PROCESS BASED MODELING FOR SIMULATING SURFACE RUNOFF AND SOIL EROSION AT WATERSHED BASIS

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ABSTRACT:

Water Erosion Prediction Project (WEPP), a process based erosion model that computes spatial and temporal distributions of surface runoff, soil loss and sediment deposition from overland flow on hillslopes and soil loss and sediment deposition from concentrated flow in small channels. In the present study, surface runoff and soil loss were simulated in a mini watershed (57 ha) of Sitlarao watershed in hilly terrain using the WEPP watershed model v. 2002.7. Measured surface runoff of mini watershed was validated with WEPP simulated surface runoff for selected rain events. The surface runoff generated for rain events of low to medium rain intensity by WEPP model matched with observation (r^2 = 0.69) while its performance was poor for high rain intensity. Simulated and measured runoff from all the rain events comprising low to high rain intensity showed low regression coefficient (r^2 = 0.25). WEPP model provide explicit spatial and temporal estimate of soil erosion and surface runoff generation of hillslope and in the watershed. Results bring out utility of WEPP model after calibration for soil and water conservation planning at micro / mini watershed level.

1. INTRODUCTION

Soil erosion, resulting mainly from forest and agricultural land use, is associated mainly with environmental impacts as well as crop productivity loss in the latter (Lal, 1995; Pimentel et al., 1995) which makes the understanding of the erosion process important to guarantee food security (Daily et al., 1998) and environmental safety (Matson et al., 1997). Various physiographic regions in the country have different sensitivity to erosion where Himalayas region which is fragile in nature witness severe soil erosion due to steep terrain, deforestation, overgrazing and intensive agriculture, resulting from population pressure.

Predicting soil erosion by water is an important natural resource management activities for evaluating the impacts of upland erosion on sediment delivery, soil productivity, and offsite water quality. A large numbers of models have been developed in last two decades and are used in soil conservation planning. Recent development in remote sensing, GIS and computation techniques have allowed growth in distributed catchment models using physical principles of mass conservation equation of sediment in contrast to earlier empirical or lumped models (Singh, 1995). A few models commonly used are listed in Table 1. The Water Erosion Prediction Project (WEPP) model was developed from 1985-1995, by the United States Departments of Agriculture and Interior, and was publicly released in 1995 (Flanagan and Nearing, 1995). WEPP (Nearing et al., 1989) is a new generation, continuous process based, soil erosion prediction model based on fundamental of infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. Several studies (Savabi et al. 1995; Laflen, 1997; Cochrane and Flanagan, 1999; Brazair, 2000) used WEPP model in USA to simulate overland flow and soil erosion processes at hillslope and watershed scale. Ghidey et al. (2001) evaluated the runoff and sediment loss prediction from the WEPP model with measured data from a 6-ha watershed. Povilaitis et al. (1996) used the WEPP model on four small catchments (0.36– 3.25 ha), while Berset (1998) used the model on a 6 ha catchment. Chandramohan and Durbude (2003) used WEPP to estimate the sediment yield Salllopat watershed in Rajsthan. Suresh Kumar and Sterk (2005) used WEPP Hillslope model to examine the influence of soil hydrological characteristics on the spatial variability in runoff generation and soil loss over hillslope in the Himalayan watershed.

The present study reports application of WEPP to Sitlarao watershed in Doon valley of Himalayan region where measurement by IIRS is in progress for surface runoff, rain characteristics and other hydrological parameters. The study attempted to evaluate simulated surface runoff with measured data using WEPP watershed model (version 2002.7).

2. MATERIAL AND METHODS

2.1 WEPP watershed model

The WEPP model predicts daily soil loss and deposition from rainfall, snowmelt, and irrigation. It consists of nine components: climate generation; winter process; irrigation; hydrology; soils; plant growth; residue decomposition; hydraulics of overland flow; and erosion and deposition. The surface hydrology component of WEPP computes the surface runoff and peak discharge using the kinematic wave equation. The WEPP erosion model computes soil loss along a slope and sediment yield at the end of a hillslope. Interrill and rill erosion processes are considered, and it uses a steady- state sediment continuity equation as a basis for the erosion computations.

