ESTIMATION OF ANNUAL AVERAGE SOIL LOSS AND PREPARATION OF SPATIALLY DISTRIBUTED SOIL LOSS MAP: A CASE STUDY OF DHANSIRI RIVER BASIN

a study report

by

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ABSTRACT

Land degradation is a pervasive environmental and economic challenge of present time in the developing countries. Soil erosion caused by water is considered as one of the major type of land degradation. So estimation of soil loss due to erosion and detection of erosion prone areas are utmost important of present time for agricultural planning and various other land management planning. This study will include the estimation of the average annual soil loss of a part (almost 80%) of Dhansiri watershed and preparation of a spatially distributed soil loss map using a comprehensive methodology that integrates remote sensing and GIS technique with a well-known empirical method (Revised Universal Soil Loss Equation). GIS data layers including, rainfall erosivity (R), soil erodability (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were computed to estimate the average annual soil loss of the study area. The average soil loss rate was estimated as 34.601536 $t.ha^{-1}yr^{-1}$ and maximum value was found as 16746.8 $t.ha^{-1}yr^{-1}$. The total soil loss for the whole watershed was found as 28.778 million t. yr^{-1}. For the validation of the soil loss estimation model Sediment delivery ratio concept was used, as observed data of sediment yield was present for the study area and no observed data of soil loss was available. Further, the soil erosion rate was classified into four severity classes as slight, moderate, severe and extremely severe as per the guidelines of FAO (2006) and spatially distributed severity class map was prepared.

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1 INTRODUCTION

Land degradation is one of the most serious global environmental problems of modern time, threatening agricultural areas at an alarming rate. Land degradation happens when natural or anthropogenic processes reduce the quality of land by decreasing the ability of land to support crops, livestock and organisms. One of the major land degradation is soil erosion (Miller, 2006). On-site impacts of soil erosion may be refer to the loss of soil from a field, the breakdown of soil structure, and the decline of soil organic matter and nutrients, leading to a decline in soil fertility and in the end to a reduced food security and vegetation cover (Stocking, 2003). The off-site effects of soil erosion includes sedimentation problems in river channels, increased flood risk and reduced lifetime of reservoirs (Verstraeten and Poesen, 1999). Water is the most common cause for soil erosion, which is accelerated by poor land use and land management practices adopted in the upland areas of watersheds, incorrect methods of tillage, unscientific agricultural practices etc. (Arekhi et al., 2012).

A quantitative and detail assessment is needed to know the extent and magnitude of soil erosion problems so that effective management strategies can be applied. And it is also very important to have a spatially distributed soil erosion map of a region or watershed. It helps in detecting soil erosion potential at different locations, and thus helps in applying required safety measures to minimize it, in order to have a better agriculture and soil conservation planning (Tiwari et. al., 2016). A well-known empirical method called Revised Universal Soil Loss Equation (RUSLE) when use in conjunction with GIS and remote sensing can beautifully display the spatial variation of long term average soil loss, both in large and small scale.

In RUSLE model, annual average soil loss is calculated by multiplying various factors such as rainfall erosivity factor(R), soil erodability factor (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice (P) factor. The main objectives of this study is to estimate the long term annual average soil loss of a part (almost 80%) of Dhansiri watershed with the help of RUSLE using GIS and remote sensing technique and prepare the spatially distributed soil loss map.

2 LITERATURE REVIEW

2.1 Introduction

In this study the estimation of annual average soil loss of a part of Dhasnsiri watershed (Area = 8317.17 Km^2) will be performed. There are various methods for estimating soil loss. So it was important to study about various methods for the selection of a method suitable for such a large area. This chapter will include a discussion about various quantitative soil loss estimation methods to select the suitable method. After selecting the method, various literature relating to that method will also be discussed.

2.2 Various quantitative methods of estimating soil erosion

Quantitative method is based on parameterisation of several factors. The complexity of these models depends on number of factors considered and complexity in calculating each factor. These type of models can be again divided into two types –

2.2.1 Physically based Models

These are the most complex model and follow strict mathematical relationships. As per Bhattarai and Dutta (2007), these models are the synthesis of individual components that affect the erosion process and has the capability of assessing both the spatial and temporal variability of erosion processes. Some physically based models are - WEPP – Water Erosion Prediction Project (Laften et al., 1991; Amore et al., 2004; Baigorria and Romero, 2007), PESERA – Pan European Soil Erosion Risk Assessment (Kirkby et al., 2008; Licciardello et al., 2009), EUROSEM – European Soil Erosion Model (Quinton et al., 2011) etc. The main weakness of a physically-based model is large amount of data requirement, which is almost impossible to get on a large scale (Merritt et. al., 2003; Quinton et al.,2011). For example a physically based model European Soil Erosion Model (EUROSEM) uses mathematical expressions to represent the processes of erosion that take place over a single storm event (Quinton et al., 2011). But this model require large amount of data such as soil-water content with depth, rill and inter-rill erodibilities, soil shear strength, soil cohesion, soil surface roughness, soil bulk density, subsurface interflow of water, plant density and evapotranspiration rates (Nearing, 2004; Morgan, 2011).

2.2.2 Empirical Models

Most of these models were developed based on field observations in specific environmental condition to which the models were applied (Terranova et al., 2009). The Universal soil loss equation (USLE) (Wischrneier and Smith 1978), a revised version of USLE Revised universal soil loss equation (RUSLE) (Renard et al., 1997), the SEDD - Sediment Delivery Distributed (Ferro and Porto, 2000) are such models that are more often used rather than other complex models. USLE and RUSLE are the kind of models which are simple to implement (Van Rompaey et al., 2001; Gao, 2008). It can be applied in areas of limited data, especially in case of developing countries as data insufficiency is a major challenge in such countries. USLE and RUSLE are proven to be a useful tool for displaying the spatial variation of soil erosion risk for a large watershed when used in combination with GIS (Zhou, 2008; Bazzoffi, 2009). In some literature it was found that USLE or RUSLE performed better than some physical model also (Kinnell, 2010; Gover, 2011). For example Tiwari et al. (2000) compared the model accuracy of USLE, RUSLE and a physical model WEPP and found RUSLE as the best model among these three model.

If we consider the strengths and weaknesses of all the models discussed above, it is reasonable to say that the comparatively simple model RUSLE in combination with GIS will be the best choice to apply in a large watershed scale. And in many situations decision makers and stakeholder are more interested in spatial variation of soil erosion than the absolute soil loss value. The RUSLE model run in a GIS platform can beautifully display the spatially distributed soil erosion risk map of a region (Lu et al., 2004; Bazzoffi, 2009). Some more past works using this method are given below –

Evans et al. (1997) used GIS based RUSLE and sediment delivery ratio concept to calculate sediment yield from a small rural watershed, old woman creek, erie and huron counties, ohio.

Sidorchuk (2009) employed RUSLE to calculate soil loss from the national territory of New Zealand and found reasonable prediction of soil loss when compared with sediment yields from the rivers.

Yuan lin et al. (2002) developed a WinGrid system that can be used to calculate the slope length factor of RUSLE from each cell for of the watershed and calculated the sediment erosion.

Marker et al. (2007) did a study in the Albegna river basin in southern Tuscany, in which they utilized the RUSLE approach to evaluate the different scenarios of land uses for current and future climatic change on a monthly basis. During the study, they kept the K-factor, LS-factor and P-factor value constant and only rainfall erosivities (R-factor) and C-factor values were changed according to the scenario settings. The analysis demonstrates the potential of this approach to assess landscape soil erosion susceptibility with scenario analysis (Marker et al., 2007). The authors state that the analyses might help to develop adaptation strategies for future climate change scenarios such as modification in land management techniques.

Beskow et al. (2009) applied USLE with GIS to estimate potential soil loss from the Grande River Basin in Brazil (6273 Km^2). Their results represented acceptable precision and allowed for identification of the most susceptible areas to water erosion.

Terranova et al. (2009) used RUSLE in combination with GIS to generate soil erosion risk scenarios in Calabria (southern Italy). They run the model for three scenarios, present scenario, the scenario with forest fire and mean values of the erosivity factor and the scenario with forest fires and the highest values of the erosivity factor.

Ranzi et al. (2012) used RUSLE approach to model sediment load in the Lo River and also checked the effect of reservoirs and land use changes on sediment yield.

Prasannakumar et al. (2012) used RUSLE in combination with GIS to estimate soil erosion risk of a small mountaneous sub watershed of kerala, India and found good result when compared with earlier works.

Biswas et al. (2015) used GIS based RUSLE method to estimate soil erosion of Barakar River basin, Jharkhand, India.

3 STUDY AREA

3.1 Location

The Dhansiri River Basin lies between 26.71 N to 25.36 N latitudes and 93.19 E to 94.55 E longitudes. The catchment area of the basin is approximately 10,187 km², lying partly in the state of Assam and partly in Nagaland. It is bounded by the Naga Hills to the east and the Mikir Hills to the west. Its northern limit is marked by the Jorhat fault and the southern limit by the Dauki fault.

