MATHEMATICAL MODEL FOR FLOW AND SEDIMENT YIELD ESTIMATION ON TEL RIVER BASIN OF INDIA

A

DISSERTATION

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CERTIFICATE

*This is to certify that the thesis entitled "**Mathematical Model for Flow and Sediment Yield Estimation on Tel River Basin of India**", being submitted by Sri **Santosh Kumar Biswal** to the National Institute of Technology Rourkela, for the award of the Degree of Master of Technology of Philosophy is a record of bona fide research work carried out by him under my supervision and guidance. The thesis is, in my opinion, worthy of consideration for the award of the Degree of Master of Technology of Philosophy in accordance with the regulations of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any Degree or Diploma.*

The assistance received during the course of this investigation has been duly acknowledged.

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Abstract:

Soil erosion is a slow and continuous process and one of the prominent problems across the world leading to many serious problems like loss of soil fertility, loss of soil structure, poor internal drainage, sedimentation deposits etc. In this study remote sensing and GIS based methods have been applied for the determination of soil erosion and sediment yield. Tel River basin which is the second largest tributary of the river Mahanadi laying between latitude 19° 15' 32.4"N and, 20° 45' 0"N and longitude 82° 3' 36"E and 84° 18' 18"E chosen for the present study. The catchment was discretized into approximately homogeneous sub-areas (grid cells) to overcome the catchment heterogeneity. The gross soil erosion in each cell was computed using Universal Soil Loss Equation (USLE). Various parameters for USLE was determined as a function of land topography, soil texture, land use/land cover, rainfall erosivity and crop management practice in the watershed. The gross soil erosion was computed by overlaying all the parameter maps of USLE in ArcGIS and compared with the observed sediment yield at the outlet. Different erosion prone areas of the study basins were identified so that conservation practices can be implemented on those areas to minimize erosion.

Key words: Universal Soil Loss Equation (USLE), sediment yield, soil erosion, RS and GIS.

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ABBREVIATIONS

CWC-Central Water Commission

DEM -Digital Elevation Model

GIS- Geographic Information System

IMD-India Meteorological Department

ISRIC- International Soil Reference and Information Centre

MUSLE-Modified Universal Soil Loss Equation

NDVI- Normalized Difference Vegetation Index

NRSC- National Remote Sensing Centre

RS- Remote Sensing

RUSLE- Revised Universal Soil Loss Equation

SDR- Sediment Delivery Ratio

SYI - Sediment Yield Index

USLE- Universal Soil Loss Equation

CHAPTER 1
INTRODUCTION

1.1 Background

Soil erosion is one of the most important land degradation and critical environmental problem across the world. The process of soil erosion starts with detachment of soil by different erosive agent followed by transportation and finally the deposition of soil at some other place. In the case of erosion by water detachment of soil particles is due to raindrop impact and shearing force of flowing water. Subsequently the sediment is transported through runoff water along the down slope. So the sediment carrying capacity depends on the length and steepness of slope and the kinetic energy of the runoff water. As the impact of raindrop and velocity of runoff water is highly depends on the land use /land cover and soil type, so soil erosion is mostly influenced by soil type and land use/land cover of the catchment area. In the present time, due to the increasing trend of urbanization, agriculture expansion and deforestation the soil erosion becomes critical problems not only in India but also across the globe.

1.2 Soil erosion modeling

Soil erosion models play critical roles in soil and water resource conservation. And its modeling is a very complex interaction that influences rates of erosion by simulating erosion processes in the watershed. Various parametric models such as empirical (statistical/metric), conceptual (semi-empirical) and physical process based (deterministic) models are available to compute soil loss. In general, these models are categorized depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model. Empirical models are generally the simplest of all three model types. They are statistical in nature and based primarily on the analysis of observations and seek to characterize response from these data (Wheater et al., 1993).

Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. They are designed for specific set of conditions of particular area. The Universal Soil Loss Equation (USLE) (Wischmer and Smith, 1965) was designed to predict soil loss from sheet and rill erosion in specific conditions from agriculture fields. Modified universal soil loss equation (MUSLE) (Williams& Berndt; Meyer, 1975) a modified version of USLE is applicable to other conditions by introducing hydrological runoff factor for sediment yield estimation. Water erosion prediction project (WEPP) (Lane and Nearing, 1989) is process based, continuous simulation model, developed to replace USLE (Okoth, 2003). Areal non-point source watershed environment response simulation (ANSWERS) (Beasley etal, 1980) designed to compute soil erosion within a watershed. The European Soil Erosion Model (EUROSEM) (Morgan et al., 1991, 1992) is a single process–based model for assessing and risk prediction of soil erosion from fields and small catchments. Morgan, Morgan and Finney (MMF) model is an empirical model developed for mean annual soil loss estimation from field-sized areas on hill slopes (Morgan et al., 1984) having strong physical base.

Table 1: Different erosion models developed in past years by researchers across the world.

NAME OF MODELS	YEAR
Universal Soil Loss Equation (USLE)	Wischmeier and Smith, 1965
Modified Universal Soil Loss Equation (MUSLE)	Williams, 1975
ANSWERS	Beasley et al., 1980
Morgan, Morgan and Finney	Morgan et al., 1984
Erosion Productivity Impact Calculator(EPIC)	Williams et al., 1984
Agricultural Non-Point Source Pollution Model(AGNPS)	Young et al., 1987
WEPP	Nearing et al., 1989
KINEROS	Woolhiser et al., 1990
Revised Universal Soil Loss Equation (RUSLE)	Renard et al.,1991
EUROSEM	Morgan et al., 1998

1.3 SOIL EROSION PROBLEMS AND NEED OF ITS RISK ASSESSMENT

Soil erosion is a global environmental crisis in the world today that threatens natural environment and also the agriculture. Accelerated soil erosion has adverse economic and environmental impacts (Lal, 1998). The current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreparable loss in productivity on about 6 million hectare of fertile land a year (Dudal, 1994). Asia has the highest soil erosion rate of 74 ton/acre/yr (El-Swaify, 1994) and Asian rivers contribute about 80 % per cent of the total sediments delivered to the world oceans and amongst these Himalayan rivers are the major contributors (Stoddart, 1969). Raymo and Ruddiman (1992) articulated that the Himalayan and Tibetan regions although covers only about 5% of the earth’s land surface, but supply around 25% of the dissolved load to the world oceans. The alarming facts figured out by Narayan and Babu (1983) that in India about 5334 Mt The soil erosion risk assessment can be helpful for land evaluation in the region where soil erosion is the main threat for sustained agriculture, as soil is (16.4 ton/hectare) 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. Das, (1985) has reported in India it is estimated that about 38 % out of a total reported geographical area, that is about 127 million hectare are subjected to serious soil erosion.

Soil resource is important to sustain the productivity in hilly terrain. Livelihood of the people in the Himalayan region is mainly dependent on farming system and especially on subsistence agriculture. Sustainable use of mountains depends upon conservation and potential use of soil and water resources (Ives & Messerli, 1989). It has been severely affecting global food security due to ever-growing population and its dependency for livelihood on limited natural resources. Landslide, mudslides, collapse of man-made terraces, soil loss from steep slopes and decline of forest / pasture areas are the main reasons for land resource degradation in the Himalayan region (ICIMOD, 1994)". Formation of Himalayan region is geologically weak, unstable and hence highly subjected to a serious problem of soil erosion. (Jain et al.2000). It has been observed that loss of fertile top soil, because of surface and gully erosion, is a common phenomenon and agricultural land has expanded to areas having marginal soil cover (Hofer, 1998).

Thus, natural resources in mountainous terrain are profoundly afflicting from land degradation as a result of intensive deforestation, overgrazing and subsistence agriculture due to population pressure, large-scale road construction and mining etc. along with anthropogenic activities. As a consequence of deforestation coupled with the influence of the high rainfall, the fragile terrains with steep slope have become prone to severe soil erosion. Garde et al., (1987) reported that the soil erosion rate in the northern Himalayan region is high and the order of 2000 to 2500 $ton/km^2/yr$.

1.4 Objectives

- To study on different mathematical models used for flow and sediment yield estimation.
- To apply suitable models for sediment yield estimation on Tel river basin.
- To identify erosion prone areas in the river basin using Remote Sensing and GIS.

CHAPTER 2
LITERATURE REVIEW

Narayana et al (1983) utilized annual soil loss data for 20 different land resource regions of the country sediment loads of some rivers, and rainfall erosivity for 36 river basins and 17 catchments of major reservoirs and developed statistical regression equations for predicting sediment yield. They found that soil erosion is taking place at the rate of 16.35 ton/ha/annum which is more than the permissible value of 4.5-11.2 ton/ha. About 29% of the total eroded soil is lost permanently to the sea. 10% of it is deposited in reservoirs. The remaining 61% is dislocated from one place to the other.

Arnold et al. (1995) developed a model ROTa (routing outputs to the outlet) for prediction of water and sediment yield on large basins. This model takes inputs from continuous-time soil-water balance models; the water and sediment movement in channels are developed within an agricultural management model. The ROTa was validated on three different spatial scales: a small watershed ARS station G at Riesel, Texas, the White Rock Lake watershed near Dallas, and The Lower Colorado River basin river basin.

Kothyari and Jain (1997) developed a method for sediment yield estimation which involves spatial disaggregation of the catchment into cells having uniform soil erosion characteristics with the help of GIS technique using the Integrated Land and Water Information Systems (ILWIS).

Jain et al (2001) did a comparative study between two soil erosion model (Morgan and USLE) for the hilly Himalayan regions by developing required parameters with the application of remote sensing and GIS. He found that for high slope region Morgan model gives better result whereas USLE overestimating the erosion amount.

