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Assessing the applicability of SWAT model to predict soil loss from watersheds in western Deccan, India

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Abstract

There is a large variation in climate, topography and soil all over the country, and hence there is uncertainty about the applicability of one single soil erosion model. So far, no soil loss model has been developed for the country. The study attempts to test the applicability of SWAT (Soil and Water Assessment Tool) to estimate sediment yield in a watershed in the Western Deccan, India. The study area is a part of the Tapi River Basin in Maharashtra state, which falls in the semi arid, the western part of the Deccan Trap Region. The banks of the river are deeply dissected by gullies and form badlands. Heavy land reclamation practices are going on these badlands for the purpose of agriculture, resulting in further degradation and soil loss in the area. SWAT (version ArcSWAT 2012_10_1.18), a physically based watershed scale hydrological model developed by the USDA-ARS was used for estimating sediment yield from the catchment. IRS Cartosat 1 stereo pair imageries and LISS IV multispectral imageries have been used to create DEM and landuse - landcover classification for the model. The soil map of the area was obtained from the National Bureau of Soil Survey and Landuse Planning and climate parameters were obtained from the Indian Meteorological Department. The average sediment yield predicted by the model is 3.9 kg/m2/yr. For the final verification of the results, the data is compared with a field study of a test catchment in the same watershed. Annual sediment yield was calculated using repeated topographic surveys at three years interval (2012 - 2015), which gave the value of 0.22 kg/m2/yr. This test catchment is a part of the sub watershed no 43 in the SWAT model. The same catchment was clipped and the SWAT model was simulated for the period from 2012 to 2015. The simulated result shows the annual sediment yield of 0.20 kg/m2/yr. Overall, the study demonstrates that the model can be successfully applied in the study area for Spatial Decision Support System (SDSS) to identify priority areas having high soil losses.

Keywords: *SWAT; IRS Cartosat; SDSS; Deccan trap; soil loss*

Introduction

It is estimated that about 169 million ha (51% of the total) are affected by major problems of soil degradation, out of a total reported geographical area of 329 million ha in India. About 127 million ha of land are subject to serious soil erosion and 40 million ha are degraded through gullying and ravination, shifting cultivation, water-logging, salinity, alkalinity, shifting of river courses, desertification, etc. About 4 million ha of land has already been classified as ‘ravinated’ (Narayana & Babu 1983). Soil loss tolerance limit in India ranges from 7.5 to 12.5 t/h but the estimated annual soil loss in the country is about 16.75 t/h on average, putting soil erosion on a high list of grave hazards in India. This is further heightened by the fact that the country is essentially agrarian with the agricultural sector still providing livelihood to a majority of the working population. Another significant implication of soil erosion is that it not only leads to the total removal of fertile topsoils, but also causes increased sedimentation in rivers and reservoirs, in turn generating devastating floods. It is, therefore, necessary to develop a Spatial Decision Support System (SDSS) to accurately estimate soil loss and sediment yield from watersheds to prioritize areas under high risk of erosion. Unlike other parts of the world, soil erosion studies and modeling are still in the stage of infancy in India. Data quality and availability also are major issues in such studies. So far, no soil loss model has been developed for the country. Few soil loss models have been applied in different regions of India in earlier studies. There is a large variation in climate, topography, landuse, and soil all over the country and hence there is uncertainty about the applicability of one single model even if they have been applied successfully in other parts of the country.

The study aims at testing the applicability of the SWAT (Soil and Water Assessment Tool) model as a Spatial Decision Support System (SDSS) to estimate sediment yield in an ungauged watershed in the Western Deccan, India. The whole Deccan Terrain in India is rocky landscape and soils are very thin and sediments are confined to only the narrow banks of the rivers. The study area is a part of the Tapi River Basin in Maharashtra state (Fig 1), (See page xxx) which falls in the semi arid, the western part of the Deccan Trap Region. The banks of the river are deeply dissected by gullies and form badlands in these areas. Heavy land reclamation practices are practiced for the agriculture, resulting in further degradation and soil loss in the area.

SWAT (Arnold et al 1993; Neitsch et al 2002) is a watershed loading/water quality model, developed by the United States Department of Agriculture - Agriculture Research Service (USDA-ARS). This is physically based, continuous time, spatially semi-distributed model, developed to simulate the impact of management decisions on water, sediment and agricultural chemical yields in river basins in relation to soil, landuse and management practices (Bouraoui et al 2005). The model has been widely applied in India under different application scenarios. The potential of a Spatial Decision Support System (SDSS) based on the SWAT model for estimating water and sediment yields in a large experimental catchment in Damodar-Baarakar Basin was assessed by Kaur et al (2003). Wagner et al (2011) utilized SWAT in a monsoon-driven mesoscale catchment of the Mula-Mutha upstream of Pune and evaluated the model's potential for water resources management under these conditions. Perrin et al (2012) used SWAT to assess the availability of groundwater in a semi-arid watershed of South India. Singh et al (2013) applied the model to the Tungabhadra catchment and Sahoo (2013) to Bandu River Basin in West Bengal. The SWAT model was evaluated for simulating sediment load for the Nagwa watershed in Jharkhand, by Singh et al (2014). Panhalkar (2014) derived the parameters required for runoff modeling using the SWAT model and geoinformatics technique to estimate the runoff of the Satluj Basin. In addition to these, many Indian workers have made use of SWAT in hydrological modeling of watersheds and catchments in different themes, such as land and water resources management, crop water productivity, formulating sustainable agriculture policies, and even flood hazard mitigation (eg, Gosain et al 2006; Jadhao & Tripathi 2009; George & James 2013; Swami & Kulkarni 2014; Manaswi & Thawait 2014; Shivhare et al 2014; Narsimlu et al 2015 and Malunjkar et al 2015, etc). Bennet et al (2013) reviewed the performance of various environmental models in their paper in 'Environmental Modelling & Software'.