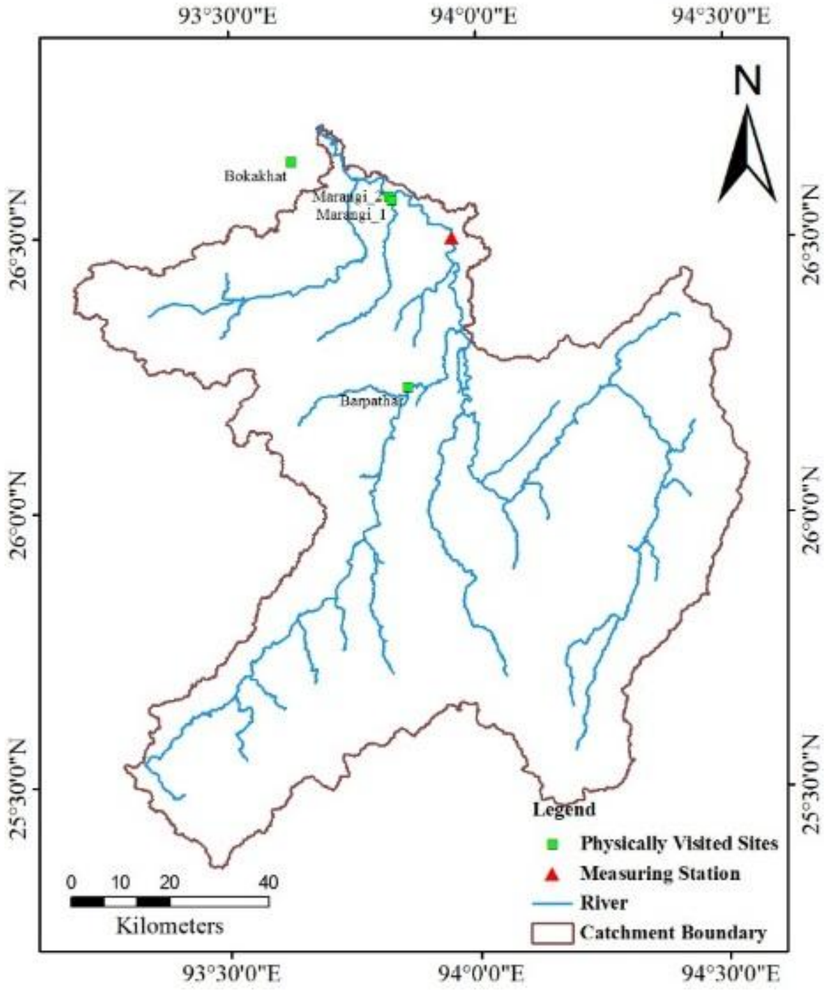

Figure 3.1 : Dhansiri Watershed

3.2 Land use

The part of the river basin that lies in Nagaland is mostly covered by mountains and hill ranges, and partly by flat alluvial tract of the Brahmaputra Valley. The part lies in assam is mostly flat and having some hilly areas in Karbi Anglong district. A large area of the watershed is covered by forest.

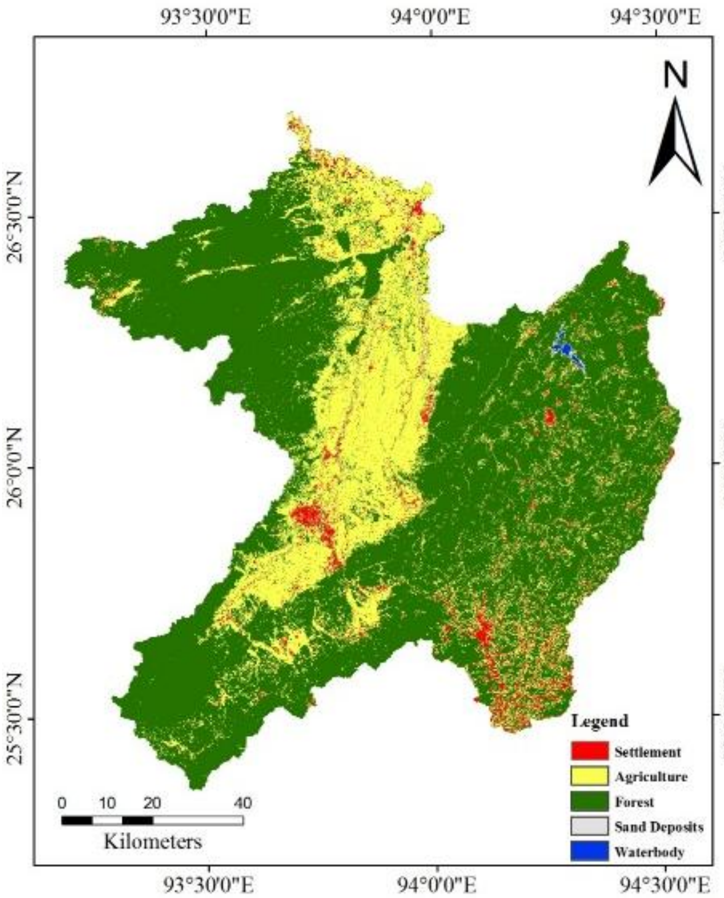

Figure 3.2 : Land use land cover map of Dhansiri Watershed

Sl. No.	Land use type	Approx. Area (km^2)	Area (%)
1	Settlement	1484.64	14.57
2	Agriculture	1734.54	17.03
3	Forest	6933.63	68.06
4	Sand Deposits	7.11	0.07
5	Water body	27.28	0.27

Table 3.1 : Approximate area under each land use type

3.3 Soil Characteristics

The lower Dhansiri River basin comprises of unconsolidated sediments of recent to sub-recent age overlain by alluvial deposits of the Pleistocene age occurring along the foothills.

3.4 Topography

The elevation of dhansiri watershed varies from 66 m to 3019 m. Due to the presence of mountaneous regions the variation of slope in this area is large. The slope varies from 0 degree to 75.1287 degree.

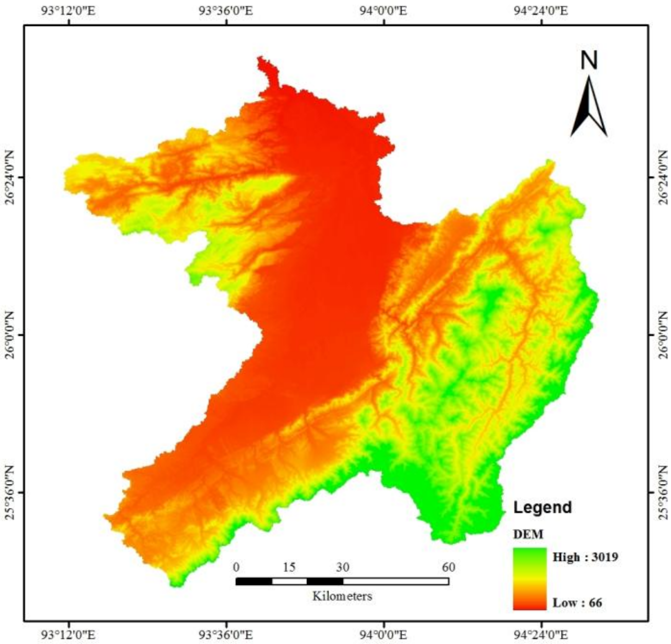

Figure 3.3 : Slope(Degrees) map of Dhansiri watershed

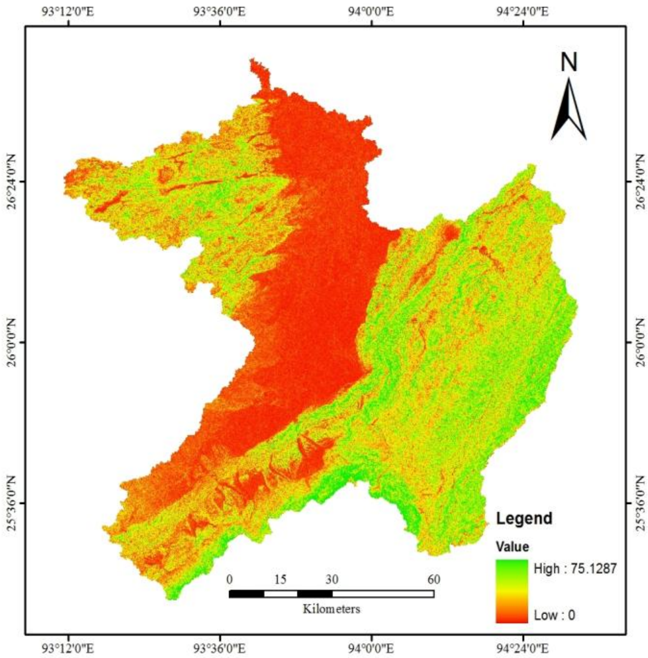

Figure 3.4 : DEM and Slope(Degrees) map of Dhansiri watershed

3.5 Climate

The river basin falling within south-west monsoonal regime, receives a mean monsoon rainfall of 1158.10 mm and the average annual rainfall in the basin is 1805.60 mm. The monsoonal rainfall causes heavy landslides in the mountainous upper catchment areas and flash floods in the lower part of the basin.

For last several years the basin has been suffering from huge soil erosion problem. Keeping that in mind the watershed was selected for this study. But the complete watershed was not included because the observed data of sediment yield is available at a station about 35 km u/s of the outlet of Dhansiri River. And observed data are needed for validation of a model. The area of our study area is 8317.17 km^2, which is about 80% of total watershed of Dhansiri.

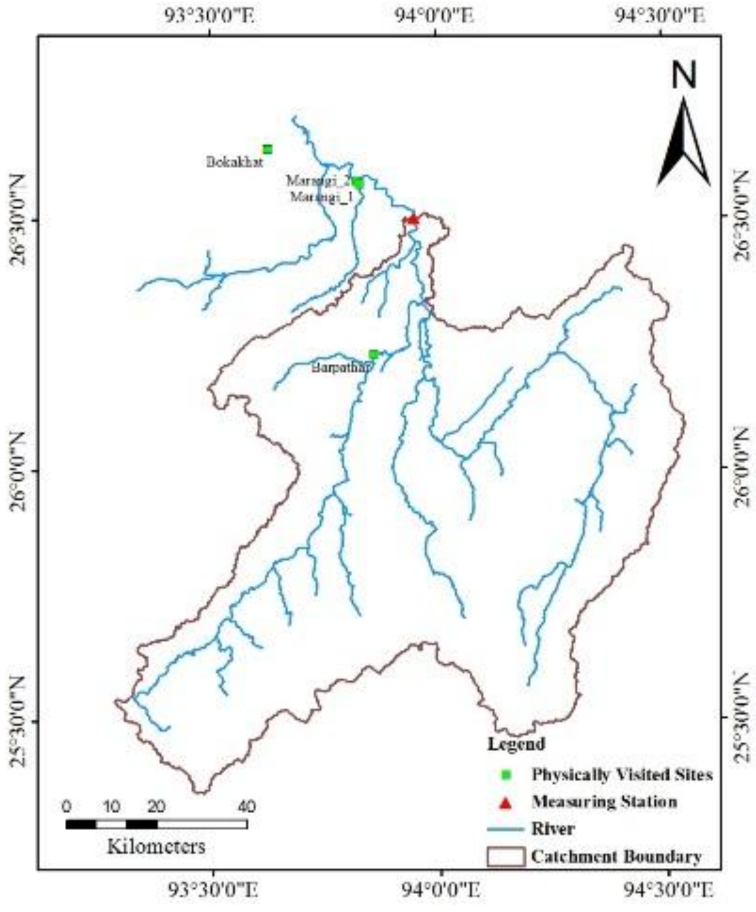

Figure 3.5 : Study area

4 METHODOLOGY

4.1 Introduction

The rate of soil loss from an area is strongly dependent upon its soil, vegetation, topographic and climatic characteristics. These factors are usually vary significantly within the various parts of a watershed. Therefore, the watershed needs to be discretised into smaller homogeneous units before making computations for soil loss. A grid-based discretization is known as the most reasonable procedure (Kothyari and Jain, 1997). The cell size to be used for discretization should be small enough so that a grid cell encompasses a hydrologically homogeneous area (Jain and Kothyari, 2000). The use of Geographical Information System (GIS) methodology is suitable for the quantification of heterogeneity in the topographic and drainage features of a catchment (Shamsi, 1996). Methods such as the USLE and RUSLE have been found to produce realistic estimates of soil loss over areas of small size (Wischmeier & Smith, 1978; Renard et al. 1997). So in the present study, the quantitative empirical model RUSLE has been applied by integrating with a Geographical Information System (GIS) and remote sensing approaches to predict soil loss rates.

