8.1. Introduction

Soil erosion is a complex dynamic process by which surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and sedimentation in reservoir. Accelerated soil erosion has adverse economic and environmental impacts (Lal, 1998). Many other problems are created by soil erosion like deposition of unfertile material on cultivated lands, harmful effects on water-supply, fishing, sedimentation of canals and rivers and most importantly the destruction of fertile agriculture land.

Soil degradation by accelerated water and wind induced erosion is a serious problem in the 21st century. Erosion is a natural geomorphic process occurring continually over the earth’s surface. However, the acceleration of this process through anthropogenic perturbations can have severe impact on environmental quality. This kind of impact is quicker to appear and more pronounced in tropical and subtropical countries like India. It is due to the interactions of soil characteristics and climate with agricultural practices and the transformation of forests into cultivated land as a result of anthropogenic influence (Morales et al., 2003). According to a study conducted by the National Bureau of Soil Survey & Land Use Planning, it is estimated that out of the total geographical area of 329 Mha of India, about 167 Mha is subject to environmental degradation due to water and wind erosion. This includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, water logging, salinity and alkalinity, shifting of river courses and desertification (Das, 1985). Narayan and Rambabu (1983) have estimated that in India about 5334 Mt (16.4 t/ha) of soil is detached annually, about 29% is carried away by the rivers into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the storage capacity.

So, planning of soil conservation measures has become prominent agenda in the view of river basin management. To plan for the measures of soil conservation the information of soil erosion is essential. Saha (2004) described soil erosion as a three stage process: (1) soil detachment, (2) transport and (3) deposition of eroded particles. Although all these process seem to occur jointly, but there are different agents behind such processes. Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, sheering or drag force of water and wind. Detached particles are transported by flowing water.
(over-land flow and inter flow) and wind and sedimented when the velocity of water or wind decreases by the effect of slope or ground cover. Thus different method should be adopted in order to quantify the soil erosion and sedimentation separately which will help of better planning and prioritizing treatments of the catchment.

8.1.1. Method for estimating soil erosion

Soil erosion is mainly caused by water and is affected by the various parameters like slope, land use, soil characteristics, climatic elements and biological activities. Thus, efforts have given to develop some equations for the estimation of water induced soil erosion by using the aforesaid parameters. Field studies for estimating soil erosion are expensive, time-consuming and have limitations in terms of the complexity of interactions and difficulty of generalizing results. Soil erosion models can simulate erosion processes in the watershed and can take many complex interactions that affect the rates of erosion. The development of Universal Soil Loss Equation (USLE) in 1978 by Wischmeier and Smith was an initiation of such process (Paul et al., 1999). The Revised Universal Soil Loss Equation (RUSLE) computes sheet and rill erosion from rainfall and associated runoff for a landscape profile. The revised and updated version of the Universal Soil Loss Equation (USLE) (Renard et al., 1990; Ferro & Minacapilli 1995; Ferro 1997; Kothyari & Jain, 1997; Ferro et al., 1998; Di Stefano et al., 1999) incorporated data from research sites in the United States for improving erosion estimates on tilled lands.

RUSLE can be used to compute soil loss on areas where significant overland flow occurs, not for lands with less or no overland flow occurs, such as undisturbed forest lands (NSERA, 1995 and Renard et al., 1997).

For the present study area Revised Universal Soil Loss Equation (RUSLE) has been prescribed because this model retains the simplicity of USLE:

\[ A = R \times K \times LS \times C \times P \]

Where, \( A \) = annual soil loss from sheet and rill erosion in tons/acre, \( R \) = rainfall erosivity factor, \( K \) = soil erodibility factor, \( LS \) = slope length and steepness factor, \( C \) = cover and management factor and \( P \) = support practice factor.

In addition to this, the model also encompasses some of the recent advances in understanding the erosion process into a water phase and sediment phase. The water phase considers the energy of the rainfall and the overland flow per raster cell, where as the sediment phase
comprises two predictive equations, one for rate of splash detachment and one for the transport capacity of overland flow.