SWAT is an integrated river basin model that is also suitable to estimate sediment yield/soil loss and can be used to target priority areas for soil conservation. Modern SDSS combines (interdisciplinary) development of methods and data processing tools for spatial decision support (SDSS). It partly also aims at stakeholder participation, in many cases developed for integrated river basin management (Volk et al 2007; 2009). There are many examples of studies of SWAT for sediment yield estimation in recent times, such as Ayana et al 2012; Briak et al 2016; Gull et al 2017; Debobroto et al 2017; Duru et al 2017; Badil et al 2017; Hallouz et al 2018; Ricci et al 2018; Yu et al 2018, etc. to name a few. Roti et al (2018) presented an outlook and reviewed runoff and Sediment Yield Estimation by SWAT Model. All these studies were applied to basin scale. The present study, in contrast, is an assessment of its validity when applied to smaller watersheds.

The study is an assessment of soil loss from an ungauged watershed from Western Deccan, India using the SWAT model. This model was selected for this study because of its ability to simulate land management processes in large watersheds. Borah & Bera (2004) have extensively reviewed the various non-point source pollution models and their applications and indicated that SWAT is suitable for long-term continuous simulations in agricultural watersheds. Since it is being applied for the first time in the Western Deccan Traps region, its applicability is also assessed by verifying it with data obtained from the field. The output of the paper could provide references for identifying target areas for soil conservation and protection in the watersheds of the Western Deccan Region, India.

Study Area

The study area forms a part of the Tapi River Basin, located in the Jalgaon district of the state of Maharashtra (Fig 1). The Tapi Basin consists of a wide variety of topographic features including residual hills, broad valleys, and trap dykes. The valley contains barren, rocky hills, dense forests, fertile alluvial plains, low rolling pediment surfaces, and intensely gullied badlands. The tributaries of the Tapi River emerging out of the surrounding highlands viz. Satpura and Ajanta Ranges have dissected the land surface greatly, leading to ravine development along both banks. The entire Tapi Basin, except for the small stretches of alluvium on either side of the major streams, is covered by the Deccan Trap. The thickness of the Deccan Trap ranges from a few hundred to thousands of meters. It is covered by alluvium in the valleys of major streams. The soil of the Tapi Basin is essentially a product of weathering of the

Deccan Trap basalt and the older alluvium. The soils which result from the weathering of the Deccan Trap are deep brown to a rich red or black. These black soils usually have high organic matter content and are typically suited to the cultivation of cotton. They are sticky when wet and crack on drying. Underlying these soils is a layer of yellowish clay of variable depth. The study area is located in the rain shadow region of the Western Ghats. Rainfall in the area is extremely seasonal, with the maximum concentration of rainfall occurring in the monsoon season from June to September. The average annual rainfall in the region varies between 630-750 mm approximately.

The Tapi alluvium has a thickness of 300 m. Part of the left bank of the Tapi River between the two left bank tributaries of Girna and Waghur Rivers shows remarkable ravine development and study focuses this area (Fig. 2). These badlands are under several phases of reclamation and are completely altered from the original topography in the last two decades. Due to increasing population pressure, every available land had been utilized for economic activities, mainly for agriculture everywhere in the country. Previously badlands were largely undisturbed due to its inhospitable topography but recently these too have come under pressure for farming. Farmers level the terrain and fill the gullies to practice agriculture but often gullies are reactivated after the heavy monsoon and accelerate the gully erosion and expand the network further. Reactivation of gullies by natural agents and farmers filling them up continues unabated as in a vicious circle (Fig 3). Fig 3c shows that the old gully network has been reactivated during the 2013 monsoon and in Fig 3d, it is seen that these gullies have been filled up and cultivated again. Fig 4a and b depict the pictures taken during the reactivation of the gully network in 2013. Fig 4c and d display the field after filling and cultivating in 2017. Such a scenario prevails all along the badlands that are found along the banks of Tapi River. The main crop grown in the area is jowar but on the leveled badlands various local vegetables and cash crops also are cultivated. The area is a classic example of the invasion of agriculture into hostile terrain. Heavy earthmoving machines are often used to level these badlands and truckloads of sediments are used to fill up these gullies (Fig 4e). The natural landscape is being disturbed in several ways, believed to have triggered soil erosion in the area. This region has been selected for the present study for this purpose.

The Model Structure

SWAT model divides the watershed into several sub-watersheds based on an automatic inbuilt procedure using a digital elevation model (DEM) data. Each sub-basin is divided into several Hydrologic Response Units (HRUs) which is a combination of land use and soil that are based on threshold percentage used to select the land use and soil (Arnold et al 1998). Since watersheds are subdivided into areas of unique soil, land use and slope range in the model, it reflects differences in all the hydrologic conditions for various crops, vegetation, and soils. Prediction of runoff for each HRU separately and routed to obtain total watershed runoff allows increased accuracy and a much better physical description of water balance. This becomes the most remarkable feature of the model. Crop growth, surface runoff,

