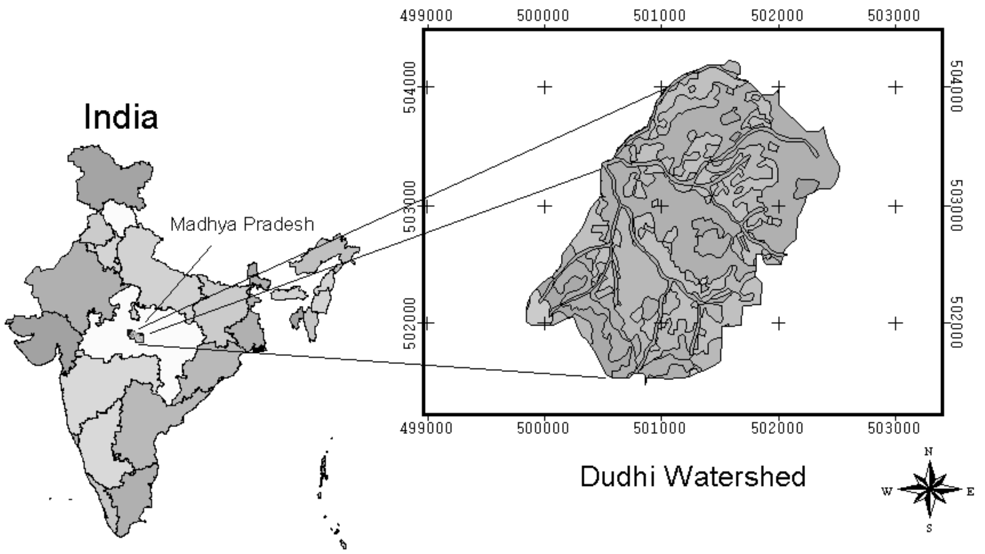

Fig. 1 Location of the Dudhi micro-watershed.

Amoli is a downstream village wherein the impacts of watershed management activities upstream have been studied. The results are based on the information received during the three primary socio-economic surveys conducted in the area. The Dudhi watershed area is characterized by undulating topography with steep valleys and flat plateau tops. The altitude of area ranges from 660 m above MSL to 720 m above MSL. Several streams originate from the hilly region, yielding a high amount of runoff, causing erosion in hilly slopes and adjoining agricultural fields.

WATERSHED MODELLING

Dudhi micro-watershed has been simulated for various physical changes that have taken place during the implementation of the watershed programme. Major watershed activities included creation of ponds and check-dams as water harvesting and recharge structures, and an afforestation programme to increase the forest cover in the area. These watershed interventions have been simulated using the SWAT model. Futuristic national forestry scenarios have been considered for this purpose, and simulated to determine the possible impact of forest policies on water and sediment yields using hydrological modelling.

The major advantage of the SWAT model is that, unlike other conventional conceptual simulation models, it does not require much calibration (Gosain *et al.*, 2005). However, the model has been validated on the basis of daily runoff yields for the present study. The validation was performed using daily precipitation and temperature data obtained for the Dudhi weather station, located within the watershed. The watershed was divided into 33 sub-watersheds for the simulation.

In general, the predicted flows compared well with the measured values. Close agreement between means and standard deviations, and the values of regression line slope and coefficient of determination, R^2 of 0.79, indicate a good relationship between measured and predicted yields (Table 1).

The American Society for Civil Engineers Task Committee on Evaluation Criteria for Watershed Models recommends the Nash-Sutcliffe coefficient as a goodness-of-fit criterion (Nash & Sutcliffe, 1970) for watershed models. This coefficient measures the goodness-of-fit to the line-of-perfect-fit (the 1 : 1 line) and 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.

The SWAT model run was made to know the impact of all interventions, i.e. forestry, ponds and check-dams all together on hydrological components. The forestry GIS layer for 2004 was used, along with executed structural changes in the form of ponds and check-dams in the watershed. Results of this simulation are shown in Table 2.

Simulated results show that reduction in surface water availability is about 11.22% for the various watershed interventions in the treated micro-watershed Dudhi. This reduction rises up to approximately 22% for the futuristic forestry scenario for 2012.

Table 1 Measured and predicted water yield statistics for Dudhi micro-watershed.

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

Table 2 Impact of watershed management activities on hydrological components

Components	Av annual outputs	Av annual outputs with forestry + 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, check-dams.

Reducing water availability has produced negative impacts on the livelihoods as is clear in the analysis which follows.

EVALUATING EXTERNALITIES IN WATERSHED MANAGEMENT

Externalities in watershed management can be defined as its role in influencing the livelihoods and hydrology of the downstream area. The nature of such externalities can be positive or negative, depending upon their impact on the downstream community. Overall evaluation and their impact on livelihoods need to be assessed for efficient management of such projects. For this purpose, a village, namely Amoli, which is located about 7 km downstream of the Dudhi micro-watershed, is considered to observe the impact of upstream watershed management on its community in the form of negative and positive externalities. It had also been reported, during the course of conducting a primary survey in the study area, of the water shortage they have been facing after the watershed activities upstream.