Khan (2001) delineated large watershed and prioritize according to their erosivity and sediment-yield index (SYI) values. He classified watershed into different category such as high priority watersheds with very high SYI value (>150) which needs immediate attention for soil and water conservation and low priority watershed with low SYI value (<50) may not require immediate attention.

Jain et al (2005) modelled the mechanics of overland flow by using the St. Venant equations and the process of soil erosion by sediment continuity equation with appropriate auxiliary equations. The spatial information for each cell of the catchment was generated using digital analysis of satellite data.

Bhattarai R. and Dutta D. (2007) studied the effect of DEM resolution on sediment yield by using two different resolutions of DEM for a small watershed in Mun River basin, Thailand. The required factors/parameters are generated through remote sensing and GIS techniques. The concept of sediment delivery ratio is used to route surface erosion from each of the discretized cells to the catchment outlet. The process of sediment delivery from grid cells to the catchment outlet is represented by the topographical characteristics of the cells.

Ni et al. (2008) developed a new hydrological model TsingHua Integrated Hydrological Modeling System (THIHMS-SW) for prediction of soil erosion and applied it to a small watershed in the region of the Loess Plateau and which produce fairly good results.

The factors of RUSLE were determined using Remote Sensing (RS) and GIS by Adediji et al. (2010) for modeling soil erosion in Katsina area of Katsina State of Nigeria. The potential mean annual soil loss was found to be 17.35 ton/acre/yr. for the study area. The study demonstrated that remote sensing and GIS can be satisfactorily used for modeling soil erosion.

Jain M.K. and Das (2010) generated transport capacity maps with the concept of transport limited sediment delivery (TLSD) using remote sensing and GIS technique. An empirical relation is also proposed and demonstrated for computation of TLSD which depend on land cover by NDVI approach.

Prasannakumar et al. (2011) used RUSLE in combination with remote sensing and GIS techniques to assess the spatial pattern and annual rate of soil erosion in the Munnar Forest Division in Western Ghats, Kerala, India. He observed that Maximum soil loss of109.31 t $h^{-1}y^{-1}$ and the areas with extreme erosion (erosion is higher than 50 t $h^{-1}y^{-1}$) are confined to 11.46% of the total area, while the area occupied by severe erosion (erosion rate between 25 and 50 t $h^{-1}y^{-1}$) is 27.53%.

A study were conducted to find out the erosion prone area of Cham Gardalan watershed, Ilam Province, Iran by Arekhi et al. (2012) with a view to minimize erosion by introducing conservation practices to those areas. The cover management factor (C) was related to NDVI with ground truth verification and other factors were computed using RS and GIS. The study showed that 31.63% of the area is under extreme erosion risk which needs immediate attention.

CSAFORDI et al (2012) developed a new workflow with the ArcGIS Model Builder with four-part framework to accelerate data processing and to ensure comparability of soil erosion risk maps.

Li et al. (2012) conducted a case study to validate the performance of the soil and water assessment tool (SWAT) and its applicability as a simulator of runoff and sediment transport processes in the Jihe Watershed Loess Plateau of north western China. They performed statistical analysis for 47 years of recorded data and found very high coefficient of determination (>0.7).

The study suggests SWAT model can be used satisfactorily for simulation of runoff and sediment yield.

Park et al (2012) developed Soil Erosion Model for Mountain Areas in Korea (SEMMA) which can be used to estimate sediment yield from hill slopes. The SEMMA model was also improved by developing several equations that were classified by rainfall depth and vegetation coverage. So this model may be applicable for soil erosion risks in burnt mountains.

CHAPTER 3
THE STUDY AREA AND DATA COLLECTION

3.1 Geography and Extent

- The Tel river basin (Tel river- which is the second largest tributary of Mahanadi River) has been chosen as the study area for the present work. It lies between latitude 19° 15' 32.4''N and, 20° 45' 0''N and longitude 82° 3' 36''E and 84° 18' 18''E and covers four districts of Odisha namely Nabarangpur, Kalahandi, Balangir and Sonpur. Kantamal station was taken as the outlet of the catchment for the present work.

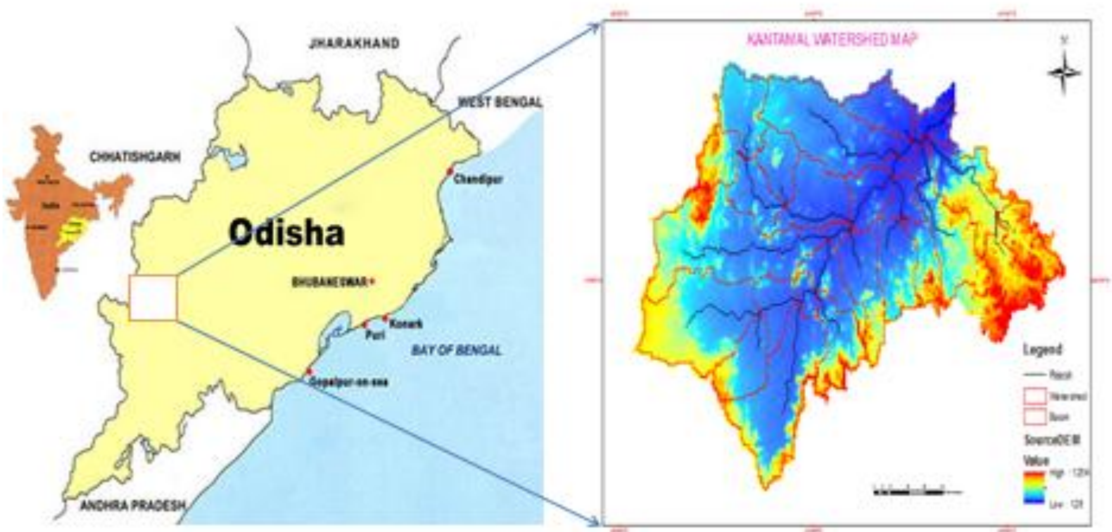

Figure 3.1: Study area map

3.2 Climate

The study area belongs to the sub-humid temperate region of India with an average rainfall ranging from 1100 to 1400 mm. Of the total annual rainfall, nearly 90% is received during the monsoon season (June–October) and the rest of the year remains nearly dry. The months of July and August are the wettest months of the year, receiving average rainfall of the order of 360 mm and 380 mm respectively. The southwest monsoon, which is the single largest contributor of monsoon rainfall in this region, normally sets in in mid-June.

The erratic nature of monsoon led to a rain fall of greater than 1100 mm in one month at some station where on the other hand, there is evidence of zero rainfall for seven or eight consecutive months in the study area. This region, therefore, often undergoes from both droughts and flash floods from time to time.

The climate is of extreme type, with May being the hottest month with mean daily maximum and minimum temperature of 42 °C and 31 °C respectively. December is the coolest month, with mean daily maximum and minimum temperature of 28 °C and 12 °C respectively.

3.3 Data Collection

Daily and monthly rainfall data were collected from Orissa rainfall monitoring system and Indian Meteorological Department (IMD), discharge and silt data were collected from India water portal (India-wris). For land use and land classification BHUVAN NRSC data was used. NDVI analysis was carried out by using LANDSAT 8 data of United State Geological Survey (USGS). International Soil Reference and Information Centre (ISRIC) 1 km soil grid data was used for soil classification.

CHAPTER 4
METHODOLOGY

Starting from the detachment of soil particles to deposition of sediment the whole phenomenon of soil erosion depends on many parameters. That's why the accurate estimation of erosion by applying complete theoretical concept is not practical. So different researchers applied statistical concept and developed a number of models and some use both statistics and fundamental physical concept and developed semi theoretical models to evaluate soil erosion which can be satisfactorily applied to different areas by considering suitable parameters. In the present study Universal Soil Loss Equation is used to estimate the soil loss from the watershed. The parameters of USLE are computed using Remote Sensing and GIS technique.

4.1 Universal soil loss equation (USLE):

The mathematical model for soil loss estimation with the greatest acceptance and used worldwide is the Universal Soil Loss Equation (USLE), developed by Agriculture Research Services (ARS) scientists Wischmeier and D. Smith, United State Department of Agriculture in the year 1965.While newer methods are now becoming available, most of them are still based upon principles introduced by the USLE. The USLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices.

- USLE is expressed as

$$A = R \times K \times LS \times C \times P \quad (1)$$

- Where A represents the potential long term average annual soil loss in tonnes per hectare (tons per acre) per year.
- R is the rainfall and runoff factor by geographic location(MJ mm ha^{-1} hr^{-1}).
- K is the soil erodibility factor(ton ha hr MJ^{-1} ha^{-1} mm^{-1}).
- LS is the slope length gradient (topographic) factor.
- C is the crop/vegetation and management factor.
- P is the support practice factor.

4.2 Description of Parameters of USLE

4.2.1 The Rainfall Erosivity Factor (R)

The rainfall erosivity index implies a numerical evaluation of rainfall pattern, which describes its capacity to erode soil from an unprotected field. The erosion index is a measure of the erosive force of specific rainfall. Rainfall Erosivity Index (R) is generally calculated from an annual summation of rainfall data using rainfall energy over 30-min duration. The relative fall velocity of the single droplet and the overall rainfall intensity determines the erosive properties of rain droplets (Hrissanthou et al., 2003).

When factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to the product value of two rainstorm characteristics: total kinetic energy of the storm times its maximum 30-minute intensity *(El)*. This product variate is an interaction term that reflects the combined potential of raindrop impact and turbulence of runoff to transport dislodged soil particles from the field. The value of this statistic for any particular rainstorm can be computed from a recording-rain gauge record with the help of rainfall energy.

