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Effect of Physical Parameters of Soil Erosion Due to Water

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Abstract : *The effect of various physical parameters on soil erosion due to water has been studied. It is very difficult to examine the effect of each of the parameter by conducting experiments in the field. A distributed soil erosion simulation model, employing large number of physical parameters, has been used for the purpose. The study is useful for those involved in the control of soil erosion due to water by improving existing catchment management practices.*

Introduction

Soil erosion due to water in the catchments with poor land management practices appear to be increasing day by day. For betrer control of soil erosion and thereby maintaining maximum levels of agricultural production, one requires complete knowledge of the factors affecting the runoff and associated soil erosion processes in a catchment.

There are numerous physical parameters that comes into the realm of soil erosion process. But to study every aspect of the effect of each of these parameters by conducting experiment in the field is a enormous task and involves lot of expenditure. A mathematical model integrating all the physical processes leading to runoff and soil erosion may prove to be a helpful tool in this respect.

Mathematical Model

Universal Soil Loss Equation (USLE) is a widely used empirical relationship that uses rainfall energy as the main driving force for predicting erosion losses. It it not possible to predict soil loss on event basis using USLE. Also, it does not help in estimating the deposition within the catchment. Therefore, it cannot best represent the dynamics of the soil erosion process. Erosion losses can also be predicted using simulation models which utilizes both the rainfall and runoff rates as the driving force for estimating the soil loss from the catchments. This study uses one such soil erosion simulation model (SESIM) (Ahluwalia et. al. 1988, Ahluwalia, 1990). This mathematical model uses finite element method to the constitutive equations of flow and dynamic form the sediment continuity equation. The detailed description of the model here will be out of the context of the present paper. However, the steps employed in the formulation of the SESIM and their brief resume is presented herein :

—Estimation of Infiltration (GAML Model)

—Water Routing (St. Venant Equations) Using Finite Element Method.

—Sediment Routing (Dynamic Sediment Continuity Equation) Using Finite Element Method

—Verification of the Model

Estimation of Infiltration

The infiltration has been estimated by using Green and Ampt model (1911) modified by Mein and Larson (1973) for steady rainfall conditions and later on improved by Chu (1978) for unsteady conditions (Ahluwalia, et. al. 1988, Ahluwalia et. al. 1990). Herein, this model is referred to as Green-Ampt-Mein-Larson (GAMPL) model. The GAML model uses the two-stage infiltration model because in reality the infiltration from rainfall normally occurs in two stages, before and with surface ponding. It conceptually considers a rainfall event to consist of a number of uniform intensity intervals. For each of the interval it identifies through the use of stage indicators, whether to use the pre-ponding or post-ponding equation for estimation of infiltration. The GAML model is a two parameter model. Its parameters namely, the hydraulic conductivity of the soil and the suction head can be easily measured by conducting experiments in the laboratory or in the field. The other input of the GAML model, saturation moisture deficit can either be measured or estimated. The potential of the GAML to be used for unsteady rainfall conditions, through the use of stage indicators, has increased its utility for field problems. The rainfall excess rate has been computed by subtracting infiltration rate from the rainfall rate of an event.

Water Routing

Water routing for overland and channel phases of the catchment has been done using St. Venant equations (Ahluwalia et. al. 1988, Ahluwalia et. al. 1990). To increase the efficiency of the solution to the constitutive flow equations kinematic wave approximation is made which still allows the solution to be obtained for wide range of the flow conditions. The application of this approximation results in the uniform flow conditions and the flow has been estimated using Manning's equation.

Finite element method (FEM) has been used to obtain the numerical solution of the constitutive equations of flow. Galerkin residual method in conjunction with both linear and cubic interpolation functions has been used for element matrix formulation. Explicit time integration technique is used in the numerical solution.

The flow characterisrics obtained from the water routing are used in the solution of dynamic continuity equation.

Sediment Routing

Sediment routing for both phases of the catchment has been performed by using dynamic form of the sediment continuity (Ahluwalia et al. 1988) equation. The available sediment load at the end of the flow regime is compared with the sediment transport capacity of the flow. The limiting one of the two is actual sediment load. Sediment transport capacity has been computed using Yalin bed-load equation (1963). Its advantage is that it is well adapted for shallow flow conditions. Also, it has been modified by Foster (1972 b) to accommodate non-uniform particle sizes in sediment flow.

