DEVELOPMENT OF REGIONAL SCALE SOIL EROSION AND SEDIMENT TRANSPORT MODEL; ITS CALIBRATION AND VALIDATIONS

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ABSTRACT

Despite of the fact that many soil erosion models have been developed in the past more than 5 decades including empirical based models like USLE and RUSLE and many process based soil erosion and sediment transport models like WEPP, EUROSEM and SHETRAN, the application of these models to regional scales remained questionable. To address the problem, a process-based soil erosion and sediment transport model has been developed to estimate the soil erosion, deposition, transport and sediment yield at regional scale. The soil erosion processes are modeled as the detachment of soil by the raindrop impact over the entire grid and detachment of soil due to overland flow only within the equivalent channels, whereas sediment is routed to the forward grid considering the transport capacity of the flow. The loss of heterogeneity in the spatial information of the topography due to slope averaging effect is reproduced by adapting a Fractal analysis approach. The model has been calibrated for Nan river basin (N.13A) and validated to the Yom river basin (Y.6) and Nam Mae Klang river basin (P.24A) of Thailand, simulated results show good agreements with the observed sediment discharge data. The developed model with few new components can also be applied for predicting the sediment discharges of the river Indus.

1. INTRODUCTION

While considerable progress has been made in measuring and modelling erosion, transport and deposition at plot and small catchment scales, major obstacles remain in scaling this work up to larger catchments and to whole regions (Geoff et al., 2000). The changing scale of model application can have a significant, but poorly understood, impact on the variance of model parameters and thus on their relative importance. The loss of spatial heterogeneity associated with a reduction in spatial scale provides a substantial obstacle to large scale modelling. It is important to consider ways of reproducing such small-scale heterogeneity from large-scale measurements (Zhang et al., 2001). The results of such models provide useful information for decision-makers and planners to take appropriate land management measures (e.g., Grenon and Batisse, 1989; Perez-Trejo, 1992, Clark and Perez-Trejo, 1995; Hill et al., 1996). Although simulation models working at regional scale may be less accurate than soil loss predictions by erosion at plot or field scale, decision-makers are usually more concerned about the detrimental effects of soil erosion, flooding and sediment inconveniences for a department or province (S. M. De jong et al., 1999).

Keeping in mind the above factors, a one-dimensional process-based soil erosion and sediment transport model has been developed to estimate the soil erosion, deposition, transport and sediment discharge at regional scale. The catchment's spatial variability is modeled as a regular square grid system with canopy interception, infiltration, depression storage, one-dimensional overland flow and sediment transport in the steepest descent direction. The overland flow is modeled in the equivalent channels, which may represent the cumulative width of all rills and gullies in each

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grid. The fraction of the ponded surface is determined on the basis of the flow accumulation value of the each grid, grid size and its land use type.

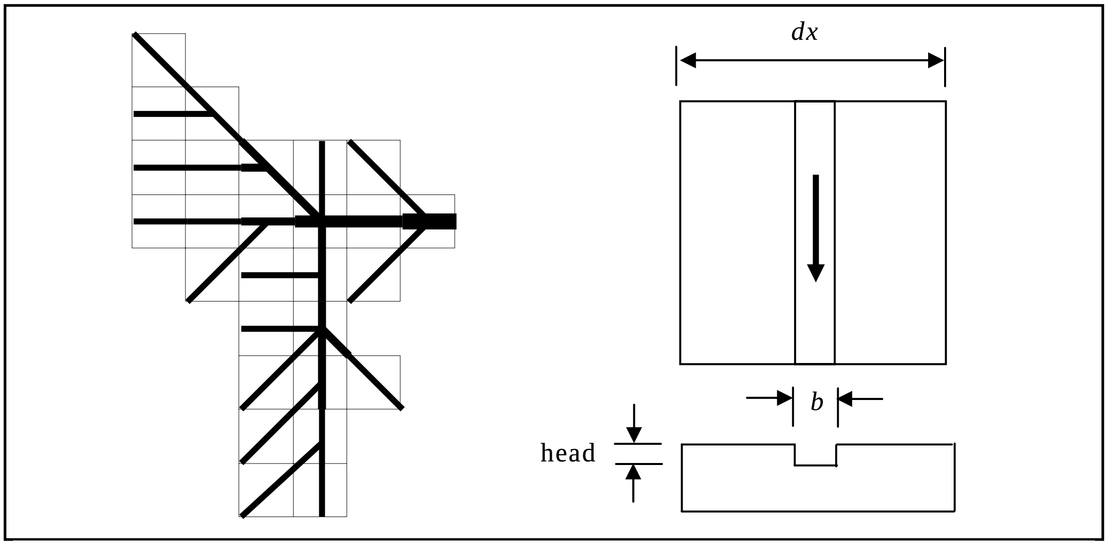

Figure 1: Modelling soil erosion and sediment transport processes considering equivalent channel-network in the watershed.