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Model	Model description		Authors
	Methods	Process	
USLE RUSLE	Empirical	Event-based	Wischmeier and Smith (1978) Renard et al. (1991)
AGNPS	Empirical	Event-based	Young et al. (1989)
MMF	Empirical	Distributed, event-based	Morgan et al. (1984) & Morgan (2001)
LASCAM	Conceptual	Lumped, distributed	Viney and Sivapalan (1999)
ANSWERS	Physically based	Distributed, event-based	Beasley et al. (1980)
LISEM	Physically based	Distributed, event-based	De Roo et al. (1996)
CREAMS	Physically based	Distributed, event-based	Foster et al. (1981)
EUROSEM	Physically based	Distributed, event-based	Morgan et al. (1998)
KINEROS	Physically based	Distributed, event-based	Smith (1981)
WEPP	Physically based	Distributed, event-based, continuous	Nearing et al. (1989)

Table 1. Erosion and sediment transport models

The WEPP model can be run for a hillslope or a watershed. The watershed version of the WEPP is an extension of the hillslope version. The base model is designed for a hillslope, predicting soil erosion from a single hillslope profile of any length up to about 400 m. The hillslope simulatemany types of non-uniformities through the use of Overland Flow Elements (OFE). It is defined as an area having uniform soil properties, slope and management. The watershed option links hillslope elements. In the WEPP model, an event is a day with observed and/or simulated runoff. A hillslope must consist of at least one overland flow element (OFE). WEPP model runs simulation for each hillslope in the watershed and then does a final simulation to merge the results and simulates channels. The main processes and method equation used in WEPP model are listed in Table 2 and more technical details available (Flanagan and Nearing, 1995).

2.2 Study site description

The study area, Sitlarao watershed is located in the Doon valley of Himalayan region in Dehradun district, India. The Doon Valley in the foot hills of Himalaya bounded by lesser Himalayas in north and Shiwalik in the South. The mean annual rainfall is 1753 mm. Most of the rain is received during monsoon season (June to September) and the remaining during

Main Processes	Sub-processes
Runoff and infiltration	Hortonian runoff Green- Ampt Mein-Larson model for infiltration Darcy-Weisbach equation for hydraulics of overland flow
Water balance	Continuous water balance on a daily basis Penman equation for ET
Plant Growth model	EPIC crop model Montieth's approach
Crop management	EPIC model—erosion–productivity impact calculator
Soil erosion	A steady-state sediment continuity equation

Table 2. The main processes of WEPP model

the winter season (December-April). The rainfall received of maximum rain intensity of 100 mm hour^{-1} in rainy months of July to September. The watershed lies between latitudes of 30° 24' 39" to 30° 29' 05" N and longitude 77° 45' 33" to 77° 57' 46" E covering an area of 5300 ha. A mini watershed in the watershed covering an area of 57 hectare was selected for field measurements of weather parameters, runoff and soil hydrologic characteristics.

The mini watershed represents steep to moderately steep sloping hills where elevation ranges from 960 to 1480m. The mini watershed drained by an ephemeral channel. Land use / land cover in the mini watershed comprises of forest cover (30 %), scrub (18 %) and crop land (51 %). These croplands used for paddy, maize cultivation in summer and wheat crop in winter seasons as rainfed. Villagers use forest land for grazing domestic animals and lopped forest trees to collect green leaves as fodder and floor bed for livestock.

2.3 Measurements of hydrological parameters

2.2.1 Runoff (discharge) time series measurements: A rectangular weir structure constructed at second order stream of watershed to record run-off measurement. The stage-level recorder (self-recording) was installed to measure discharge rate of sub-mini watershed. The instantaneous discharge was calculated using rectangular weir formula. The total discharge was calculated using daily runoff-hydrographs.

2.2.2 Rainfall measurement: An automatic weather station was installed near to Dungakhet at elevation of 800 m M.S.L. falls at middle part of the watershed. Climatic data viz., rainfall, temperature, relative humidity, wind velocity, wind direction and solar radiation data were collected at 15 minutes interval during rainy season (July-August) and one hour interval during remaining period of the year. Besides this, one self-recording was also installed at upper part of the watershed at Pipalsar village in the watershed. This self-recording rain gauge was located very near to runoff discharge measurement site that records rain at 15 minute interval.

