Land Use and Water Resources Research

Assessment of a SWAT model for soil and water management in India

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Abstract

The potential of a Spatial Decision Support System (SDSS) for estimating water and sediment yields was assessed in a large (92.46 km^2) experimental catchment in the Damodar-Barakar basin. The SDSS is based on a SWAT model and was operated under prevailing resource management conditions. Application of the proposed SDSS predicted average water and sediment yields of 383.37 mm yr^{-1} and 21.28 t ha^{-1} yr^{-1} were predicted as against actual observations of 390.69 mm yr^{-1} and 25.35 t ha^{-1} yr^{-1} for the validation periods 1981–1983; 1985–1989 and 1991. Simulations of the annual dynamics of total water and sediment yields showed good to moderately good correlation coefficients of 0.83 and 0.65; model efficiency coefficients of 0.54 and 0.70; mean relative errors of –4.28 % and –17.97% and root mean square prediction errors of 71.8 mm and 9.63 t ha^{-1}, respectively. The study demonstrated that the proposed SDSS could also be used to identify priority areas having high water and soil losses within the test catchment. The presence of large areas under long duration paddy rice and maize crops and/or low forest cover appeared to be the major reasons for the high water and soil losses from some experimental areas.

Introduction

Extensive soil erosion and its attendant ills has already contributed very significantly to the impoverishment of the land and people of India. Sheet erosion exists throughout almost the whole country (Anon, 1996). It has been estimated that this soil loss is taking place at an annual average rate of about 16.75 t/ha, far above the permissible soil erosion rates of 7.5 to 12.5 t/ha/yr for various regions in the country. If the present trend is allowed to continue, it is estimated that one-third of the arable land is likely to be lost within next 20 years.

About 10% of the total 5334 million tonnes (MT) of soil lost annually from the Indian sub-continent is deposited in various reservoirs, reducing their carrying capacity to just one-quarter of what was assumed at the time these were designed (Dhruva Narayan and Ram Babu, 1983) and hence an annual damage of about 25 million dollars due to the incidence of serious floods in about 2% (i.e. 6.7 m ha) of the country. In addition, as the eroded soil carries huge amounts of essential nutrients, it is estimated that there is an additional annual loss of about 560 million dollars due to the loss of about 6.2 MT of plant nutrients (Suraj Bhan, 1997). In terms of annual food grain production, soil erosion accounts for a loss equivalent to about 40 million tonnes. Thus such a situation demands concerted efforts in planning and implementation of soil and water conservation measures, together with integrated catchment management programmes in the catchment areas.

Many soil and water conservation programmes have been initiated in India at river basin scales since the early seventies. However, a review of these programmes by Vaidyanathan (1991) revealed many shortcomings. These included:

- a lack of adequate, accurate and scientific information on the natural resources at the catchment level;
- inadequate organization and the skills needed for collection and interpretation of data required for precise planning;
- a reliance on intuition, engineering experience, rule-of-thumb and simple site-specific techniques for making management decisions.
- an acute shortage of systematic impact studies,.

Agricultural land and water use decisions present several challenges to a decision maker who often has to consider multiple and frequently conflicting agronomic, economic, social and environmental goals. Also, environmental impacts of land use decisions are often not apparent until long after these decisions are implemented while attempts to extrapolate from homogeneous experimental plots to large, heterogeneous regions often result in unacceptable errors. Further, available resources within government are not sufficient for immediate treatment. In this context, it becomes very necessary to locate those problem areas that need priority attention. Once identified, a variety of area-specific and cost-effective techniques can be used to minimise the impacts of various agricultural and other activities on the total environment of the experimental catchment/area. At present, this is not being done at sub-catchment levels, thereby leading to — at times — either an unnecessary saturation of representative catchments with various conservation strategies or implementation of conservation strategies at not so critical locations and a wastage of government funds.

It is in this context, that quantitative system tools such as Spatial Decision Support Systems (SDSS), including simulation models and Geographic Information Systems (GIS), are of great use.

The study reported here was attempted to assess and demonstrate the potential of one such SDSS for estimating water and sediment yields, under current resource management systems, in the Nagwan sub-catchment in the Damodar-Barakar basin in India and for identifying high soil and water loss contributing source areas in an experimental catchment, the Nagwan, in the Damodar-Barakar basin in India.