The sum of the computed storm *El* values for a given time period is a numerical measure of the erosivity of all the rainfall within that period. The rainfall erosion index at a particular location is the longtime-average yearly total of the storm *El* values. The storm *El* values reflect the interrelations of significant rainstorm characteristics. Summing these values to compute the erosion index adds the effect of frequency of erosive storms within the year.

So R is expressed as

$$\boldsymbol{R = \frac{1}{n}\sum_{i-1}^{n}\left(\sum_{j-1}^{m} E_j\,(I_{30})_j\right)} \qquad (2)$$

Where n = Total number of years,
m = Total number of rainfall storms in i^{th} year,
I30 = Maximum 30 min intensity (mm hr −1),
E_j=Total kinetic energy (MJ ha−1) of j^{th} storm of i^{th} year
and is given as:

$$\boldsymbol{E_j = \sum_{i-1}^{p} e_k \times d_k} \qquad (3)$$

Where p = Total number of divisions of jth storm of ith 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)

$$\mathbf{e_k} = 0.29\left(1 - 0.72\boldsymbol{e}^{(\mathbf{-0.05 i_k})}\right) \qquad (4)$$

4.2.1.1 Iso-Erodent Map

The estimation of rainfall erosivity factor R by equations given above is a cumbersome procedure and requires a long term rainfall data. To avoid this, concept of Iso-Erodent map is developed by joining points with same erosion-index value (which implies equally erosive average annual rainfall). The average number of erosion index units per year along each Iso-erodent gives the value of R in the erosion equation. Iso-erodent maps for different regions are prepared which can be easily used to get R value of a particular area to estimate soil loss from the area.

Using the data for storms from several rain gauge stations located in different zones, linear relationships were established between average annual rainfall and computed EI30 values for different zones of India and Iso-erodent maps were drawn for annual and seasonal EI30 values following equation was developed for Eastern Ghat high Zone of Orissa by (S.Sudhishri and U.S.Patnaik, 2004), and used in the present study where RN is the average annual rainfall in mm.

$$R = -6.61 + 0.82P \qquad (5)$$

Where P = annual precipitation of the catchment area.

For the present study, Eq. 5 is used to compute annual values of R-factor by replacing P with actual observed annual rainfall in a year.

4.2.2 The Soil-Erodibility Factor (K)

Soil erodibility factor is a combined effect of different physical processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. It is defined as the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow, on a 9-percent slope 72.6 feet long. Continuous fallow, for this purpose, is land that has been tilled and kept free of vegetation for a period of at least 2 years or until prior crop residues have decomposed. So it is influenced by different characteristics of the soil like soil texture, organic content, mineral composition etc. The Table 2 shows values of K for different soil categories at several research stations in India (Gurmel Singh et al. 1990).

Table 2: Values of K at different stations in India.

Stations Name	Soil	Values of K
Agra	Loamy sand , Alluvial	0.07
Dehradun	Dhulkot silt, Loam	0.15
Hyderabad	Red chalka sandy loam	0.08
Kharagpur	Soils from lateritic rock	0.04
Kota	Kota-clay loam	0.11
Oottakamund	Laterite	0.04
Rehmankhera	Loam, alluvial	0.17
Vasad	Sandy loam, alluvial	0.06

4.2.3 The Topographic Factor (LS)

The rate of soil erosion by water is very much affected by both slope length and gradient (percent slope). The two effects have been evaluated separately in research and are represented in the erosion equation by L and S, respectively. In field application of the equation, however, it is convenient to consider the two as a single topographic factor, LS. The factor LS is the expected ratio of soil loss per unit area on a field slope to corresponding loss from the basic 9-percent slope, 72.6 feet long.

Slope length is defined as the distance from the point of origin of overland flow to either of the following, whichever is limiting for the major part of the area under consideration: (1) the point where the slope decreases to the extent that deposition begins or (2) the point where runoff enters a well-defined channel that may be part of a drainage network or a constructed channel such as a terrace or diversion (15). Numerous plot studies have shown that the soil loss per unit area is proportional to some power of slope length. The value of LS may be expressed as

$$LS = \left(\frac{L}{22.13}\right)^m \times (0.065 + 0.045S + 0.0065S^2) \qquad (6)$$

The LS formula can be used in a considerable way in ArcGIS as given bellow:

$$LS = \left(\frac{Flow\ Accumulation \times Cell\ Resolution}{22.13}\right)^m \times\ (0.065 + 0.045S + 0.0065S^2) \qquad (7)$$

Where L=slope length
S=slope (%)
m= exponent vary with the slope range given in the Table 3.

Table 3: **Different values of m for different slope range.**

Slope (%)	**Value of exponent 'm'**
<1	0.2
1-3	0.3
3-5	0.4
>5	0.5

4.2.4 The Cropping-Management Factor (C)

The value of cropping management factor depends on land use/land pattern of the area such as vegetation type, stage of growth and cover percentage etc. Therefore, it is very essential to have good knowledge concerning land-use pattern in the basin to generate reliable C factor values.

The cropping-management factor is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated.

The C values can be computed by two methods one is the traditional method in which different values are assigned to different land use. With the advances in remote sensing technique in recent years we can compute the value of C from the normalized difference vegetation index (NDVI) images generated from different satellite data like landsat7,landsat8 etc.

Landsat 8 data of the study area with spatial resolution of 30 m was used for generation of NDVI image. After the production of the NDVI image, the following formula was used to generate a C factor map from NDVI values

$$\mathbf{C} = \mathbf{e}^{\left(-\boldsymbol{\alpha}\left((\mathbf{NDVI})/(\boldsymbol{\beta}-\mathbf{NDVI})\right)\right)} \tag{8}$$

Where α and β are unit less parameters that determine the shape of the curve relating to NDVI and the C factor .The values of 2 and 1 were selected for the parameters α and β, respectively which seems to give good results(Reshma Parveen & Uday kumar 2012). As the C factor ranges be-tween 0 and 1, a value of 0 was assigned to a few pixels with negative values and a value of 1 to pixels with value greater than 1.

4.2.4.1 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) is based on the concept that vegetation vigour is an indication of water availability or lack thereof. The NDVI is a measure of the “greenness,” or vigor of vegetation. It is derived based on the known radiometric properties of plants, using visible (red) and near-infrared (NIR) radiation. NDVI is defined as:

$$\boldsymbol{NDVI} = \frac{\boldsymbol{NIR-R}}{\boldsymbol{NIR+R}} \tag{9}$$

Where NIR and RED are the reflectance in the near infrared and red bands. NDVI is a good indicator of green biomass, leaf area index, and patterns of production because, when sunlight strikes a plant, most of the red wavelengths in the visible portion of the spectrum (0.4–0.7 mm) are absorbed by chlorophyll in the leaves, while the cell structure of leaves reflects the majority of NIR radiation (0.7–1.1 mm). Healthy plants absorb much of the red light and reflect most NIR radiation. In general, if there is more reflected radiation in the NIR wavelengths than in the visible wavelengths, the vegetation is likely to be healthy (dense). If there is very little difference between the amount of reflected radiation in the visible and infrared wavelengths, the vegetation is probably unhealthy (sparse). However, this can also result from partially or non-vegetated surfaces. NDVI values range from−1 to +1, with values near zero indicating no green vegetation and values near +1 indicating the highest possible density of vegetation.

4.2.5 Land use / Land cover map

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. Remote sensing is an essential tool to study land-use pattern because it facilitates observations across larger extents of Earth's surface than is possible by ground-based observations and also provide a synoptic overview of the whole area in a very short time span. This leads to quick and truthful representation of the land cover in the best possible manner. It provides an insight to coordinate relationship among residential, industrial and recreational land uses, besides providing broad-scale inventories of natural resources management and the significance of water features as points of reference in the landscape and monitoring environmental issues and planning economic development.

4.2.6 The Support Practice Factor (P)

The erosion control practice factor (P-factor) or the support practice factor is defined as the ratio of soil loss with a given surface condition to soil loss with up-and-down-hill plowing. P-factor values involve treatments that retain liberated particles near the source and prevent further transport. The P-factor accounts for the erosion control effectiveness of such land treatments as contouring, compacting, establishing sediment basins, and other control structures. Practices that reduce the velocity of runoff and the tendency of runoff to flow directly downslope reduce the P-factor (Goldman et al. 1986; Novotny and Chesters 1981)

In general, whenever sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil it can carry. The most important of these supporting practices for cropland are contour tillage, strip cropping on the contour, terrace systems, and stabilized waterways. The factor P in the erosion equation is the ratio of soil loss with the supporting practice to the soil loss with up-and-down-hill culture. Improved tillage practices, sod-based rotations, fertility treatments, and greater quantities of crop residues left on the field contribute materially to erosion control and frequently provide the major control in a farmer's field.

4.3 Sediment Yield (SY) and Sediment Delivery Ratio (SDR)

Sediment yield is dependent on gross soil loss in the watershed and on the transport of eroded material out of the watershed. The total amount of sediment that is delivered to the outlet of the watershed is known as the sediment yield (Julien, 2010).

Sediment yield (SY) is the total sediment outflow from a drainage basin over a specified period of time and it is generally measured in tons per year. For a given watershed or basin, the specific degradation (SD) is obtained by dividing sediment yield (SY) by the drainage area A of the watershed.

$$\mathbf{SD} = \frac{\mathbf{SY}}{\mathbf{A}} \tag{10}$$

Where, SD = specific degradation in metric tons/ha./year,

SY= sediment yield

A = drainage area in ha.

The sediment delivery ratio (SDR) defined as the ratio of the sediment yield (SY) at given stream cross section to the gross soil erosion (GSE) from the watershed upstream of the measuring point. The SDR can be expresses as:

$$\mathbf{SDR} = \frac{\mathbf{SY}}{\mathbf{GSE}} \tag{11}$$

The value of SDR gives information about how much percentage of eroded particles actually reach the outlet of the watershed.