The soil erosion processes are modeled as the detachment of soil by the raindrop impact over the entire grid surface and detachment of soil due to overland flow only within the equivalent channels, whereas sediment is routed to the forward grid considering the transport capacity of the flow and the existing sediment load.

As soil erosion is modelled with larger grid sizes, then we have to average the land use type and topographic details by some way, which reduce the variance in the DEM and land use types (loss of heterogeneity in topography and land use information). For investigating the effect of slope averaging on the soil erosion and sediment transport modelling, process simulations were carried out by keeping one land use type (major) on the entire sub-catchment and changing the grid resolutions only (Habib *et al*., 2001). Results showed that slope averaging effect is much severe than the land use averaging on soil erosion and sediment yield modelling. So for regional scale soil erosion assessment it is essential to consider the effect of slope averaging at least in order to make a soil erosion model relatively invariant to spatial scales. The reduction in predicted erosion with progressively coarser scales is caused by the loss of spatial heterogeneity in topography. A fractal approach, which was proposed by the Zhang. *et al*. (1999), is adapted for scaling down the slopes and scaling up the model equations for slope.

The model has been calibrated for Nan river basin (N.13A) and applied to the Yom river basin (Y.6) and Nam Mae Klang river basin (P.24A) of Thailand, simulated results show good agreements with the observed sediment discharge data.

2. MODEL DESCRIPTION

The overland flow component is developed by routing the flow in the steepest descent direction, for all flow elements starting from zero flow accumulation value to the maximum. The location of next cell (i_2,j_2) receiving the flow is determined on the basis of the flow direction value of the processing cell. Flow routing equation is applied between the centers of two consecutive cells as channel equation with no lateral flow, which is added at the inlet of control volume i.e. cell (i_1,j_1). The overland flow, soil detachment due to overland flow and sediment transport is modeled in the equivalent channels, which may represent the cumulative width of all rills and gullies in each grid.

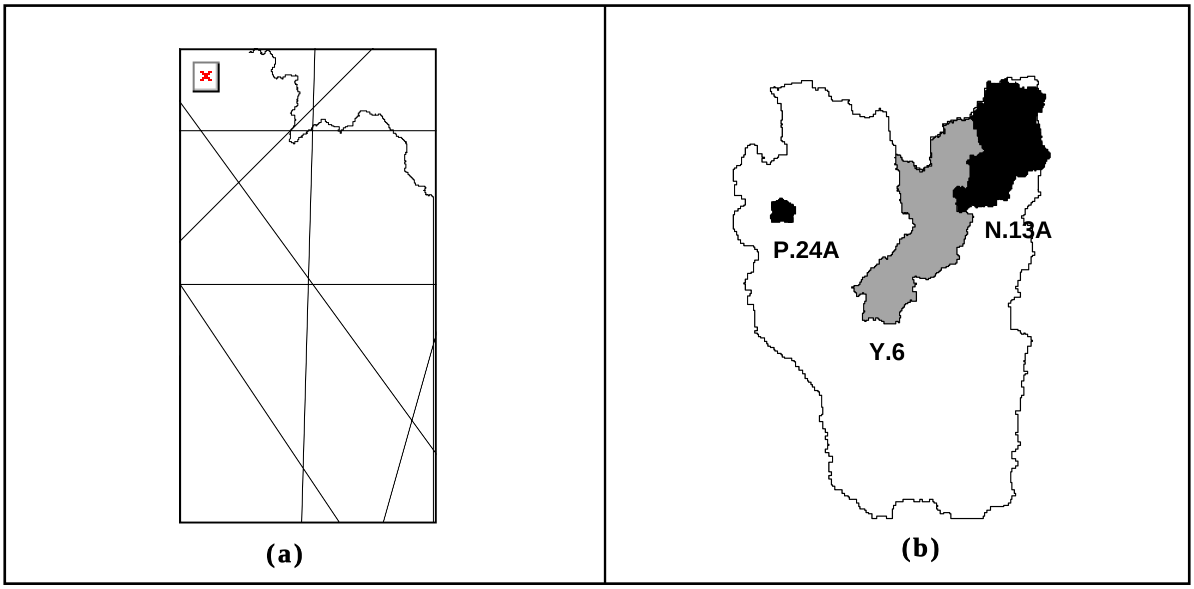

Figure 2. (a) Map of Thailand showing the Chao Phraya river basin up to C.2, (b) Sub-catchments of Chao Phraya river basin for Model validations

2.1 Proposed overland flow widths

Width of the equivalent channel for each grid is proposed as given in equation (1), the coefficient and exponents of the proposed equation were determined by the series of process based numerical simulations best suited for the study area.

$$b\,(i, j) = K.n\,(i, j)^{0.2}\,(dx)\,[iflacc(i, j)]^{0.40} \qquad (1)$$

Where $b\,(i, j)$ is the width of equivalent channel in any cell (m), $iflacc\,(i, j)$ is the flow accumulation value for the ith grid, $n\,(i, j)$ is Manning's coefficient of roughness value to represent the land use type of the each cell, dx is the grid size (m), K is an width adjusting coefficient and a value of 0.016 is found satisfactory for regional scale applications with using 1 km grid size.