Site characteristics

Encompassing nearly 9576 ha, the experimental Nagwan sub-catchment (No.7 (1), Fig. 1) is located in the upper part of the Sewani River between 23°59'–24°05'N and 85°18'–85°23'E within the Damodar-Barakar basin in the Hazaribagh district of Jharkhand State. The Damodar–Barakar catchment, with an area 17.61 million ha, is the second most seriously eroded area in the world (El-swaify *et al*., 1982). It belongs to the Chhotanagpur plateau and experiences erratic and uneven rainfall. The area experienced 16 serious floods between 1923 and 1943. After the 1943 floods, the Government of India prepared a unified river basin development plan, including provision for flood control, irrigation, power generation, navigation and soil conservation. This led to the construction of five dams, namely Tilaya, Maithon, Panchet, Konar and Tenughat, by the Damodar Valley Corporation (D.V.C.). Throughout the catchment, the general picture is that of long stretches of gently sloping uplands. About 24% of total area is well terraced, where paddy rice is grown. Of the rest, about 23% is under forest, 12.2% is cultivatable wastelands; 15.73% is uplands; 13% current fallows and about 5.13% and 6.19% are uncultivable wastelands and habitations respectively. About 34.5% of the total area is subjected to severe sheet and gully erosion. Signs of erosion are conspicuous in cultivated fields.

Geologically, the area is quite complex. About 86% of the area has a slope range of 1–6%. The soils are mainly of clay loam type. The area experiences a sub-humid, sub-tropical monsoon type of climate, characterised by hot summers (40°C) and mild winters (4°C). The total annual precipitation of 1206 mm is distributed mainly between June and September, with about 15 rainy days per month. The average 30-minute storm intensity is about 100 mm/hr. About 55% of the Nagwan catchment is under agriculture, 17.22% is under forest and about 21.77% is a wasteland. The main agricultural crops grown during the *kharif* season (June to September) are rice and maize and during *rabi* season (October to March) are wheat, gram and mustard.

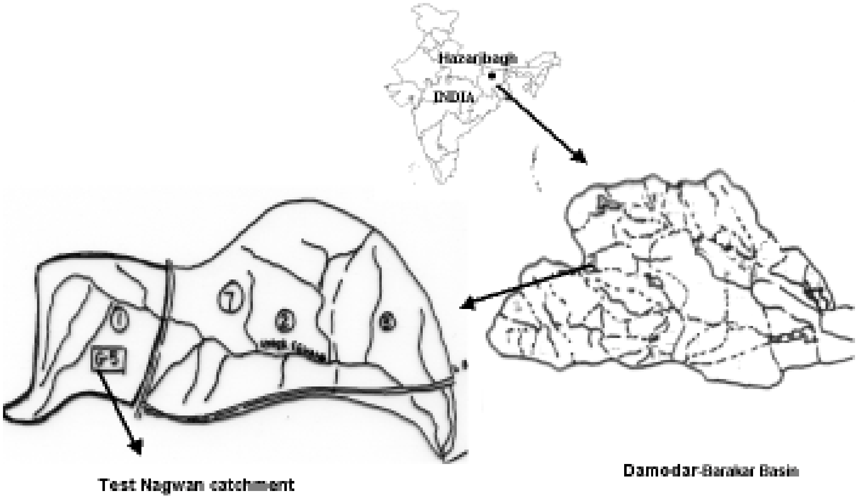

Fig. 1 Location map of test Nagwan watershed

Rice–mustard, paddy–wheat, and maize–mustard are the main crop rotations followed in the area but much of the catchment is single cropped with paddy rice as the major crop and maize as the second most common crop. Agriculture is mostly rainfed, (about 80% of the area). The remaining 20% receives irrigation mainly from wells. This, together with the prevalence of conventional cultivation practices, characterised by conventional tillage or no tillage, low fertiliser/manure consumption and local crop varieties, is mainly responsible for the low crop productivity in the area.

Proposed SDSS

Structure

The proposed SDSS comprised an Arc–View interface based Soil and Water Assessment Tool (SWAT), a catchment scale hydrological model developed by USDA-ARS (Diluzio *et al.*, 1997). The SWAT hydrological model component of the proposed SDSS operates on a daily time step and is developed to predict long-term impacts of land management practices on water, sediment and agricultural chemical yields in large complex catchments with diverse soils, land use and management conditions.