The sediment continuity uses sediment detachment rate that is estimated by summing up the inter-rill and rill detachment rates. Inter-rill erosion take place because of raindrop impact. It has been assumed that the transport capacity of the flow in the inter-rill areas is just sufficient to supply the sediment to the rills to be transported down the slope. If the transport capacity of the flow is more than the available sediment load due to inter rill erosion, rill erosion occurs. In this study, equations as suggested by Foster (198-) have been used to estimate the inter-rill and rill erosion rates in the overland phase of the catchment that has to be routed down the slope. The sediment discharge from the overland flow phase becomes lateral inflow for the channel phase.

Finite element method is used to obtain the numerical solution of the sediment continuity equation. Galerkin residual method is used in conjunction with both linear and cubic interpolation functions for element matrix formulation.

Verification of the Model

Finite element solutions, using both linear and cubic interpolation functions, of the flow routing component of the model has been compared with the analytical solution (Eagleson, 1970) and the reported laboratory data (Crawford and Linsley 1966). The FEM solutions have compared reasonably well with both the analytical solution and the reported laboratory data.

The soil erosion simulation model has been verified by comparing the simulated runoff and loss amounts, resulting from a number of rainfall events, with the reported field data (Akan and Ezen, 1982). A similar comparison was made by using the ICRISAT data. A reasonably good agreement has been found while comparing the simulated results with the published data for both cases.

Effect of Parameters on Soil Erosion

The SESIM described in the last section has been used to study the effect of various physical parameters on the soil erosion by water. It is difficult to quantitatively verify the effect of variation of each parameter, due to the paucity of relevant data. Therefore, the results of the study has only been examined for the possible likelihood in terms of the trends available from the output of the above model.

Effect of Surface Roughness

Three values of Manning's roughness coefficient 0.01, 0.05 and 0.25 representing very smooth to very rough surface likely to occur (Engman, 1986) have been seleeted for simulating the sedimentgraphs. Impact of changes in roughness coefficient values is very significant in the simulated sedimentgraphs (Fig. 1). Figure (1) shows that the surface roughness increases the soil loss resulting in increase in the peak of sedimentgraph. The total soil loss is higher in case of rough surface as compared to that for smooth surface. This is due to the fact that as the depth of flow due to surface roughness increases the shear stress of flow also increases resulting in increased sediment detachment rate due to flow.

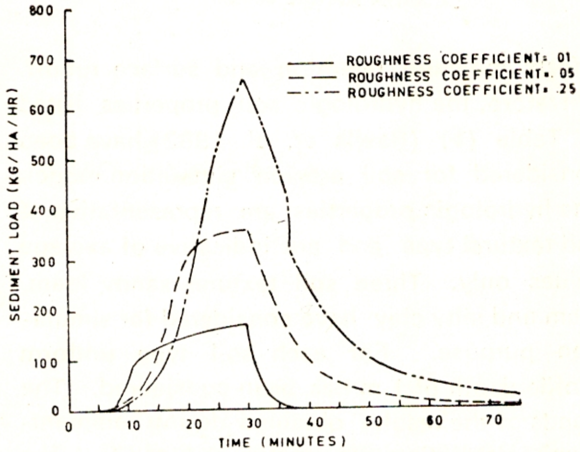

FIG 1 SEDIMENTGRAPHS FOR DIFFERENT VALUES OF MANNING'S ROUGHNESS COEFFICIENT

Effect of Saturation Moisture Deficit

The saturation moisture deficit values 0.20, 0.24 and 0.28 have been selected for simulation. The results obtained for sedimentgraph simulation are shown in Fig. (2). The peak sediment load and total soil loss is higher in case of low saturation moisture deficit as compared to high deficit values. This is due to the fact that the total volume of runoff and the peak runoff rate are higher in case of low moisture deficit values as compared to those for higher moisture deficit values.