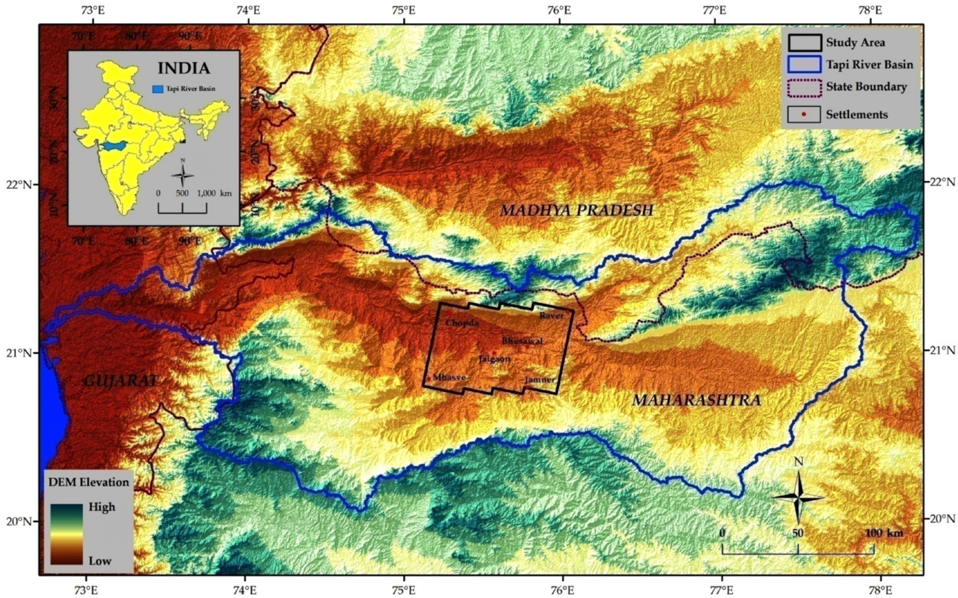

Fig. 1. Location map of the study area

Fig. 2. Field view of the study area

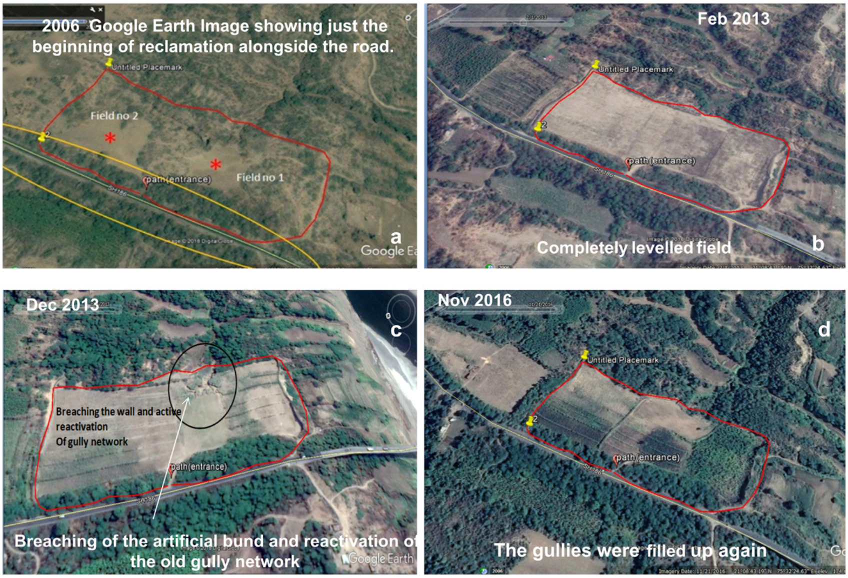

Fig. 3. Google Earth images of the Gully a- 2006, showing just the beginning of reclamation of badlands for agriculture by blocking a gullyhead, b- Feb 2013, expansion of the reclaimed area for agriculture, c- Dec-2013, displaying the reactivation of the old gully network, d- Nov-2016 showing refilling of the gullies and expansion of the fields.

Fig. 4. Photographs showing the reactivation of gullies in 2013 (a and b) and filling up of the gullies and cultivation of crops in 2017 (c,d,e).

sediment yield, nutrient cycles, soil water content, and management practices are simulated for each HRU individually and then aggregated for the sub-watershed by a weighted average.

Erosion and sediment yield is estimated for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975). The channel sediment routing equation uses a modification of Bagnold’s sediment transport equation (Bagnold 1977) that estimates the transport concentration capacity as a function of flow velocity. Sediment yield is expressed as the following in the SWAT Model as described by Wischmeier & Smith (1978);

Sed= 11.8 * (Qsurf * qpeak * Ahru) 0.56 * Kusle*Cusle*Pusle*Lusle*Fcfrg Eq 1

Where Qsurf is the surface runoff volume (mm/ha), qpeak is peak runoff rate (m3/s), Ahru is the area of the HRUs (ha), Kusle is the USLE soil erodibility factor, Cusle is the USLE cover and management factor, Pusle is the USLE support practice factor, Lusle is the USLE topographic factor and Fcfrg is the coarse fragment factor.

Model Calibration and Evaluation

Before the model simulation, the first step was to ensure satisfactory model performance by calibrating and validating the model. Model calibration is an essential step because it is an adjustment of parameters of the model within recommended ranges to optimize the agreement between observed data and model simulation results (Tolson & Shoemaker 2007). There has been very little research on soil loss from the study area and also there is no gauging station for sediment yield anywhere in the basin. However, streamflow of the river collected from a hydrological station located upstream for the year 2003 to 2011 was used as an input variable for calibration and validation. The data was split into two-time spans and the period between 2003 and 2006 was used for calibration while data from 2007–2011 was used for validation. SUFI-2 (Sequential Uncertainty Fitting version 2) program was used for calibration, and uncertainty analysis was performed in SWAT CUP. The parameters used for calibration and uncertainty analysis were CN2, ALPHA_BF, GW_DELAY, GWQMN, ESCO, SOL_AWC, GW_REVAP, RCHRG_DP, REVAPMN.

To evaluate model performance, Nash–Sutcliffe Efficiency (Ens) and the relative error (Bias) were determined for the entire period of calibration and validation period (Cai et al 2012). The Nash–Sutcliffe Efficiency and the relative error can be computed by the following formula:

$$\text{Bias} = \frac{\sum_{i=1}^{n} Pi - \sum_{i=1}^{n} Oi}{\sum_{i=1}^{n} Oi} \times 100\% \qquad \text{Eq 2}$$

$$\text{Ens} = 1 - \frac{\sum_{i=0}^{n} (Oi - Pi)^2}{\sum_{i=1}^{n} (Oi - \overline{Oi})^2} \qquad \text{Eq 3}$$

where, Oi and Pi indicate the observed and predicted values, the mean values of the observed data is Oi and the number of data is indicated by n. The model performance is better with the lower absolute value of Bias, whereas a higher value of Ens (which is the fraction of the variance in the observation explained by the model) indicates higher accuracy.