Implementation

Delineation of the experimental sub-catchment boundaries and the development of associated databases were the first fundamental steps performed by the proposed SDSS. The Nagwan and sub-catchment boundaries were delineated from a digital elevation model (DEM), generated from basic 10 m interval contour data (1: 25 000 scale) for the area (Kaur and Dutta, 2002). This led to the delineation of 15-sub catchments within the experimental area. This was followed by the determination of all the geomorphic parameters of the overland and channel areas using the raster-grid functions of Arc-View GIS. These were stored as attributes of derived vector themes. Next, the land use and soil maps and the related soil and land use data files were loaded and clipped to the DEM of the catchment, followed by re-classification and re-sampling at the DEM cell size. The digital soil and land use/land cover maps for the Nagwan catchment were generated from paper maps obtained from the Soil Conservation Department of the Damodar Valley Corporation, Hazaribagh, Jharkhand. To capture the heterogeneity in soil and land use of the experimental catchment, each sub-catchment within it was further divided into one or more Hydrologic Response Units (HRU), representing a unique combination of the land use and soil types. This resulted in a total of 44-HRUs for the whole area.

The weather variables necessary for driving the proposed SDSS were precipitation, air temperature, solar radiation, wind speed and relative humidity. If available, these can be input either directly into the proposed SDSS or can be simulated through the weather generator component of the model. The proposed model always simulates solar radiation, wind speed and relative humidity data. The input parameters required for this were obtained through a WXPARM program developed at Blackland research centre. Eleven-year daily weather data (from 1981 to 1992), obtained from Indian Meteorological Department (IMD), were used for this purpose.

The proposed SDSS requires the generation of catchment-specific soil, crop and management inputs for its implementation. Six soil files were prepared, specific to the six soil types distributed over the experimental catchment, (see Table 1). Basic soil properties such as sand, silt, clay, organic carbon percentages and soil hydrological groups were obtained from the Soil Conservation Department of DVC, Hazaribagh while bulk density, available water capacity, saturated hydraulic conductivity, moist soil albedo and a soil erodibility factor were derived from stand-alone software developed by the Grassland Soil and Water Research Laboratory of USDA-ARS. In contrast to the soil files that are required prior to any simulation, a crop file containing all the crop-input parameters already resides in the program file directory of the SWAT-ARC View interface. This file gets copied when a project is created through the interface. In the present study, the original crop file was altered for rice and maize by replacing the values for the maximum total biomass, maximum harvest index, minimum harvest index, maximum potential leaf area index, maximum crop height and maximum rooting depth parameters, with their actual values for Hazaribagh district obtained from D.V.C., Hazaribagh. The management inputs on planting, harvesting, irrigation, nutrient/pesticide application and tillage operations (Table 2) were obtained through the primary Participatory Rural Appraisal (PRA) exercises conducted in the test area. Since most of the experimental

Table 1 Soil class specific data for Nagwan watershed

Soil Properties	Soil Class					
	Silty Loam	*Loamy Sand*	*Sandy Loam*	*Loam*	*Clay Loam*	*SiltyClayLoam*
Hydrological Group	C	B	B	C	D	D
Sand (%)	51.30	80.40	62.95	50.77	34.35	39.74
Silt (%)	29.40	11.70	20.09	22.52	22.26	24.53
Clay (%)	19.30	7.90	16.96	26.71	43.39	35.73
Organic carbon (%)	0.56	0.47	0.29	0.26	0.22	0.31
Estimated bulk density (g/cc)	1.43	1.62	1.48	1.39	1.28	1.32
Estimated available water capacity (cc/cc)	0.12	0.09	0.10	0.11	0.12	0.12
Estimated saturated hydraulic conductivity (mm/hr)	8.40	40.87	10.33	3.90	1.71	2.28
Estimated moist soil albedo	0.26	0.29	0.35	0.37	0.38	0.35
Estimated soil erodibility (K)	0.33	0.29	0.34	0.26	0.19	0.26

Table 2 Land and water management practice scenarios incorporated in proposed SDSS