2.2.3 Soil hydrologic characteristics: Soil survey was conducted to characterize the dominant soils in two hillslopes in the mini watershed representing dominant land use/ land cover types. The typical pedons representing hillslope positions under cropland and forestland were studied. Soil sample of surface layer (0-15 cm.) were collected to determine soil texture, organic matter and rock fragments. The Disc Tension Infiltrometer measurements were made at the hillslope positions to measure saturated hydraulic conductivity in various land use types.

2.4 Model input files and parameters

The input data need to be specified in four data files: a slope file, a soil file, a management file and a climate file. Break Point Climate Data Generator (BPCDG), a stand-alone program, was used in the study to create climate data for WEPP. Slope percent and slope length information for each hillslope were calculated based on toposheet and field measurements during survey. The slope in the mini watershed varies from undulating (3 -5 percent) to very steep sloping (> 50 percent). Croplands are terraced fields. The terraces of maize fields having slope of 3 -7 per cent whereas terraces in valley fills are very gentle sloping (1-3 percent). Forest lands are moderately steep to very steep. The soils in sub-mini watersheds were dominantly sandy loam in texture. The soils of the crop land containing coarse fragments 5-10 percent in surface to 25-35 percent in subsurface layer. Forest soils containing 30- 45 per cent rock fragments in the sub soils. The texture in hilltop were silt loam and shallow to moderately deep. Soils in the valley fills were loam to silt loam in texture. Soils of scrub lands are coarse sandy loam in texture and containing 50- 70 per cent rock fragments in the soil. The soils were very deep and excessively drained. Soil organic carbon in the surface soils varies from 0.93 to 2.13 per cent in the surface soil. Input data for the land management file were generated for each hillslopes. The upper hillslopes in the mini watershed having moderately dense to degraded forest (Sal forest - *Shorea robusta*). Maize crop in the uplands is grown in kharif season. A very small area of valley fills was used for paddy cultivation where grass strip was chosen from database to represent paddy crop.

3. RESULTS AND DISCUSSION

The mini watershed was defined by seven numbers of channels and represented by fifteen numbers of hillslopes (Figure 1). Each hillslope was made up of one or more overland flow elements (OFE).

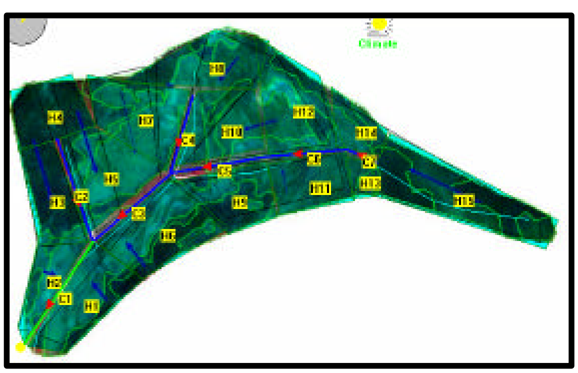

Figure 1. Various Hillslopes in the mini watershed shown on the Std. FCC of LISS IV satellite data

In the year 2003, a total of 55 rain events produced 1345 mm. of rainfall and out of that total of 34 events produced 457 mm. of surface runoff passing through the watershed outlet. The area of each hillslope their average annual surface runoff and soil loss are shown in the table 3. The average annual soil erosion in the mini watershed was predicted of 45 tones/ ha/yr. H1, H2, H6 and H9 hillslopes were cultivated for paddy and its upper part (OFE) has forest cover. H12 and H14 Hillslopes were predicted very high rates of soil erosion. These hillslopes predominantly had land cover of degraded forest and maize cultivation in the rainy season.

WEPP watershed model was run for year 2003 to simulate surface runoff and soil erosion. The major part of runoff produced in July, August and September months. The total discharge of the mini watershed was measured for the rain events in the month of July and August, 2003. Total 20 no. of rain events (Table 3) in July and August months were simulated with measured surface runoff of the mini watershed.

