ANALYSIS OF SOIL EROSION AND SEDIMENT YIELD USING EMPIRICAL AND PROCESS BASED MODELS

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Abstract
Soil erosion has been recognized as a global threat against the sustainability of natural ecosystem. But, modeling of soil erosion and sediment yield has been regarded as the one of difficult task as it is a highly dynamic process in spatial scale. The main objective of this study was to simulate soil erosion and sediment yield using both empirical and process based models. The Revised form of Universal Soil Loss Equation (USLE), known as Revised Universal Soil Loss Equation (RUSLE), has been applied in a sub-basin of Mun river basin, Thailand. The results obtained from RUSLE model are compared with the results obtained from a process-based soil erosion and sediment transport model. The method involves spatial disintegration of the catchment into homogenous grid cells to capture the catchment heterogeneity. The spatial discretization of the catchment and derivation of the physical parameters related to erosion in the cell are performed through GIS techniques. The simulated outcomes from process-based model are found to be closer to observations as compared to the outcomes of the empirical approach.

Keywords: RUSLE, process-based model, soil erosion, sediment yield

INTRODUCTION
Soil erosion is recognized as a major problem arising from agricultural intensification, land degradation and possibly due to global climatic change. It is the matter of concern that the population is increasing in a rapid rate and the resource like soil, which is necessary to sustain the population, is steadily sinking day by day. The information on the sources of sediment yield within a catchment can be used as a perspective on the rate of soil erosion occurring within that catchment. Estimation of sediment yield from catchments is important for many reasons. Not only deposition of sediment transported by river into a reservoir reduces the reservoir capacity but also sediment deposition on river bed and banks causes widening of flood plains during floods.

Deforestation, urbanization and agricultural intensification are the major factors which influence the rate of erosion and sedimentation. Since it is not possible to monitor the influence of every land-use practices in all ecosystems under all weather conditions, erosion predictions are used to rank alternative practices with regard to their likely impact on erosion. Assessment of soil erosion as to how fast soil is being eroded is helpful in planning conservation work. What is required, then, is a method of predicting soil loss under a wide range of conditions – that is model. Modeling can provide a quantitative and consistent approach to estimate soil erosion and sediment yield. Models available in the literature for sediment yield estimation can be grouped into two categories: (i) physically-based models; and (ii) empirical models. Physically based models are intended to represent the essential mechanisms controlling erosion process. These models are the synthesis of individual component that affect the erosion process. The physically-based models include AGNPS (Young et al., 1987), ANSWERS (Beasley et al., 1980) and WEPP (Nearing et al., 1989). Simple empirical methods such as the Universal Soil Loss Equation (USLE) (Musgrave, 1947), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1991) are frequently used for the estimation of surface erosion and sediment yield from catchment areas (Ferro & Minacapilli 1995; Ferro 1997; Kothyari & Jain, 1997). Due to the spatial variation in rainfall and to catchment heterogeneity, both
these variables are spatially varied. Such variability has promoted the use of data intensive process-based distributed models for the estimation of catchment erosion and sediment yield viz. by discretizing a catchment into sub-areas each having approximately homogeneous characteristics and uniform rainfall distribution (Young et al., 1987). To encapsulate the spatial variation of the parameters like topography, soil and land use etc. in a watershed, the use of Geographical Information System (GIS) methodology is well suited. GIS can be used for the discretization of the catchments into small grid cells and for the computation of such physical characteristics of these cells as slope, land use and soil type, all of which affect the processes of soil erosion and deposition in the different sub-areas of a catchment. In the present study, revised form of USLE model, RUSLE is used in conjunction with a raster-based GIS, to predict erosion potential on a cell by cell basis and to determine the catchment sediment yield by using the concept of sediment delivery ratio. Similarly, a process-based soil erosion and sediment transport model is also applied and finally the performances of empirical and process based model are evaluated.