Crop Name	*Tillage*	*Irrigation*	*Planting/ Sowing*	*Harvesting*	*Fertilizer*
Maize	Depth: 25 mm With cultirow on14th June	NIL	15th June Biomass_target:: 16 kg/ha Harvest Index_target: 0.32	15th Sept.	FYM: 1.5 t/ha Urea:10 kg/ha (Basal)
Long Duration Rice	Depth: 50 mm With cultiweeder on 1st Sept.	1-Pre-sown on 4th Sept. of 120 mm	5th Sept. Initial LAI: 1.1 Initial Biomass: 800 kg/ha Biomass _target:: 12.5 kg/ha Harvest Index_target: 0.32	5th Jan DAP: 25 kg/ha	FYM: 1.5 t/ha Urea: 15 kg/ha (Basal)
Upland Rice	Depth: 50 mm on 22nd June	1-Pre-sowing of 120 mm	25th June Initial Biomass: 800 kg/ha Biomass _target: 12.5 kg/ha Harvest Index _target: 0.36	25th Sept.	FYM: 1.5 t/ha (Basal) DAP: 25 kg/ha
Good Canopy Forest	NIL	NIL	Initial LAI: 3.5 Initial Biomass: 5000 kg/ha	NIL	NIL
Poor Canopy Forest	NIL	NIL	Initial LAI: 2.5a Initial Biomass: 2500 kg/h	NIL	NIL

catchment was under either no or poor conservation practices, the present whole area was assumed to be under no conservation practice (i.e. with P factor value = 1). All these input files were generated sequentially through the interface and the SDSS was run for the calibration and the validation periods after setting the initial soil moisture storage and base-flow factor values at 1. Evapotranspiration was estimated using the Priestley-Taylor method.

Calibration and validation

The two hydrological years, 1984 and 1992, associated respectively with the highest and the lowest water and sediment yields in an 11-year period from 1981 to 1992, were selected for the proposed SDSS calibration. The input variables used for calibration were soil properties and curve number. The curve number (USDA Soil Conservation Service, 1972) was allowed to vary within the categories for good and fair hydrological conditions and the available water capacity was set within the range of its natural uncertainty for the study region. These calibrated parameters were then used for the test and validation on the input data for the remaining nine years (from 1981–1983; 1985–1989 and 1991). Correlation coefficient (R), Mean Relative Error (MRE), Root Mean Square Prediction Difference (RMSPD), (Green and Stephenson, 1986) and model efficiency coefficient (Nash and Sutcliffe, 1970) statistical measures were used for assessing the kharif season water and sediment yield predicting potential of the proposed SDSS for the calibration and the validation data sets (Tables 3 and 4).

Water and sediment yield estimations with SDSS

Table 3 (a and b) depicts the results on the goodness of fit tests between the observed and the SDSS-predicted total water and sediment yields from the experimental catchment for the calibration data set. It could be observed that the SDSS-calibrated available soil water capacity and curve number values yielded reasonably good correlation coefficient values of 0.76 and 0.54 and model efficiency coefficient values of 0.71 and –0.67 between the observed and the predicted total water and sediment yields respectively.

Validation of the proposed SDSS with the calibrated input parameters showed that, compared with the actual average total water and sediment yields (Tables 4a and b) of 390.69 mm yr^{-1} and 25.35 t ha^{-1} yr^{-1}, the proposed SDSS-predicted average total water yield of 383.37 mm yr^{-1} (with correlation coefficient of 0.83; model efficiency of 0.54; mean relative error of –4.28 % and root mean square prediction error of 71.8 mm yr^{-1}) and the average total sediment yield of 21.28 t ha^{-1} yr^{-1} (with correlation coefficient of 0.65; model efficiency of 0.70; mean relative error of –17.97 % and root mean square prediction error of 9.63 t ha^{-1} yr^{-1}) from the test watershed. Fig. 2 illustrates the observed *v.* predicted monthly water and sediment yields from the experimental catchment for the 9-year validation period. The above results thus clearly showed that even under Indian conditions, with coarser resolution of input information, the proposed SDSS could simulate the temporal dynamics of the total water and sediment yields reasonably well and quite close to those reported for regions in the US and Germany (Srinivasan *et al*., 1998; King and Arnold, 1998).

Catchment prioritisation with SDSS

As observed from the average annual runoff map (Fig.3a) of the Nagwan catchment, the proposed SDSS simulated moderate (300–400 mm) to high (> 400 mm) runoffs for the sub-catchments 7, 12, 11 and 1, 2, 3, 4, 6, 8, 15 respectively while the lowest runoffs (< 300 mm) were produced by nos.