5.1 Watershed Delineation

Delineation is part of the process known as watershed segmentation, i.e., dividing the watershed into discrete land and channel segments to analyze watershed behavior. Creating a boundary that represents the contributing area for a particular control point or outlet and used to define boundaries of the study area, and/or to divide the study area into sub-areas.

In the present study ArcGIS 10.2 is used to delineate the watershed with the help of 30m*30m DEM collected from landsat8. The flow chart Figure 5.1 shows the process of delineating watershed.

Appendix–I shows the DEM, Flow Direction, Flow Accumulation, Drainage Network map of the delineated watershed.

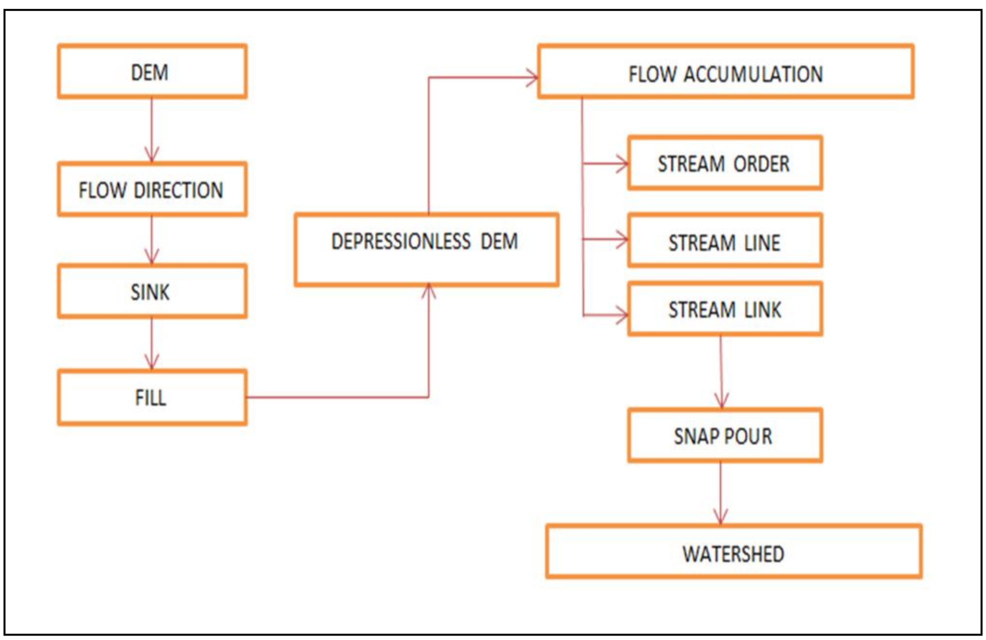

Figure 5.1 Flow chart of watershed delineation

5.2 Estimation of USLE parameter for the study area

5.2.1 Estimation of the Rainfall Erosivity Factor (R)

Daily rainfall data from 15 stations of the study area were collected. The average annual rainfall is computed by giving thiessen polygon weightage factor (Table 4) to individual stations. Figure 5.2.1 shows the thiessen polygon of the study area.

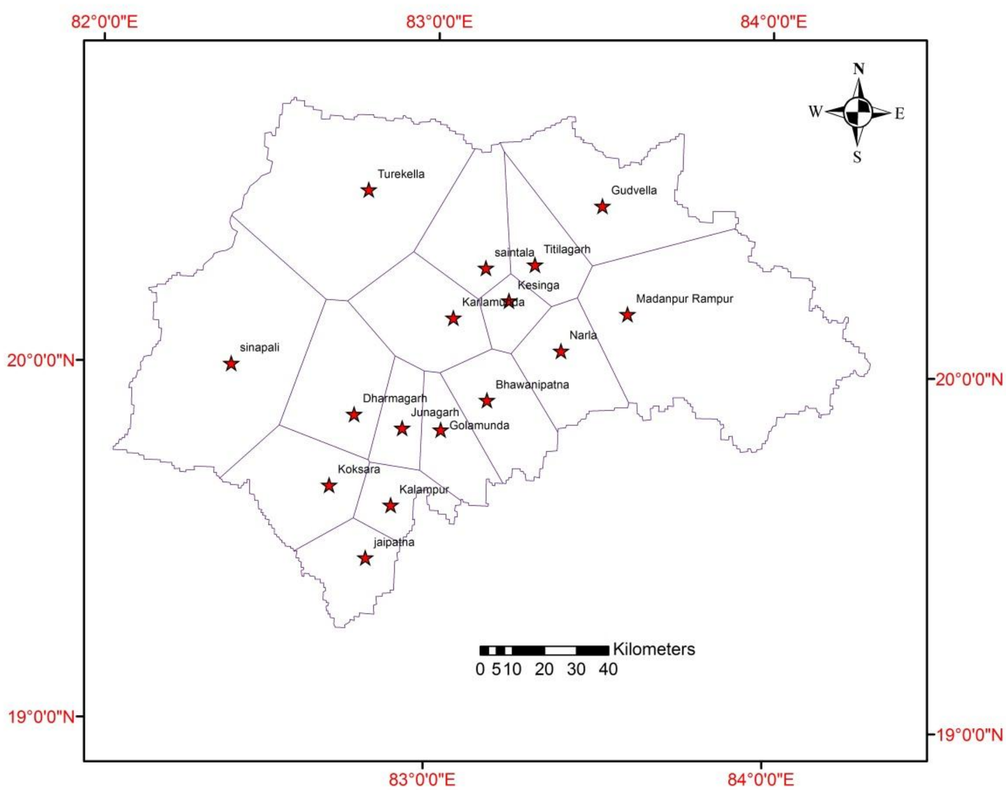

Figure 5.2.1 Thiessen polygon of the study area

Table 4: The weightage factor of rain gauge stations of the study area.

STATIONS NAME	WEIGHTAGE FACTOR
Bhawanipatna	0.042647
Kesinga	0.092616
Karlamunda	0.042813
Madanpurrampur	0.054449
Narla	0.020913
Dharmagarh	0.022582
Junagarh	0.032925
Kalampur	0.050774
jaipatna	0.059698
Koksara	0.244859
Golamunda	0.029584
Turekella	0.15458
sinapali	0.15156

From equation (5) R is computed for the study area for 1999-2011 years and is shown in the Table 5.

Table 5: Values of R from year 1999 to 2011

Year	Values of R (MJ mm ha–1 h–1 year–1)
1999	969.8983
2000	1040.208
2001	1341.611
2002	677.5698
2003	1452.768
2004	1083.29939
2005	943.278761
2006	1535.34191
2007	1221.29662
2008	1350.94814
2009	1176.9241
2010	1188.11852
2011	936.084925

5.2.2 Estimation of the soil erodibility factor (K)

The computation of values of K for the study area is done with the International Soil Reference and Information Centre (ISRIC) 1 km soil grid data (Figure 5.2.2).

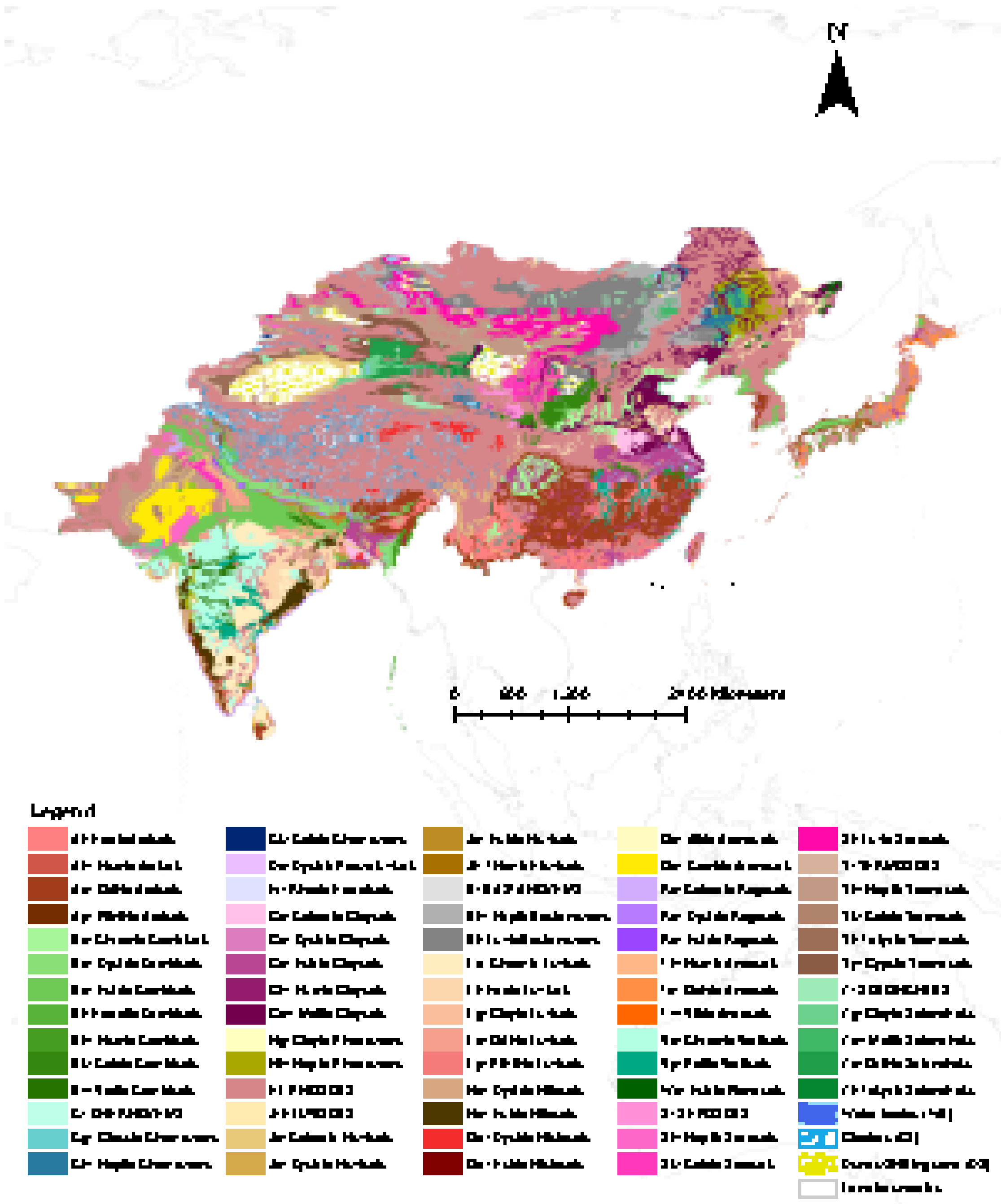

Figure 5.2.2: The soil map of South Asia with legend (FAO)

