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A Review on Frequently used Physical Runoff and Soil Erosion Watershed Models

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Abstract—*Numerous ongoing researches are there on points like which model will give increasingly perfect outcomes with that of the observed discharges. It was contended that even complex modeling doesn't provide reliable results. Environmental change and soil heterogeneity has an essential role in finding the surface runoff and soil loss. A number of models exist for study of the surface runoff, soil loss and sediment yield processes. However, these models differ significantly in terms of their ability and complexity, input requirements, illustration of processes, spatial and temporal scale accountability, realistic applicability, and types of output they deliver.The present study reviews 3 physically based runoff, soil loss and sediment yield models with respect to these factors together with their shortcomings and strengths. A model can perform well in one range of conditions and lack its performance in other set of conditions, therefore, it becomes necessary to choose the appropriate model for the particular watershed after proper evaluation to get the accurate and desired results. The current study provides aguideline for choosing of a proper model to the reader for a given application or case study.*

1. INTRODUCTION

Soil erosion is a main concern for environment and natural resources leading to the reduction in field production and soil quality resulting to land disintegration. About 0.3–0.8% (2–12million hectares) of the world's arable land is affected by regular soil degradation every yearmaking soil incongruous for agricultural production [1].Soil disintegration ismostly influenced by normal variables, for example, atmosphere, soil, geography, vegetation and anthropogenic exercises, for example, soil protection measures furthermore, culturing frameworks [2].Diverse hydrologic wonders and hydrologic cycle are to be wholly examined so as to discover the variability in environmental conditions. Presently days, different hydrological models have been created over the world to discover the effect of atmosphere and soil characteristics on hydrology and water assets. Each model has got its own special attributes. The data sources utilized by various models are precipitation, air temperature, soil properties, geology, vegetation cover, hydrogeology and other physical parameters. Improved comprehension of how each of these elements affects water supply and quality requires improved capacities to comprehend fundamental procedures and their influence on water accessibility and use. This involves utilizing an all encompassing methodologies which coordinates hydrologic forms at the watershed scale to decide a general watershed reaction to changing atmosphere [3].

2. Physical models

Physical models depend on key physical equations and their solutions define sediment and runoff in a catchment. These models represent the fundamental mechanisms controlling soil loss and sediment yield and consider physical characteristics, for example, geography, topography, land use, atmosphere, plant growth and flow characteristics. Conservation of mass and momentum equations for flow and conservation of mass equations for sediment are standard equations utilized in these model definitions. These models require a lot more data information and parameters for simulation efforts, and are commonly over-parameterized. Utilization of large number of parameters advantage to yield a better fit of observed data and increment in level of freedom. Although, it isn't important thatmodels with large number of parameters dependably accomplish preferred outcomes over models with limited number of parameters [4].

3. Description of models.

3.1 SWAT.

The Soil and Water Assessment Tool (SWAT) is a river basin scale, continuous time and spatially distributed physically based model developed to estimate the effect of land management practices on water, sediment, and agricultural chemical yields in compound catchments with varying soils, land use and management conditions over long periods of time [5,6]. SWAT includes Hydrologic Response Units (HRUs) to describe spatial heterogeneity in terms of land cover, soil characteristics and slope within a catchment. The SWAT model carries two steps for the simulation of hydrology: the land phase and routing phase. The land phase monitors the amount of sediment, nutrient and pesticides loading to the main channel in each sub-basin. SWAT offers two methods for predicting surface runoff: The Soil Conservation Service (SCS) Curve Number (CN) procedure and the Green and Ampt infiltration method. Using daily or sub-daily rainfall amounts, SWAT simulates overland runoff volumes and peak runoff rates for each HRU. SCS curve number procedure is less data intensive than the Green-Amptmethod [7]. Sediment yield is calculated using a Modified Universal Soil Loss Equation (MUSLE).

3.2. HEC-HMS / HEC-RAS

The Hydrologic Modeling System (HEC-HMS) is developed to simulate the complete hydrologic processes of dendritic watershed basins. The model includes many traditional hydrologic analysis processes such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also contains procedures necessary for continuous simulation including evapo-transpiration, snowmelt, and soil moisture accounting. Advanced capabilities are provided for gridded overflow simulation using the linear quasi-distributed runoff transform. Furthermore, tools are provided for model optimization, forecasting surface runoff, depth-area reduction, assessing model uncertainty, soil loss and sediment transport, and water characteristics and quality. HEC-HMS uses the Modified Universal Soil Loss Equation (MUSLE) approach [8] to estimate watershed sediment yield .HEC-HMS uses basic channel algorithms to route sediment between sub-basins including uniform equilibrium, volume ratio, linear reservoir and Fischer's Dispersion methods.