Table 3(a) Goodness-of-fit tests for observed *v.* predicted Water yields during calibration period (1984 & 1992)

Calibration Year	*Month(s)*	*Water yield(s) mm* *Observed*	*Predicted*
84	6	210.00	266.93
	7	72.00	57.38
	8	187.00	115.45
	9	45.00	79.92
	10	26.00	33.17
92	6	51.00	87.26
	7	57.00	63.57
	8	96.00	87.43
	9	28.00	27.06
	10	26.00	17.53
Mean		**79.80**	**83.57**
STD		**66.50**	**71.38**
R^2		**0.76**	
Model Efficiency		**0.71**	

Table 3(b) Goodness-of-fit tests for observed *v.* predicted Sediment yields during calibration period (1984 & 1992)

Calibration Year	*Month(s)*	*Sediment yield(s) $t\ ha^{-1}$* *Observed*	*Predicted*
84	6	13.43	28.70
	7	9.56	3.41
	8	8.34	3.22
	9	3.96	2.07
	10	0.79	0.03
92	6	10.28	11.16
	7	4.80	3.74
	8	8.96	2.63
	9	0.00	0.40
	10	0.00	0.05
Mean		**6.01**	**5.54**
STD		**4.77**	**8.75**
R^2		**0.54**	
Model efficiency		**–0.67**	

Table 4(a) Goodness-of-fit tests for yearly observed *v.* predicted water yields during validation period (1981–83; 1985–89 & 1991)

Year	*Observed (mm)*	*Predicted (mm)*
81	267.00	215.91
82	309.00	222.98
83	290.00	272.19
85	472.10	393.57
86	599.00	649.16
87	495.00	621.33
88	315.60	260.09
89	417.50	380.71
91	351.00	434.38
Mean (mm)	**390.69**	**383.37**
STD (mm)	**112.33**	**162.52**
R^2	**0.83**	
Model efficiency	**0.54**	
RMSPD (mm)	**71.77**	
MRE (%)	**–4.28**	

Table 4(b) Goodness-of-fit tests for yearly-observed *v.* predicted sediment yields during validation period (1981–83, 1985–-89 & 1991)

Year	*Observed ($t\ ha^{-1}$)*	*Predicted ($t\ ha^{-1}$)*
81	19.09	6.72
82	19.40	9.02
83	25.93	14.48
85	34.32	19.92
86	51.96	56.20
87	22.47	33.08
88	13.76	11.05
89	18.24	25.14
91	23.00	15.89
Mean ($t\ ha^{-1}$)	**25.35**	**21.28**
STD ($t\ ha^{-1}$)	**11.52**	**15.48**
R^2	**0.65**	
Model efficiency	**0.70**	
RMSPD (t/ha)	**9.63**	
MRE (%)	**–17.97**	

5, 9, 10, 13 and 14. Similarly, the average annual soil loss map (Fig. 3b), simulated by the proposed SDSS, showed that moderate (10–40 $t\ ha^{-1}$) to high (> 40t ha^{-1}) soil losses were produced by nos. 1, 2, 3, 4, 8, 12, 13, 14 and 6, 11 and 15 respectively while the lowest (< 10 $t\ ha^{-1}a$) soil losses were produced by nos 5, 7, 9 and 10.

Water and soil losses from a catchment are a function of its topography (i.e. slope), physiography (i.e. land use, soil type, soil depth) and climatic and management conditions. Table 5 shows percentage areas under different management practices, slopes, land uses and soil textural classes in the experimental sub catchment. In general, this has very deep (>100 cm) soils and was either unmanaged or poorly managed. It could be further observed that sub-catchments 1, 2, 3, 4, 6, 8, 10, 11, 12, 13 and 14 were primarily (> 75% of area) in the 0-3% slope class while the sub-catchments 5, 7, 9 and 15 had within 75% in 0-3% slope class and about 25–47.6% area in the greater than 3% slope class; of these, sub-catchments 5 and 7 were the steepest. Comparing Table 5 with Figs. 3a and b, it can be seen that although sub-catchment 14, with a less steep slope (i.e. only 1.35% area in the >3% slope class) and smaller (i.e. 23%) forest cover than sub-catchment 13 (with 13.46% under > 3% slope class and 38% forest cover) had higher runoff (276 mm) than the latter sub-subcatchment (233 mm), yet its soil loss was less (10.46 $t\ ha^{-1}$) than that for the latter (14.16 $t\ ha^{-1}$). The relatively higher runoff values from sub-catchment 14 as compared to sub-catchment 13 could be attributed mostly