4.2 Revised Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) determines soil loss at any given point as a function of rainfall energy and intensity, soil erodibility, slope length, slope gradient, soil cover, and conservation practices (Wischmeier and Smith 1978). The Revised Universal Soil Loss Equation (RUSLE) has the same form as the USLE, but includes revisions for slope length and slope gradient calculations, more elaborate calculations for soil cover and conservation practices (Renard et al. 1997). However, RUSLE can estimate only annual average soil loss from rill and interill erosion caused by rainfall splash and overland flow, but not from gully and channel erosion (Renard et al., 1997). Therefore GIS methods are used to partition the areas into overland and channel types to estimate the soil loss in individual grid cells of overland areas.

The RUSLE method is expressed as

$$A=R.K.L.S.C.P$$

(4.1)

where

A= Computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R, expressed in ton.acre^{-1}.yr^{-1} or ton.ha^{-1}.yr^{-1}.

R = rainfall-runoff erosivity factor, the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K = soil erodibility factor - the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6 ft (22.13 m) length of uniform 9% slope in continuous clean-tilled fallow.

L = slope length factor, the ratio of soil loss from the field slope length to soil loss from a 72.6 ft (22.13 m) length under identical conditions.

S = slope length factor, the ratio of soil loss from the field slope length to soil loss from a 72.6 ft (22.13 m) length under identical conditions.

C = cover-management factor, the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = support practice factor, the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope.

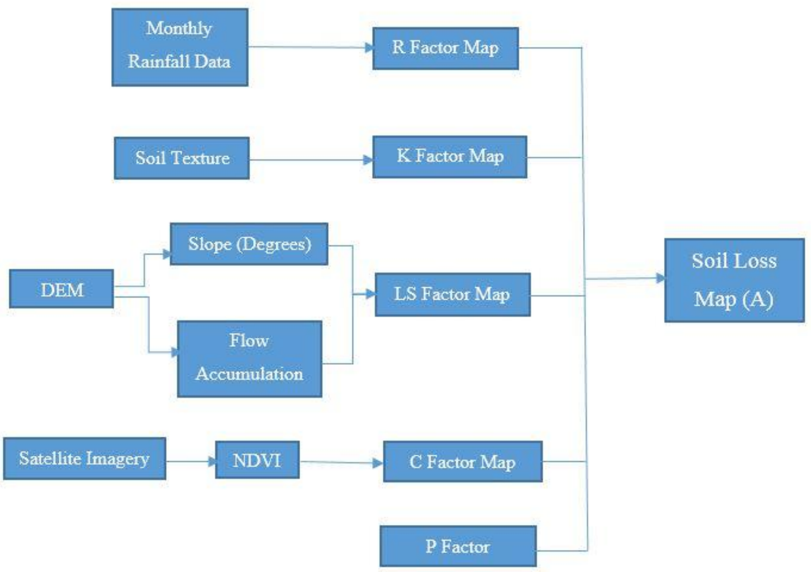

Figure 4.1 : Flowchart of RUSLE soil loss estimation using GIS and remote sensing technique

4.2.1 Rainfall Runoff Erosivity Factor (R)

Rainfall erosivity is defined as the aggressiveness of rain to cause erosion (Lal, 2001). The rainfall and runoff erosivity factor (R) of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) was derived from research data from many sources. The data indicate that when factors other than rainfall are held constant, soil losses from cultivated fields are directly proportional to a rainstorm parameter: the total storm energy (E) times the maximum 30-min intensity (I_{30}). The sum of the EI_{30} values of the storm events for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI_{30} values in a particular locality is the rainfall erosivity factor (R) for that locality (Renard et al., 1997).

The energy of a rainstorm is a function of the amount of rain and of all the storm's component intensities. The median raindrop size generally increases with greater rain intensity (Wischmeier and Smith, 1978), and the terminal velocities of free-falling water drops increase with larger drop size (Gunn and Kinzer, 1949). Since the energy of a given mass in motion is proportional to velocity squared, rainfall energy is directly related to rain intensity. The relationship, based on the data of Laws and Parsons (1943), is expressed by the equation

$$e = 916 + 331\ \log_{10} i \qquad i \leq 3\ inch.h^{-1}$$

$$e = 1074 \qquad\qquad i > 3 inch.h^{-1} \tag{4.2}$$

where 'e' is kinetic energy in ft.tonf.acre^{-}1.inch^{-1}, and 'i' is intensity in inch.h^{-1} (Wischmeier and Smith, 1978). A limit of 3 inch.h^{-1} is imposed on 'i' because median drop size does not continue to increase when intensities exceed 3 inch.h^{-1} (Carter et al. 1974).

Brown and Foster in the year 1987 used a unit energy relationship of the form to relate energy with rainfall intensity.

$$e_r = e_{max} \times\ \ 1 - a \times \exp(-b.i) \tag{4.3}$$

where, e_{max}= a maximum unit energy as intensity approaches infinity

a and b = coefficient

e_r= energy in MJ.ha^{-1}.mm^{-1} and

i = Rainfall intensity in mm.h^{-1}

Brown and Foster (1987) in their analysis recommended a value of 0.29, 0.72 and 0.05 for e_{max}, a and b respectively.

Then rainfall erosivity factor (R) can be calculated as

$$R = \frac{{}_{i=1}^{j}(EI_{30})_i}{N} \tag{4.4}$$

where $(EI_{30})_i$ = $(EI_{30})_i$ for storm i, j = number of storms in an N year period.

Now, $E = (\ \ {}_{r=1}^{k} e_r v_r)$ in MJ.ha^{-1} and I_{30}= maximum 30 min intensity (mm/hr)

where v_r is the rainfall volume (mm) during the r^{th} time period of a rainfall event divided in k parts.

As per the RUSLE handbook (Renard et al., 1997) rainfall event of less than 0.5 inch or 12.7 mm were omitted from the erosion index computations, unless at least 0.25 inch or 6.35 mm of rain fell in 15 min and a storm period with less than 0.05 inch or 1.27 mm over 6 hr was used to divide a longer storm period into two storms.

Later Renard et al. (1997) mentioned in RUSLE handbook that all the future calculations should be made using equation given by Brown and Foster (1987), especially in countries other than USA.

Now for calculating R factor by the above methods, high resolution pluviographic rainfall data have to be present in the target area for a long period (about 15 to 20 years), only then the calculation of E and I30 is possible. Due to unavailability of such high resolution data in many regions of the world researchers proposed some simplified method to evaluate R factor which generally correlate R factor with the monthly or annual rainfall or combination of both. For this region of the country Das and Sarma (2017) have developed two empirical methods for calculating rainfall erosivity factor by using readily available rainfall data. The methods are

i. When daily rainfall data are available

$EI30_{month} = 5.933\ Rain10 - 127.602\ Days10 + 3.365\ Rain_{month}$ (4.5)

ii. When daily rainfall data are not available

$EI30_{month} = 4.755\ Rain_{month}$ (4.6)

where, $EI30_{month}$ is the monthly sum of EI30 value of all the storm events occur in a month.

Rain10 is the monthly rainfall for days with rainfall greater than 10mm.

Days10 is the number of days in a month with rainfall greater than 10mm.

$Rain_{month}$ is the monthly rainfall considering all the rainfall events.

Now, Rainfall Erosivity Factor (R) = $\frac{\sum_{i=1}^{12} EI30_{month(i)}}{n}$ (4.7)

where, $EI30_{month(i)}$ is the $EI30_{month}$ of i^{th} month of a year and $'n'$ is the number of years considered to calculate the R factor

In this study the Eq. 4.5, Eq. 4.6 and Eq. 4.7 were used to prepare the rainfall erosivity factor map of the study area.

4.2.2 Soil Erodibility Factor (K)

Soil erodibility is a complex property and is considered as the ease with which soil is detached by splash during rainfall or by surface flow or both. Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil-erodibility factor (K). The soil-erodibility factor (K) in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas. The soil erodibility factor (K) is the rate of soil loss per rainfall erosion index unit [ton. acre. h(hundreds of acre. ft-tonf. in)$^{-1}$] as measured on a unit plot. The unit plot is 72.6 ft (22.1 m) long, has a 9% slope, and is continuously in a clean-tilled fallow condition with tillage performed upslope and downslope (Wischrneier and Smith, 1978). Recommended minimum plot width is 6 ft (1.83 m). The soil erodibility factor (K) is the average long term soil and soil profile response to a large number of erosion and hydrologic processes. Various physical, chemical and mineralogical soil properties and their interactions affect K values. Moreover different simultaneous erosion mechanism may differently relate to various soil properties. Several attempts were made to relate measured K values to soil properties. The most widely used and frequently cited relationship is the soil-erodibility nomograph (Wischmeier and Smith, 1978). A useful algebraic approximation (Wischmeier and Smith, 1978) of the nomograph for those cases where the silt fraction does not exceed 70% is

$$K = [2.1 - 10^{-4}(12\text{-}OM)\ M^{1.14} + 3.25(s-2) + 2.5(p-3)] / 100 \quad (4.8)$$

Where, OM = Percent organic matter

M = Product of the primary particle size fractions: (% modified silt or the 0.002-0.1 mm size fraction)×(% silt + %sand)

s = Classes for structure

p = Soil permeability

K is expressed as ton.acre^{-1} per erosion index unit with U.S. customary units of ton. acre.h (hundreds of acre.ft-tonf.inch)$^{-1}$. Division of the right side of this K-factor equations with the factor 7.59 will yield K values expressed in SI units of t.ha.h.ha^{-1} MJ^{-1}mm^{-1}.