Table 1. Goodness-of-fit Tests for Observed v. Predicted Flow Discharge during Calibration (2003-2007)

Year	Months	Observed (cms)	Predicted (cms)
2003	6	200	466.5
	7	430	564.1
	8	256	321.9
	9	160	179.8
	10	70	85.61
2004	6	150	242.5
	7	200	350
	8	100	334.8
	9	50	250.1
	10	50	126.6
2005	6	150	357.1
	7	100	205.1
	8	225	291.2
	9	100	142.1
	10	50	68.05
2006	6	400	573.9
	7	430	523.7
	8	214	306.7
	9	110	157.9
	10	53	76.25
2007	6	298	427.3
	7	370	529.7
	8	274	394.1
	9	147	211
	10	68	99.06
	Mean	186.16	291.40
	STD	122.48	159.25
	R^2	0.82	
	Model Efficiency	0.64	

Nash-Sutcliffe efficiency coefficient (Ens) was found to be 0.82, R2 was 0.84, RMSE was 1.3 and PBIAS was 4.4, implying an overall good fit of the model. When the regression coefficient was determined separately for the calibration and validation period, slightly different values were obtained (Table 1 and 2). However, they still show a good fit between the observed and predicted flows. The result of the iteration between the observed and predicted is depicted in Fig 5.

Table 2. Goodness-of-fit Tests for Yearly Observed V. Predicted Flow Discharge during Validation Period (2008-2011)

Year	Observed (cms)	Predicted (cms)
2008	154	217
2009	368	360
2010	329	310
2011	314	288
Mean	291.20	293.52
STD	94.10	59.15
R^2	0.79	
Model Efficiency	0.61	

SWAT Simulation and sediment yield estimation

After the sensitivity analysis, the final setup was to put in the files to run the model. The SWAT model version ArcSWAT 2012_10_1.18, developed by Stone Environmental Inc. in collaboration with Texas A & M Spatial Science Laboratory and Blackland Research and Extension Centre (Di Luzio et al 2004) was used to develop the SWAT input files.