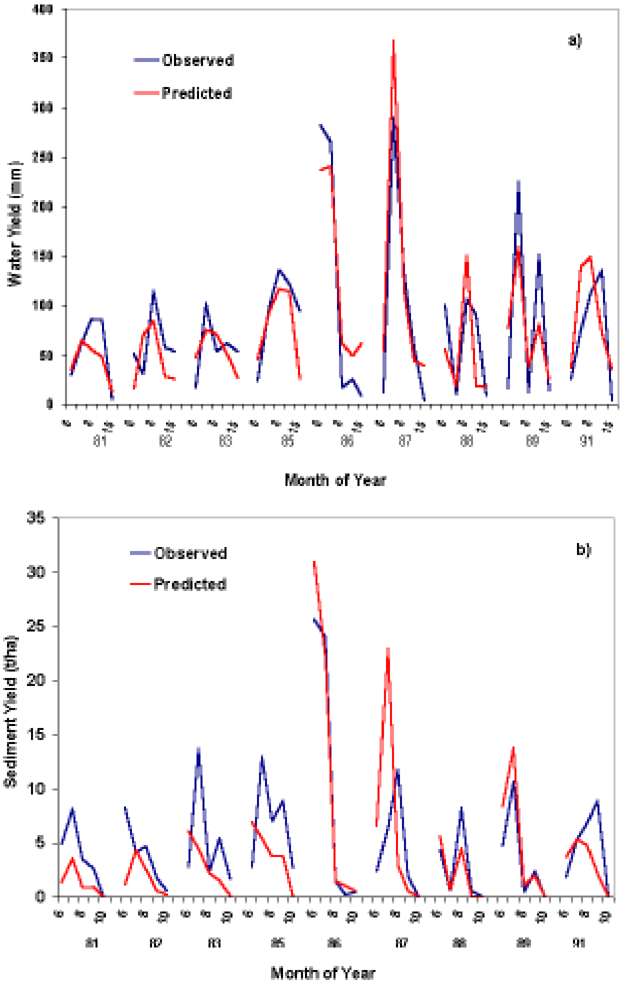

Fig. 2 Monthly observed *v.* predicted total water (top) and sediment yields (below)from the Nagwan catchment for a 9-year validation period.

to the presence of larger areas under long duration *kharif* paddy rice (9%) and light textured soils (70%), compared to just 5% area long duration *kharif* paddy rice and about 19% of light textured soils. The long duration *kharif* paddy rice, grown between September and January, generally leaves the land surface bare and exposed during the intense rainfall periods of July and August, thereby leading to more runoff (Singh *et al.*, 1981). However, this high runoff from sub-catchment 14 was not associated with concomitant higher soil losses due to the presence of a much larger area (68.75%) under non-erosive upland paddy rice and a much smaller area (0.12%) under erosive maize (Singh *et al.*, 1981) as compared to the sub-catchment 13 which had only 43.84% upland rice and 8.4% maize. Sub- catchments 10, 11 and 12 also, with almost the same forest cover (25.7–34.1%) and rather less steep slopes than sub- catchments 9, 13 and 14, contributed much higher runoffs and soil losses than the latter because of larger areas under long duration *kharif* paddy rice (21–46%) and maize (26.7–28.2%) compared with only 0–9% and 0–8.4% respectively. Further, the smaller runoff and soil loss from sub-catchment 12 as compared to sub-catchment 11 could be attributed to the predominant presence of light textured soils (71%) in the latter with only 54% in the former. Although sub-catchments 5 and 7 were under almost same slope class (i.e. 46.53 and 47.62% area in >3 % slope class and the remainder were in the 1-3% slope class, respectively), yet sub-catchment 7 contributed far higher runoff (395.5 mm) and soil loss (7.77 t ha^{-1}) than sub-catchment 5 (175.77 mm and 0.50 t ha^{-1}, respectively) because sub-catchment 5 had no long duration *kharif* rice and 14.01% erosive maize while sub-catchment 7 had about 28.02% and 47.62%, respectively. Sub-catchments 5, 7 and 9 come under the steep slope class (>3%) yet their runoff and soil loss values were substantially lower than sub-catchments 1, 2, 3, 4, 6, 8, 11 and 12, with just 1–3% slope, because of extensive forest cover (23–52% compared with 0–32.2%).