Using the concept of equivalent channels (Figure 1), inter-rill and rill/gullying erosion can be modelled in a more physically based manner. The splash detachment may be assumed on the entire grid surface which represents the sheet or inter-rill erosion whereas flow detachment and transport is considered within the widths of equivalent channels which may represent the rill and gullying erosion for each grid of the catchment.

2.2 Soil detachment due to raindrop impact

Detachment due to raindrop impact is estimated for each time step using Torri et al. (1987) equation.

$$D_R = (1 - C_g)\, k.(KE)e^{-zh} \qquad (2)$$

Where D_R is soil detachment by raindrop impact (g m^{-2} s^{-1}), k an index of the detachability of the soil (g J^{-1}), KE is total kinetic energy of the rain (J m^{-2}), z is an exponent ranging between 0.9 to 3.1, h is the depth of surface water layer (mm), C_g is proportion of ground cover in each grid.

The rainfall energy reaching the ground surface as direct throughfall (*KE(DT)*, J m^{-2} mm^{-1}) is estimated as a function of rainfall intensity using the equation developed by Brandt (1989).

$$KE\,(DT) = 8.95 + [8.44.\log\,(I)] \qquad (3)$$

Where KE(DT) is the kinetic energy of direct throughfall (J m^{-2} mm^{-1}), I is rain intensity (mm hr^{-1}). The energy of leaf drainage is estimated as a function of the effective canopy height using the following relationship developed experimentally by Brandt (1990).

$$KE\,(LD) = [15.8\,(PH)^{0.5}] - 5.87 \qquad (4)$$

Where KE(LD) is the kinetic energy due to leaf drip (J m^{-2} mm^{-1}), PH is effective height of the plant canopy (m).

$$KE = (1 - C_C)KE(DT).H_{DT} + C_C.KE(LD).H_{LD} \qquad (5)$$

Where KE is total kinetic energy of the rainfall (J m^{-2}), C_C is canopy cover in the model square grid, H_{DT} is depth of direct through fall (total rain (mm)), and H_{LD} is the depth of leaf drips (net rain (mm)).

2.3 Soil detachment due to overland flow

For modelling soil detachment due to overland flow, equation derived by the Ariathurai and Arulanandan (1978) has been used.

$$D_F = K_f\left(\frac{\tau}{\tau_c} - 1\right) \qquad \text{for} \quad \tau > \tau_c \qquad (6)$$

$$D_F = 0 \qquad \text{for} \quad \tau < \tau_c \qquad (7)$$

Where D_F is overland flow detachment (Kg m^{-2} s^{-1}), K_f is overland flow detachability coefficient (Kg m^{-2} s^{-1}), τ_c is critical shear stress for initiation of motion, which is obtained from the Shield's curve (N m^{-2}), and τ is hydraulic shear stress (N m^{-2}) as given in equation (8).

$$\tau = \gamma\, h\, S \qquad (8)$$

Where γ is specific weight of water (N m^{-3}), h is depth of overland flow (m) and S is slope of the ground surface. K_f is best regarded as a calibration coefficient, to be determined by fitting the simulated variation of sediment discharge to be measured. Though there is possibility of relating this factor with the soil cohesion as also proposed by Styczen and Nielsen (1989). It is possible that it may also vary with the scale of the model grid square to account for the aerial averaging of soil erosion processes and overland flow variables (Wicks *et al.*, 1996).

To estimate critical shear stress by Shield's curve, the values of dimensionless Shield's parameter (F_*) are hard coded in the source code of the model for the range intervals of Boundary Reynold's number (R_{N*}). And then critical shear stress values are obtained by the following equation.

$$\tau_c = F_* (\gamma_s - \gamma) D_s \qquad (9)$$

Where γ_s is the specific weight of sediment particles (N m^{-3}), γ is specific weight of water (N m^{-3}).