Various researchers developed regression equations for various classes of soils. Substantial intercorrelations were found to be exist among many properties of soil hence affecting the true significance of each property in predicting K values.

Shirazi and Boersma (1984) gathered all available published global data (225 soils) of measured K values and grouped into textural classes. Only soils with less than 10% of rock fragments by weight (>2 mm) were considered. The mean values of the soil erodibility factor for soils within these size classes were then related to the mean geometric particle diameter of that class. The resulting relationship is

$$K = 7.594 \times \quad 0.0034 + 0.0405 \times exp \quad -\frac{1}{2} \quad \frac{\log D_g + 1.659}{0.7101} \quad ^{2} \qquad R^2 = 0.983 \quad (4.9)$$

where

$$D_g = \exp \ 0.01 \times \quad (f_i \times \ln m_i) \qquad (4.10)$$

where f_i = Primary particle size fraction in percent

m_i= Arithmetic mean of the particle size limit of that size

The Eq. 4.9 was used in this study to prepare the soil erodibility map of the study watershed.

4.2.3 Slope length and Steepness Factor (LS)

Both the length (L) and the steepness(S) of the land slope substantially affect the rate of soil erosion by water. The two effects have been evaluated separately in research and are represented in the soil loss equation by L and S respectively. In field applications, however, considering the two as a single topographic factor, LS**,** is more convenient. Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel (Wischmeier and Smith, 1978). The LS factors given in USLE and RUSLE are given below

i. USLE (Wischmeier and Smith, 1978)

$$LS = (\frac{\lambda}{22.13})^{m} \times (0.065 + 0.045 \times s + 0.0065 \times s^2) \qquad (4.11)$$

where

m = 0.5 if s≥5 λ= Slope length in meter

m = 0.4 if 3≤s<5 s = Slope in percentage

m = 0.3 if 1≤s<3

m = 0.2 if s<1

ii. RUSLE (McCool et al., 1987)

$$L = (\frac{\lambda}{22.13})^m \tag{4.12}$$

where $m = \frac{\beta}{\beta+1}$, $\beta = \frac{(\frac{\text{Sin}\theta}{0.0896})}{(3\times(\text{Sin}\theta)^{0.8}+0.56)}$ and λ = Horizontal projection of slope length

$$S = 10.8\times\text{Sin}\theta + 0.03 \quad \text{if } s < 9$$

θ= Slope angle in degrees

$$S = 16.8\times\text{Sin}\theta - 0.5 \quad \text{if } s \geq 9 \tag{4.13}$$

LS is calculated by multiplication of L and S

Moore and Burch (1986) proposed an unit stream power based physical LS factor. According to them if the USLE is to be applied to real-world catchments, whether they are large or small, then it is recommended that the length-slope factor derived from unit stream power theory be used rather than the original equation given by Wischmeier and Smith (1978). This allows a greater range of topographic attributes (slope, slope length, and catchment convergence) and rilling to be explicitly accounted for within the soil loss calculations (Moore and Burch, 1986). The LS factor as proposed by them was

$$LS = (\frac{al}{22.13})^{0.4} \times (\frac{\text{Sin}\theta}{0.0896})^{1.3} \tag{4.14}$$

where a = Catchment Shape parameter = $\frac{A}{bl}$

A= Partial catchment area or upslope contributing area

l = is the distance along a streamline from the most remote part of the partial catchment area to the contour element b, as shown in Figure 4.2.

θ = Slope angle in degrees

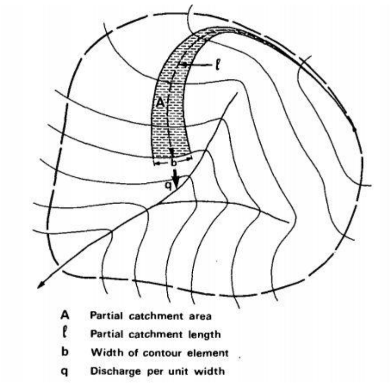

Figure 4.2 : Schematic representation of specific catchment area

Upslope contributing area (A) is the area from which the water flows into a given grid cell. It is used as a measure of water flux in Eq. 4.8. Upslope contributing area per unit contour width A_j for the given grid cell j is computed from the sum of grid cells from which the water flows into the cell j,

$$A_j = \frac{1}{b} \times \sum_{i=1}^{n_j} \mu_i \times a_i \quad (4.15)$$

where a_i is the area of grid cell, n_j is the number of cells draining into the grid cell j, μ_i is the weight depending on the run-off generation mechanism and infiltration rates, and b is the contour width approximated by the cell resolution. This approximation is acceptable if the DEM is interpolated with the adequate resolution which depends on the curvature of terrain surface. It was assumed that $\mu_i = 1$ and $a_i = b \text{ x } b$ =constant, so the upslope contributing area is simply $A_j = n_j \text{ x } b$ (Mitasova et al., 2007)

In GIS platform n_j can be approximated as flow accumulation as flow accumulation gives the number of cells draining into that grid cell.

Hence above LS factor equation can be rewritten as

$$LS = (\frac{al}{22.13})^{0.4} \times (\frac{\text{Sin}\theta}{0.0896})^{1.3}$$

$$al = \frac{A}{bl} \times l = \frac{A}{b} = A_j = n_j \times b = \text{flow accumulation } \times \text{cell size}$$

Therefore, $LS = (\frac{\text{flow accumulation } \times \text{cell size}}{22.13})^{0.4} \times (\frac{\text{Sin}\theta}{0.0896})^{1.3}$ (4.16)

Flow accumulation can be derived from DEM using spatial analyst tool in ArcGIS. At first the DEM has to be filled and then flow direction has to be performed. Using

Flow Direction as an input Flow Accumulation can be derived in ArcGIS. Slope angle θ, for each grid can be found by using the Spatial Analyst tool in ArcGIS.

The Eq. 4.16 was used to prepare the LS factor map of the study area.

4.2.4 Cover Management Factor (C)

Vegetation cover is the next important factor that controls soil erosion risk. In the Revised Universal Soil Loss Equation, the effect of vegetation cover is incorporated in the cover management factor. It is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier & Smith, 1978). The value of C mainly depends on the vegetation cover percentage and growth stage. In the Revised Universal Soil Loss Equation (Renard et al., 1997) the C-factor is subdivided into 5 separate sub-factors that account for the effects of prior land use, canopy cover, surface cover, surface roughness and soil moisture respectively. For a large watershed, it is hardly possible to estimate C using the RUSLE guidelines due to a lack of sufficiently detailed data (Van der Knijff et al. 1999).

De Jong (1994) derived the following function for estimating USLE-C from NDVI (Normalised Difference Vegetation Index) (revised in De Jong et al., 1998):

$$C = 0.431 - 0.805 \cdot NDVI \tag{4.17}$$

The above model had a correlation coefficient of –0.64, which is modest but seem to be a good relation. The function was tested on several NDVI profiles. In general, estimated C-values were found to be very low. Furthermore, De Jong's equation is unable to predict C values over 0.431.

Van der knijff (1999), after performing a lot of experimentations came to a nonlinear relationship between C and NDVI which seemed to be adequate.

$$C = \exp(-\alpha \frac{NDVI}{(\beta - NDVI)}) \tag{4.18}$$

where α and β are the parameters that determine the shape of the NDVI-C curve. As per Van der knijff and a α value of 2 and a β value of 1 gave reasonable result. The equation produced more realistic C values than those estimated assuming a linear relationship (Van der knijff, 1999).

NDVI is the most widely used remote-sensing derived indicator of determining vegetation cover and growth, which for Landsat 5 TM satellite imagery is given by the following equation:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (4.19)$$

NDVI values range between -1.0 and +1.0. Photosynthetically active vegetation shows a very high reflectance in the near IR portion of the electromagnetic spectrum (Band 4, Landsat 5 TM), in comparison with the visible portion specially red (Band 3, Landsat 5 TM), and hence NDVI values for photosynthetically active vegetation will be very high.

The Eq. 4.18 was used to prepare the cover management factor map for our study area.

4.2.5 Support Practice Factor (P)

The support practice factor (P) in RUSLE is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modifying the flow pattern, grade or direction of surface runoff and by reducing the amount and rate of runoff (Renard et al., 1997). The values of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices and the minimum values correspond to built-up-land and plantation area with strip and contour cropping. For this study the maximum value of 1 was considered as there is no known conservation practice present in the watershed.

All the factors were calculated for the study area and converted into raster layers of 30 m spatial resolution. All the raster layers were multiplied in raster calculator to get the spatially distributed soil erosion map.

4.2.6 Sediment Delivery Ratio (SDR)

When soil erosion occurs, a fraction is transported through channel system and contributes to sediment yield while the other fraction is deposited in the channel. Sediment yields can be quantified using the Sediment Delivery Ratio (SDR) concept. SDR can be expressed as the ratio of sediment yield calculated at a point of the channel to gross upland soil erosion. Gross erosion includes sheet, rill, gully and channel erosions. But RUSLE estimates only rill and interill or sheet erosion, which is considered as the major contributor of gross erosion (Ouyang et. al., 1997). SDR can be affected by a number of factors including sediment source, texture, nearness to the main stream, channel density, basin area, slope, length, land use/land cover, and rainfall-runoff factors. A watershed with steep slopes has a higher sediment delivery ratio than a watershed with flat and wide valleys. In general, the larger the area size, the lower the sediment delivery ratio. The drainage area method is most often and widely used in estimating the sediment delivery ratios in previous research as stated by Ouyang et. al., 1997.

The following methods are used in this study for calculating the Sediment delivery ratio for the watershed.