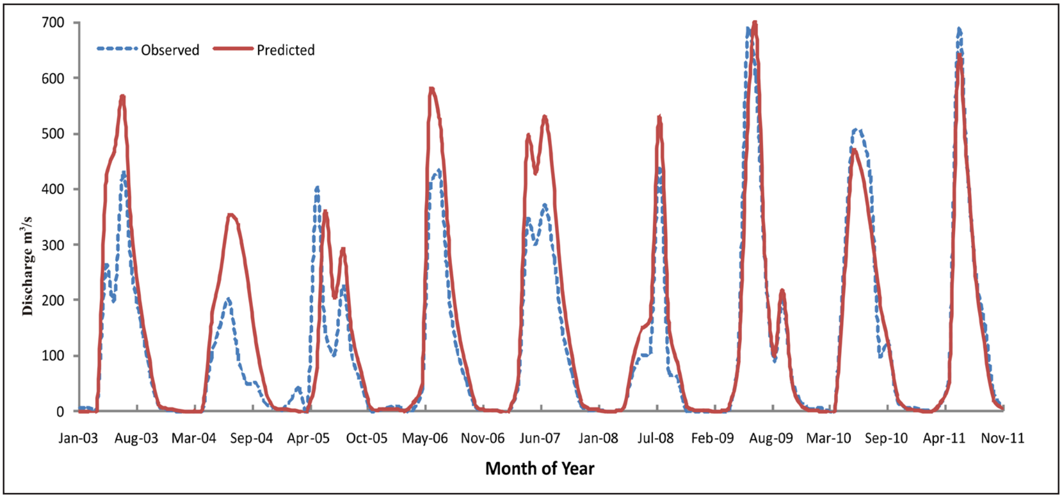

Fig. 5. Monthly observed v. predicted stream discharge after iteration

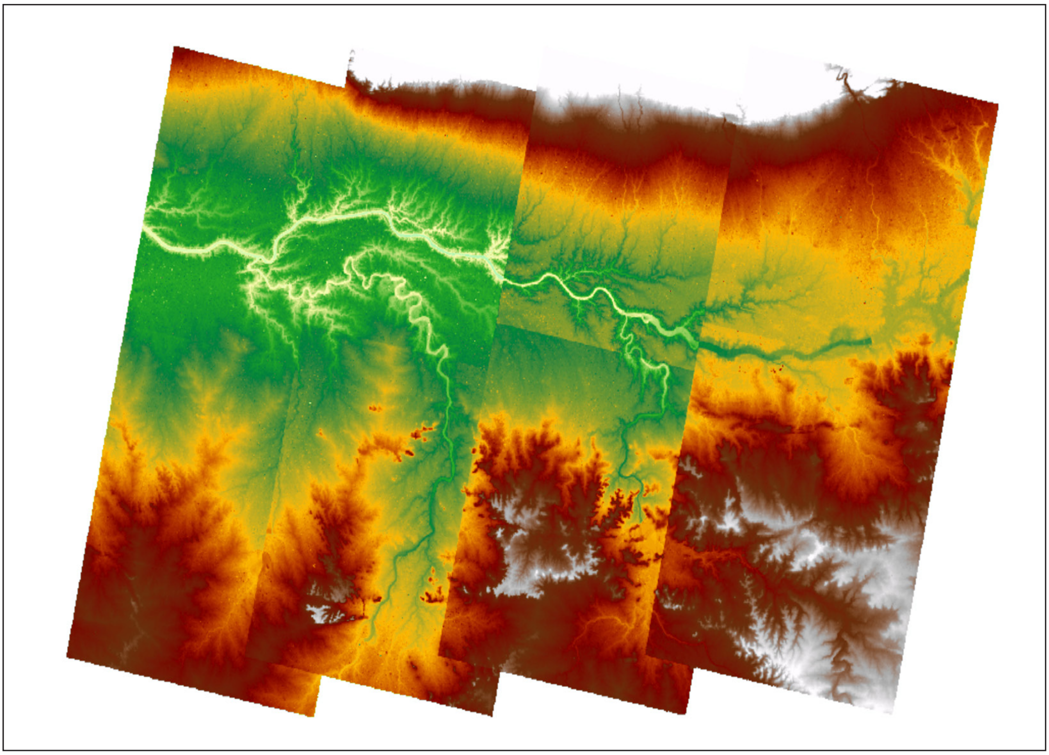

Fig. 6. Cartosat DEM with 10 m resolution

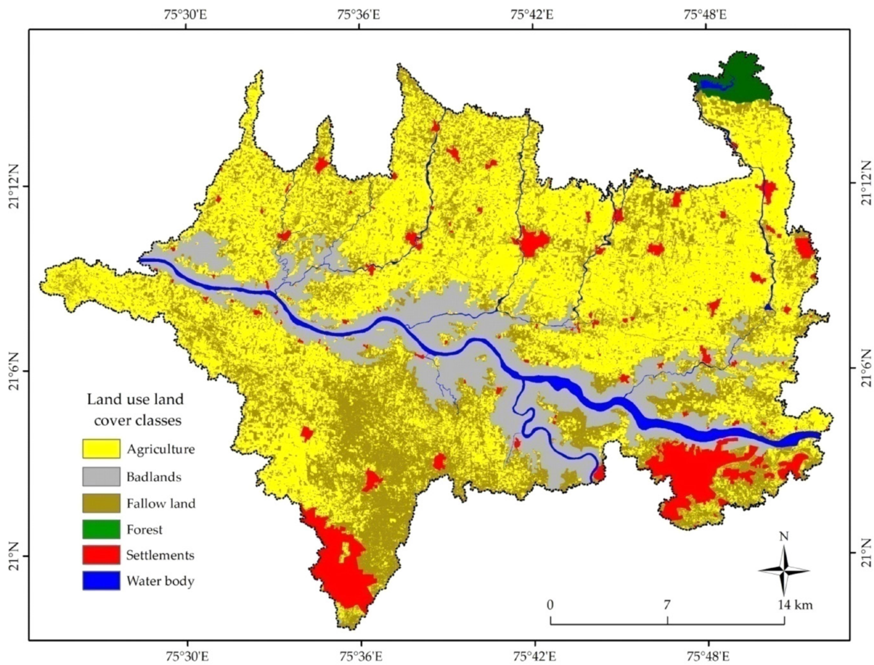

Fig. 7. Landuse/ Landcover map

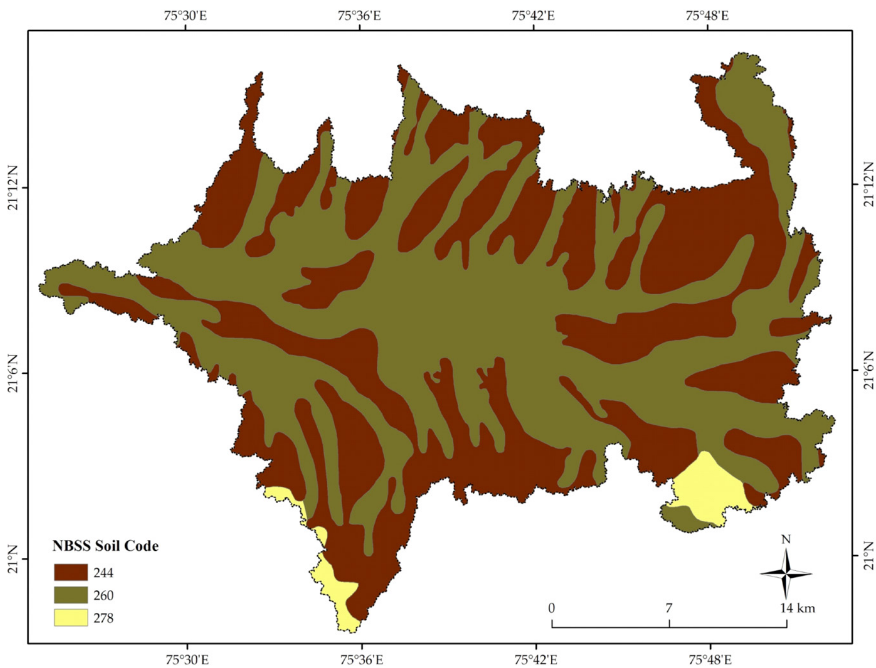

Fig. 8. Soil map

Table 3. Landuse Landcover Classes for the SWAT Model

Land use Class	Area (Km^2)	Area (%)	SWAT Code
Agriculture	379.64	47.32	AGRL
Badlands	118.91	14.82	BALD
Fallow land	226.33	28.21	AGRR
Forest	8.00	1.00	FRSD
Settlements	45.18	5.63	URBN
Water body	24.22	3.02	WATR

The model requires climatic data input such as daily precipitation, solar radiation, temperature, relative humidity, and wind speed. These parameters were obtained from the (IMD) Indian Meteorological Department of Pune, India. IRS Cartosat 1 (2.5 m resolution) stereo images were obtained for 8 scenes and a digital elevation model (DEM) was developed from these images using LPS 9.2. A DEM with 10 m resolution (Fig 6) was created which has been used as an input parameter for the model. A land use/cover classification was conducted from two scenes of IRS (Indian Remote Sensing) P6 LISS-4 (5.8 m resolution) images using ERDAS IMAGINE 9.2. Information related to different land use practices and types of crops grown in the fields has been obtained during a detailed fieldwork conducted before the classification exercise. Several training samples were obtained for each land use class.

