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Reductions in Sediment Yield Through Different Management Practices in the Mohgaon Watershed

Engineering

KEYWORDS : SWAT; Soil Erosion; Sediment Yield; modelling; Best Management Practices (BMPs).

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ABSTRACT

This paper evaluated the impacts of best management practices (BMPs) on sediment yield reduction in Mohgaon Watershed. Soil and Water Assessment Tool model was used in evaluating the impacts of implementing BMPs. The SWAT model is calibrated and validated following a sensitivity analysis combining Latin Hypercube sampling and One-factor-At-a-Time simulation. The calibrated model was then applied in the Mohgaon Watershed to simulate BMPs including Conservation tillage, Parallel Terraces and Channel Protection. The three scenarios were simulated independently as well as a combination scenario was also simulated. Results showed that considerable reductions in sediment concentrations occurred when the BMPs were simulated. The results will help in deciding suitable conservation practices to be implemented over the watershed to reduce sedimentation yield.

Introduction

Soil and water are critical resources in the watershed that should be managed properly for continued supply of ecosystem services, such as good water quality and quantity, to support a wide and diverse range of utilization. However, many of the watersheds in developing countries are in a state of degradation as a result of overexploitation and mismanagement of land resources. Excessive soil erosion is one of the manifestations of land degradation. Many issues, such as sedimentation, ecological degradation, and pollution, are also associated with soil erosion, and may affect aquatic and coastal ecosystems as well. It has impacts for long terms as it causes loss of the fertile topsoil leading to reduced the productivity of land and hence less crop yield.

In Madhya Pradesh, soils are under risk due to long dry periods followed by heavy rainfall, falling on slopes with fragile soils and low vegetation cover. Soil erosion leading to sedimentation is a serious problem here. Nearly all the area exposed other than the forest cover is affected by erosion by water.

Quantification of soil loss is one of the greatest challenges in natural resources and environmental planning (Arekhi et al.2010). BMP effectiveness has been studied mainly through field experiments, but computer modelling has been increasingly used as a valuable alternative.

Erosion models have increasingly been attributed to the fast growth of both geographic Information Systems (GISs) and computer technology. A number of models have been applied to investigate erosion problems in various regions around the world. While field experiments are costly and difficult to repeat, computer simulations can be run to test various implementation scenarios. In addition, watershed models simulate BMP effectiveness at larger scales, which cannot be feasibly achieved by field experiments. Modelling impacts of BMPs at watershed scale is quite tough a task requiring simulation of not only the watershed conditions and agriculture production system but also sediment transport and fate. The model has proven to be an effective tool for evaluating BMP implementation, alternate land use, and other factors contributing to lower pollutant levels (Arabi et al., 2008; Gassman et al., 2007; Bracmort et al., 2006; Stewart et al., 2006; Chaplot et al., 2004;Whitall et al., 2004; Santhi et al., 2001). This study extends to include an array of BMPs and combination scenarios. Objectives of the study is to predict sediment yield at the catchment outlet and simulate the BMPs over the watershed to reduce soil erosion and hence sedimentation.

The Watershed Simulation Model

SWAT, a model developed at the USDA's Black lands Research Centre, is a continuous-time, spatially distributed simulator developed to assist water resource managers in predicting impacts of land management practices on water, sediment and agricultural chemical yields. The model is well suited for large complex watersheds with varying soils, land use and management conditions over long periods of time (Nietsch, et al., 2001; Arnold et al., 1998; ASCE, 1999). SWAT makes use of watershed information such as weather, soil, topography, vegetation, and land management practices to simulate watershed processes such as surface and subsurface flow; erosion and sedimentation of overland as well as channel flows; crop growth for user specified agricultural management practices, and nutrient cycling for various species of nitrogen and phosphorus, among others. The model commonly operates on daily time scale. Spatially, the model subdivides a watershed in to sub-watersheds, or sub-basins, based on topographic information of the watershed. The sub-watersheds could be further classified into spatial modelling units known as hydrologic response units (HRUs) depending on heterogeneity of the land uses and soil types within the sub-basins. At the scale of an HRU, watershed variables such as soil types and properties, land use and related management features, weather, and topographic parameters would be considered homogeneous. As a distributed model, a major concern that may arise regarding the practicality of SWAT may be its data requirements. For Mohgaon, fortunately the data required (e.g., soil, land use, topography, and weather) were available from government agencies. For watersheds that lack weather data, the model has a stochastic weather simulator that generates synthetic data based on monthly weather statistics derived from long-term records available from a station geographically located near the watershed. In addition, the model operates on an ArcGIS platform, which greatly assists in the generation of model input parameters. All these comprehensive features make SWAT an ideal choice for use in integrative watershed management systems.