STUDY AREA

The study area is the M91 sub-watershed of the Mun river as shown in Figure 1. The Mun River basin lies between latitude 14° N and 16°N, and longitude 101°E and 105°E. The Mun River is the largest right bank tributary of the Mekong River, situated in the northeastern part of Thailand. The Chi River joins the Mun River at about 100 km upstream of the confluence with the Mekong River. Chi-Mun basin covers 15 % area of Mekong basin and the discharge contribution of the basin is 6.1 % in dry season and 4.7 % in rainy season. The total draining area of Mun basin is approximately 69,000 km². In an average year, the contribution of Chi-Mun to the Mekong is approximately 25,000 MCM, which is equivalent to an annual runoff of 210 mm or 800 m³/s. Roughly two thirds of this comes from the Mun River. The average annual rainfall in the basin is 1200 mm which varies from 1600 mm in the east and 1000 mm in the west part of the basin. It covers five provinces (Nakhon Ratnasima, Buri Ram, Surin, Sisaket and Ubon Ratchathani) entirely and three (Maha Sarakham, Rio Et and Yasothon) partly.

Between 1990 and 1995, the average deforestation rate in the Lower Mekong basin was 1.6 % per annum - one of the highest rates in the world. The erosion in the basin is mainly rainfall based runoff erosion subjected to the effects of land use. Chi-Mun basin comprises of more than 20 dams. And, the deposition of sediment transported by river into the reservoir is reducing the reservoir capacity. The average annual loading of the suspended sediments during the 90s at the Chi-Mun/Mekong Junction was 0.96 million tons/yr. The M91 sub-watershed is selected for this study based on the location of the sediment gauging station M91, which is not affected by the reservoir located in the downstream. The size of the M91 sub-watershed is about 128 km² with an average annual sediment yield of 12,648 tons.

METHODOLOGY

The rate of soil erosion from an area is strongly dependent upon its soil, vegetation and topographic characteristics beside rainfall and runoff. These factors are found to vary greatly within the various sub-areas of a catchment. Therefore, the catchment needs to be discretized into smaller homogeneous units before making computations for soil loss. A grid-based discretization is found to be the most reasonable procedure in both process-based models as well as in other simple models (Beven, 1996; Kothyari & Jain, 1997).

Methods such as the USLE have been found to produce realistic estimates of surface erosion over areas of small size (Wischmeier & Smith, 1978). The USLE is expressed as:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]  \hspace{1cm} (1)

Where \( A \) = Average annual soil loss predicted (ton ha⁻¹), \( R \) = Rainfall runoff erosivity factor (MJ mm ha⁻¹ hr⁻¹), \( K \) = Soil erodibility factor (ton ha hrMJ⁻¹ ha⁻¹ mm⁻¹), \( L \) = Slope length factor and \( S \) = Slope steepness factor, \( C \) = Cover management factor and \( P \) = Support practice factor.
The value of USLE factors are computed on the methods described by Agricultural Handbook 703 (Renard et al., 1996).

Mathematically, \( R \) is computed as:

\[
R = \frac{1}{n} \sum_{i=1}^{n} \left( \sum_{j} E_j (I_{30}) \right)
\]

(2)

Where \( n \) = Total no. of years, \( m \) = Total number of rainfall storms in \( i^{th} \) year, \( I_{30} \) = Maximum 30 minutes intensity (mm hr\(^{-1}\)), \( E_j \) = Total kinetic energy (MJ ha\(^{-1}\)) of \( j^{th} \) storm of \( i^{th} \) year and is given as:

\[
E_j = \sum_{k} e_k * d_k
\]

(3)

Where \( p \) = Total number of divisions of \( j^{th} \) storm of \( i^{th} \) year, \( d_k \) = Rainfall depth of \( k^{th} \) division of the storm (mm), \( e_k \) = Kinetic energy (MJ ha\(^{-1}\) mm\(^{-1}\)) of \( k^{th} \) division of the storm and is given as: (Renard et al., 1996)

\[
e_k = 0.29(1 - 0.72e^{-0.05i_k})
\]

(4)

Where \( i_k \) = Intensity of rainfall of \( k^{th} \) division of the storm (mm hr\(^{-1}\))

If \( \lambda \) is the horizontal projection of the slope length (in meter), then \( L \) factor is given as,

\[
L = \left( \frac{\lambda}{22.1} \right)^m
\]

(5)

Where \( m \) = Variable slope length exponent.