HEC-RAS is developed to carry one and two-dimensional unsteady flow calculations, one-dimensional steady flow calculations, sediment transport computations, and water quality analysis.HEC-RAS updates channel bathymetry relying on sediment mechanics. The model solves the sediment continuity (Exner) equation over control volumes centered on every cross section. Transport capacity is computed for each grain class using one of seven transport functions, including four (MPM, Laursen-Copeland, Ackers-White and Wilcock) that can be calibrated or adapted for site specific conditions. HEC-RAS compares the transport capacity calculated for each grain class to the sediment supply entering the control volume. The model gives a localized sediment deficit or surplus from the difference between the capacity and the supply, which translate into erosion and deposition respectively.

3.3. WEPP

The WEPP is a physically based distributed model. It predicts runoff and soil loss from a watershed using basics of stochastic weather generation, infiltration theory, hydrology, soil characteristics, hydraulics, and erosion mechanics. The model was initially created for soil and water conservation planning, and environmental evaluation. It provides estimate of spatial and temporal distribution of soil loss or deposition in a watershed over an extensive range of conditions. The distributed input parameters for the model includes rainfall amount and intensity, soil texture and plant growth parameters, residue decomposition parameters, effects of tillage implements on soil characteristics and residue amount, slope shape, steepness and orientation, and soil erodibiliy. The WEPP runs in continuous as well as single-storm simulation mode. The hillslope version of the model has nine components that are climate generation, hydrology, soil, plant growth, residue decomposition, winter processes, irrigation, hydraulics of overland flow, and soil loss. Three components: channel hydrology and hydraulics, channel erosion, and impoundments were added in the watershed addition. A short description is provided here for ready reference. Infiltration is obtained using the Green-Ampt.,Mein-Larson equation. Overland flow is routed using either an analytical solution to the kinematic wave equations or by regression equations obtained from the kinematic approximation. Peak runoff rate at the channel or watershed outlet is obtained by two methods:

- The procedure used in the CREAMS model [9]; and
- A modified rational equation used in the EPIC model [10].

The user is allowed to select the method for the simulations. The model takes into consideration inter-rill and rill erosion process in hillslopes as well as in channels. The movement of suspended sediment in rill, interrill, and channel flow areas is obtained using steady state continuity equation at peak runoff rate. Watershed sediment yield is calculated, taking into account, soil detachment from hillslopes and channels, transportation, and deposition of sediment in hillslopes and channels. Sediment deposition and sediment discharge from impoundments is simulated using mass conservation and overflow rate concepts.

Table 1: Details of applications of some selected physical based Runoff, soil erosion and sediment yield models in different parts of the world

S. No	MODEL NAME	REGION	Area	METHOD OF PERFORMANCE EVALUATION	AIM OF WORK	Results/Conclusion
1.	WEPP	Umroi watershed, India	239.4 hectares	t-tests, NSE, percent-deviation, RMSE	To develop BMP Plan	WEPP is suitable for implementation of BMPs (results fit at 95% significance level of t-test) [11].
		Karso Watershed, India	2793 hectares	R2, NSE, PD, t-test	Simulation of daily runoff and sediment yield	Satisfactory model performance (R2 = 0.86–0.91 for runoff and R2 = 0.81–0.95 for sediment yield) [12].
		Kamech catchment, Cap Bon, Tunisia	245 hectares	RMSE, NSE, t-test	Daily and annual simulation of runoff and sediment yield	Error ranged from 3% - 59% for hydrologic output; not fit for sediment yield (errors >250%) [13]
2.	SWAT	Lolab watershed of Pohru Catchment	28,162 hectares	NSE & R2	To evaluate the performance of Swat model	This study showed better efficiencies for both runoff and soil loss [14].
		Lixici Watershed, China	69,750 hectares	NSE, R2, PB	To investigate the impact of land use change on soil erosion and sediment yield.	Satisfactory model performance (R2 = 0.78–0.94 for runoff and R2 = 0.72–0.88 for sediment yield); Model suitable for BMPs [15].
		Save catchment, South-west France	111,000 hectares	R2, NSE, RE, NSE	Evaluation of runoff, sediment, and organic carbon yield and identification of critical soil erosion areas	Performance less than satisfactory (R2 = 0.56 for runoff and R2 =0.51 for sediment yield) [16].
3.	HEC-RAS / HEC-HMS	AttanagaluOya and Dee Eli Oya catchment	337.06 km2	Graphical Plots	To evaluate the performance of the model	The HEC-HMS 3.4 computer model can be reliably used to simulate AttanagaluOya flows with calibration and validation [17].

Table 2: Comparison of some selected physical based Runoff, soil erosion and sediment yield models in different parts of the world.