The world soil grid map of ISRIC is processed in Arc GIS 10.2 to get the soil map of the study area (Figure5.2.2.1) .Different soil type was then identified by using the legends of the Figure 5.2.2.

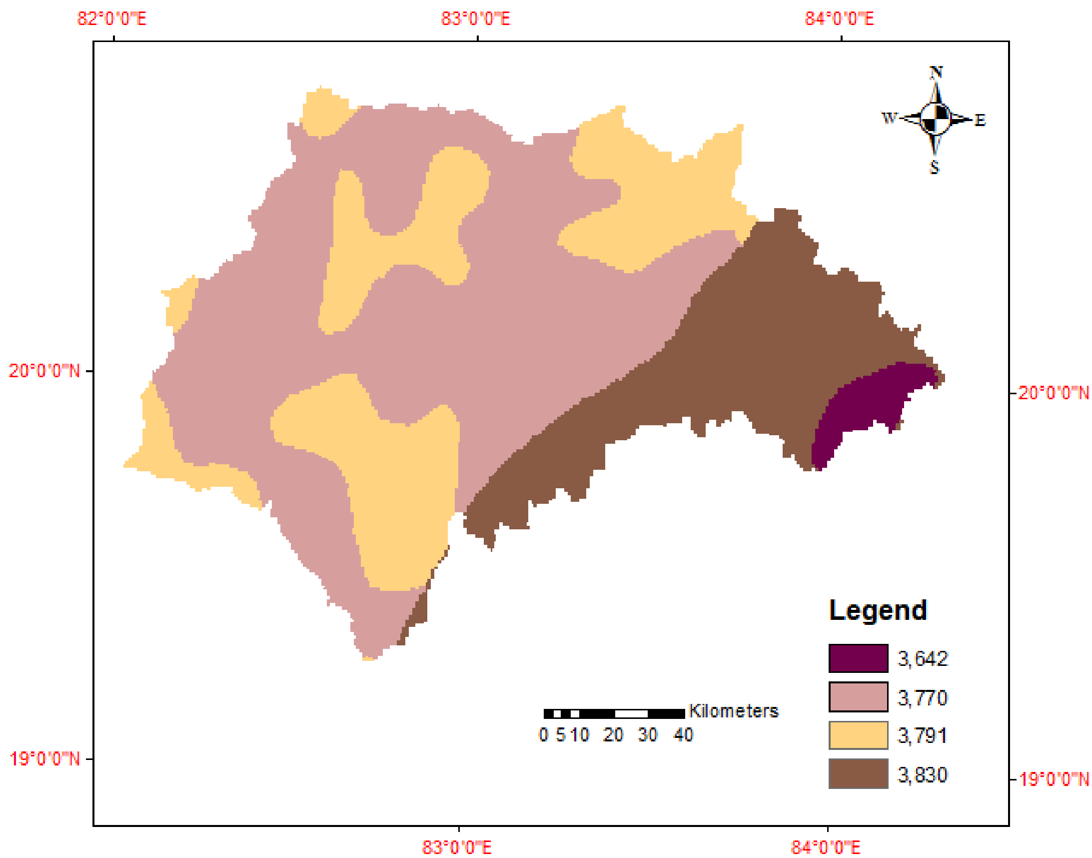

Figure 5.2.2.1: Soil map of the study area

The Table 2 is used to assign values of K for different soil types and the soil erodibility factor (K) map (Figure 5.2.2.1) was generated.

Table 6: Values of K for different soil types of the study area.

Sl no.	Soil Type	Values of K
1	Laterite (Ferric Luvisols)	0.04
2	Laterite (Chromic Luvisols)	0.04
3	Clay-Loam (Eutric Nitosols)	0.11
4	Loam (Humic Acrisols)	0.17

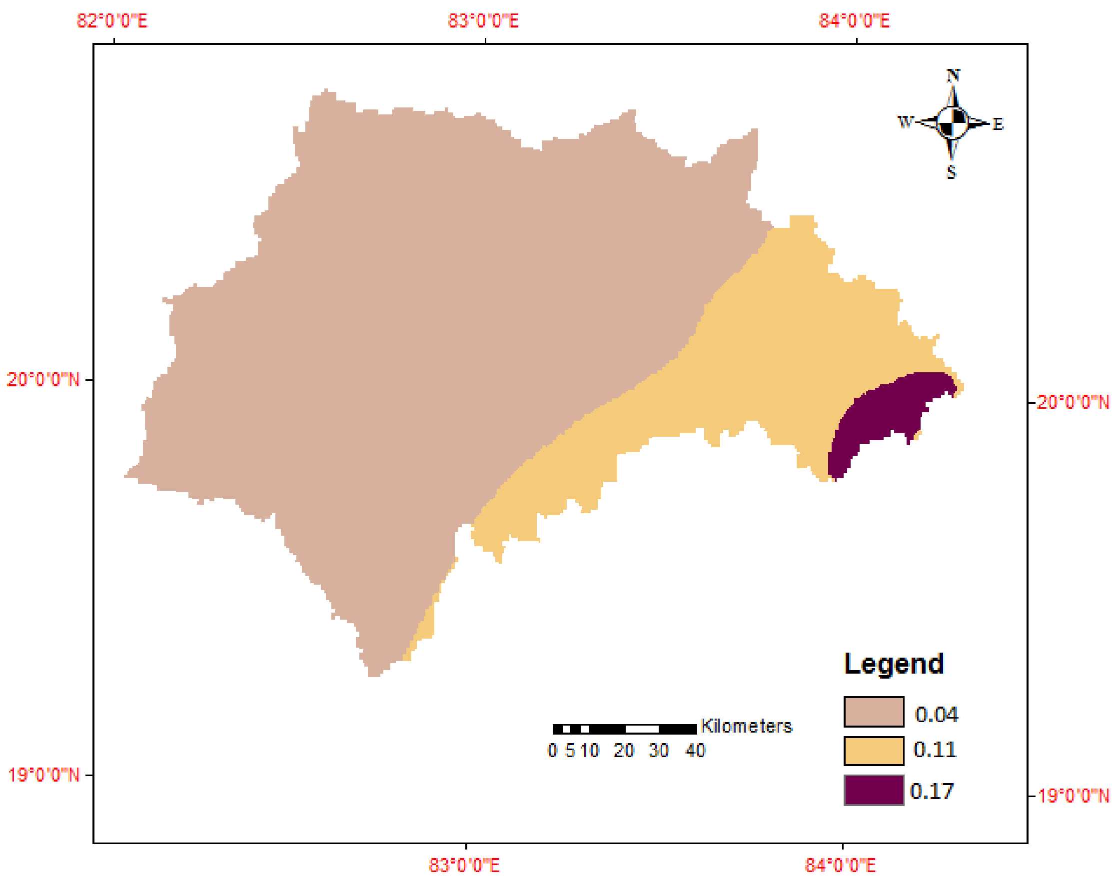

Figure 5.2.2.2: K map of the study area

5.2.3 Estimation of the Topographic factor (LS)

The DEM map of the study area is generated through watershed delineation process as described in the Figure 5.1. With the help of the raster processing tool the slope map (Figure 5.2.3) was generated.

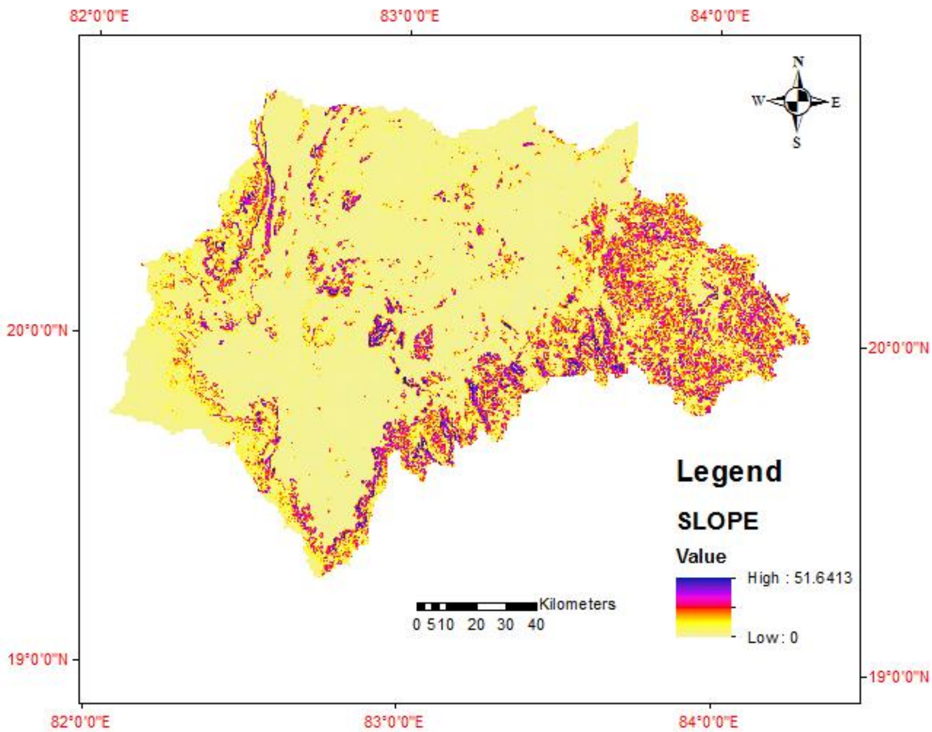

Figure 5.2.3: Slope map of the study area

The equation (7) is used for the estimation of topographic factor (LS) of the study area along with DEM and slope map. The LS map of the study area after raster processing in ArcGIS is shown in Figure 5.2.4.