Materials and Methods

Watershed Description and Model Inputs

DATA	SOURCE
Topography/DEM	**http://www.ersdac.or.jp/GDEM/E/1.html**

Land Use/ Land Cover	USGS
Soil	FAO GeoNetworkportal
Temperature, Wind, precipitation, speed, solar radiation, and relative humidity	http://globalweather.swat.tamu.edu
Runoff and Sediment Data	CWC Bhopal

Table 1: Model input information for Mohgaon Watershed

The Mohgaon watershed in Narmada Valley is a rift valley situated between the Narmada North fault and the Narmada South fault. These in turn are part of the longer Narmada-Son lineament, which is an active fault zone, and a distinguishing tectonic feature of central India. Extensive basaltic flows known as Deccan Traps have come out of these faults and underlie most of the basin. Apart from this there are some granite, and the Gondwana shale and sedimentary rocks in parts of the hills and plains and alluvial deposits near the river courses. A layered block called a graben has dropped down in the middle relative to the blocks on either side of the faults due to ancient spreading of the earth's crust. The Two faults parallel the river's course, and mark the boundary between the Narmada block and the Vindhya and Satpura blocks that have risen relative to the Narmada Graben. In between the two blocks there is an alluvial plains area of about 500 kms length and 35–45 kms width stretching from Jabalpur district to Barwani district which overlies the Deccan traps and Gondwanas on both banks of the river. The watershed area is a part of

Burhner River, sub-basin of Narmada river basin of Madhya Pradesh in India. The study area lies between longitude - E and latitude -N covering the catchment area around 3974 km^2 up to Mohgaon gauge station which is at the outlet of the catchment. The gauge station, 010215004 GDSWQ site of Central Water Commission situated in Mohgaon at the elevation of 454 m. The Burhner river rises in the Maikala range situated south-east of Gwara village in district Mandla of Madhya Pradesh at the elevation of about 900 m at the north latitude to east longitude. The Burhner River has 4 main tributaries Hallon, Kukra, Haphin and Kanai. It flows in westerly direction upto a length of 177 km to join the Narmada River near Monot. Climate of the basin can be classified as sub-tropical and sub humid with average annual rainfall of 1,547 mm. The evapotranspiration varies from 4 mm day in winter to 10 mm/day in summer. The catchment area comprises both flat and undulating lands covered with forest and cultivated lands. Soils are mainly red and yellow silty loam and silty clay loam. Forest and agricultural lands share nearly 58 and 35% of the catchment area, respectively.

Model Calibration and Validation

Variable	Model component	Description	Range
CN2	FLOW	Curve number	76-87
ALPHA_BF	FLOW	Base flow alfa factor	0-1
GW_DELAY	FLOW	Groundwater delay time	30-450
GWQMN	FLOW	Groundwater 'evaporation' coefficient	0-2
GW_REVAP	FLOW	Threshold depth of water in shallow aquifer required for return flow	0-0.2
ESCO	FLOW	Soil evaporation compensation factor	0.8-1
ALPHA_BNK	FLOW	Base flow alpha factor for bank storage	0-1
SOL_K.sol	FLOW	Soil Hydraulic Conductivity	-0.8-0.5
CH_N2	Sediment	Manning's n value for the main channel coefficient	0.001-0.1
SPCON	Sediment	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing coefficient	0.001-0.008
PRF	Sediment	Peak rate adjustment factor for sediment routing in the main Channel coefficient	0-1
SPEXP	Sediment	Exponent parameter for calculating sediment re-entrained in channel sediment routing coefficient	1-2
CH_EROD	Sediment	Channel erodibility factor coefficient	0.9-1
CH_COV	Sediment	Channel cover factor	0-1
USLE_C	Sediment	Minimum value of USLE C factor for land cover/plant	0.001-0.005
USLE_P	Sediment	USLE equation support practice factor	0.9-1