Total potential detachment at any cell (x) and time (t) [$e(x, t)$] is then calculated as the sum of splash and flow detachments as given in equation (10).

$$e(x, t) = D_R (x, t) + D_F (x, t) \qquad (10)$$

2.4 Soil transport & deposition due to overland flow

Transportability of the detached material depends on the amount of the detached material and the remaining transport capacity of the flow (transport capacity – existing sediment discharge from upstream). When transport capacity of the flow is greater than the sediment load, the actually detached load (erosion) is estimated as described in equation (11). If the transport capacity of the flow in that particular cell at time (t) will be lesser than the sediment load, then excess material will drop as "deposition" and the actually detached load will be zero from that cell at that time step, and the load carried by the flow will be equivalent to the transport capacity.

$$e1(x, t) = [T_C (x, t) - Q_S (x, t)] \leq e(x, t) \qquad (11)$$

Where $e1(x, t)$ is actually detached load, $T_C (x, t)$ is transport capacity of the flow and $Q_S (x, t)$ is sediment load from up stream.

In the source code of the model five transport capacity (T_C) equations are incorporated (Habib, 2001) to use for different set of conditions for which they were originally developed as to make simulation closer to the field conditions. An appropriate equation can be selected at the calibrating stage.

2.5 Governing equations for overland flow

The Saint–Venant equations for one-dimensional kinematic forward flow routing used for the overland flow model development are continuity equation and momentum equations as given in equation (12) and equation (13). As the continuity equation is applied between the center points of the two consecutive grids, so in the continuity equation lateral flow is taken as zero, which is separately added at the inlet of the control volume (inlet grid (i, j)).

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{12}$$

$$S_f = S_0 \tag{13}$$

Where Q is discharge or volume flow rate at distance x ($m^3\ s^{-1}$), A is cross-sectional area (m^2), x is distance along the flow (m) and t is time (s). Lateral flow from each grid at each time step is added to the inlet ((i,j) grid) only, as the total flow rate in $m^3\ s^{-1}$. S_f is the friction slope and for kinematic wave it is taken equal to the slope of the ground surface.

2.6 Governing equations for 1-d Kinematic sediment transport routing.

For one-dimensional forward sediment transport routing, the kinematic mass balance equation (Woolhiser et al., 1990) has been used, which is applied between centers of two consecutive grids ((i,j) and (i_2,j_2)) considering the flow direction matrix. Total detachments are calculated as the sum of the splash detachment and detachment due to overland flow. After considering the transport capacity of the flow, the total actually detached load ($e_1(x, t)$: erosion) is determined which is assumed that flow can carry, and this load is considered as the lateral sediment flow and is added at the inlet of the control volume.

$$\frac{\partial (AC)}{\partial t} + \frac{\partial (QC)}{\partial x} = 0 \tag{14}$$

Where C is sediment concentration ($m^3\ m^{-3}$), A is cross–sectional area of flow (m^2) and Q is discharge ($m^3\ s^{-1}$).

3. MODELLING STRATEGY AT REGIONAL SCALES

As at regional scales (particularly for Chao Phraya river basin), the sediment yield analysis showed that there are two to five rainstorms, which produces severe sediment loads in the rivers (Habib *et al*., 2000). Keeping in mind this idea, modelling soil erosion and sediment transport for surface part only should be sufficient to capture the soil erosion and sediment discharge characteristics within the basin.

Secondly, modelling soil erosion and sediment transport on regular square grid discritization system with one-dimensional overland flow and sediment transport routing is computationally faster as compared to two-dimensional surface routings. Moreover, using the benefit of one-dimensional routings we can represent many rills and gullies to be flowing parallel each other from one grid to another using the concept of equivalent channels at regional scales. So, modelling overland flow not on the entire grid surface but only within the equivalent channels seems to be more realistic as flow is hard to be observed on a large surface having 1 km^2 area. By this approach, sheet or inter-rill erosion can be modelled by considering splash detachment on the entire grid surface, whereas overland flow and detachment due to overland flow is assumed to occur within the widths of equivalent channels including its transport to the next grid, which may represent the rill and gullying erosion.

Thirdly, as land use averaging effect is not as severe as the slope averaging on the soil erosion and sediment transport modelling (Habib *et al.*, 2001), so down scaling the slopes to higher resolutions (which are suitable for soil erosion modelling (50 to 100 m)) is at least enough for modelling soil erosion and sediment transport at regional scales. And then model equations for slopes can be scaled up in terms of the scale, to make a model relatively invariant to spatial scales, as for as slope averaging is concerned.

4. DOWNSCALING THE SLOPE

A fractal theory is adapted to solve this problem. The variogram technique for the definition of fractal parameters is demonstrated to provide a relationship between the slope and the spatial resolutions of the measurement. The fractal parameters are estimated from the standard deviation of elevation in a 3 × 3 pixel window of the DEM to account for local variability in the surface. As standard deviation of elevation is found to be the most invariant property of different scale DEMs of the same area (Zhang *et al*., 1999). The slopes estimated using the technique outlined are a significant improvement on those estimated directly from the coarse resolution data. Slopes estimated in this way allow the more effective use of available coarse resolution data in regional scale modelling studies.