In recent times Remote Sensing and Geographic Information System (GIS) has emerged as powerful tools for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output and for interaction with models. There is considerable potential of GIS technology to prepare soil erosion inventory, soil erosion modelling and erosion risk assessment. Erosional soil loss is most frequently assessed by RUSLE. Spanner et al. (1982) first demonstrated the potential of GIS for erosional soil loss assessment using RUSLE. Several studies indicate the potential utility of RS and GIS techniques for quantitatively assessing soil erosion rates (Saha et al., 1991; Saha and Pande, 1993; Mongkolsawat et al., 1994). RUSLE model was used for quantification of soil loss by water erosion in GIS environment using various satellite remote sensing derived inputs (ASD, 2002). The availability of GIS tools and more powerful computing facilities makes it possible to overcome difficulties and to develop continuous temporal models based on available regional information.

8.1.2. Method for estimating sedimentation

Several models of revised USLE (RUSLE and MUSLE) are still used for the estimation of sediment yield of any basin, but these quantities are found to have large variability due to the spatial variation of rainfall and catchment heterogeneity. Such variability has promoted the use of data-intensive process-based distribution models for the estimation of catchment sediment yield viz. by dividing a catchment into sub-areas having approximately homogeneous characteristics and uniform rainfall distribution (Young et al., 1987; Wicks and Bathurst, 1996). The use of Geographical Information System (GIS) technique is well suited for the quantification of heterogeneity in topographic and drainage features of a catchment (Shamsi, 1996; Rodda et al., 1999). Thus for the present study the Sediment Yield method proposed by Jain and Kothyari, 2000 has been adopted. The method is using GIS tools for dividing of the catchments into small cells and for the computation of such physical characteristics that affect the processes of soil erosion in the different sub-areas of a catchment. For the estimation of soil erosion the method requires any Soil loss model. Further GIS techniques are used to divide the sub-areas into overland and channel types, to estimate soil erosion for individual grid cells and to determine the catchment sediment yield by using the concept of sediment delivery ratio.
8.2. Estimation of soil loss of the Haora River basin by using RUSLE

8.2.1. Rain erosivity (R)

The rain erosivity factor has been estimated from the annual rainfall distribution map of the Haora River basin (Fig-8A). The maximum rainfall distribution is seen towards the western part of the basin (2348 mm) and it is decreasing towards east. The lowest rainfall distribution has been noticed in the southern part of Baramura hill (2040.24 mm). The annual average rainfall erosivity factor (Ra) ranges between 941.03 to 756.57 t.h^{-1}.y^{-1}. Although the maximum distribution of rainfall is restricted in and around Agartala and the Bangladesh plain, high rain erosivity is noticed in the entire north, north-east and north-western side of the basin (Fig-8B).

Fig-8.1 (A) Annual rainfall distribution map, (B) Rainfall erosivity map of the Haora River basin
8.2.2. Soil erodibility (K)

A detailed table has been prepared to show the taxonomy, texture, structure, area and the calculated K values associated with the different soil types (Table-8.1). Soil type varies from one place to another based on topographical and lithological characteristics.

In the soil distribution map (Fig-8.2A) it is noticed that Loamy type of soil is dominant in the entire river basin. K values of different soil types have been estimated from the Nomograph (after Wischmeier and Smith, 1978) of RUSLE. By plotting the K values against each soil type, the soil erodibility map of the study area has been prepared (Fig-8.2B). The K factor map shows that the maximum value of soil erodibility in the whole study area is 0.54 and
minimum of 0.2 having a mean of 0.34. In the Baramura part and other hilly tracts of the eastern side of the basin, covering an area of 72.04 km² (Soil No. 2-5) are possess fine loamy type of soil. These soils are having moderate K value ranging from 0.21- 0.30. Low relief areas of alluvial plains, flood plains, a portion of inter-hill valley region is spread over 171.94 km² of area and possess high K value ranges between 0.51 and 0.60 (Fig-8.2B). The minimum K value (0.19) is found in the remaining part of the inter-hill valley region occupies about 147.63 km² of the basin (Fig-8.1A).