Amongst the higher runoff and soil loss contributing sub-catchments (15, 6 and 11), no. 11 had the lowest runoff

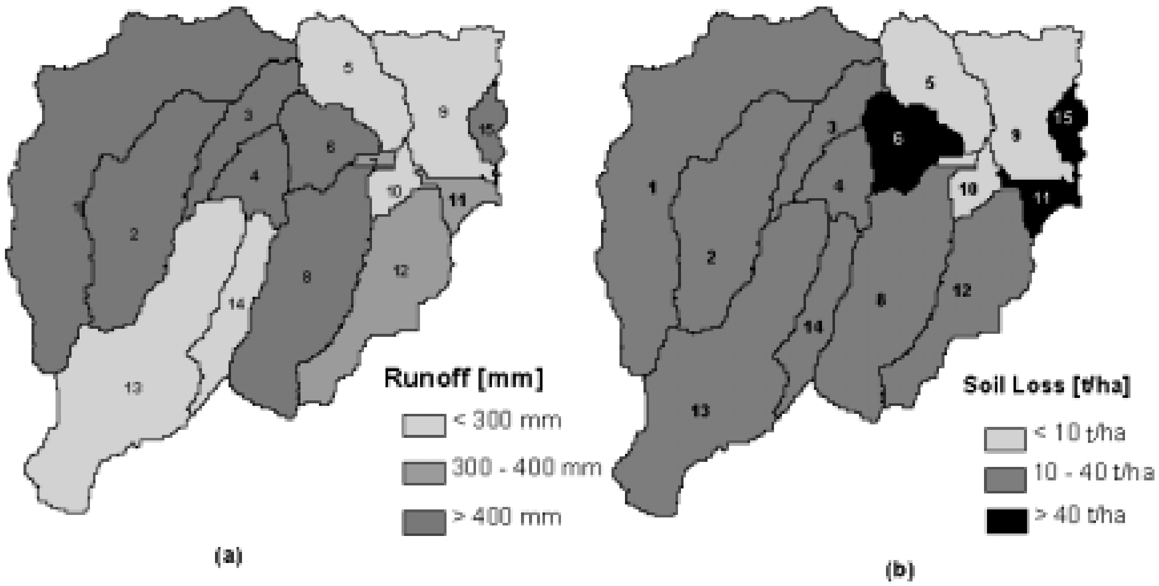

Fig. 3 SDSS generated average annual (a) run-off and (b) soil loss maps of the Nagwan catchment

Table 5 Percentage areas under different management practice, slope, land use and soil textural classes for the sub-catchments within the Nagwan catchment

Sub-watershed	Area (ha)	Per cent Area in Management Class		Per cent Area in Slope Class			Per cent Area in Land Use Class					Per cent Area in Soil Textural Class					
		None	Poor	1-3%	3-5%	>5%	Upland Rice	Long Duration Rice	Upland Maize	Good Canopy Forest	Poor Canopy Forest	Silty Clay Loam	Clay Loam	Silty Loam	Loam	Sandy Loam	Loamy Sand
1.00	2008.65	5.18	94.82	93.01	5.32	0.00	67.71	29.14	0.46	0.00	2.69	0.21	22.22	42.42	8.19	0.46	26.49
2.00	980.52	20.21	79.79	90.39	6.33	0.00	82.82	5.71	0.00	3.61	7.86	23.50	0.61	27.73	2.41	3.64	42.11
3.00	326.02	52.54	47.46	71.42	18.12	4.70	62.20	24.52	0.00	4.70	8.83	5.95	4.90	79.84	2.21	7.10	0.00
4.00	271.47	31.32	68.68	99.28	0.72	0.00	69.40	30.60	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
5.00	490.38	97.52	2.48	28.89	46.53	0.00	33.64	0.00	14.01	6.10	46.25	86.82	0.00	8.95	2.48	0.00	1.75
6.00	352.49	43.62	56.38	86.59	12.24	0.00	63.69	27.02	6.95	0.00	2.33	12.24	0.00	80.80	0.00	0.00	6.95
7.00	25.93	100.00	0.00	49.20	47.62	0.00	0.00	28.02	47.62	0.00	24.35	34.92	0.00	17.46	0.00	0.00	47.62
8.00	1090.57	62.73	37.27	91.05	5.38	0.00	45.70	40.97	3.81	0.00	9.52	12.04	0.00	59.71	13.16	15.09	0.00
9.00	675.51	25.17	74.83	62.08	36.31	0.00	35.88	40.12	0.00	0.37	23.63	0.79	0.00	97.22	1.99	0.00	0.00
10.00	128.73	89.78	10.22	97.76	0.00	0.00	0.00	58.56	7.32	0.32	33.80	51.27	0.00	10.22	0.00	38.51	0.00
11.00	126.66	53.96	46.04	89.21	6.72	0.00	0.00	46.04	28.24	1.30	24.43	0.00	0.00	31.83	14.00	54.17	0.00
12.00	744.69	79.47	20.53	71.34	8.28	0.00	20.10	21.00	26.61	8.74	23.56	3.58	0.00	12.35	12.85	71.22	0.00
13.00	1549.87	66.85	33.15	79.28	13.46	0.00	43.84	4.71	8.39	4.55	38.52	2.43	0.00	18.28	60.54	12.66	6.08
14.00	349.94	88.30	11.70	76.34	1.35	0.00	68.75	8.82	0.12	0.00	22.31	0.00	0.00	51.64	2.14	46.21	0.00
15.00	112.44	0.23	99.77	74.73	25.27	0.00	25.50	74.50	0.00	0.00	0.00	0.00	0.00	92.96	6.81	0.23	0.00