4.1 Introduction to fractal approach for scaling down the topography

A fractal is an object whose shape is independent of the scale at which is regarded (Turcotte, 1992). Huang and Turcotte (1989) indicated the Earth's topography generally obeys fractal statistics and the mean fractal dimension (D) is 1.52. D ranges from 1.02 for completely smooth surfaces to 1.99 for very irregular surfaces. In the natural environment, most landscapes can be considered to be fractal (Moore, 1993), although there are some limitations. Andrle and Abrahams (1989), for example, found that Talus slope surfaces are not self-similar and therefore the fractal properties may break down at very small scales.

A variety of methods have been proposed to determine the fractal dimension of topography (Klinkenberg and Goodchild, 1992; Mandebrot, 1982 and Russ, 1993 for examples of the techniques that can be used).

The essence of the variogram technique is that the statistical variation of the elevations between samples varies with the distance between them. The independent variable is the distance between pairs of points while the dependent variable is the variance of the differences in the data values for all samples a given distance apart (Klinkenberg and Goodchild, 1992). This method can be used to calculate the fractal dimension in a region when the log of distance between samples is regressed against the log of the mean-squared difference in the elevations for that distance (Klinkenberg and Goodchild, 1992).

According to the variogram technique, the relationship between the elevations of two points and their distance can be converted to the following formula:

$$(Z_p - Z_q)^2 = kd^{4-2D} \qquad (15)$$

$$\frac{Z_p - Z_q}{d} = \alpha d^{1-D} \qquad (16)$$

Where Z_p and Z_q are the elevations (m) at points p and q, d is the distance (m) between p and q, k and $\alpha = +k^{0.5}$ are constants and D is the fractal dimension. The value $\frac{Z_p - Z_q}{d}$ is actually the surface slope. It can be assumed, therefore, that the percentage slope S is related to its corresponding scale (grid size) d by the equation.

$$S = \alpha d^{1-D} \qquad (17)$$

This relationship implies that if topography is fractal, then slope will also be a function of the scale of measurement.

4.2 Estimating scaling parameters for calculation of high resolution slopes from coarse resolution data

In order to use equation (17) to calculate local slope at a specified finer scale (d), it is necessary to develop a method for calculating the local fractal parameters from the coarse resolution data. The slope is determined by the difference in elevation between two points a given distance apart. The distance can be represented by grid size in a DEM and the roughness of relief in an area can be substituted by the standard deviation (σ) of the elevation. When the standard deviations in the sub-areas of various resolution DEMs were compared by Zhang *et al*. (1999), it was found that there is a large variation in the standard deviation between different sub-areas but only a slight decrease from high resolution to low resolution in the same sub-area. The coefficient α and the fractal dimension D vary in different sub-areas; however, they are mainly controlled by the standard deviation of the elevations.

The relationships found by Zhang *et al*. (1999) between D and α and σ when the scaling coefficients derived from eastern Asia and south east Spain were plotted against the corresponding standard deviation of elevation and the slopes were calculated by D8 method, the regression equations are:

$$\alpha = 0.33733\ (\sigma)^{1.4004} \qquad (18)$$

$$D = 1.13589 + 0.084521\mathrm{n}(\sigma) \qquad (19)$$

4.3 Adapting fractal approach for local topography

For the estimation of fractal parameters, i.e., the fractal dimension (D) and the fractal constant (α) as proposed by Zhang *et al*. (1999), considering the variogram technique, uses the equation (18) and (19), which are applicable for the entire South East Asia. For the application of fractal theory to smaller areas requires estimation of local fractal parameters. To serve the purpose, the equation for the estimation of fractal dimension was kept same, whereas equation for the fractal constant (α) was needed to be revised. It was done by first estimating the fractal dimension (D) by using equation (19) and then fractal constant (α) by using equation (17), as we know the actual slopes for each grid at coarser resolutions. Once the fractal constant and fractal dimension both are evaluated, then the scatter diagram between fractal constant and standard deviation (σ) has been plotted. And the equation for fractal constant can be derived as the best fitted line to the scatter diagram (using second order polynomial) as given in equation (20):

$$\alpha = K_1\ (\sigma)^2 - K_2\ (\sigma) \qquad (20)$$

Now using equation (19) and (20) in equation (17), scaled slope at any scale (grid size) can be obtained.

4.4 Up–scaling the model equations

Considering the previous section, it is clear that for estimating soil erosion and sediment discharge at regional scales accurately using coarse resolution data, the soil erosion and sediment transport model needs scaling up. Therefore, the slope S is scaled down to the point/plot/hill slope scale using equation (17) (to a scale of 50 to 100 m), and the model equations for slopes are scaled up as αd^{1-D}, in order to make the soil erosion and sediment transport model relatively invariant to spatial scales. Whatever is the grid size for modelling, soil erosion and sediment discharge results should be same for that catchment.