An analysis based on primary survey data on average time spent on water collection for livestock and domestic purposes shows that downstream community of Amoli village spends 3.89 % more time compared to the pre-watershed scenario. Contrary to this, up-stream villages have shown reduction in total time spent on water collection for livestock and domestic purposes. The results of analysis are shown in Table 3.

Table 3 Average time spent by households (in hours) in water collection.

Village	Watershed	Pre–watershed		Post–watershed		% Change in time (domestic)	% Change in time (livestock)
		Domestic uses	Livestock uses	Domestic uses	Livestock uses		
Amoli	DMiW	1.59	3.00	1.66	3.00	3.89	0.00
Dabri	DMcW	2.51	2.95	1.96	2.60	–21.76	–11.64
Bichhua	DMcW	0.77	1.04	0.76	0.99	–1.54	–5.29

Livelihood analysis has been carried out for the households of the Amoli village to know the changing profile of the community in the shadow of watershed activities, which are taking place upstream, by using the methodology proposed by Lodha & Gosain (2005). The methodology consists of normalization of primary data sets of chosen socio-economic indicators and then formulating household development index and other indices in accordance with the work of UNDP on Human Development Index. The household development index is estimated by taking the simple arithmetic mean of all calculated indicators. Values of all indicators distributed among four social groups for three survey years are depicted in Fig. 2.

The village development index (VDI) has marginally decreased (Table 4). The performance of stressed community index is negative and there is also an increase in the number of stressed households (NSH) index, indicating that negative externalities have also affected the poor people. The values of standard deviations for various indicators for successive surveys have been increasing, suggesting more inequalities and skewed distribution of benefits among households.

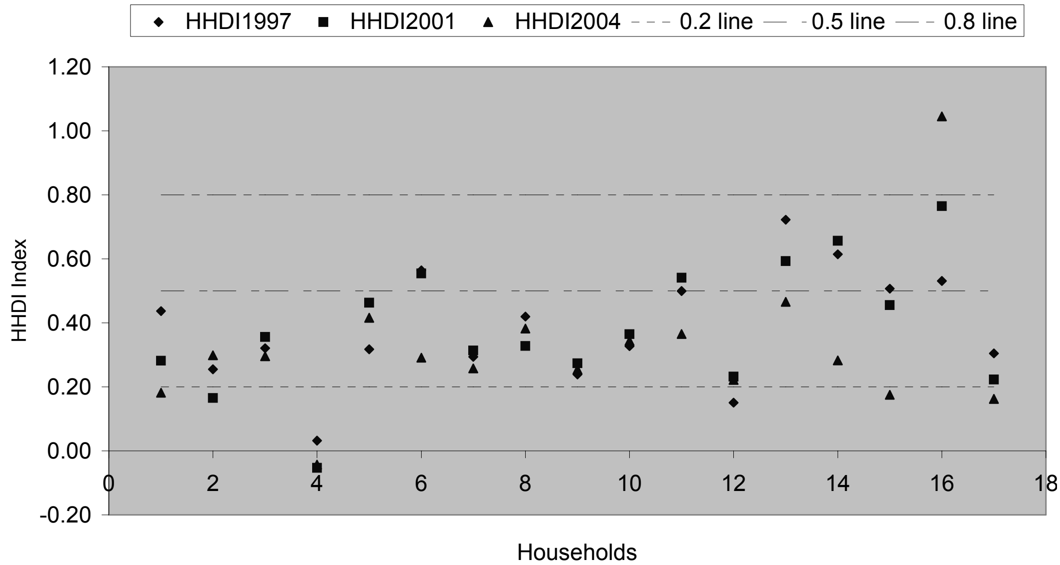

Fig. 2 Values of HHDI index calculated for households of Amoli village for three survey years.

Table 4 Developmental indices for Amoli village.

Indices / Years	1997	2001	2004
Village Development Index VDI	0.384	0.383	0.318
Stressed Community Index SCI	0.091	0.089	0.09
Number of Stressed Households NSH	2	2	4

CONCLUSIONS

Various watershed management activities have varying effects on the hydrological components. The simulation modelling for Dudhi micro-watershed shows heavy reduction in total runoff. Such situations contribute less surface runoff downstream. The community of Amoli village downstream of the treated watershed is subjected to water stresses without doing much themselves to their resources. Such negative externalities need to be evaluated and should be addressed appropriately in time and monetarily to avoid possible future water conflicts.

Livelihood analysis of Amoli village demonstrates the vulnerability of the system. India's rural–urban divide is big. The rural growth rate is only about 2%, compared with the overall growth of beyond 9%. Watershed programmes in India have helped in bringing local prosperity and equity, but still need strengthening from the view point of rural growth. Such programmes need to be established as part of the overall rural development, besides the natural resources management.

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