Table-8.1 Individual soil taxonomy, texture, structure and K value of the soils

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>Soil Taxonomy</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>OC</th>
<th>Permeability</th>
<th>Structure</th>
<th>Area (km²)</th>
<th>K value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laterite</td>
<td>43.6</td>
<td>24.2</td>
<td>32.2</td>
<td>1.0</td>
<td>1</td>
<td>1</td>
<td>8.376</td>
<td>0.192</td>
</tr>
<tr>
<td>2</td>
<td>Fine loamy Typic Dystrochrepts/Paleudults</td>
<td>53.1</td>
<td>21.3</td>
<td>25.6</td>
<td>1.0</td>
<td>3</td>
<td>2</td>
<td>25.49</td>
<td>0.410</td>
</tr>
<tr>
<td>3</td>
<td>Fine loamy Umbric/Oxic Dystrochrepts</td>
<td>36.6</td>
<td>41.5</td>
<td>21.9</td>
<td>1.8</td>
<td>1</td>
<td>2</td>
<td>31.82</td>
<td>0.392</td>
</tr>
<tr>
<td>4</td>
<td>Fine loamy Umbric/Typic Dystrochrepts</td>
<td>52.2</td>
<td>23.4</td>
<td>24.4</td>
<td>1.0</td>
<td>1</td>
<td>1</td>
<td>19.52</td>
<td>0.358</td>
</tr>
<tr>
<td>5</td>
<td>Fine loamy Umbric Dystrochrepts</td>
<td>58.2</td>
<td>23.6</td>
<td>18.2</td>
<td>1.0</td>
<td>1</td>
<td>1</td>
<td>1.178</td>
<td>0.447</td>
</tr>
<tr>
<td>6</td>
<td>Fine loamy Typic Kandiudults</td>
<td>55.2</td>
<td>20.1</td>
<td>24.7</td>
<td>0.7</td>
<td>1</td>
<td>1</td>
<td>18.18</td>
<td>0.369</td>
</tr>
<tr>
<td>7</td>
<td>Fine loamy Typic Dystrochrepts</td>
<td>49.1</td>
<td>21.4</td>
<td>29.5</td>
<td>1.1</td>
<td>1</td>
<td>1</td>
<td>140.3</td>
<td>0.290</td>
</tr>
<tr>
<td>8</td>
<td>Fine loamy Typic Epiaquepts</td>
<td>8.8</td>
<td>56.6</td>
<td>34.6</td>
<td>1.7</td>
<td>5</td>
<td>2</td>
<td>14.18</td>
<td>0.348</td>
</tr>
<tr>
<td>9</td>
<td>Coarse loamy Typic Dystrochrepts</td>
<td>58.9</td>
<td>18.1</td>
<td>23</td>
<td>1.6</td>
<td>1</td>
<td>1</td>
<td>7.625</td>
<td>0.354</td>
</tr>
<tr>
<td>10</td>
<td>Fine loamy Typic/over sandy Typic Epiaquepts</td>
<td>64.4</td>
<td>17.7</td>
<td>17.9</td>
<td>1.2</td>
<td>5</td>
<td>1</td>
<td>166.2</td>
<td>0.543</td>
</tr>
<tr>
<td>11</td>
<td>Fine loamy Typic Haplumbrepts</td>
<td>33.8</td>
<td>39.4</td>
<td>26.8</td>
<td>1.8</td>
<td>1</td>
<td>1</td>
<td>19.53</td>
<td>0.299</td>
</tr>
<tr>
<td>12</td>
<td>Fine Typic Dystrochrepts</td>
<td>60</td>
<td>16.7</td>
<td>23.3</td>
<td>1.2</td>
<td>1</td>
<td>1</td>
<td>5.451</td>
<td>0.364</td>
</tr>
</tbody>
</table>

8.2.3. Topographic erosivity (LS)

The LS values in the present study area are ranges between 0.01 and 27.94. The lowest values for the LS factor are mainly found along the river that flows towards west, because the amount of slope is very low. High (>20) LS values are found mainly in the eastern part of the basin and very high LS values (>25) are noticed along the ridge and flank of the Baramura
Hill. Very low (<15) LS values are existing over 114.63 km² area of the basin in the alluvial zone along the main course of the Haora River. The moderately steep to very steep sloping landforms are covering an area of 50.42 km² (Fig-8.3) and posses LS values of more than 25 (Fig-8.3).

![Fig-8.3 Topographical factor of the Haora River basin](image)

### 8.2.4. Biological erosivity (CP)

The C values in the Haora River basin varies from 0.004 to 1. The C coefficient of RUSLE model for the study area is derived from both NDVI and land cover/landuse analysis. The lower C values are seen in the north-east, east and south-eastern part of the basin, where majority of land is characterized by dense to moderately dense forest. However, the degraded forest and agricultural land areas are occupying the southern and western part of the basin, having high C values (Fig-8.4). The highest C coefficient value (value-1) is noticed in the built-up areas in and around Agartala and also along the river (Fig-8.4). The present study reveals that 37.46% of the total study area is under dense to moderately dense forest cover, where C factor ranges between 0.02 and 0.04.