Instead of estimating the scaled slopes at any fixed downscaling size (d), the scaled slopes at finer sizes are estimated from the coarse resolution information in the form of standard deviation of the elevation. An ASCII file is made available for the standard deviations for the each cell of the catchments. Computer code reads that standard deviations, and estimates the fractal constant and fractal dimension using equations (19) and (20), and finally scaled slopes can be determined at any user specified scale using equation (17).

5. DATA SOURCES FOR MODEL CALIBRATION/VALIDATIONS

Model has been calibrated and validated for various sub–catchments of the Chao Phraya river basin, Thailand as shown in Figure 2.

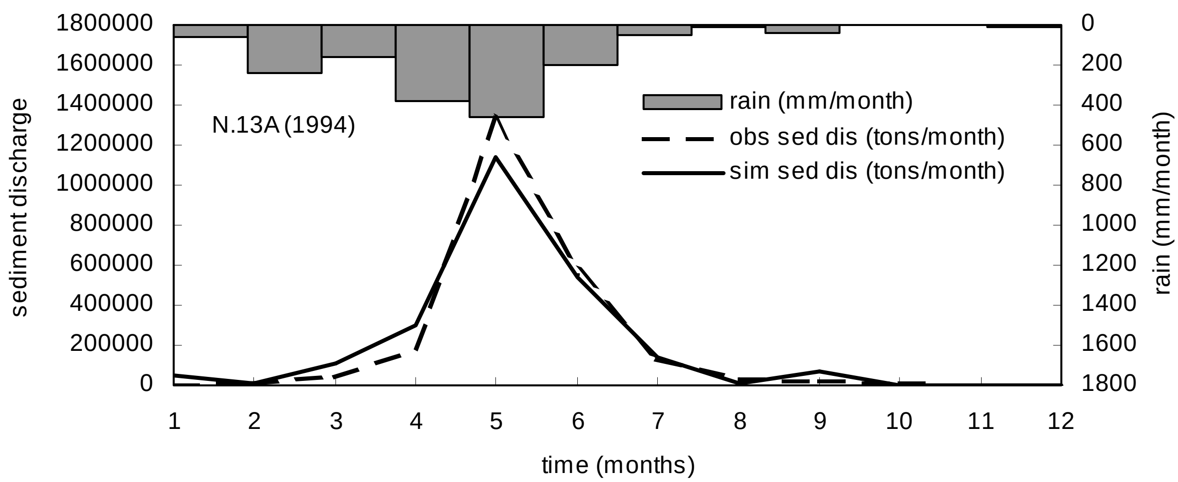

Figure 3: Simulation results of sediment discharge for Nan river basin at Ban Bun Nak (N.13A)

5.1 Meteorological Data

The meteorological data available in this catchment include rainfall data, which was collected from Royal Irrigation Department (RID, 1993-1998). There are 140 rain gauges, which have only daily rainfall records. The missing rainfall data is filled by averaging the rain gauges in the vicinity. Hourly data are needed for hydrologic and soil erosion simulations and were estimated by dividing the rain duration. The rain duration is assumed to be equal at night and day time and related to daily rain amount. The duration is assumed to be 6 hours for the daily rainfall less than 10 mm, 12 hours for daily rainfall ranges 10–30 mm, 24 hours for daily rainfall more than 30 mm.

5.2 Topographical data

Topographical parameters were extracted by using the GTOPO30 (http://edcdaac.usgs.gov/gtopo30/gtopo30.html). GTOPO30 is a global digital elevation model

(DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometre). It was derived from several raster and vector sources of topographic information, completed in late 1996, and was developed over a three-year period through a collaborative effort led by staff at the U.S.Geological Survey's EROS Data Centre (EDC).

5.3 Land use and Soil data

The land use data used for the modelling is USGS (United States Geographical Survey's) Earth Resources Observation System (EROS) Data Centre, the University of Nebraska–Lincoln (UNL) and Joint Research Centre of European Commission, of about 1 km resolutions. Dataset is based on 1-km AVHRR data spanning April 1992 through March 1993.

As raindrop impact detachment coefficients and overland flow detachment coefficients have relation with the textural classification of soil. For USDA textural classification, the data from International Soil Reference and Information Centre (ISRIC) was used for extracting the soil related model parameters. It consists of homogenized, global set of 1125 soil profiles. The data is available at relatively coarser resolutions of 5 minutes (about 10 km).

6. MODEL CALIBRATION/VALIDATIONS

6.1 Model calibration for Nan river basin

The catchment area of Nan River basin at Ban Bun Nak (N.13A), Amphoe Sa, Nan is 8551 km^2, and the outlet is situated at Lat. 18^o-33'-12" N, Long. 100^o–46'-08" E, on right bank from Ban Bun Nak.