The slope-length exponent ‘\( m \)’ is related to the ratio \( \beta \) of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation:

\[
m = \frac{\beta}{(1 + \beta)}
\]

(6)

For moderately susceptible soil in both rill and interrill erosion, McCool et al. (1989) suggested the equation:

**Figure 1. M91 sub-basin**
\[ \beta = \frac{11.1607 \sin \theta}{3.0 (\sin \theta)^{0.5} + 0.56} \]  
(7)

Where \( \theta \) = Slope angle (degrees)

The slope steepness factor \( S \) is evaluated from (McCool et al., 1987).

\[
S = 10.8 \sin \theta + 0.03 \quad \text{for } s < 9\%
\]
\[
S = 16.8 \sin \theta - 0.50 \quad \text{for } s \geq 9\%
\]  
(8)

Where \( \theta \) = Slope angle (degrees)

\( C \) and \( P \) factors were assigned to different grid according to land cover while \( K \) factor was estimated using the soil data.

**Sediment delivery ratio**

In a catchment, part of the soil eroded in an overland region deposits within the catchment before reaching its outlet. The ratio of sediment yield to total surface erosion is termed the sediment delivery ratio (\( DR \)). Values of \( DR \) for an area are found to be affected by catchment physiography, sediment sources, transport system, texture of eroded material, land cover etc. (Walling, 1983, 1988). However, variables such as catchment area, land slope and land cover have been mainly used as parameters in empirical equations for \( DR \) (Hadley et al., 1985; Williams & Berndt, 1972; Kothyari & Jain, 1997).

Ferro & Minacapili (1995) and Ferro (1997) hypothesized that \( DR \) in grid cells is a strong function of the travel time of overland flow within the cell. The travel time is strongly dependent on the topographic and land cover characteristics of an area and therefore its relationship with \( DR \) is justified. Based on their studies, the following empirical relationship was assumed herein for a grid cell lying in an overland region of a catchment:

\[
DR = \exp(-\gamma t_i)
\]  
(9)

Where \( t_i \) is the travel time (h) of overland flow from the \( i^{th} \) overland grid to the nearest channel grid down the drainage path and \( \gamma \) is a coefficient considered as constant for a given catchment.

The travel time for grids located in a flow path to the nearest channel can be estimated if one knows the lengths and velocities for the flow paths. In grid-based GIS analysis, the direction of flow from one cell to a neighboring cell is ascertained by using an eight direction pour point algorithm. Once the pour point algorithm identifies the flow direction in each cell, a cell-to-cell flow path is determined to the nearest stream channel and thus to the catchment outlet. If the flow path from cell \( i \) to the nearest channel cell traverses \( m \) cells and the flow length of the \( i^{th} \) cell is \( l_i \) (which can be equal to the length of a square side or to a diagonal depending on the direction of flow in the \( i^{th} \) cell) and the velocity of flow in cell \( i \) is \( v_i \), the travel time \( t_i \) from cell \( i \) to the nearest channel can be estimated by summing the time through each of the \( m \) cells located in that flow path:

\[
t_i = \sum_{i=1}^{m} \frac{l_i}{v_i}
\]  
(10)