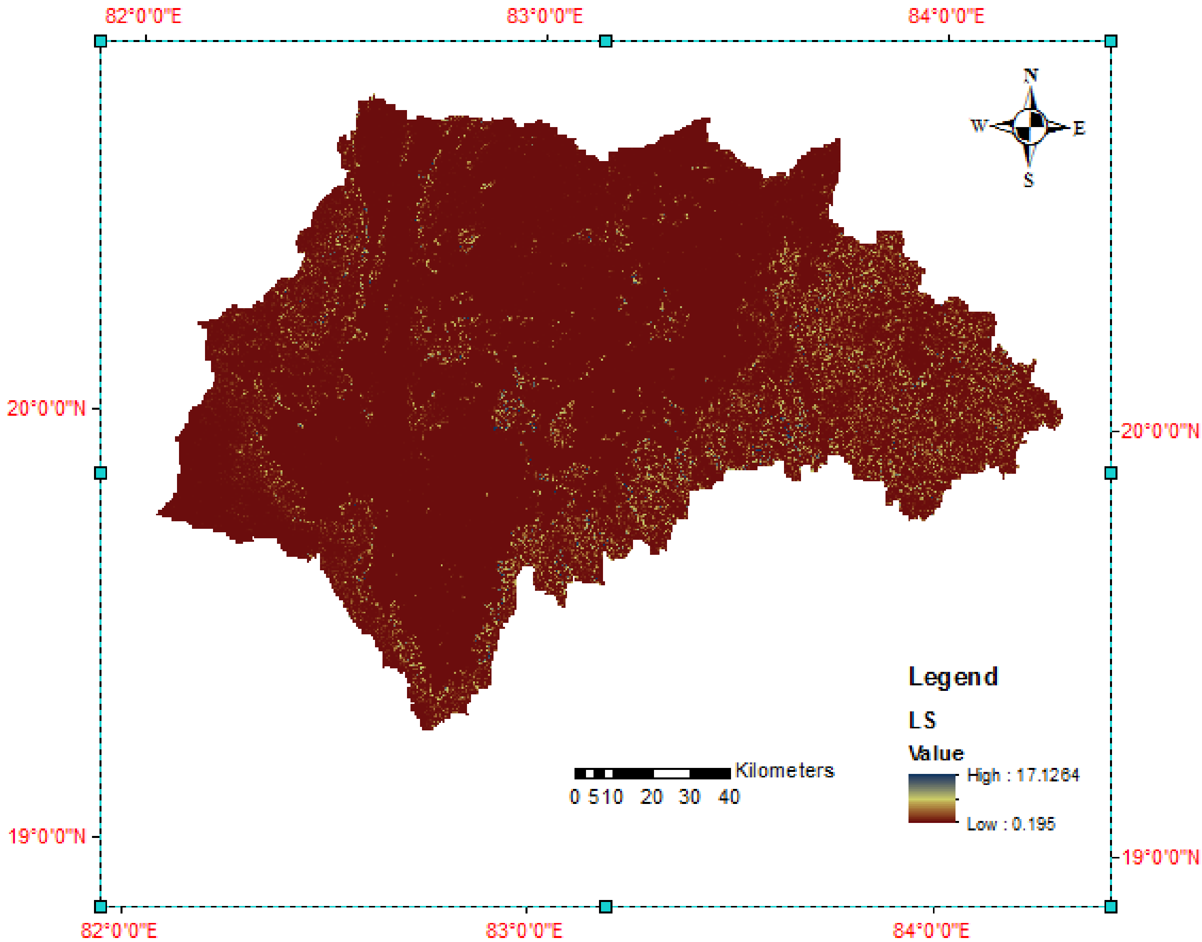

Figure 5.2.4: LS map of the study area

5.2.4 Estimation of the Cropping-Management Factor (C)

The land use map was collected from NRSC (BHUVAN) and supervised classification was done in Erdas Imagine 2014 and values of C (Table 7) were assigned to different land use for the study area. The C value map for land use of the study area starting from 2005 to 2011 is given in appendix-II.

Table 7: Values of C for different Land Use of the study area.

Land Use	Values of C
Urban	0.5
Agriculture	0.3
Fallow	1
Ever green forest	0.004
Deciduous forest	0.05
Degraded forest	0.4
Grassland	0.11
Wasteland	0.6
Scrubland	0.1
Rivers/Water bodies	1
Shifting Cultivation	0.65

5.2.5 Estimation of the Support Practice Factor (P)

The support practice factor P represents the effects of those practices such as contouring, strip cropping, terracing, etc. that help prevent soil from eroding by reducing the rate of water runoff.as there is no soil conservation methods are practiced in the study area therefore the value of P is assumed as 1.

5.3 Estimation of Gross Soil Erosion (A)

The parameters of the USLE which includes rainfall runoff erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice factor (P) is used to estimate the annual soil loss from the catchment area. Ranges of values for the parameters in the Tel River basin are given in Table 8.

Table 8: Value range of parameters of USLE of the study area.

USLE Parameters	Values
Rainfall Runoff Erosivity (R)	677.5698~1456.76
Soil Erodibility (K)	0.04~0.17
Topographic Factor (LS)	0.195~17.12
Cover Management (C)	0.004~1
Support Practice Factor (P)	1

After generating all the parameters map of USLE, the maps are converted to uniform grid size (cell resolution) of 100m. In order to estimate the annual soil loss for the basin, the above parameters were multiplied using the raster calculator tool from the year 1999 to 2011. Figure 5.3 shows the gross soil loss map of Tel River basin of the year 2011. Appendix-III shows the gross soil loss maps from the year 1999 to 2011.

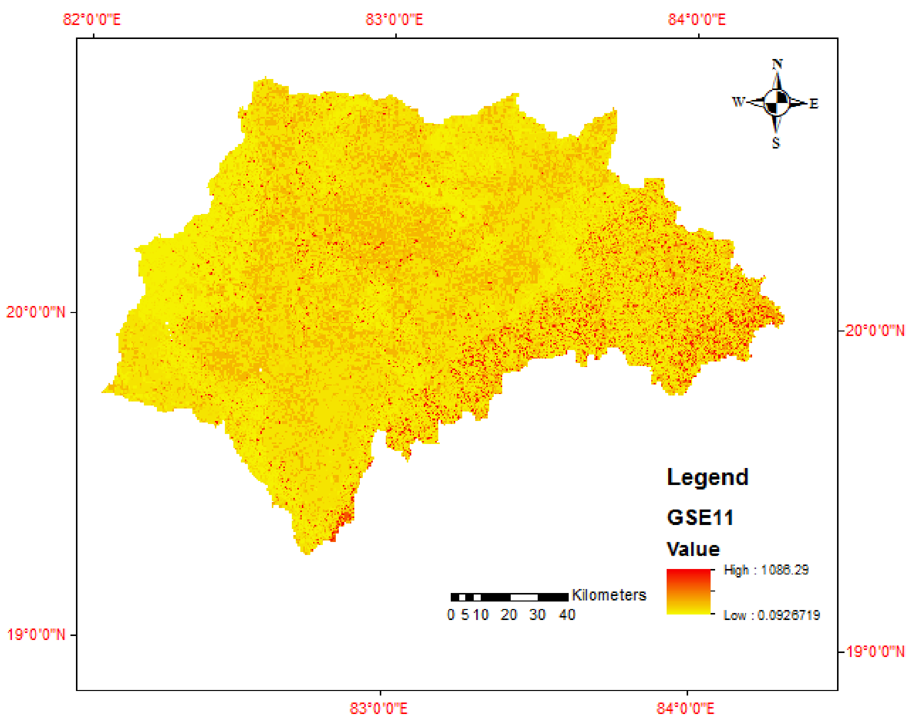

Figure 5.3: Gross soil loss of the study area for the year 2011

5.4 Sediment Yield (SY) And Sediment Delivery Ratio (SDR) of the study area

The annual sediment yield of the study area is computed from the Daily Sediment Yield (SY) data collected from the CWC. The sediment delivery ratio is calculated using the equation (11). The annual soil loss, annual sediment yield and sediment delivery ratio of the study area from the year 1999 to 2011 shown in Table 10. From the Table 10 it shows that the 2003 has highest soil loss i.e. 9.02 tons/year/ha followed by 2006 and 2001 8.36 and 8.33 tons/year/ha respectively the 2002 has the lowest soil loss i.e. 4.21 tons/year/ha followed by 2011 and 2005 5.20 and 5.86 tons/year/ha respectively.