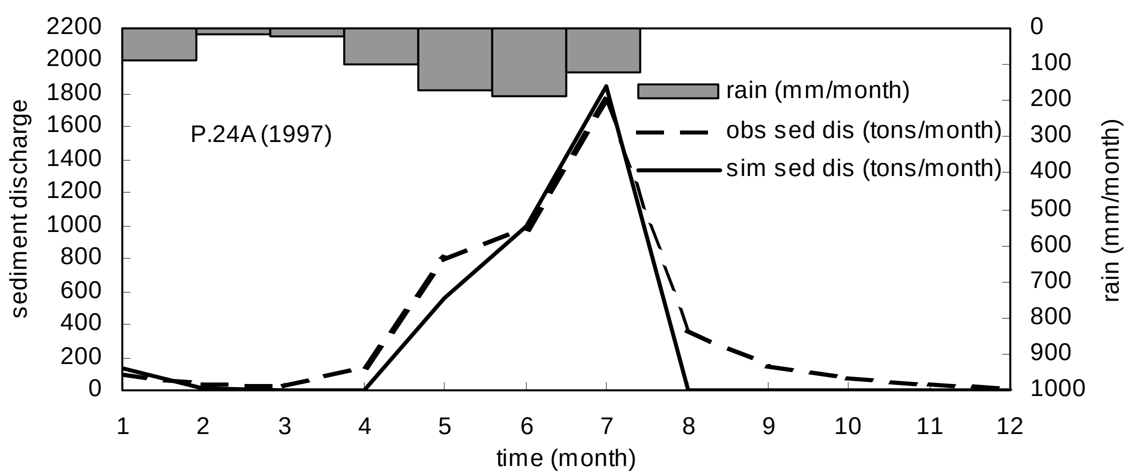

Figure 4. Simulation results of sediment discharge for Ping river basin at Nam Mae Klang (P.24A)

The discharge is recorded by staff gage, with a frequency of recording of 5 times daily, and the mean daily discharge is obtained by the arithmetic mean of 5 readings. No overbank flow conditions observed. Method of sampling is Depth Integrating and sediment sampler used for the measurement is US.D-49 (RID, 1993-1998).

6.2 Strategy

Modelling is carried out by considering the surface flow only in the river grids, therefore, no attempt is made to calibrate the observed hydrographs, but major parameters were adopted from previous hydrological modelling studies (Jha, 1997, and Yang, 1998). We do not expect short term sediment yield to match because damping effect by surface sediment flow is not considered, since all sediment load is generated by major rainstorms, surface modelling should be adequate to explain integrated sediment yield observations. Therefore, parameter calibration is carried out for monthly-observed sediment discharges. The monthly-simulated results are shown in Figure 3.

6.3 Model Validation

6.3.1 Nam Mae Klang River basin (P.24A), Thailand

The catchment area of Nam Mae Klang river basin is 460 km^2, and the outlet is situated at Lat. 18^o-25'-01" N, Long. 98^o-40'-29" E, on left bank at Pracha Uthit bridge, Amphoe Chom Thong, Chiang Mai. The discharge is recorded by staff gage, with a frequency of 5 times daily at 06:00, 09:00, 12:00, 15:00, 18:00, and the mean daily discharge is obtained by the arithmetic mean of 5 readings (RID, 1993–1998).