Date of rain event	Rainfal l (mm)	Rainfall duration (minutes)	Maximum rain intensity (mm/hr)
21.7.03	36	28	61.5
22.7.03	60.5	170	100
27.7.03	11.5	23	75
28.7.03	58	144	74
29.7.03	75	125	90
31.7.03	27	514	13
01. 8.03	13.5	60	32
03. 8.03	25	45	92
04. 8.03	25	69	30
05. 8.03	17	113	25
07.8.03	12.5	60	24
09.8.03	50	60	100
11.8.03	36.2	148	33
16. 8.03	25	37	40
19.8.03	25	30	84
20.8 .03	25	75	84
26. 8.03	25	45	80
28. 8 .03	40.5	59	60
29.8.03	57	14	200
30.8.03	13	46	42

Table 3. Rain characteristics of selected rain event used for simulation

Analysis revealed that in general, rain events with higher rain intensity (>50 mm/ hr) was poorly simulated for the surface runoff whereas it simulated very well with surface runoff of low to medium rain intensity (< 50 mm/hrs). The model simulated to higher surface runoff generation with rain event of high to very high intensity rain (100 mm/ hr).

Hillslopes	Area (ha)	Forest cover* class	Average surface runoff (mm)	Average soil erosion (kg/m $^{-2}$)
H1	4.04	b	778.9	2.32
H2	2.28	b	709.7	2.29
H3	3.19	e	252.0	1.52
H4	3.48	e	275.3	2.34
H5	4.42	b	674.6	4.52
H6	4.93	c	648.3	2.33
H7	4.39	a	721.4	7.40
H8	3.97	c	464.1	4.65
H9	3.41	d	669.3	1.88
H10	3.59	a	98.7	1.89
H11	3.05	a	98.1	1.89
H12	4.8	c	438.1	11.05
H13	0.65	a	180.4	2.25
H14	1.57	d	545.6	16.74
H15	9.23	e	233.1	5.08
Total	57.00	-	454.0	4.50

*Forest cover class: a - no forest cover, b - 10-30 %, c - 30-60 %, d - 60-90 %, e - >90 %

Table 4. Annual surface runoff and soil erosion of various hillslopes of the mini watershed

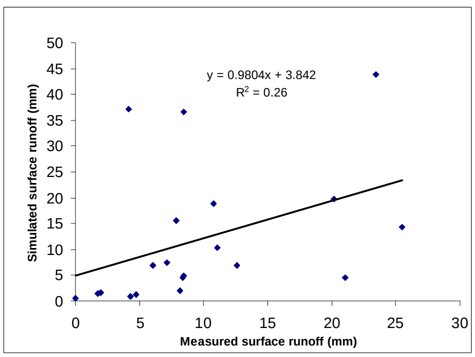

Figure 2. Measured and simulated surface runoff with all 20 nos. of rain-events in 2003.

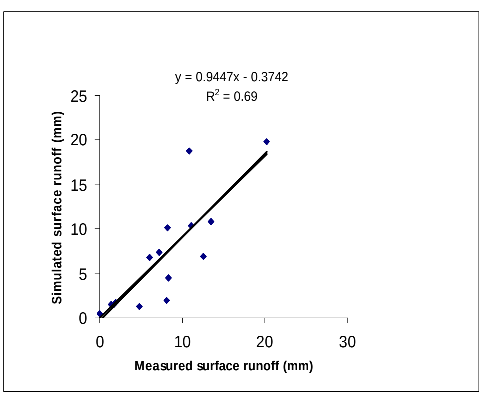

Figure 3. Measured and simulated surface runoff with selected rain-events of low to medium rain intensity in 2003.

Simulated and measured runoff from all the rain events comprising low to high rain intensity showed low regression coefficient (r^2 = 0.25) (Fig. 3) . The line of best fit of measured and simulated surface runoff of selected rain events with low to normal rain intensity (<50 mm / hr) indicated moderately high coefficient of determination (r^2 = 0.69) (Fig. 4). Gronsten and Lundekvam (2005) observed that model simulated well for the runoff events with low rain intensity during winter but poorly with high rain intensity in non-winter season.

4. CONCLUSIONS

Process based models becoming increasingly popular in simulating surface runoff and soil loss for various land use and management practices. These models are able to better account for local variability in topography, soil and land use conditions. They provide better understanding of hydrological processes in the watershed. The study revealed that, WEPP watershed version simulated quite well for the surface runoff generated with rains of low and normal rain intensity but it performed poorly for runoff produced with high rain intensity. Soil erosion was estimated at hillslope as well as watershed scale. WEPP output provides the detail information of soil erosion and surface runoff generation on event basis, monthly and average annual basis. It provide information on where, when and how much surface runoff and soil loss is occurring. This information is very much required to the conservationist for identifying suitable conservation measures and deigning structure at field level to check soil erosion and conserve surface runoff water.

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