The values of P factor are determined on the basis of the soil conservation techniques practiced in the study area. From the field survey no conservation technique for controlling this excessive erosion has been found. Still primitive techniques of agriculture (both in settled and shifting cultivation) are practised within the whole basin. Due to absence of any conservation technique, the P value has been fixed at 1 for the entire basin.
8.2.5. Estimation of Potential soil loss

After calculating the individual data layers, the individual values for each grid are multiplied in order to get the potential and actual rate of soil erosion. Potential soil erosion expresses the inherent susceptibility of bare soil to erosion without any protective cover of vegetation. This way it provides information on the worst possible situation that might occur.

The potential soil loss has been calculated by using four physical parameters in RUSLE method i.e. i) rainfall erosivity, ii) soil erodibility, iii) Slope length and iv) slope steepness.
The minimum potential loss is found in the plain areas and also along the river course having the rate ranges between 0 and 3000 tons.h⁻¹.y⁻¹. The maximum amount of potential soil loss is found in the steep slope area, where the rate is more than 9000 tons.h⁻¹.y⁻¹ (Fig-8.5).

8.2.6. *Estimation of actual soil loss*

Actual soil erosion refers to present endangerment of soil erosion, taking into account the contemporary land cover and management practices that modify the potential erosion. Actual soil loss of the Haora River basin is estimated by multiplying the landcover/landuse and adopted conservation practice values with potential soil loss values. More than 250 km² area of the basin is having very less amount of soil loss (<150 tons.h⁻¹.y⁻¹). This area as a whole can erode a maximum of 20000 tons.y⁻¹ of soil. On the other hand only 45 km² area is experiencing high rate of soil erosion (>1500 tons.h⁻¹.y⁻¹) and can produce a maximum of 120000 tons.y⁻¹ (Fig-8.6).

![Fig-8.6 Actual soil loss map of the Haora River basin](image)

8.3. *Estimation of sediment yield rate of the Haora River basin*

The following parameters are needed for the estimation of sediment yield rate by using the SDR method:

8.3.1. *Estimation of V coefficient*

For estimating velocity of flow (V coefficient) for any particular cell, firstly the A coefficient map has been prepared. A coefficient map can be estimated by assigning particular values...
(Table-8.2) to different landcover and landuse practices (Haan et al., 1994). In the A coefficient map it is found that maximum A coefficient value (3.08) is existing in the northern part and in some places of south-western part of the basin those are covered with waste lands (Fig-8.7). On the contrary low A coefficient value (0.44) has been observed in the dense forest of Baramura and near Agartala.

![A-coefficient map of the Haora River basin](image1)

**Fig- 8.7 A-coefficient map of the Haora River basin**

![V coefficient map of the Haora River basin](image2)

**Fig- 8.8 V coefficient map of the Haora River basin**

After estimating the A coefficient value for individual cell, the steepness of the slope of each cell have to multiplied to get the velocity of the flow ($V$ coefficient) for the individual cells. In the $V$ coefficient map of the Haora River basin, the maximum $V$ coefficient value (12.53)
is found along the ridge and valley topography covered with waste lands (Fig-8.8). The low \( V \) coefficient value is observed along the Haora River and in the Baramura part those are covered with dense vegetation (Fig-8.8).

Table-8.2  A coefficient value for different land cover-landuse

<table>
<thead>
<tr>
<th>Landcover- Landuse</th>
<th>Dense forest</th>
<th>Evergreen forest</th>
<th>Open scrub</th>
<th>Agriculture</th>
<th>Forest plantation</th>
<th>Shifting cultivation</th>
<th>Waste land</th>
<th>Water bodie</th>
<th>Built up area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A value</td>
<td>0.76</td>
<td>0.65</td>
<td>1.55</td>
<td>2.65</td>
<td>0.94</td>
<td>2.86</td>
<td>3.08</td>
<td>0.96</td>
<td>0.44</td>
</tr>
</tbody>
</table>

8.3.2. *Estimation of Travel time of flow*

Travel time of the flow \( (t) \) means the duration taken by the overland flow to reach the nearest channel grid down to the drainage path from the upland grid. It is estimated from the overland flow value \( (L \) coefficient\) and the velocity of the flow \( (V \) coefficient\). Overland flow value has been estimated with the help of flow direction and flow accumulation map.