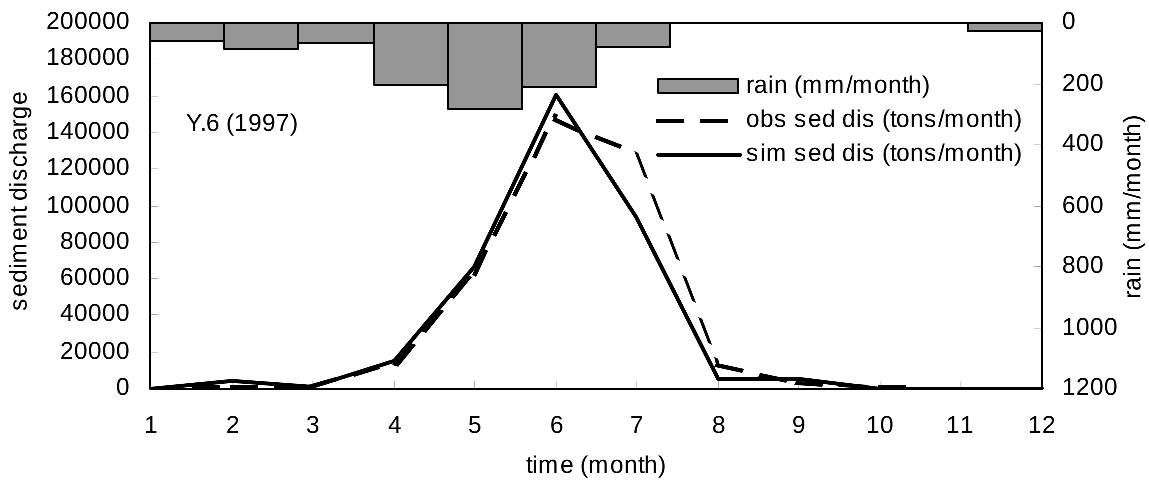

Figure 5. Simulation results of sediment discharge for Yom river basin at Ban Kaeng Luang (Y.6)

For sediment discharge measurement, method of sampling is Depth Integrating and sediment sampler used for the measurement is US.DH-59 (RID, 1993-1998).

There are three landuse types, i.e. Paddy, Forest and Grassland. Grassland is the major land use in the catchment. There are two soil types, and according to textural classification both are Sandy Clay Loam with different d_{50} values. There is one rain gauge station contributing rain to this catchment.

The catchment is modelled for hydrology, soil erosion and sediment discharge for the water year (April-march) of 1997. Monthly simulation results for soil erosion and sediment discharge are shown in Figure 4, the monthly-simulated sediment discharge is matching well with the observed one, except in few months. In 4th and 5th months, the simulated sediment discharges are slightly underestimated as compared to the observed sediment discharge. The reason of underestimation is the contribution from the river part in these months, which have not been considered while modelling. Similarly in 8th, 9th and 10th months, simulated sediment discharges are almost zero, whereas observed have some values. It is due to the fact that surface part cannot contribute any sediment load when there is no rainfall and surface flow on overlands, so sediments can neither be detached nor transported to the outlet location. In these months observed sediment discharges are generated due to river bed erosion, which is due to shear stresses and transport developed by the base flow only and the reasoning is confirmed by considering ground water flow contributions in river grids (Habib, 2001).

6.3.2 Yom River Basin at Ban Kaeng Luang (Y.6), Thailand

The catchment area of Yom river basin at Ban Kaeng luang is 12984 km^2, and the outlet is situated at Lat. 17^o-26'-03" N, Long. 99^o-47'-32" E, on left bank from Kaeng Luang, Amphoe Si Satchanalai, Sukhothai. The discharge is recorded by staff gage, with a frequency of recording of 5 times daily, and the mean daily discharge is obtained by the arithmetic mean of 5 readings. No overbank flow conditions are observed.

There are five land use types; grassland is the major land use in the catchment. There are also five soil types. The total number of rain gauges contributing rainfall to the catchment are 23. The model has been validated for the water year 1997.

The monthly-simulated results are shown in Figure 5. Monthly-simulated results are well reproduced except for the 7th and 8th months. As in 7th month there are few rains, and contribution from the surface part only is very small. As sediment generation from the river part due to ground water flow is not considered in the simulation so simulated sediment discharge in this month is lesser as compared to the observed sediment discharge. Same is the case for the 8th month. This reasoning is justified by simulating the daily sediment discharges by considering the ground water flow contributions in the river grids (Habib, 2001).

7. CONCLUSIONS

A regional scale soil erosion and sediment transport model has been developed by considering the surface flow contributions only, giving concept of equivalent channels for representing soil erosion from rills and gullies, and by up-scaling the model equations for the slopes to reproduce the loss of heterogeneity in the spatial information for topography.

Model has been calibrated for the Nan river basin (N.13A), for the year 1994 (by averaging with other catchments). Then model is applied/validated to the Yom river basin (Y.6) for the water year of 1997 and to the Nam Mae Klang river basin (P.24A) for the water year of 1997.

For these sub-catchments, in general, simulation results are well reproduced using the same model calibrating parameters for soil and land use types, only discrepancy is found in Nam Mae Klang river basin for the flow detachment coefficients (K_f). For Nam Mae Klang river basin, flow detachment coefficients required to match the sedi-graph are relatively lower as compared to the similar soil types. This discrepancy is expected due to assigning the same values of equivalent channel widths for 0 and 1 flow accumulation value grids.

Though in some simulation results, peak discharges are slightly underestimated which indicates the sediment contributions from the groundwater flow in the river grids, but overall simulated results explain the sediment generation and deposition processes in the river system.

Developed regional scale soil erosion and sediment transport model can simulate well soil erosion even at daily temporal scales, whereas sediment discharges are presented at monthly temporal scales (which is sufficient for maintaining the regional scale sediment budgets) without considering the groundwater flow component in the river grids.

The developed model with a few more new components is also quite useful for simulating the sediment discharges due to future climate and land-use change scenarios for the river Indus.

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