Effect of Soil Textural Changes

Hydrologic soil properties are significantly affected by the soil texture which consequently

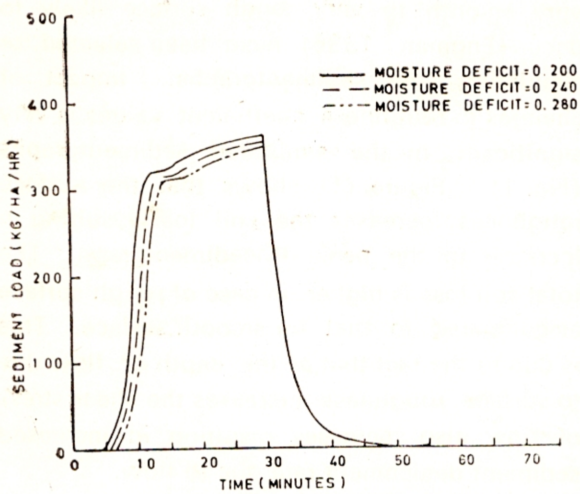

FIG. 2 SEDIMENTGRAPHS FOR DIFFERENT VALUES OF SATURATION MOISTURE DEFICIT

affects moisture retention and surface runoff. Therefore, the hydrologic soil properties listed in Table (1) (Rawls et. al. 1982) have been considered for soil erosion simulation model. The hydrologic properties are representative of soil textural type and are indicative of average values only. Three soil textures-sandy loam, loam and silty clay have considered for simulation purpose. For each soil type uniform profile depth of 1 m has been considered. The trends of the results obtained during sedimentgraph simulation are shown in Fig. (3). The total sediment yield and the sediment discharge rate are higher for silty clay followed by loam and sandy loam soils. This is due to the fact

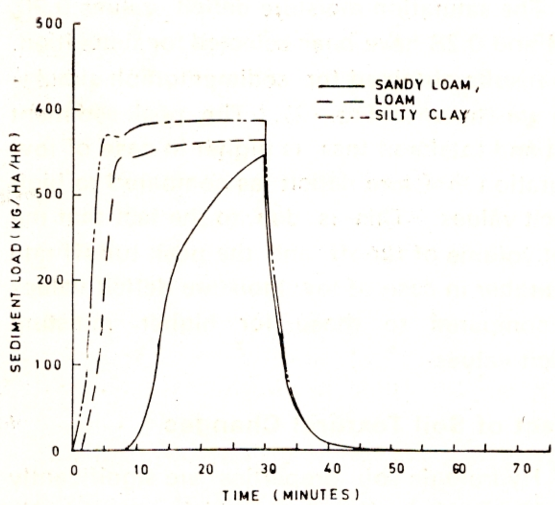

Fig. 3 Sedimentgraphs for Different Soil Types

that the volume of runoff and peak runoff rate are maximum for silty clay followed by loam and sandy loam.

Effect of Soil Depth

With change in soil depth the unavailable and the available water in the soil profile also changes affecting the deep percolation and evapotranspiration losses. Therefore, the saturation moisture deficit before any storm is influenced by the depth of soil of the area. To study the effect of change of soil depth on soil erosion, three soil depths 500 mm, 1000 mm and 1500 mm, that falls in the range of root zone depth of the common crops, have been considered for simulation. The soil loss and peak sediment rate are higher for the shallow soil as compared to those realised on deep soil Fig. (4). This is due to the fact that the volume of runoff and the peak runoff rate for the soil with shallow depth are higher compared to those with deeper soils.

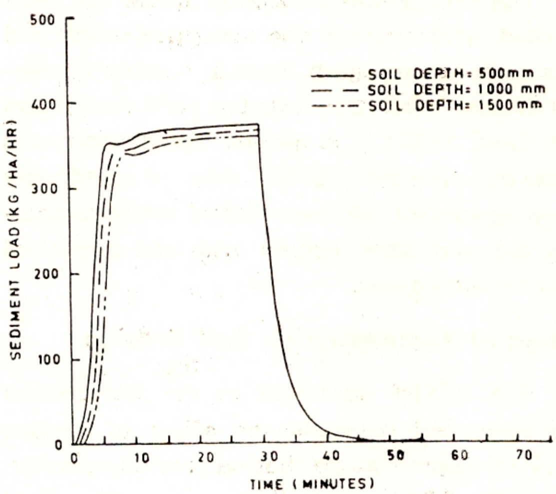

Fig. 4 Sedimentgraphs for Different Soil Depths

Effect of Slope Length

Three overland flow plane slope lengths 15 m, 30 m and 60 m are simulated to study their influence on the soil erosion. For each case the plot area is kept the same. It is observed that the total soil loss and peak sediment rates are higher for higher slope lengths (Fig. 5). This is because of the fact