For the present study, the method for the determination of the overland flow velocity proposed by the US Soil Conservation Service was chosen due to its simplicity and to the availability of the information required (SCS, 1975). The flow velocity is considered to be a function of the land surface slope and the land cover characteristics:

\[
v_i = a_i * S_i^b
\]  
(11)
Where $b$ is a numerical constant equal to 0.5 (SCS, 1975; Ferro & Minacapilli, 1995), $S_i$ is the slope of the $i$th cell and $a_i$ is a coefficient related to land use (Haan et al. 1994). Introducing equations (10) and (11) into equation (9) gives

$$D_{E_i} = \exp\left(-\sum_{i=1}^{n} \frac{l_i}{a_i S_i^b} \right)$$ (12)

Note that $l_i / S_i^{0.5}$ is the definition of travel time used by Ferro & Minacapilli (1995). Values of the coefficient $a_i$ for different land uses were adopted from Haan (1994).

If $S_E$ is the amount of soil erosion produced within the $i$th cell of the catchment estimated using equation (1), then the sediment yield for the catchment, $S_y$, was obtained as below:

$$S_y = \sum D_R * S_E$$ (13)

Where $N$ is the total number of cells over the catchment and the term $DR$ is the fraction of SE that ultimately reaches the nearest channel. Since the $DR$ of a cell is hypothesized as a function of travel time to the nearest channel, it implies that the gross erosion in that cell multiplied by the $DR$ value of the cell becomes the sediment yield contribution of that cell to the nearest stream channel. The $DR$ values for the cells marked as channel cells are assumed to be unity.

**Process-based distributed model**

The distributed model developed in the University of Tokyo (Mughal, 2001) contains overland flow simulation model coupled with sediment transport model. For overland flow model development, Saint Venant equations are used. The continuity equation and momentum equations are used for the overland flow model.

The continuity equation is represented as

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$ (14)

The continuity equation is applied between the center points of the two consecutive grids. Similarly, the moment equation can be represented as:

$$S_{f} = S_p$$ (15)

Where $t =$ time, $x =$ distance along the longitudinal axis of the water course, $A =$ cross sectional area, $Q =$ discharge through $A$, $s_f =$ friction slope and $s_o =$ bed slope

Above two equations are combined to obtain overland flow equation with only one unknown ‘$Q$’ using kinematic wave approximation scheme.

$$\frac{\partial Q}{\partial x} + \alpha \beta Q^{\alpha-1} \frac{\partial Q}{\partial t} = q$$ (16)

Where $\alpha = \left( \frac{n P_{1/3}}{1.49 S_{x}^{0.75}} \right)^{\beta} \text{ And } \beta = 0.6$

The soil erosion and sediment transport is modeled as the detachment of soil by raindrop impact, leaf drip impact, detachment by overland flow over the entire grid and one-dimensional transport or routing of the eroded material by overland flow on the regular square grid discretized system.

Detachment due to raindrop impact process is modeled based on relationships between detachment and kinetic energy of the rainfall due to both direct through fall and leaf drip impact as a function of their kinetic energies. This enables the effects of different heights of vegetation and canopy and residue to be simulated explicitly.
The rainfall energy reaching the ground surface as direct throughfall \((KE (DT), \text{J m}^{-2} \text{mm}^{-1})\) is assumed the same as that of the natural rainfall. It is estimated as a function of rainfall intensity from equation derived by Brandt (1989).

\[
KE (DT) = 8.95 + 8.44 \log (I)
\]

Where \(KE (DT)\) is the kinetic energy of direct fall \((\text{J m}^{-2} \text{mm}^{-1})\), \(I\) is the rainfall intensity \((\text{mm hr}^{-1})\)

The energy of leaf drainage is estimated from the following relationship developed experimentally by Brandt (1990)

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

The total kinetic energy of the rainfall can be calculated by multiplying energies obtained from the equations (17) and (18) by their respective depths of direct throughfall and leaf drainage received and summing the two values:

\[
KE = (1-C_c) KE (DT) . H_{DT} + C_c . KE (LD) . H_{LD}
\]

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

Detachment due to rainfall impact is estimated for each time step using Torri et al. (1987) equation, which relates the detachment due to raindrop impact with the total kinetic energy of the rainfall.