Vanoni (1975) used the data from 300 watersheds throughout the world to develop a model by the power function. This model is considered a more generalized one to estimate SDR.

$$SDR = 0.4724 A^{-0.125} \quad (4.20)$$

Where, A = drainage area in square km.

The USDA (1972) developed a SDR model based on the data from the Blackland Prairie, Texas. A power function is derived from the graphed data points:

$$SDR = 0.5656 A^{-0.11} \quad (4.21)$$

Where, A = drainage area in square km.

Boyce model (1975)

$$SDR = 0.3740 A^{-0.2382} \quad (4.22)$$

Where, A = drainage area in square km

Williams and Berndt's (1977) used slope of the main stream channel to predict sediment delivery ratio. The model is written as:

$$SDR = 0.627 (SLP)^{0.403} \quad (4.23)$$

where SLP = % slope of main stream channel.

5 DATA PREPARATION AND CALCULATION

5.1 Rainfall Runoff Erosivity Factor (R)

In this study Rainfall runoff erosivity factor was calculated by using the newly developed regional model for calculating Rainfall Erosivity Factor (Das and Sarma, 2017) for 45 sites, where the rainfall data are available. Then kriging spatial interpolation was applied in ArcGIS to get a spatially distributed R factor map of the watershed area. Among the selected sites 35 are situated inside the watershed boundary and the rest of the sites are situated outside the watershed but near the watershed boundary. Sites from outside the watershed boundary were selected as it would give us a more accurate interpolated result. If those sites were not selected then

R factor for near boundary areas would be extrapolated, which may give more erroneous result. The rainfall database used in this study was a combination of Raingauge station data (16) and 0.25 degree gridded Aphrodite Precipitation data (29). Aphrodite's daily gridded precipitation is the only long term (1951-2007) continental scale daily product that contains a dense network of daily raingauge data for Asia including the Himalayas, South and Southeast Asia and mountainous areas in the Middle East (https://climatedataguide.ucar.edu/climate-data/). The Aphrodite's precipitation data was extracted through Matlab and R factor for 29 sites were calculated. The Rain gauge station precipitation data were processed in MS excel and calculated the R factor for the 16 sites.

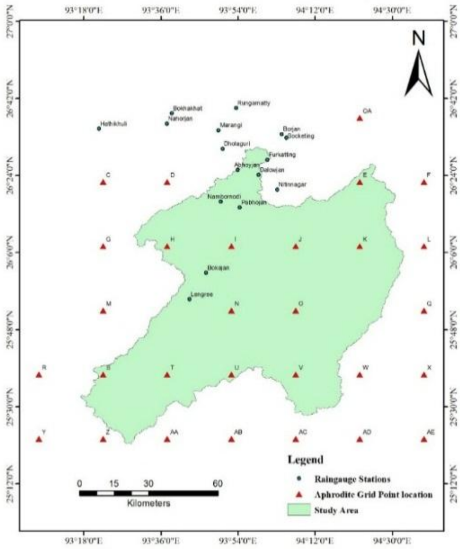

Figure 5.1 : Locations of various raingauge stations and aphrodite grid points

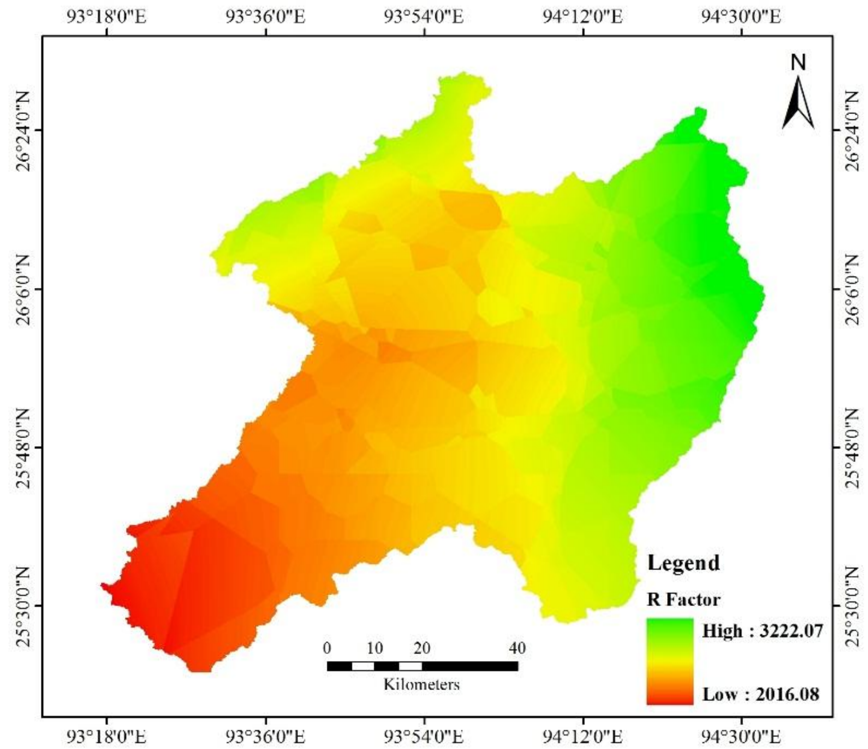

Figure 5.2 : Spatially distributed map of R factor (MJ.mm/ha.h.yr)

The Figure 5.2 shows the variation of R factor from 2016.08 MJ.mm/ha.h.yr to 3222.07 MJ.mm/ha.h.yr. The east part of the watershed is observed to have higher R factor value. A few area in the North West side of the watershed are also showing high R factor value. Both of these areas are hilly areas. The low R factor value mostly observed at flat areas and some hilly areas are also showing low R factor value.

5.2 Soil Erodibility Factor (K)

In this study soil erodibility was calculated for 91 sites, of which soil sample was physically collected from 4 sites, data for 47 sites were collected from IWMP (Integrated Watershed Management Programme) reports, and data for 40 sites were collected from FAO's Harmonized World Soil Database. The Harmonized World Soil Database is a 30 arc-second raster database with over 15,000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5,000,000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981) (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). Particle size distribution analysis was done for the physically collected soil samples. Wet sieving, dry sieving and

Hydrometer test was performed to find out the fraction of sand, silt and clay present in the samples. After that K factor was calculated for each point through MS excel using Eq. 4.9 and Eq. 4.10. The calculated K factors for 91 sites were then spatially interpolated in GIS using Kriging method for the whole watershed.

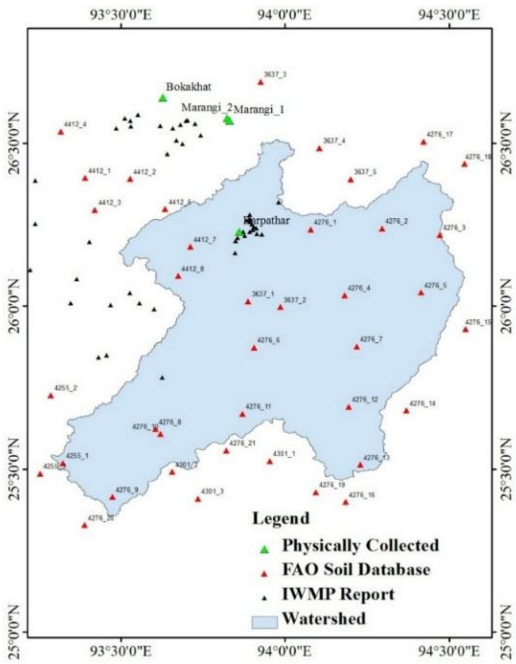

Figure 5.3 : Locations of various soil data points used in calculation of K factor

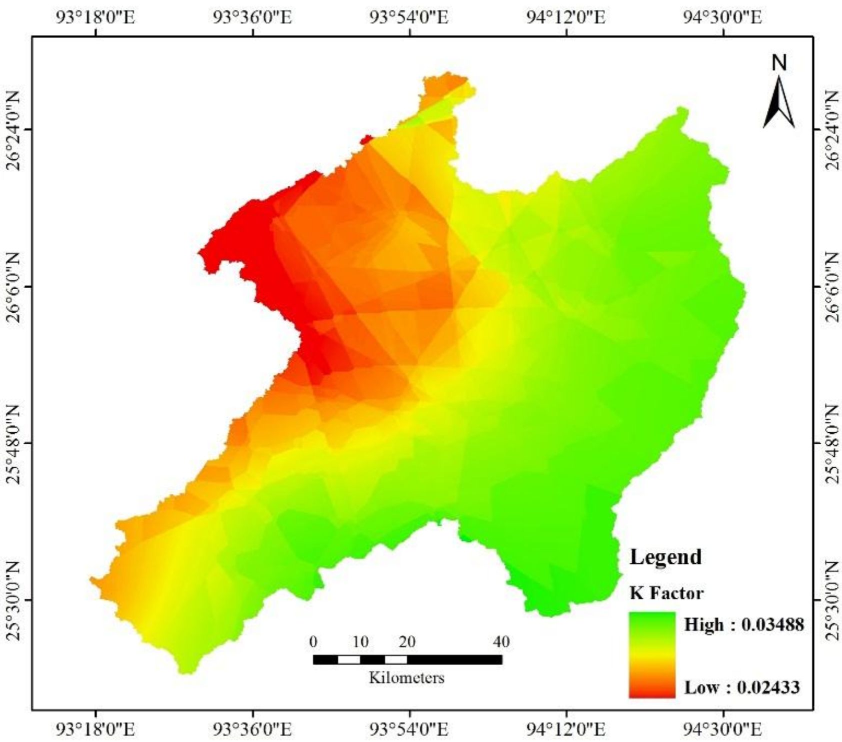

Figure 5.4 : Spatially distributed map of K Factor (t.ha.h./ha.MJ.mm)

Figure 5.4 shows the variation of K factor from 0.02433 to 0.03488 $t.ha.h.ha^{-1}.MJ^{-1}mm^{-1}$. To see the variation of K factor with respect to various soil type, the K factor was calculated for 3 hypothetical soil samples pure sand, pure silt and pure clay respectively and got the result as 0.00452 for pure sand, 0.041592 for pure silt and 0.010214 for pure clay, which is clearly showing that soil erodibilty is highly dominated by silt content of soil.