TABLE 1 : Hydrologic Soil Properties Classified by Texture (Rawls et al. 1982)

Soil Texture	Effective Porosity cc/cc	Av. Suction at Wetting Front, mm	Hydraulic Conductivity mm/hr	Water Content 1/3 Bar Tension, cc/cc	Water Content at 15 Bar Tension cc/cc
Sandy Loam	0.412	110.1	10.9	0.0207	0.095
Loam	0.434	88.9	3.4	0.27	0.117
Silty Clay	0.423	292.2	0.5	0.387	0,25

that the flow velocity is highest in case of 60 m slope length followed by 30 m and 15 m lengths.

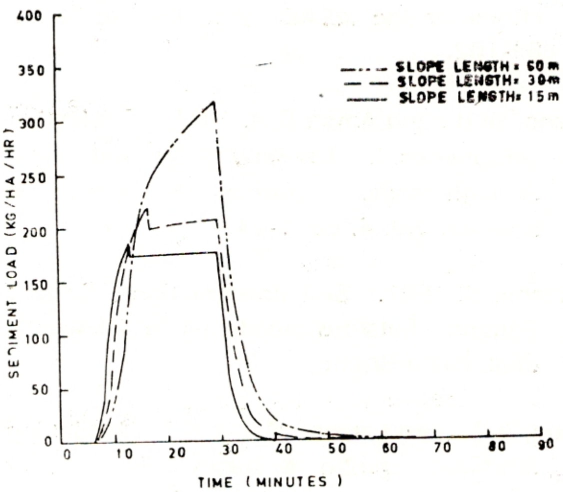

Fig. 5 Sedimentgraphs for Different Slope Lengths

Effect of Flow Plane Slope

To study the effect of slope of flow plane three slopes 0.05, 0.5 and 5.0 percent are considered for simulation. The sediment flow increases and decreases rapidly during the rising and falling stages of the sedimentgraphs on the steeper slopes. The soil loss decreases considerably with the decrease in the slope due to corresponding decrease in velocity of flow and a negligible soil loss has been observed for 0.05 per cent slope (Fig. 6).

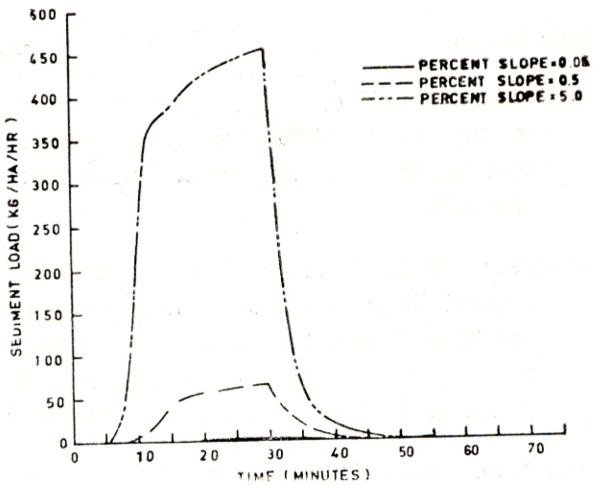

Fig. 6 Sedimentgraphs for Different Slopes of Overland Flow Plane

Effect of Cropping Management Factor

The value of cropping management factor may vary from 0 to 1 depending upon the condition of the land from good covered with crops for several years to cultivated bare continuous fallow (Hudson, 1981). Three cropping management factor values 0.4, 0.5 and 0.6 are selected for simulation purpose and all other parameters of the model are kept same. Approximately 25 percent increase in the soil loss has been observed with increase in the cropping management factor value in each simulation.

CONCLUSIONS

A study on the effect of various physical parameters on the soil erosion due to water that can occur in a catchment has been made. It has been observed that each of the parameters the surface roughness, saturation moisture deficit, soil texture, soil depth, slope length, slope of the flow plane and cropping management factor significantly effects the total amount of soil erosion and peak sediment rate due to corresponding change in the volume of runoff and peak runoff rates. All these parameters must be suitably taken into account in the planning and design of the appropriate soil erosion control measures.

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