Soil loss mapping is done by classifying areas in different soil erosion zones from slight to very severe for the study area. Table 9 shows the various soil loss zones of the study area and the percentage of area that belongs to the specified soil loss zone for the year 2011and the same others years starting from 1999 to 2011 is shown in the appendix-V. Appendix-IV shows the Classified Soil Zone Area of the Study Catchment.

Table 9: Area under various soil loss zones of the study area for the year 2011

Soil loss zone	Range (in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0-5	1368193	68.30876
Moderate	5-10	489007	24.41429
High	10-40	126323	6.306835
Severe	40-80	12283	0.613244
Very severe	>80	7148	0.356873

Table 10: The annual soil loss, annual sediment yield and sediment delivery ratio of the study area from the year 1999 to 2011

Year	Gross soil loss of Tel River basin (tons/year)	Gross soil loss of Tel River basin(tons/year/ha)	Observed sediment yield (tons/year)	Observed sediment yield (tons/year/ha)	Delivery Ratio
1999	12138561.10	6.02	3215717.44	1.60	0.26
2000	13018519.41	6.46	2369835.46	1.18	0.18
2001	16790784.81	8.33	18760898.52	9.31	1.12
2002	8479934.15	4.21	1985683.36	0.99	0.23
2003	18181872.32	9.02	7483835.82	3.71	0.41
2004	13557807.41	6.73	9058092.42	4.49	0.67
2005	11805400.98	5.86	5527458.36	2.74	0.47
2006	16841732.65	8.36	14647476.11	7.27	0.87
2007	14473670.91	7.18	6201973.18	3.08	0.43
2008	15679104.40	7.78	9199498.07	4.56	0.59
2009	13957978.28	6.93	7187516.57	3.57	0.51
2010	13312444.86	6.60	1619748.90	0.80	0.12
2011	10488518.32	5.20	5581119.52	2.77	0.53

CHAPTER 6
CONCLUSIONS

Soil erosion continues to be a serious issues in Tel River Basin of the state Orissa, India. The prime focus of the present study was to generate mapping for prediction of soil erosion rates in the Tel River Basin. A comprehensive approach of Remote Sensing and GIS Technique with USLE model to estimate the gross soil loss and to evaluate the spatial distribution of soil loss rates under different land uses at the basin. From the present study, the following conclusions are drawn:

1. From the present study it was found that approximately 25% of the basin area comes under moderate zone, 6% under high to severe zone and almost 1% comes under very severe zone of soil erosion which needs immediate implementation of soil conservation practices in the basin.
2. The Sediment Delivery Ratio found out to be 0.5 for the present study period starting from 2003 to 2011 which indicates that 50% of the gross soil erosion is reaching the outlet of the river basin which may cause silting problem in the downstream if any hydraulic structure built down stream of Tel River Basin

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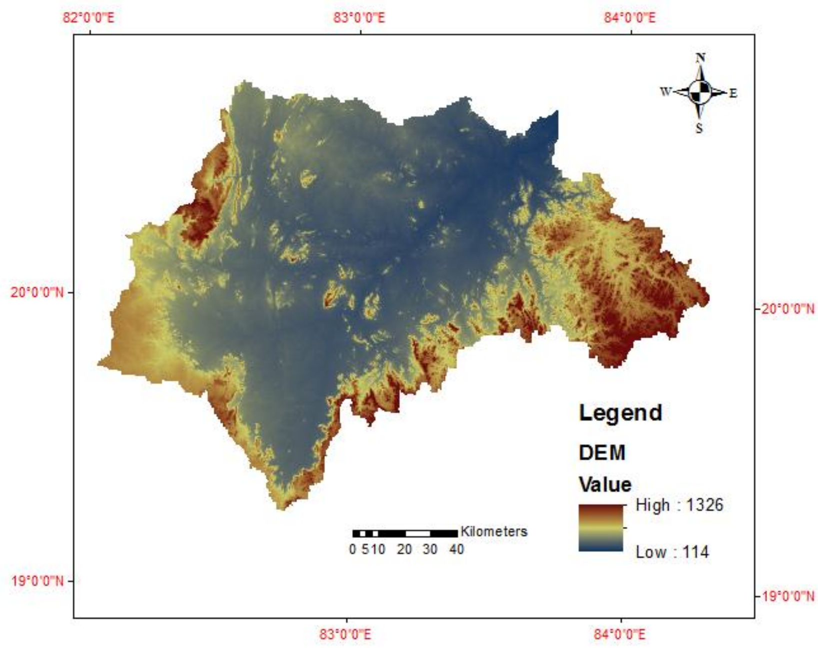
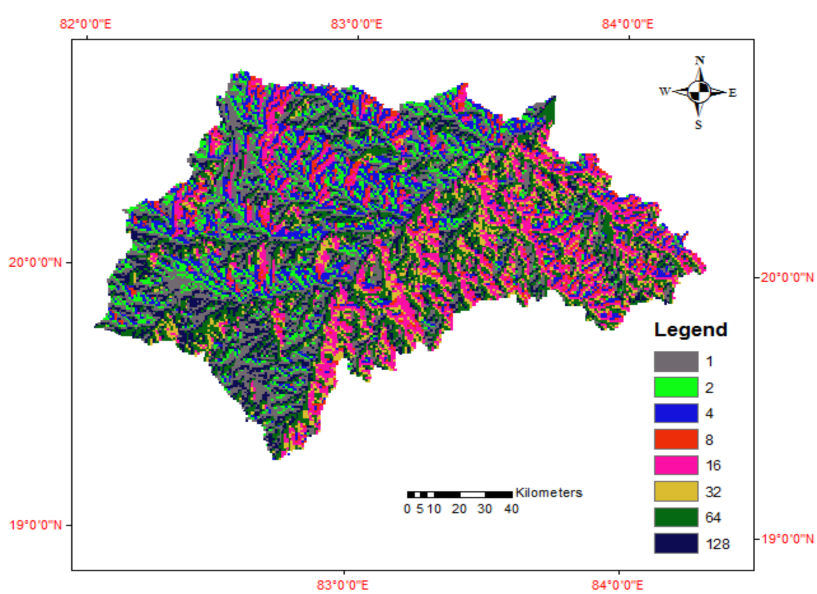
- http://www.itc.nl/
- http://ncffa.org/
- rainfall.ori.nic.in/
- http://www.scitechpark.org.in/

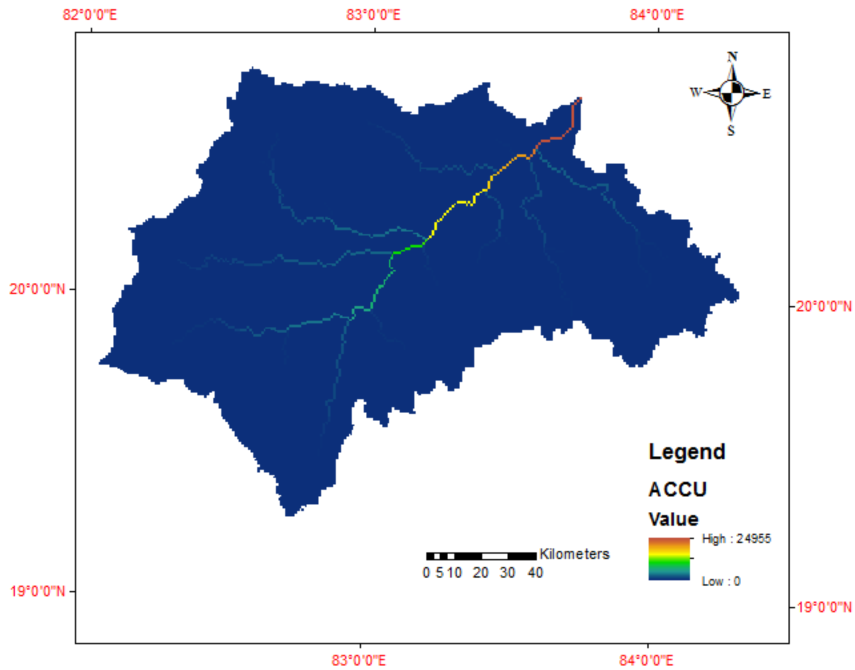
APPENDIX-I: Shows the DEM, Flow Direction, Flow Accumulation, Drainage Network map of the delineated watershed.