Table 4. Soil Code, Description and SWAT Code used in the Model

Soil Code	Area (Km^2)	Area (%)	Description	SWAT Code
260	417.75	52.07	Very deep, Moderately well-drained, fine, calcareous soil on very gently sloping plains and valley with moderate erosion; and slight salinity; associated with slightly deep, well- drained, fine soil with moderate erosion.	AA-SO-IL
244	364.45	45.43	Slightly deep, moderately well drained, fine soil on very gently sloping plains and valleys with moderate erosion and moderate salinity, associated with moderately deep, well-drained, clayey, calcareous soil with moderate erosion.	BB-SO-IL
278	20.07	2.50	Very shallow, excessively drained, clayey soils on moderately steeply sloping undulating to rolling lands with mesas and buttes with severe erosion and strong stoniness; associate with very shallow, excessively drained, loamy soils with severe erosion and strong stoniness	CC-SO-IL

Table 5. Swat Soil Input Data and Description

Soil Parameters	**Soil Code 260**	**Soil Code 244**	**Soil Code 278**	**Description**
SNAM	AA-SO-IL	BB-SO-IL	CC-SO-IL	Soil Name
NLAYERS	1	1	1	Soil Layers
HYDGRP	B	B	B	Soil Hydrological group
SOL_ZMX (mm)	1823	1654	1587	Maximum rooting depth of soil profile (mm)
ANION_EXCL (fraction)	0.5	0.5	0.5	Fraction of porosity (void space) from which anions are excluded
SOL _CRK (m^3/m^3)	0.5	0.5	0.5	Potential of Maximum crack volume of the soil profile expressed as a fraction of the total soil volume.
TEXTURE	CH	CH	ML	Soil Texture
SOL_Z (mm)	375	276	253	Depth from soil surface to bottom of layer (mm)
SOL_BD (g/cm^3)	1.38	1.23	1.30	Moist bulk density (Mg/m3 or g/cm3)
SOL_AWC (mm/mm)	0.32	0.25	0.15	Available water capacity of the soil layer (mm/H2O/mm soil)
SOL_CBN (%wt)	0.19	0.13	0.35	Organic carbon content (%soil weight)
SOL_K (mm/ hr)	650	430	654	Saturated hydraulic conductivity (mm/hr)
Clay (%wt)	8	6	5	Clay content (% soil weight)
Silt (%wt)	65	60	59	Silt content (% soil weight)
Sand (%wt)	26	33	35	Sand content (% soil weight)
Rock (%wt)	1	1	1	Rock fragment content (% total weight)
SOL_ALB (fraction)	0.001	0.001	0.002	Moist soil albedo
USLE_ K	0.14	0.13	0.17	USLE soil erodibility factor
SOL_EC (ds/m)	0	0	0	Electrical conductivity (ds/m)

Land use map of the region has been prepared by employing supervised classification using a maximum likelihood algorithm and parallelepiped nonparametric rule method. Accuracy assessment was performed from a reference template margining the data with 200 randomly selected samples on the imagery, from which overall accuracy and Kappa statistics were derived with 96% accuracy. This is used as an input for the C factor (crop) and P (management practice) factor in the model. Fig. 7 demonstrates the areas under different land use classes and Table 3 displays the area of each landuse class and the SWAT code used in the model.

Soil map of the study area was obtained from the National Bureau of Soil Survey and Land Use Planning, Nagpur (NBSS and LUP) India. The area under investigation falls under three different types of soil (Fig 8). Table 4 indicates the description, as well as the soil and swat code used in the model and the final input format of the soil parameter, is displayed in Table 5.

The number of HRUs generated by the model is controlled by a threshold value given for each sub-basin. A threshold value was calibrated and adjusted appropriately to account for various land use types covering a significant area in the watershed while defining the HRUs. Taking into consideration the land use, physiography and soil types of the area, a threshold of 10% was used in the iteration for both land use and soil. This means that any land use and soil type that occupied less than 10% of the land in the sub-basin have been excluded in creating the HRU.

The model generated 67 sub-watersheds and 218 HRUs. Sediment yield of each sub-watershed and the whole catchment after simulation was 3.9 kg/m^2 and displayed in Table 6. Fig 9 demonstrates a soil loss map of the 67 sub-basins. The region has been further prioritized under four soil loss categories ranging from safe to severe erosion risk zone and depicted in Fig. 10. This prioritization has been done based on the soil loss tolerance limit of Deccan Plateau as suggested by (Mandal & Sharda 2011).

Model verification

The goodness of fit test between the observed and predicted stream flows depicted in Table 1 and 2 indicate the reliability of the model to be used as Spatial Decision Support System to identify target areas to focus in the basin under review. However, the calibration and validation were performed by using the streamflow but sediment yield. Hence, to further verify the result of the simulation, the simulated result has been compared with a field generated result conducted by the author of a test catchment in the same watershed. The area of the selected test catchment is 25527 m^2 which is a part of the subwatershed no 43 in the model. A topographical survey was conducted using dGPS in October 2012. Fig 11a indicates the location of the test catchment on the Carto DEM and Fig 11b is the Google Earth image showing the location of the test catchment. In all, 751 points were measured within the test catchment (Fig 11c) and a DEM was generated from the data with 25 cm resolution. The same catchment was resurveyed after a gap of three years in the same manner in October 2015. Both the

DEMs were used to calculate volume loss and to determine sediment loss from the catchment. Fig 12a indicates DEM of 2012 and Fig 12b shows the DEM of 2015. Using Arc GIS, the net gain and net loss of the catchment after 3 years has been calculated. The result indicates that the annual soil loss from this catchment is 0.22 kg/m^2. This test catchment falls within sub-watershed no 43 in the model (Fig 11d). This was clipped from the whole watershed and the SWAT model was simulated for the period 2012 to 2015, which is the monitoring period in the field. The new simulation of the test catchment generated 25 sub-watersheds and 39 HRUs. The simulated result shows the annual sediment yield of 0.20 kg/m^2. Table 7 demonstrates the final soil loss from the catchment using both the techniques.