S.NO	MODELS IN COMPAR-ISON	AREA	REMARKS
1.	HEC-HMS & WEPP	Upper Baitarani River basin of Eastern India	The percent deviation of total runoff volume simulated by HEC-HMS ranges between −2.55 and 31%, while it varies from −13.96 to 13.05% for the WEPP model which suggests that the WEPP model simulates annual flow volumes more accurately than the HEC-HMS model for most years. Overall, it is concluded that the HEC-HMS model is superior to the WEPP model for simulating daily stream-flow in the Baitarani River basin of Eastern India [18].
2.	WEPP & SWAT	Zhangjiachong Watershed in the Three Gorges Reservoir Area	In the calibration period, the model efficiency (ENS) values for the WEPP and SWAT were 0.864 and 0.711 for runoff, and 0.847 and 0.678 for sediment yield, respectively. In the validation period, the ENS values for WEPP and SWAT were 0.835 and 0.690 for runoff, and 0.828 and 0.818 for sediment yield, respectively. The results of ENS and the other criteria indicate that the results of both models were acceptable [19].

3.	WEPP & SWAT	Torogh Dam Watershed Basin	In the calibration period, the Nash–Sutcliffe coefficient (NSE) values for the SWAT and WEPP were 0.698 and 0.854 for runoff, and 0.667 and 0.832 for sediment load, respectively. In the validation period, the NSE values for SWAT and WEPP were 0.678 and 0.824 for runoff, and 0.809 and 0.816 for sediment load, respectively. The results indicate that both models gave reasonable results in comparison with measured values [20].

4. Discussion

Many of the present physically based runoff, soil erosion and sediment yield models have the capability to realistically simulate surface overflow, soil erosion and can be applied to address a wide range of water resources and environmental problems. In order to evaluate if the model has the ability to deliver the required output, applications of the 3 physically based runoff, soil loss and sediment yield models in different parts of the world were reviewed and these are presented in table 2.The data utilized to support the model is an important factor influencing the performance of model predictions. To test the model quality, validation of the calibrated model is essential. To ensure the validity of any model it is essential that simulation results are compared with measured data. Then the validated model can be used for simulation in other areas of similar characteristics. Furthermore, some cases have been added in order to compare the different models to check the better model in the same set of conditions (table 2).

5. Selection of a Model.

Each model has its own execution capabilities in runoff and sediment yield modeling and their application depends on the objectives of the study and the degree of precision needed. On the basis of the review work, the proper model selection should incorporate the following:

- **Recognition of problem:** The initial step in modeling is to know the ideal yield required from the simulation. So as to limit the danger of utilizing wrong tools for the activity.
- **Selection of models:** Before model determination one should realize that what sort of system is to be modeled; components to be modeled (hill-slope sediment, channel sediment, surface runoff etc. on day by day/month to month/ regular/yearly basis); spatial variability (lumped or distributed); temporal variability (continuous or event based); quality, length and time of information accessible for study; physiographic and climatic state of the framework; cost included. The criteria for model choice should likewise incorporate straightforwardness of its application, exactness, quality and impediments, parameters consistency and yield affectability to changes in parameters. The models with GIS integration capacity are broadly preferred for the works of critical significance. The information / data should be adequate to assess diverse parameters of governing equations utilized for simulating runoff and soil loss.
- Model assessment and Sensitivity analysis: The effect of appropriate uncertainty sources which influences unwavering quality and precision of model yield must be distinguished before model assessment. Sensitivity analysis ensures the effect of info parameters on yield factors and model execution. To ensure model validity, simulation results can be compared with the observed measurements, even though before validation, practically these models also need model calibration with field data.
- **Use of certified/acknowledged model:** The validated model then can be used for simulation of runoff, soil loss and sediment process in other areas of similar conditions. Even though, all models and their results require a critical evaluation, and also, uncertainties should be incorporated, quantified and should be taken into consideration when interpreting results.

6. Summary and Conclusions.

Floods and soil erosion are global threats that have an adverse effect on environment, its productivity and quality of life. Therefore, assessment of these terms is of an utmost importance to plan the management practices to minimize the effects of these threats. The amount of runoff produced by any watershed needs to be appropriately predicted for planning and managing safety measures during the drought and flood conditions. Similarly, the amount of soil loss needs to be predicted and simulated to implement best management practices to avoid silting of reservoirs and rivers.The study gives a clear idea to the reader to select a proper model for a given application and will help to sort out which model should be used in which type of watershed. This paper reviewed few physical models and issues involved with performing runoff and sediment modeling at the watershed scale. Furthermore, a model can perform well in one range of conditions and lack its performance in other set of conditions, therefore, it becomes necessary to choose the appropriate model for the particular watershed after proper evaluation to get the accurate and desired results.

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