\[
D_R = (1-C_g) k. (KE) e^{-zH}
\]

Where \(D_R\) is the soil detachment by raindrop impact \((\text{g m}^{-2})\), \(k\) an index of the detachability of the soil \((\text{g J}^{-1})\) and depends on the soil texture (Morgan, 1996), \(KE\) is the total kinetic energy of the rain \((\text{J m}^{-2})\), \(z\) is an exponent and working value of 2.0 is therefore as representative of a range of values between 0.9 and 3.1, \(H\) is the depth of surface water layer \((\text{mm})\) and \(C_g\) is the proportion of ground cover in each processing cell or flow element.

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

\[
D_F = K_f \left( \frac{T}{T_c} - 1 \right) \text{for } T > T_c
\]

\[
D_F = 0 \text{ for } T \leq T_c
\]

Where \(D_F\) is the overland flow detachment \((\text{kg m}^{-2} \text{s}^{-2})\), \(K_f\) is overland flow detachability coefficient \((\text{kg m}^{-2} \text{s}^{-1})\) and can be determined experimentally, \(T_c\) is the critical shear stress for initiation of motion from the Shield’s curve and \(T\) is the hydraulic shear stress \((\text{N m}^{-2})\) as given by

\[
T = \gamma . h . S
\]

Where \(\gamma\) is specific weight of water \((\text{N m}^{-3})\), \(h\) is depth of overland flow \((\text{m})\) 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.

Total potential detachment at any cell \((x)\) and time \((t)\) \(\{e(x,t)\}\) is then calculated as the sum of splash and flow detachment as given in equation (24),

\[
e(x,t) = D_R (x,t) + D_F (x,t)
\]

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 (24). 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.

For one-dimensional forward sediment transport routing, the kinematic mass balance equation can be applied between centers of two consecutive grids considering the flow direction. Total detachments are calculated as the sum of the splash detachment and detachment due to overland flow. After considering the transport capacity of flow, the total actually detached load 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.

\[
\frac{\partial (AC)}{\partial t} + \frac{\partial (QC)}{\partial x} = 0
\]
Where $C$ is the sediment concentration, $A$ is the cross-sectional area of flow and $Q$ is discharge or volume flow rate.

Since there is only one unknown in sediment mass balance equation, that is sediment concentration at any time and space. The above equation can be rewritten in terms of sediment discharge as

$$\frac{\partial (Q/V)}{\partial t} + \frac{\partial (Q)}{\partial x} = 0$$

(26)

Where $V$ = mean velocity of flow and $Q_s$ = Sediment discharge

Using finite difference approach, sediment discharge $Q_s$ can be obtained since other parameters in the equation are know.

**Data preparation and simulation**

For RUSLE model, 3 hourly rainfall data from year 1985-2000 was obtained from Thailand Meteorological Department (TMD) for $R$ factor computation. $R$ value was computed using equations (2), (3) and (4). The long term annual averaged $R$ value for the station Tha Tum was computed to be 968.14.

Topographical parameters ($L, S$) were extracted by using SRTM-DEM of resolution 90 m. Equation (5) was used for $L$ factor calculation while $S$ factor was computed using equation (8) for each cell.

The values for the factors $K$, $C$ and $P$ were estimated for different grids using the soil and land cover data. The data in the Land Use and Soil layers were obtained from the CDROM “Thailand on a disc”. These data were provided by the Department of Land Development (DLD) in the scale of 1:250,000. $K$ values were assigned on the basis of soil texture (Schwab et al. 1981) and are presented in Table 1.

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Organic matter content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0.0356</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>0.0487</td>
</tr>
</tbody>
</table>

$C$ value, which depends on land use, was obtained from different literature (Schwab et al. 1981, Morgan, 1995). The $C$ values used in the study are shown in Table 2.