Table 6. Final Output of Sediment Yield for Each Sub-Watershed

Basin No.	**Sediment Yield (kg/m^2)**	**Basin No.**	**Sediment Yield (kg/m^2)**	**Basin No.**	**Sediment Yield (kg/m^2)**	**Basin No.**	**Sediment Yield (kg/m^2)**
1	3.5	18	5.2	35	2.7	52	5.1
2	3.3	19	4.2	36	3.2	53	5.6
3	4.9	20	3.9	37	2.9	54	2.8
4	2.4	21	5.6	38	4.2	55	6.2
5	4.4	22	5.9	39	3.9	56	1.8
6	3.8	23	5.3	40	2.5	57	1.7
7	3.3	24	1.8	41	3.5	58	7.0
8	4.2	25	4.2	42	2.6	59	3.4
9	3.1	26	5.3	43	2.5	60	3.6
10	4.7	27	4.6	44	5.0	61	6.1
11	3.8	28	2.5	45	2.6	62	5.6
12	2.1	29	4.4	46	3.6	63	3.1
13	2.9	30	3.7	47	5.7	64	4.9
14	4.9	31	4.8	48	4.1	65	3.9
15	3.9	32	3.6	49	3.9	66	3.7
16	4.1	33	6.0	50	1.5	67	2.8
17	3.5	34	3.1	51	4.5		
	Average Sediment Yield 3.9 kg/m^2						

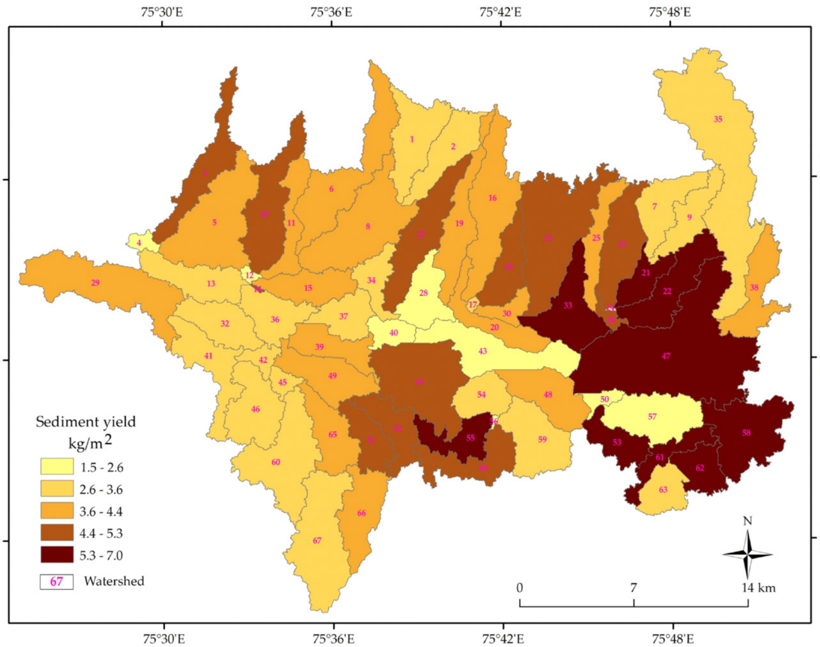

Fig. 9. Sediment yield of each sub watershed

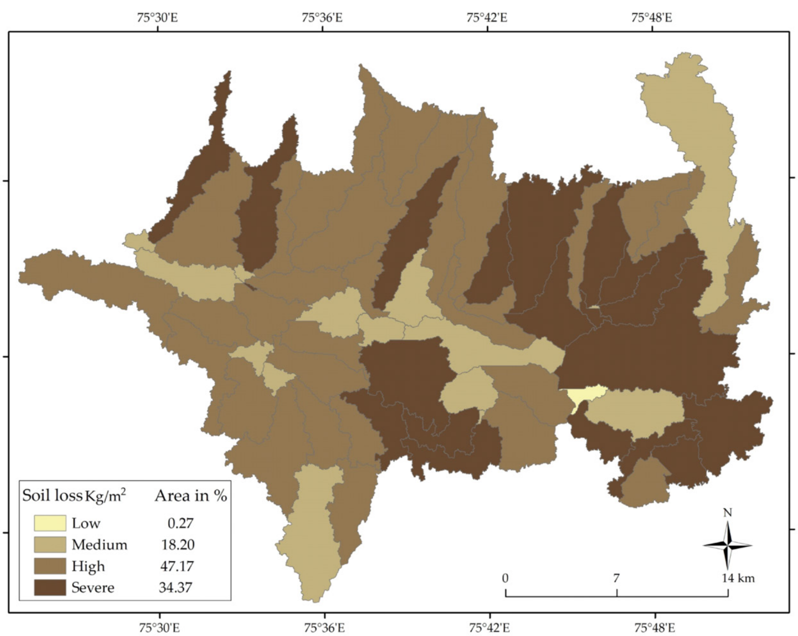

Fig. 10. Watershed prioritization based on the sediment yield

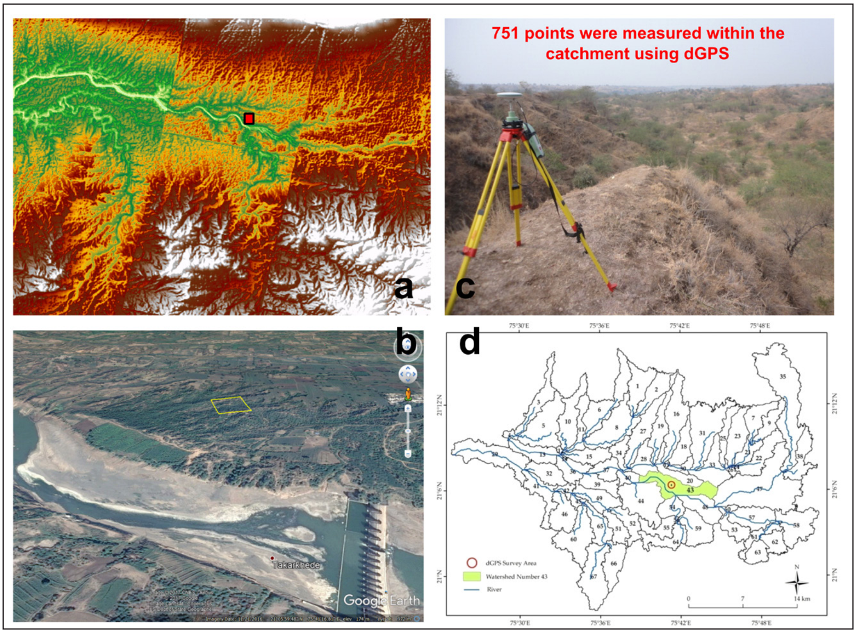

Fig. 11. a) location of the test catchment on the Carto DEM, b) Google earth image showing the location of the test catchment, c) 751 points were measured within the test catchment using dGPS to create DEM, d) location of the test catchment within sub watershed no 43 in the model.