5.3 Slope length and Steepness Factor (LS)

In this study SRTM 1 arc second resolution DEM downloaded from https:// earthexplorer.usgs.gov website was used for the calculation of Topographic (LS) factor. Firstly the watershed was delineated using ArcSWAT, the outlet point for the watershed was kept at CWC Golaghat discharge and sediment measuring station, as it is important to validate the result with the observed data. The DEM for the watershed was then extracted using spatial analyst tool in GIS with delineated watershed as the mask. After that flow accumulation and slope (in degrees) maps were derived for the extracted DEM. The watershed was divided into overland area and channel area before calculating the LS factor (Jain, 2000). LS factor was calculated only for the overland areas. Threshold value of flow accumulation was taken as 5556 (~ 5 km^2 upland area) to make the differentiation. Then the grid wise Topographic Factor (LS) was calculated by using the Eq. 4.16 in raster calculator of ArcGIS.

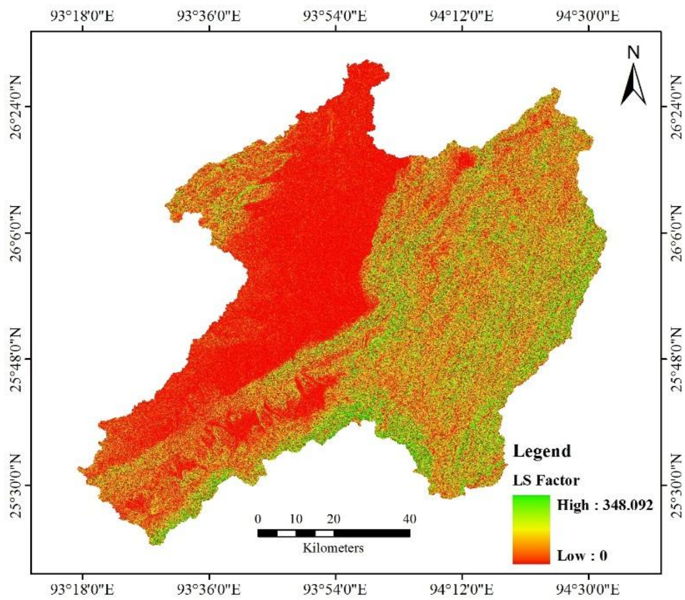

Figure 5.5 : Spatially distributed LS factor map

Figure 5.5 shows the variation of LS factor from 0 to 348.092. From the Figure 5.5 it can be observed that LS factor is high for areas with high elevation or hilly area, and low for areas with low elevation.

5.4 Cover Management Factor (C)

In this study cloud free Landsat 5 TM satellite imagery (Date of acquisition: 04 Nov, 2011) was used for the calculation of Cover management factor. Landsat 5 TM images have 7 bands. However for the calculation of NDVI only 2 bands are required, band 3 (Red) and band 4 (NIR). NDVI was calculated using ERDAS Imagine 9.2. C factor map was then derived by using the Eq. 4.18 in ArcGIS using raster calculator.

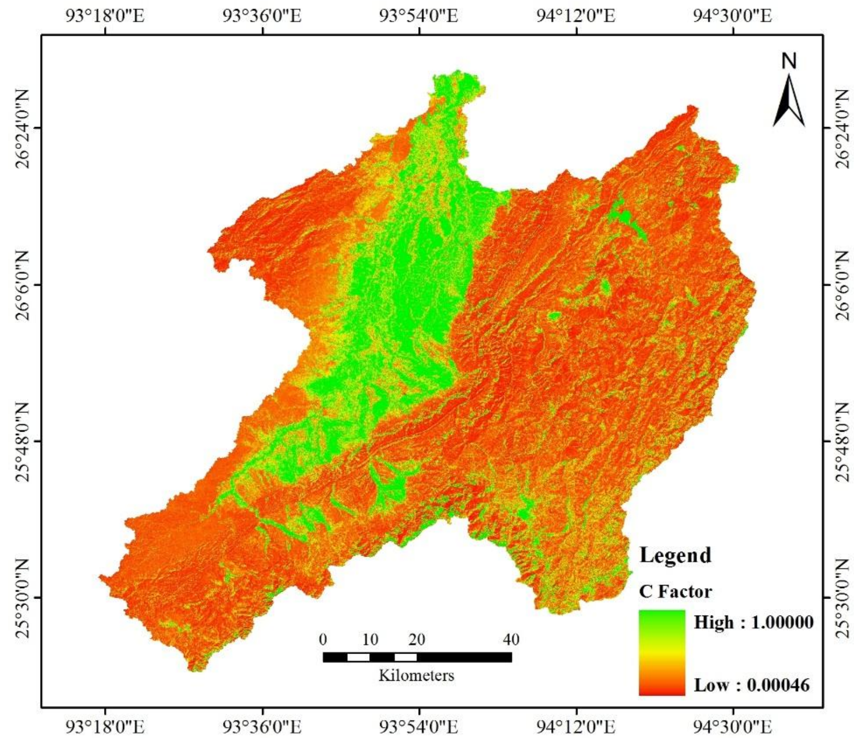

Figure 5.6 : Spatially distributed map of C Factor

The C Factor values of the watershed varies from 0.00046 to 1 as shown in Figure 5.6. The equation for calculating C factor in this study shows an inverse relation between C Factor and NDVI value, hence densely vegetated area has low C value and less chance of getting eroded. From Figure 5.6 it can be clearly observed that the heavily forested hilly areas are having very low C value, however agricultural areas, or areas with less vegetation in the flatter portion of the watershed are showing high C factor value.

5.5 Sediment Delivery Ratio (SDR)

The sediment delivery ratio (SDR) is a lumped concept. In this study the sediment delivery ratio was calculated by four different empirical methods as stated in 4.2.6. The calculated sediment delivery ratios are –

i. USDA (1972)

SDR $= 0.5656\times(\text{Watershed Area in km}^2)^{-0.11}$

$= 0.5656\times(8317.17)^{-0.11}$

$= 0.2096$

ii. Del Vanoni (1975)

SDR $= 0.4724\times(\text{ Watershed Area in km}^2)^{-0.125}$

$= 0.4724\times(8317.17)^{-0.125}$

$= 0.1528$

iii. Boyce Model (1975)

SDR $= 0.3740\times(\text{ Watershed Area in km}^2)^{-0.2382}$

$= 0.3740\times(8317.17)^{-0.2382}$

$= 0.04356$

iv. Williams and Berndt's (1972) :

SDR $= 0.627\times(\text{Slope of mainstream channel})^{-0.403}$

$= 0.627\times(0.013667)^{-0.403}$

$= 0.1112$

Here slope of mainstream channel is taken as slope of longest flow channel of the watershed.

From the above calculations it can be seen that SDR calculated by different methods vary from 0.04356 to 0.2096. This range of SDR will be used for the validation of the soil loss estimated by RUSLE method for the study area.

6 RESULTS AND DISCUSSION

After multiplication of the six factors as per RUSLE formula (Eq. 4.1) we got the average annual soil loss of the study area and is shown in Figure 6.1. From Figure 6.1 it can be observed that the annual soil loss of the area ranges between 0 and 16746.8 $t.ha^{-1}yr^{-1}$. The mean value of soil loss is 34.6015 $t.ha^{-1}yr^{-1}$.

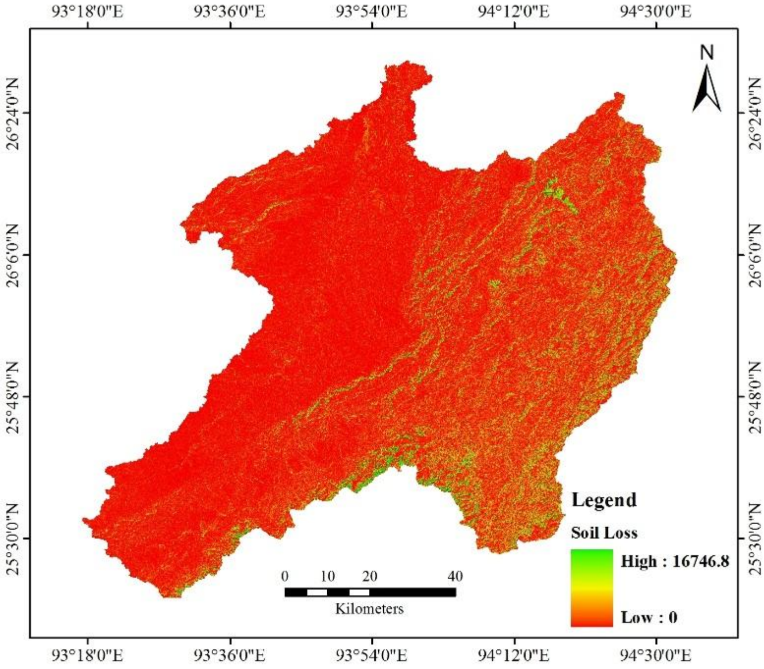

Figure 6.1 : Spatially distributed soil loss Map of Dhansiri Watershed

The maximum value 16746.8 is the value of soil loss of only one pixel, it does not signify any overall soil loss scenario of the study area. The calculation of soil loss of that pixel is shown below -

Pixel Size = 30 m X 30 m

Area of one pixel = 900 m^2 = 0.09 ha

Therefore the soil loss in that pixel = 16746.8 X 0.09 = 1507.212 $t.yr^{-1}$

The total soil loss of the study watershed = Watershed Area X Mean Value

= 831717.0456 ha X 34.6015356 $t.ha^{-1}yr^{-1}$.

= 28.778 million $t. yr^{-1}$

From the observed data of CWC sediment concentration measuring station we calculated the average sediment yield. Though we have 20 years sediment concentration data, but we could use only 5 years data. Because there is a huge drop in sediment concentration value from the year 1995 due to the construction of Doyang reservoir in the upland areas of the watershed.