<table>
<thead>
<tr>
<th>SN</th>
<th>Land Use</th>
<th>C value basis</th>
<th>C Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cultivated land</td>
<td>Crops, disturbed land</td>
<td>0.4000</td>
</tr>
<tr>
<td>2</td>
<td>Forest land</td>
<td>Forest</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

In case of $P$ factor, the value is taken 0.5 for agricultural land and for rest of the land use; $P$ value is assigned to be 1.

In case of process-based model, it is necessary to calibrate the model for water discharge before applying it to the sediment yield comparison. The model was calibrated for monthly mean discharge at the outlet of sub-watershed M91. The model was run for the period of 6 months from June 1990 to November 1990. The results obtained from the model calibration are compared with the mean observed discharge and the comparison is shown in the Figure 2(a). Similarly, model verification was done for the period of June to November 1991. The results obtained from the model are compared with the mean observed discharge and the comparison is shown in the Figure 2(b).
The landuse parameter used during the calibration and verification is presented in Table 3.

Table 3. Different land use parameters (Source: Mugal, 2001)

<table>
<thead>
<tr>
<th>Land use type</th>
<th>n</th>
<th>Canopy cover (frac.)</th>
<th>Canopy height (m)</th>
<th>Ground cover (frac.)</th>
<th>Leaf Area Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agr. land</td>
<td>0.040</td>
<td>0.60</td>
<td>1.00</td>
<td>0.020</td>
<td>3.52</td>
</tr>
<tr>
<td>Forest</td>
<td>0.060</td>
<td>0.70</td>
<td>30.0</td>
<td>0.030</td>
<td>2.84</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

During SDR calculation, the sensitivity analysis of the parameter $\gamma$ showed that the computed values of $S_y$ were not very sensitive to the value of $\gamma$ used in equation (12). $\gamma$ value was varied from 0.1 to 1.5 and it was observed that $S_y$ value varied by only 10%. So, $\gamma$ value is taken equal to 1 in the computation for the simplicity. The sediment contribution of each grid to the outlet was computed with the help of erosion potential map and SDR map. And, the sediment yield at the outlet was compared with the field measured data which was obtained from RID.

The simulation was carried out for two DEM resolutions: 90 m and 30 m (resampled from 90 m). The computed and observed value of average annual sediment yield at the catchment outlet is presented in Table 4. In case of 30 m resolution, the simulated yield is closer to the observation than the value obtained using 90 m DEM resolution. These results show that the DEM resolutions greatly influence the outcomes of the models. Table 5 shows the different USLE parameters and SDR values and it can be seen from this table that the $L$ and $S$ factors are different for these two DEMs of different resolutions. Change in grid size affects slope values and ultimately affects the values of $L$ and $S$ factors. $L$ factor is dependent on grid size and slope, whereas $S$ factor depends on slope only. The sediment yield maps obtained using 90 m and 30 m DEM resolution are shown in Figures 3 (a) and 3 (b).

Table 4. Computed and observed value of annual sediment yield

<table>
<thead>
<tr>
<th>Station</th>
<th>Observed (tons/Km$^2$)</th>
<th>Computed for 90 m DEM resolution (tons/Km$^2$)</th>
<th>Computed for 30 m DEM resolution (tons/Km$^2$)</th>
<th>% error for 90 m DEM</th>
<th>% error for 30 m DEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>M91</td>
<td>98.81</td>
<td>505.41</td>
<td>322.46</td>
<td>411.49</td>
<td>226.34</td>
</tr>
</tbody>
</table>

Table 5. DEM effect on USLE parameters and SDR

<table>
<thead>
<tr>
<th>DEM resolution</th>
<th>$L$ Factor</th>
<th>$S$ factor</th>
<th>SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 m</td>
<td>1-3.38</td>
<td>0.03-6.73</td>
<td>0.781</td>
</tr>
<tr>
<td>30 m</td>
<td>1-1.61</td>
<td>0.03-11.98</td>
<td>0.831</td>
</tr>
</tbody>
</table>
Simulation was carried for monthly basis and the time series of computed and observed sediment yield is shown in Figure 4. Improved results were obtained for DEM resolution of 30 m compared to the results obtained from 90 m resolution.