but the highest soil loss which could be attributed to the presence of the highest forest cover (25.7%) and the highest extent to maize crop cultivation (28.2%). Sub-catchment 15 had higher runoff but lower soil loss than no. 6 due to no forest cover, no maize cultivation and 74.5% of its area under long duration *kharif* rice. In contrast, sub-catchment 6 was associated with 2.32% forest cover, 6.9% maize and 27% long duration rice. Hence the proposed SDSS was observed to be mimicking even HRU and sub-catchment scale water and soil losses quite realistically, thereby suggesting its good application potential for priority area identification in the experimental catchment.

Conclusions

The present investigation demonstrates the potential of the proposed SDSS for assessing the impact of various on-going resource management practices on water and sediment yields from the Nagwan catchment. It has also shown the potential for identifying high water- and soil-loss producing areas and thus removes any subjectivity in locating such critical regions to enable effective focusing of central / state government funds.

References

Anon, 1996. Working group report, IX Plan for HADP, NGDP, Planning Commission, Government of India.

Dhruva Narayan, V.V. and Ram Babu. 1983. Estimation of soil erosion. Indian *J. Irrigation Drainage Engg*, **109**, 419–434.

Diluzio, M., Srinivasan, R., and Arnold, J.G. 1997. An Integrated User Interface for SWAT Using ArcView and Avenue. Proc. Annual Int. Meeting, ASAE, Minneapolis, Paper No 972235. 15 pp.

EI-swaify, S.A., Dangler, E.W., and Armstrong, C L. 1982. *Soil Erosion by Water in Tropics*. University of Hawaii, College of Agriculture, Research Extension Series 24, 173 pp.

Green, R.A. and Stephenson, D., 1986. Criteria for comparison of single event models. *Hydrological Sci. J.*, **31**, 395–411.

Kaur, Ravinder and Dutta, D. 2002. GIS-based digital delineation of watershed and its advantage over conventional manual method - A Case Study on watersheds in Hazaribagh and Bankura Districts of Jharkhand and West Bengal. *Ind. J. Soil Cons*., **30**, 1–-7.

King, K.W. and Arnold, J.G. 1998. A comparison of two excess-rainfall/runoff modeling procedures on large basin. Trans. ASAE, Paper No. 98-2228. 20pp.

Nash, J.E., and Sutcliffe, J.V. 1970. River forecasting through conceptual models, 1. A discussion of principles, J.Hydrol., **10**, 282-290.

Singh, G., Ram Babu and Chandra, S. 1981. *Soil loss prediction research in India.* Bulletin No. T-12/D-9, Central Soil and Water Conservation Research and Training Institute, Dehradun, India.

Srinivasan, R., Ramanarayanan, T.S., Arnold, J.G. and Bednartz, S.T. 1998. Large area hydrological modeling and assessment. Part II: Model application. *J. Amer. Water Resour. Assoc.*, **34**, 91–101.

Suraj Bhan, 1997. Strategy for watershed development and management. *J. Soil Water Conservation*, **41**, 21–-24.

USDA Soil Conservation Service. 1972. *National Engineering Handbook*, *Section 4, Hydrology*. U.S. Dept. of Agriculture, Washington,D.C.

Vaidyanathan, A., 1991. Integrated watershed development: Some major issues. Foundation day lecture, Society for promotion of waste lands development, New Delhi. Supp. 6, 1–19.