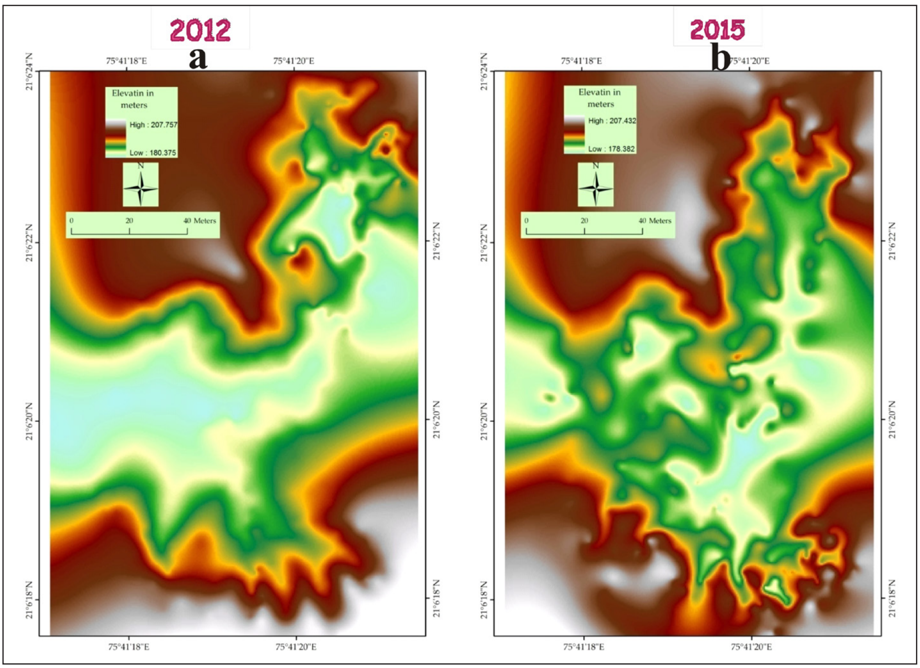

Fig. 12. DEM created from dGPS survey with 25 cm resolution-2012 and 2015

Table 7. Final Soil Loss from the Test Catchment Using Field Survey and Model Simulation

Parameters	dGPS Surveyed DEM- 2012	dGPS Surveyed DEM- 2015
Total Volume	22956.46 m^3	22601.30 m^3
Area	25527 m^2	25527 m^2
Sum	1721416.63 m	1684132.90 m
Mean	195.06 m	190.83 m
S.D.	5.73	5.39
Minimum Elevation	180.375 m	178.382
Maximum Elevation	207.757 m	207.432
Average annual soil loss from the catchment	0.22 kg/ m^2/ yr	
Average annual soil loss from the catchment		
Field data	0.22 kg/ m^2/ yr	
Simulated by SWAT	0.20 kg/ m^2/ yr	

Discussion

Overall goodness of fit between the observed and predicted streamflow indicates that the model can be used effectively to prioritize target areas (Fig 8). The predicted values tend to overestimate a few times but the overall fit is within the desirable range. The reliability of the simulated results has been doubly verified by comparing the test watershed with the field generated result. The result of the model shows the average soil loss from the whole watershed to be 3.9 kg/m^2. If this value is correct, it is assumed that any sub-watershed or HRU within the whole one should yield a similar result with the field generated soil loss result of the same area. The test watershed after repeated topographic survey yielded soil loss of 0.22 kg/m^2/yr. SWAT model simulation for the same test watershed shows a very close value of 0.20 kg/m^2/yr. Both the verification methods gave satisfactory results that the SWAT model has the potential to be used as the Spatial Decision Support System (SDSS) to estimate sediment yield under current resource management systems in the area.

In India, a default value of 11.2 tons/ha/yr (1.12 kg/m^2/yr) (Mandal et al 2006) is used as SLTL (Soil loss tolerance limit). But for Peninsular Plateau, SLTL ranges between 2.5-12.5 tons/ha/yr (0.25 - 1.25 kg/m^2/yr) (Mandal & Sharda 2011). Based on this criterion, the soil loss from the entire watershed under review was categorized as a low, medium, high and severe as depicted in Fig 10. If we consider the lowest threshold limit of 0.25 kg/m^2/yr, the entire study area has gone above this threshold limit. More than 80% of the area is showing high to severe soil loss annually. Areas under “severe” category occupy 35% of the total area under review and they by and large correspond to badlands close to human settlement. This indicates that the badlands are getting affected by human activities and require immediate attention. A re-evaluation is necessary about the current land use pattern followed by the farmers.

Conclusion

The study demonstrates the potential of the SWAT model for examining the impact of ongoing land use practices on the sediment yield in the ravinated areas of the Tapi River Basin. The main limitation of modeling river basins and watersheds in the study area is the absence of gauging stations within the vicinity but the results were satisfactory. The study could estimate the soil loss from the watershed for the first time and identified the areas that require immediate remedial measures and thus indicating the suitability of the model for such types of basins as a decision support system. The finding can provide references in the future for identifying target areas for soil conservation and protection in the watersheds of the Western Deccan Region, India.

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