Process-based model output for the period of June to November 1990 is shown in the Figure 5 in comparison with the observed monthly sediment yield. As seen in the figure below, the simulated value is showing good agreement with the observed monthly sediment yield at the catchment outlet. Different soil parameters used in the model simulation are shown in Table 6. The model performance was evaluated in terms of different parameters. The Efficiency Index (EI) value of 0.78 and $R^2$ value of 0.92 shows that model results possess high correlation with the observed value.

Similarly, model was run for the period of 6 months from June to November 1991. Model output is shown in the Figure 6 compared to the observed monthly sediment yield.
As seen in Figure 6, the simulated value is showing good agreement with the observed monthly sediment yield at the catchment outlet. In this simulation, Efficiency Index (EI) value was obtained to be 0.93 and R^2 value of 0.93 shows that model results possess high correlation with the observed value. The error statistics of the model is shown in the Table 7.

![Figure 5. Comparison of observed and simulated monthly sediment yield (1990)](image)

Table 6. Soil parameters used in model simulation

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Soil detachability index, K_s (g/j)</th>
<th>Overland flow detachability index, K_f (mg/m²)</th>
<th>Density of particle (Kg/m³)</th>
<th>Median particle dia (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy clay loam</td>
<td>3.50</td>
<td>0.60</td>
<td>2680</td>
<td>45.0</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>2.00</td>
<td>0.40</td>
<td>2650</td>
<td>47.0</td>
</tr>
</tbody>
</table>
The result obtained from RUSLE and process-based model is shown in Table 8. The results shows that the RUSLE computed values were higher than the observations from the period of August to October 1990. But the process-based model results are showing good agreement with the observations for same duration.

Table 8. Performance comparison of the models

<table>
<thead>
<tr>
<th>Date</th>
<th>Simulated sediment yield (tons)</th>
<th>Observed</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RUSLE</td>
<td>Process-based</td>
<td></td>
</tr>
<tr>
<td>Jun-90</td>
<td>1098.49</td>
<td>120.01</td>
<td>24.00</td>
</tr>
<tr>
<td>Jul-90</td>
<td>291.21</td>
<td>152.92</td>
<td>469.00</td>
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<tr>
<td>Aug-90</td>
<td>1716.33</td>
<td>250.40</td>
<td>225.00</td>
</tr>
<tr>
<td>Sep-90</td>
<td>2791.47</td>
<td>327.00</td>
<td>753.66</td>
</tr>
<tr>
<td>Oct-90</td>
<td>7988.80</td>
<td>2696.00</td>
<td>196.32</td>
</tr>
<tr>
<td>Nov-90</td>
<td>121.85</td>
<td>0.77</td>
<td>159.00</td>
</tr>
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CONCLUSIONS

This study was an attempt to estimate soil erosion and sediment yield in a river basin using a conceptual method, RUSLE and compare the results with a process based model. The results have showed that the computed and observed values have significant difference for empirical model and DEM resolutions influence the outcomes. The error between computed and observed annual average sediment yield was found to be 411.49% in case of 90 m DEM resolution. After resampling 90 m DEM into 30 m resolution, the computed % error was 226.34%. The improvement was due to the effect of DEM resolution on L, S and SDR factors. The variation in the result may be due to the certain assumptions made during the analysis like computation of soil erodibility value on the basis of soil texture and use of constant C values in stead of time varying. In time series computation, process-based model performance was better than RUSLE method. From June to October 1990, the error between simulated results by process-based model and observations is within 70%. Although there are many input parameters for the process-based model, it resembles the real process of detachment, erosion and
transportation of sediment and hence should give better result than the empirical approach. It should be noted that USLE is intended primarily concerned on predicting long-term annual average erosion by water on distributed slopes, not for computation and time series analysis of sediment yield.

REFERENCES