These maps have been derived from DEM and drainage map in Arc GIS software. In the overland flow map highest length of flow (0.015m) is found in the Baramura and other hilly tracts of the basin (Fig-8.9). About 92.16 km\(^2\) area surrounding the main flow of the Haora River and its tributaries are receiving very low flow (0.0001m) (Fig-8.9).
In the $t$ coefficient map (Fig-8.10) it is found that maximum $t$ coefficient value is restricted in the eastern part of the basin particularly in the Baramura hills (0.018sec). About 58% of the basin area is having low $t$-coefficient and it is lowest along the main channel (Fig-8.10).
8.3.3. 

Estimation of sediment yield

Sediment yield has been calculated by multiplying actual soil loss obtained from RUSLE method with the sediment Delivery ratio. Sediment delivery ratio ($D_r$) is the exponent of the travel time of overland flow (Ferro et al., 1995 and Ferro, 1997) from each overland grid to the nearest channel grid down to the drainage path.

From the $D_r$ coefficient map it is clear that there is no distinct variation in high and low $D_r$ coefficient value as the basin does not posses high relative relief (Fig-8.11). Highest $D_r$ coefficient value is noticed towards the Baramura hills, particularly in the south-eastern part of the basin (1.02), but more than 70% of the basin is having low $D_r$ coefficient value (Fig-8.11).

Plate-8.1 Evidences of sedimentation in different spots along the Haora River

Variation in soil loss & sediment yield is quite common throughout the basin (Plate-8.1). The maximum amount of sedimentation is found along the river course (>4500 tons. y$^{-1}$), but the amount of soil loss over those areas are quite low (>1500 tons. h$^{-1}.y^{-1}$) (Plate-8.1). In the steep hill areas the rate of sedimentation is approximately zero (Fig-8.12), but the amount of soil loss is ranging from 1-150 tons. h$^{-1}.y^{-1}$ (Fig-8.6).
8.4. Corelation between discharge and sediment load of the Haora River

The average discharge of the Haora River is about 13.80 m$^3$.s$^{-1}$. In the year 1991, 1993, 2003 and 2007 the discharge rates were above the annual average, which indicates the occurrence of flood in those years (Fig-8.13A). On the contrary, in the years of 1992, 1994 and 2009 the annual discharge rates were lower than the average and they indicated the draught years.

From the graph of discharge and sediment load of the Haora River a strong correlation is found (0.558) (Fig-8.13B). It indicated that during flood year the amount of sediment load remain higher than the normal years.

**Fig-8.13 (A) Discharge Graph  (B) Co-relation graph of discharge and sediment load of the Haora River (Source-CWC)**
8.5. Sediment load of the Haora River

From the sediment load data it is found that the average rate of annual sediment load of the Haora River is about 6473.71 tons. During the flood years the amount of sediment load is increased due to high discharge. The maximum amount of sediment load is observed in the year 1993 (14000 tons). On the other hand minimum rate of sediment load is observed in 1992 (500 tons). Since 1993 the average rate of sediment load has been increasing (Fig-8.14).

![Graph showing deviation between observed and estimated sediment yield rate](image)

*Fig-8.14 Annual sediment load of the Haora River (Source-CWC)*

*Fig-8.15 Graph showing deviation between observed and estimated sediment yield rate*
8.6. Validation of sediment yield method with hydrological data

To validate the sediment yield method (SDR), a comparison between the observed hydrological data (CWC) and the estimated data has been done. Since the hydrological data of the Haora River is taken from the lower catchment of the river, it indicates maximum amount of sediment that is carried down the river from the whole basin. The hydrological data shows the average annual sediment load is about 6473.71 tons, whereas the estimated data shows the rate is 4704.94 tons, which is almost matching with the observed data. One major limitation for validating data obtained from the SDR method with the observed data is that there is only one gauge station within the whole basin and that is located at the lower reach of the Haora River. If there was more stations, the accuracy of the validation would have been higher.

From the comparison between the annual observed data and the estimated data it is found that the difference is positive in the years 1991, 1993, 2003, 2007 those are marked as flood years. In rest of the years the difference is negative (Fig-8.15).
8.7. References


Wicks, J.M., Bathurst, J.C., 1996. SHESED: A physically based, distributed erosion and sediment yield component for the SHE hydrological modelling system. J. Hydrol. 175, 213-238.