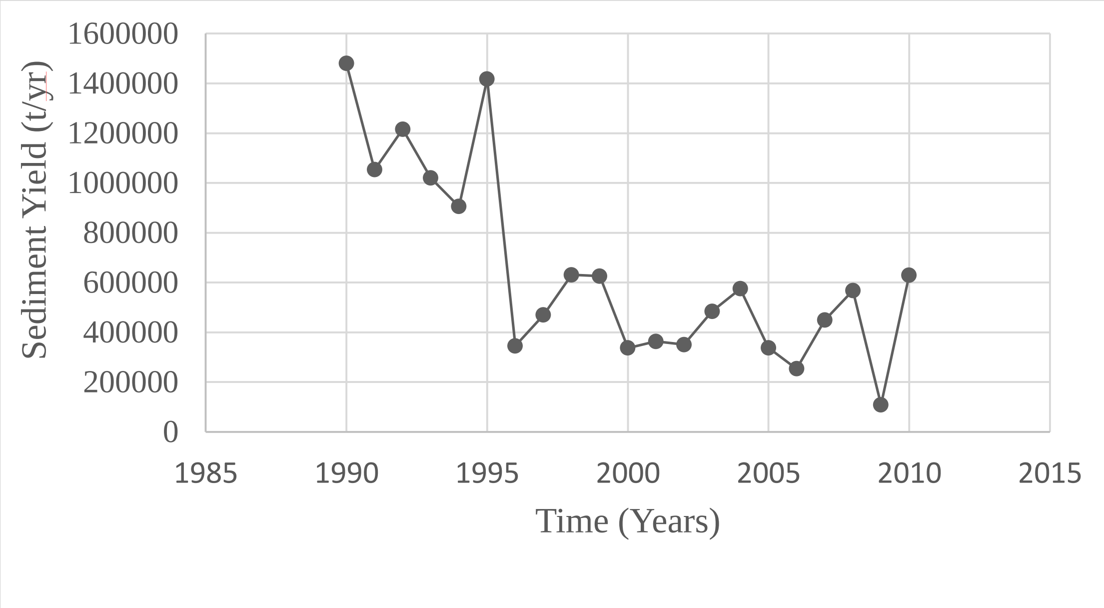

Figure 6.2 : Temporal variation of sediment yield

So we used only the sediment yield data of 1990 to 1995 for validation, as the later period data do not represent the natural condition. The sediment yield data was basically suspended sediment yield, so in order to calculate the Sediment delivery ratio, bed load was added to average suspended sediment yield. The bed load was taken as 15% of the suspended load (Mehdi, 2008; Sitaula, 2007). After the bed load addition, the average sediment yield became 1359321.146 t/yr.

So the Sediment delivery ratio will be, $SDR = \frac{Sediment\ Yield}{Soil\ loss} = \frac{1359321.146}{28778686.964} = 0.0472$

The SDR range found in section 5.5 is 0.04356 to 0.2096, and 0.0472 falls in the range. The small value of sediment delivery ratio may be due to various reasons, such as large size of the watershed, flat slope class coverage in a large portion of the watershed (Figure 6.4) and deposition of eroded sediment in the bunds of paddy field before reaching the stream.

The average annual soil losses of the study Watershed were then grouped into different severity classes based on the criteria of soil erosion risk classification suggested by FAO (2006). The details of severity classes and the spatial distribution of the same in the study area are shown in Table 6.1 and Figure 6.3 respectively.

Table 6.1 : Soil loss severity classes with loss rate and area covered

Severity Class	**Soil Loss (t.ha^{-1}.yr^{-1})**	**Area (km^2)**	**Area(%)**
Slight	<30	6504.8	78.21
Moderate	30-80	1015.4	12.21
Severe	80-150	393.9	4.73
Extremely Severe	>150	403.1	4.85

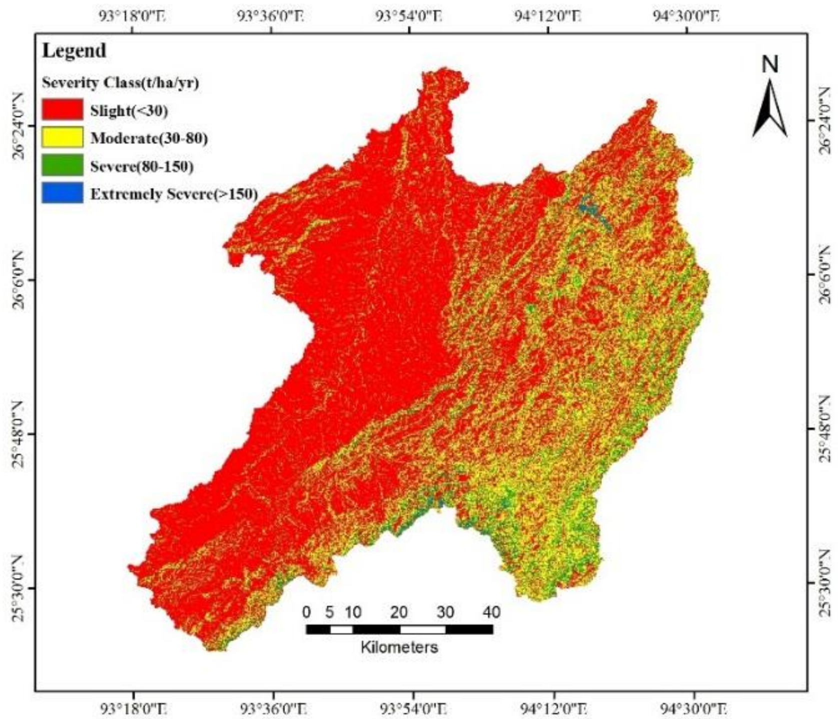

Figure 6.3 : Map of soil erosion severity classes of the study area

More than 75% of the watershed is facing a soil loss less than 30 t/ha/yr while 4.85 % areas comes under extremely severe soil loss category. The areas with extreme severe soil loss should give more importance in terms of erosion control. Comparing Figure 6.3 and Figure 6.4 it can be easily observed that extremely severe erosion occurs mostly in areas with high slope values. While slight erosion are mostly observed in areas with low slope values. This may be due to the high/low LS factor values in the respective regions as LS factor calculation is highly dependent on slope value.

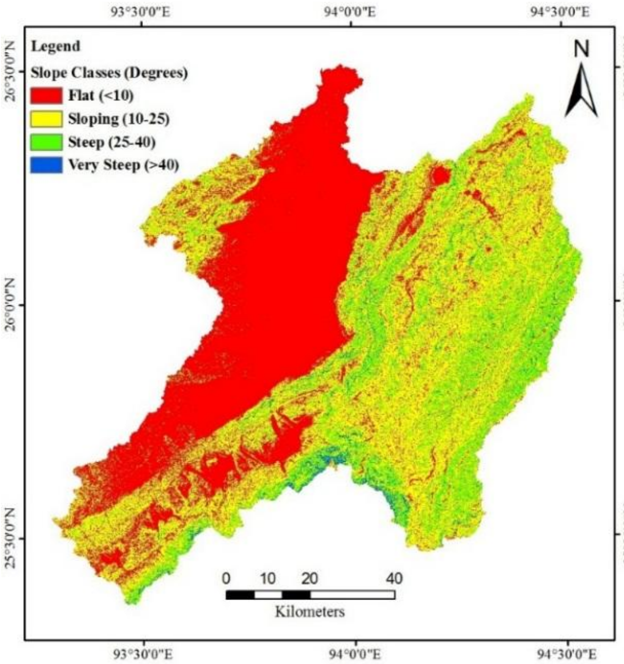

Figure 6.4 : Slope class map as per Gale (2000) of the study area

7 CONCLUSION

A quantitative assessment of average annual soil loss for a part (almost 80%) of Dhansiri watershed was performed with RUSLE method in GIS platform considering rainfall, soil, topographic and satellite imagery datasets. GIS and remote sensing technique was successfully used to calculate all the factors and prepare a 30 m resolution spatially distributed raster map for each factors (i.e R,K,LS and C). The spatially distributed map of annual average soil loss rate was prepared by multiplying the raster maps of each factor using raster calculator in GIS platform. The average soil loss rate was estimated as 34.601536 $t.ha^{-1}yr^{-1}$ and maximum value was found as 16746.8 $t.ha^{-1}yr^{-1}$. The total soil loss for the whole watershed was found as 28.778 million t. yr^{-1}. The result was validated using Sediment Delivery Ratio concept. The predicted soil loss rate and its spatial distribution map can be informative in comprehensive and sustainable watershed management to mitigate soil erosion hazard.

REFERENCES

- Amore, E., Modica, C., Nearing, M.A. and Santoro, V.C., 2004. Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian Basins. *Journal of Hydrology*, 293(1–4): 100–114.
- Arekhi, S., Bolourani, A.D., Shabani, A., Fathizad, H. and Ahamdy-asbchin, S., 2012. Mapping soil erosion and sediment yield susceptibility using RUSLE, Remote Sensing and GIS (Case study: Cham Gardalan Watershed, Iran).

  Advances in Environmental Biology, 6(1): 109–124.
- Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams, 1998. Large area hydrologic modeling and assessment part I: model development, J. Am. *Water Resour. Assoc.*, 34(1), 73–89
- Arnoldus, H.M.J., 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. In: De Boodt, M., Gabriels, D. (Eds.), *Assessment of Erosion*. Wiley, Chichester, UK, pp. 127e132
- Atkinson, E., 1995. Methods for assessing sediment delivery in river systems. *Hydrological Sciences -Journal- des Sciences Hydrologiques*,40,2
- Baigorria, G.A. and Romero, C.C., 2007. Assessment of erosion hotspots in a watershed: Integrating the WEPP model and GIS in a case study in the Peruvian Andes. *Environmental Modelling & Software*, 22(8): 1175–1183.
- Bazzoffi, P., 2009. Soil erosion tolerance and water runoff control: minimum environmental standards. *Regional Environmental Change*, 9(3): 169–179.
- Beskow, S., Mello, C.R., Norton, L.D., Curi, N., Viola, M.R. and Avanzi, J.C., 2009. Soil erosion prediction in the Grande River Basin, Brazil using distributed modelling. *Catena*, 79(1): 49–59.
- Bhattarai, R. and Dutta, D., 2007. Estimation of soil erosion and sediment yield using GIS at catchment scale. *Water Resources Management*, 21(10): 1635– 1647.
- Biswas S & Pani P, 2015. Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India , *Model. Earth Syst. Environ*. 1:42