Table 2: Model parameters, description and range used for calibration

The model was calibrated on mean monthly basis for monthly stream flow and sediment yield using the automatic calibration tool in SWAT_CUP SUFI2 for a period of 5 years (2002-2006) using the stream flow and sediment yield records from CWC Bhopal. Calibration was done for the Mohgaon gauging station using SWAT model default values and then adjusting sensitive parameters based on available data and knowledge about the study area. The final set of parameters obtained from the calibration process were then entered into the SWAT model and the results were evaluated (2000-2001 were used as a "warm-up" years, values from that year were not evaluated). The model was validated for the same study area for a period from 2007 through 2010. The type, a brief description, and range of the variable used for calibration along with the component(s) that the variable influences are listed in Table 2. Nash-Sutcliffe modelling efficiency (NSE) (Nash and Sutcliffe 1970) and mean, standard deviation, coefficient of determination (R2*)*, and were used to evaluate and quantify model performance during calibration and validation. A value greater than 0.75 for monthly NSE can be considered very well; between 0.65 and 0.75 can be considered good while its value between 0.5 and 0.65 is considered satisfactory (Moriasi et al. 2007).

BMPs Simulated

The simulated BMPs included Parallel Terraces, Conservation tillage, Grade Stabilisation Structures and Channel Protection for the reduction of sediment yield. A brief description of each of the BMP and its representation in the model (post-BMP) condition is given below (Table 3). The model parameters and their altered values in post-BMP scenario are represented in below. Considering hydrologic processes simulated by SWAT, these parameters and their values were selected on the basis of published literature and study of watershed characteristics.

Parallel Terraces:

Scenario	Representing SWAT Parameters

S.No.	Description	Function	Variable	Value when scenario simulated
1	Baseline	No Conservation Practice	-	-
2	Conservation Tillage	Thoroughly mixed residue, nutrient, and pesticides throughout the soil depth Soil Depth	EFFMIX DEPTIL	0.75 0.25
3	Parallel Terraces	Reduce overland flow Reduce rill-sheet erosion	CN2 USLE_P	86 0.12
4	Channel Protection	Reduce gully erosion Increase channel cover Reduce channel erodibility	CN2 CH_COV CH_EROD	74 0.5 0.01
5	Combo of 2, 3 and 4	Combination of the above	-	-

Table 3: Table for the representation of BMPs and their functions

Terraces are broad earthen embankments constructed across the slope to intercept runoff water and control erosion (Schwab et al., 1995). Terracing in SWAT is simulated by adjustment of parameters CN2 and USLE_P (Waidler et al., 2011). CN2 affects the amount of modelled surface runoff, while USLE_P is the support practice factor of the USLE equation, and thus effective for soil loss at the level of HRUs. For the terraces scenario (TER), the values of CN2 were reduced by 5 from the calibration values and USLE_P was set to 0.12 (Arabi et al., 2008; Tuppad et al., 2010). We decided to simulate terraces without considering slope length in accordance to the studies of Gassman et al. (2006), Tuppad et al. (2010), Rocha et al. (2012), and Secchi et al. (2007). It has to be noted that at present no terraces occur on the watershed as a measure to conserve soil erosion.

Considering no terrace occurs in the watershed, the baseline value of USLE_P was set to 0. Terraces were established on 100% of the agricultural area, and thus simulated by adjusting the parameters CN2 and USLE_P value.

Channel protection:

Many streams in the watershed are subject to channel erosion. The channel protection practice is to cover channel segment with erosion resistant material to reduce gully erosion. This scenario quantifies the benefits of reducing channel erosion by increased vegetative cover of channel banks or the stabilization using riprap. In the model, the channel erodibility (CH_EROD) was reduced from 0.01 to 0.001 in all sub-basins. The channel cover factor (CH_COV) was adjusted to 0.5, and channel Manning's roughness coefficients was reduced by 10.

Conservation Tillage:

Conservation tillage practice involves less tillage. As a result, the amount of residue on the surface after harvesting of the crop increases. Conservation cropping was simulated by using appropriate SCS_CN values and by maintaining residue on the surface. An intensive tillage operation before planting such as disk plough in the pre-BMP condition was replaced with generic conservation tillage in the post-BMP condition. In SWAT model, the tillage operations differ in terms of mixing efficiency (EFFMIX) which shows the fraction of materials (residue, and nutrient) on the soil surface that are mixed uniformly throughout the depth of soil represented by DEPTIL (depth of mixing caused by tillage operation). The EFFMIX values for disk plough and conservation tillage were taken as 0.70 and 0.27, respectively.

Results and Discussions

Model Calibration and Validation

The outlet of study area watershed i.e. Mohgaon gauging station has been used for runoff and sediment calibration. The monthly observed runoff and sediment yield was calibrated for the 5 year period (2002-2006).

The results of the calibration and validation indicated that SWAT model predicted reasonably well for the hydrologic and topographic characteristics of Mohgaon watershed with a value of R^2 0.75, which is a good performance of model Moriasi et al. (2007).

BMPs Evaluated

The BMPs simulated in the Mohgaon watershed primarily aim at the reduction of soil erosion and sediment yield, on field, in path and at outlet. Hence we simulated the BMPs, and evaluated their impact on sediment load suspension for the 4 year period from 2007 to 2010. The BMP scenario results were compared to the baseline simulation and expressed in average percentage change.

Reductions by BMPs at water

Parallel Terraces:

Terraces enhance the pounding of water on the surface hence allowing higher rates of infiltration. The velocity of the remaining surface runoff would be reduced and thus the erosive power would be significantly reduced. Terraces also reduce the length of the slope which reduces the peak runoff rate (Arabi *et al., 2008). Peak runoff rate is directly proportional to the soil erosion rate. This explains the significant reduction of the sediment loading at the outlet in the simulation of terraces. Simulation of parallel terraces amounted in the reduction of 36.43% in the sediment yield against the baseline* simulation.

Conservation Tillage:

Conservation tillage was applied to the same area as Parallel Terraces. The conservation tillage resulted in reduction of 41% sediment at the watershed outlet. Soileau et al. (1994) found a reduction of 56% in sediment from conservation tillage compared to conventional tillage in a 0.038 km^2 watershed in northwestern Alabama.

Channel Protection:

The results showed that simulation of channel protection along the second and third order streams amounted in reduction of sediment at Mohgaon outlet up to 49%. The roughness of the stream channels is increased by planting grass in the channel or se of riprap during the dry season which, during the rainy season when the flow is high reduces its velocity and thus traps the sediment also.

Adaptation of Channel protection measure in Mohgaon watershed can be of much importance in reducing sediment as the farmers cultivate close to the streams and channels and even in the channel width, which go dry during the dry seasons an when the rain comes the sediment and sometimes even the crops get washed by the increased stream water.

Combined Scenarios:

A combination of all the three BMPs was simulated over the watershed. Parallel terraces were simulated over the agricultural area, taking into consideration minimum tillage i.e. conservation tillage practice for cultivation and thereafter Channel Protection for trapping the sediment in the stream channels. The combination was prepared to increase the effectiveness of BMPs in reducing soil erosion and sediment load without occupying additional farm land of cropping. The combination resulted in a reduction of 69% of sediment yield at the outlet. This is not to represent that individual BMP are not effective in reducing sediment load, rather, it is showing that consideration of using a combined BMP scenario is a better management strategy.

Scenarios	Sediment
Baseline	-
Parallel Terraces	36.43%
Channel Protection	49%
Conservation Tillage	41%
Combo of 2, 3 and 4	69%

Table 4: Impact of BMPs on sediment yield reduction

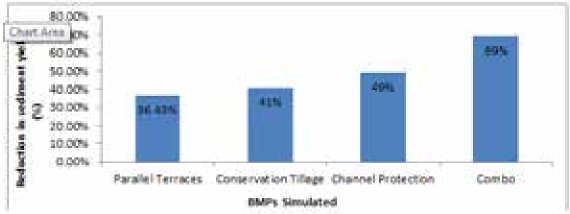

Figure 1: Reduction in Sediment Yield with implementation of BMPs

Conclusion

Overall, SWAT model performs satisfactory and provides viable platform to simulate impacts of BMPs on watershed scale. Model predictions on the impacts of the BMPs and their combination scenarios were found consistent with previously reported studies. Results of the simulation suggested that the combination of Conservation tillage, Parallel Terraces and Grassed Waterways was most effective in reducing the sediment load at the outlet. The results will assist in decision making to implement appropriate conservation practice to reduce soil erosion and sedimentation.

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