- Bridge, J.S., 2003. River and Floodplains: Forms, Processes, and Sedimentary Record. *Massachusetts: Blackwell Publishing*.
- Boyce, R.C., 1975. Sediment routing with sediment delivery ratios. Present and Prospective Technology for ARS. *USDA*, Washington, D.C.
- Cox and Madramootoo, 1998, Application of geographic information systems in watershed management planning in St. Lucia, *Computers and Electronics in Agriculture* 20, 229–250
- De Jong, S.M., Brouwer, L.C. & Riezebos, H. Th., 1998. Erosion hazard assessment in the Peyne catchment, France. Working paper DeMon-2 Project. Dept. *Physical Geography*, Utrecht University.
- Evans, J. E., & Semon, D. E., 1997. A GIS model to calculate sediment yields from a small rural watershed, old woman creek, erie and huron counties, ohio. *Ohio Journal of Science*, 97(3), 44-52
- FAO, 2006. *Guidelines for Soil Description*. 4th Edition, Rome.
- Ferro, V. and Porto, P., 2000. Sediment delivery distributed (SEDD) model. *Journal of Hydrologic Engineering*, 5(4): 411–422.
- Fournier, F., 1960. Climat et erosion. Presses Universitaires de France, Paris. Haan, C. T., Barfield, B. J. & Hayes, J. C. (1994). *Design Hydrology and Sedimentology for Small Catchments.* Academic Press, New York.
- Gale, N., 2000. The relationship between canopy gaps and topography in western Ecuadorian rain forest. *Biotropica*, 32(4a): 653–661.
- Gao, P., 2008. Understanding watershed suspended sediment transport. Process in Physical Geography, 32(3): 243-263.
- Gover, G., 2011. Misapplications and misconceptions of erosion models. In Morgan, R.P.C. and Nearing, M.A. (eds.) *Handbook of Erosion Modelling*. Chichester, West Sussex: Wiley-Blackwell, pp. 117-134.
- Hyndman, R. J., and A. B. Koehler, 2006. Another look at measures of forecast accuracy, *Int. J. Forecast*., 22(4), 679–688
- Jain, M.K. and Kothyari, U.C., 2000. Estimation of soil erosion and sediment yield using GIS. *Hydrological Sciences Journal*, 45(5): 771–786.
- Kinnell. P.I.A., 2010. Event Soil Loss, Runoff and universal soil loss equation family of models: a review. *Journal of Hydrology*, 385(1–4): 384–397.

- Kirkby, M.J., Irvin, B.J., Jones, R.J.A., Gover, G. and PESERA team., 2008. The PESERA coarse scale erosion model for Europe. I. – Model rationale and implementation. *European Journal of Soil Science*, 59(6): 1293–1306.
- Kothyari, U. C. & Jain, S. K., 1997. Sediment yield estimation using GIS. *Hydrol. Sci. J.* 42(6), 833-843.
- Krause, P., and Boyle D., 2005. Advances in Geosciences Comparison of different efficiency criteria for hydrological model assessment, *Adv. Geosci*., 5(89), 89–97
- Laften, J.M., Lane, L.J., and Foster, G.R., 1991 WEPP: a new generation of erosion prediction technology. *Journal of Soil and Water Conservation*, 46(1): 34–38.
- Lal R., 2001. Soil degradation by erosion. *Land Degrad Dev* 12(5):519–539
- Lal, R., 1977. Analyses of factors affecting rainfall erosivity and soil credibility. *In: Soil Conservation and Management in the Humid Tropics* (ed. D. J. Greenland & R. Lai), Wiley, Chichester, West Sussex, UK.
- Licciardello, F., Govers, G., Cerdan, O., Kirkby, M.J., Vacca, A. and Kwaad, F.J.P.M., 2009. Evaluation of the PESERA model in two contrasting environments. *Earth Surface Processes and Landforms*, 34(5): 629–640.
- Lin, C., Lin, W., Chou, W., 2002. Soil erosion prediction and sediment yield estimation: The taiwan experience. *Soil and Tillage Research*, 68(2), 143-152.
- Louriero, 2001. A new procedure to estimate the RUSLE EI_{30} index based on monthly rainfall data and applied to the Algarve region, Portugal, *Journal of Hydrology*, 250 , 12-18
- Lu, D., Li, G., Valladares, G.S. and Batistella, M., 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degradation & Development*, 15(5): 499–512.
- Marker M, Angeli L, Bottai L, Costantini R, Ferrari R, Innocenti L, Sililiano G., 2007. Assessment of land degradation susceptibility by scenario analysis: A case study in Southern Tuscany, Italy. *Geomorphology* 93 (2008): 120-129.
- Mehdi Y. and Rahim H., 2008. Ratio of bed load to total sediment load in coarse-bed rivers. *Fourth International Conference on Scour and Erosion* 2008, pp 513-518

- Meyer, L. D. & Wischmeier, W. H., 1969. Mathematical simulation of the processes of soil erosion by water. *Transactions of the ASAE*. 12 (6): 0754-0758
- Miller, G.T., 2006. *Environmental Science: Working with the Earth*. 11th ed. Belmont, CA: Thompson Brook/Cole.
- Mitasova H., Hofierka J., Zlocha M., Iverson L., 1996. Modelling topographic potential for erosion and deposition using GIS, *International Journal of Geographical Information Systems*, 10:5, 629-641
- Moore I, Burch G., 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Sci Soc Am J* 50:1294–1298
- Morgan, R.P.C. and Nearing, M.A., 2011. *Handbook of Erosion Modelling*. Chichester, West Sussex: Wiley-Blackwell.
- Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Binger, R. D. Harmel, and T. L. Veith, 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *Trans.* ASABE, 50(3), 885–900.
- Nearing, M.A., 2004. Soil erosion and conservation. In Wainwright, J. and Mulligan, M. (eds.) *Environmental Modelling: Finding Simplicity in Complexity*. London: John Wiley & Sons, Ltd., pp. 277–290.
- Ouyang D. and Bartholic J., 1997. Predicting Sediment Delivery Ratio in Saginaw Bay Watershed, Proceedings of the *22nd National Association of Environmental Professionals Conference*, Orlando, 19-23 May 1997, pp. 659-671.
- Prasannakumar, V., Vijith, H., Abinod, S., and Geetha, N., 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers*, 3(2): 209–215.
- Quinton, J.N., Krueger, T., Freer, J., Brazier, R.E. and Bilotta, G.S., 2011. A case study of uncertainty: Applying GLUE to EUROSEM. In Morgan, R.P.C. and Nearing, M.A. (eds.) *Handbook of Erosion Modelling*. Chichester, West Sussex: Wiley-Blackwell, pp. 80–97.
- Ranzi, R., Le, T.H. and Rulli, M.C., 2012. A RUSLE approach to model suspended sediment load in the Lo River (Vietnam): Effects of reservoirs and land use changes. *Journal of Hydrology*, 422–423, pp. 17–29.

- Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K. and Yoder, D. C., 1997. Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). *Agriculture Handbook* Number 703, Washington, DC: US Department of Agriculture.
- Renard, K. G., & Freimund, J. R., 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. *Journal of Hydrology*, 157(1-4), 287-306.
- Santhi, C., Arnold J. G., Williams J.R., Dugas W. A., Srinivasan R., and Hauck R., 2002. Validation of the SWAT model on a large river basin with point and nonpoint sources, *J. Am. Water Resour. Assoc*., 37(5), 1169–1188
- Shamsi, U. M., 1996. Storm-water management implementation through modelling and GIS. *J. Wat. Résout: Plan.Manage*. ASCE 122(2), 114-127
- Shirazi, M.A., and L, Boersma., 1984. A unifying quantitative analysis of soil texture. *Soil Sei. Soc. Am. J.* 48:142-147.
- Sidorchuk, A., 2009. A third generation erosion model: the combination of probabilistic and deterministic components. *Geomorphology*, 110(1–2): 2–10.
- Sitaula P. B. ,Garde M., Burbank W. D. , Oskin M., Heimsath A., Gabet E., 2007, Bedload-to-suspended load ratio and rapid bedrock incision from Himalayan landslide-dam lake record. *Quaternary Research* 68 (2007) 111–120
- Stocking, M.A., 2003. Tropical soils and food security: the next 50 years. Science, 302
- Terranova, O., Antronico, L., Coscarelli, R. and Iaquinta, P., 2009. Soil erosion risk scenario in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (Southern Italy). *Geomorphology*, 112(3–4): 228–245.
- Tiwari, A.K., Risse, L.M., and Nearing, M., 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. *Transaction of the American Society of Agricultural Engineers*, 43(5): 1129–1135.
- Tiwari H., Rai S., Kumar D., Sharma N., 2016. Rainfall erosivity factor for India using modified Fourier index. *Journal of Applied Water Engineering and Research*, 4 (2), 83-91
- USDA, 1972. Sediment sources, yields, and delivery ratios. National Engineering Handbook, Section 3 Sedimentation.

- Van der Knijff J M, Jones R J A, Montanarella L., 1999. Soil Erosion risk Assessment in Europe, European Commission, European Soil Bureau.
- Van Rompaey, A.J.J., Verstraeten, G., Van Oost, K., Govers, G. and Poesen, J., 2001. Modelling mean annual sediment yield using a distributed approach. *Earth Surface Processes and Landforms*, 26(11): 1221–1236.
- Vanoni, V.A., 1975. Sedimentation Engineering, Manual and Report No. 54. *American Society of Civil Engineers*, New York, N.Y.
- Verstraeten, G. and Poesen, J., 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. *Geomorphology*, 29(3-4): 275-292
- Walling, D. E., 1988. Erosion and sediment yield research—some recent perspectives. *J. Hydrol*. 100, 113-141.
- Williams, J.R., and H.D.Berndt., 1977. Sediment yield prediction based on watershed hydrology. *Trans. Of the ASAE*. pp 1100-1104.
- Wischmeier, W.H. and Smith, D.D., 1978. Predicting Rainfall-Erosion Loss: *Agricultural Research Service Handbook* No. 282, Washington, D.C., USDA, 48 p
- Zhou, 2006. Large scale soil erosion modeling for a mountainous watershed, *WIT Transactions on Ecology and the Environment*, Vol 89
- Zhou, P., 2008. Landscape-scale soil erosion modelling and ecological restoration for a mountainous watershed in Sichuan, China. *Tropical Forestry Reports* 35, University of Helsinki.

APPENDIX-I

Figure : During the labortary experiment for particle size distribution analysis of the soil samples collected from field