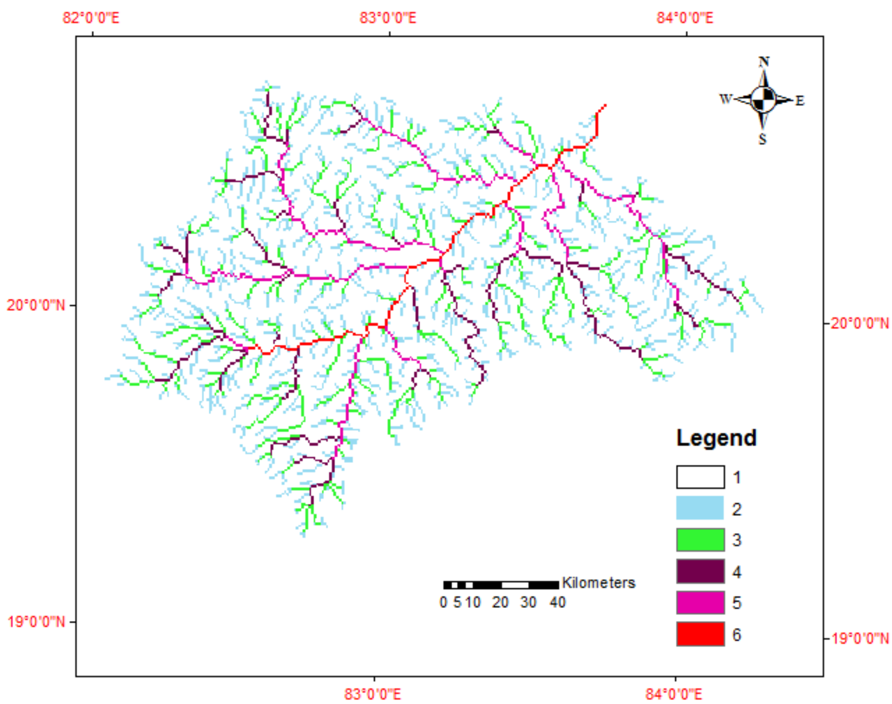
DEM map of the study area



Flow Direction map of the study area

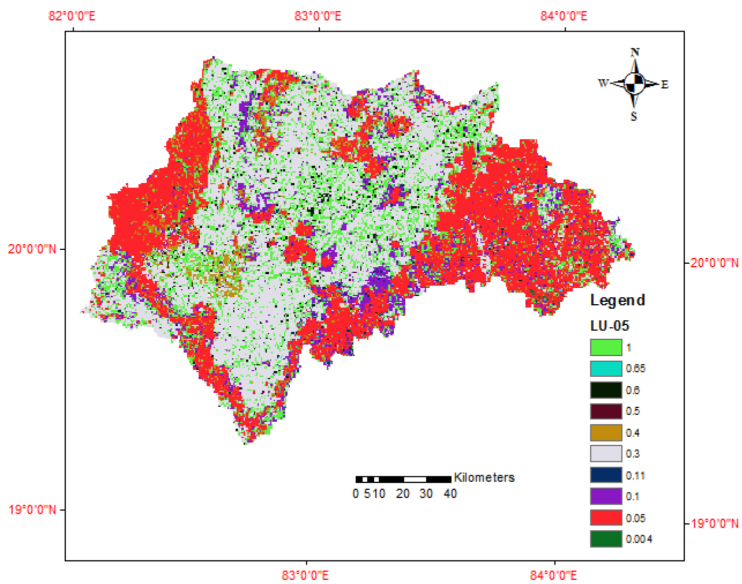


Flow Accumulation map of the study area

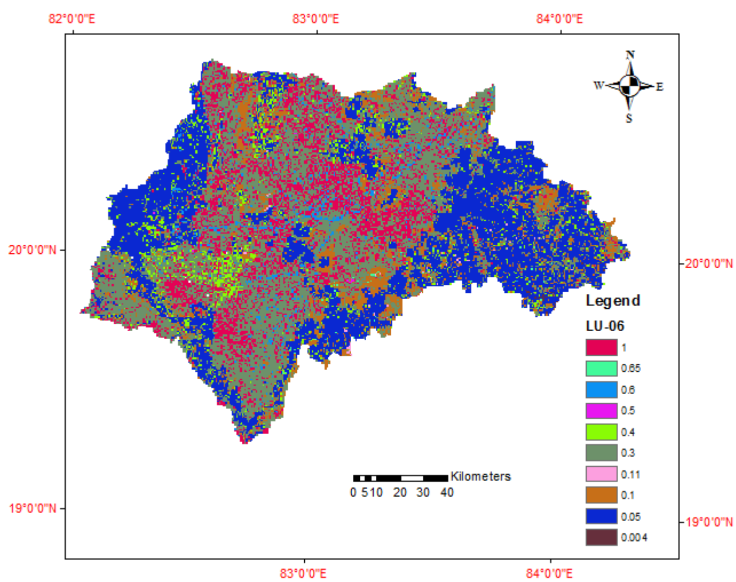


Drainage Network map of the study area

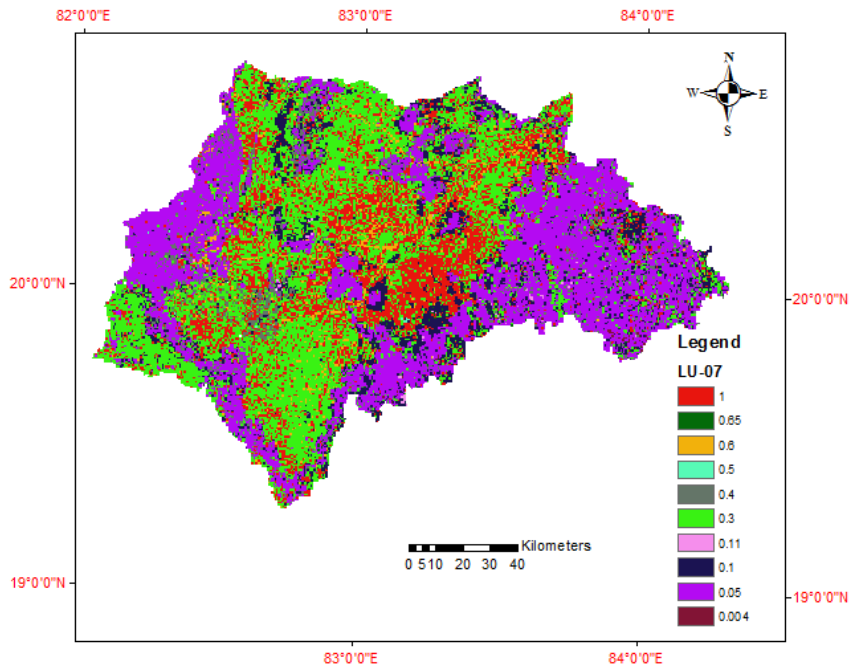
APPENDIX II: The C value map for land use of the study area starting from 2005 to 2011



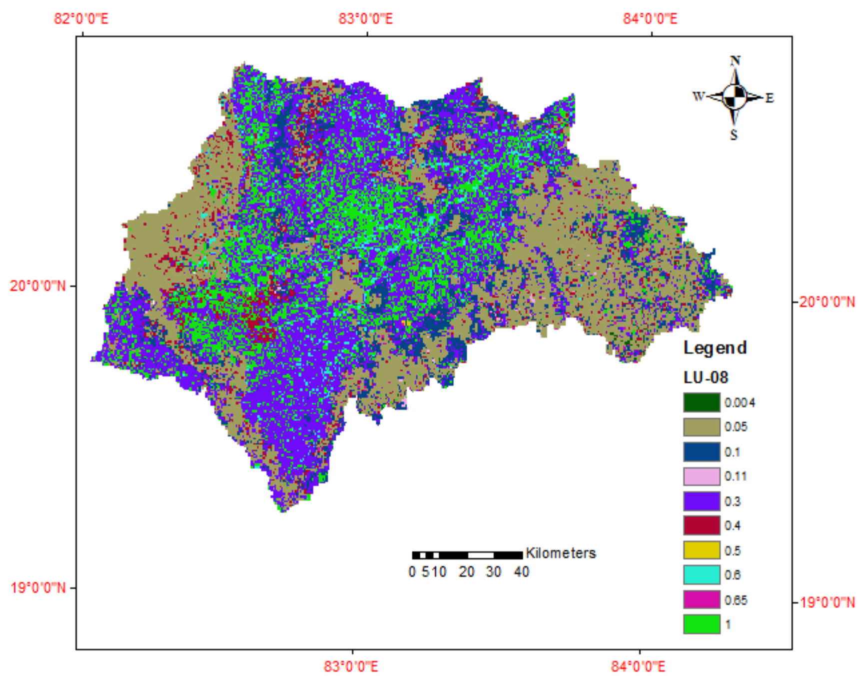
C value for the year 2005



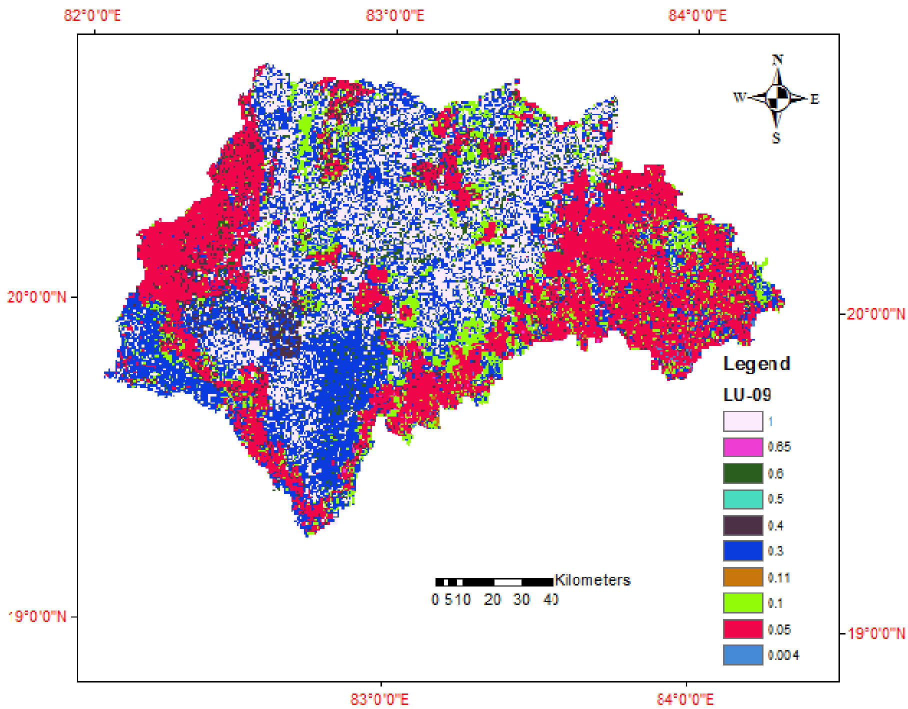
C value for the year 2006



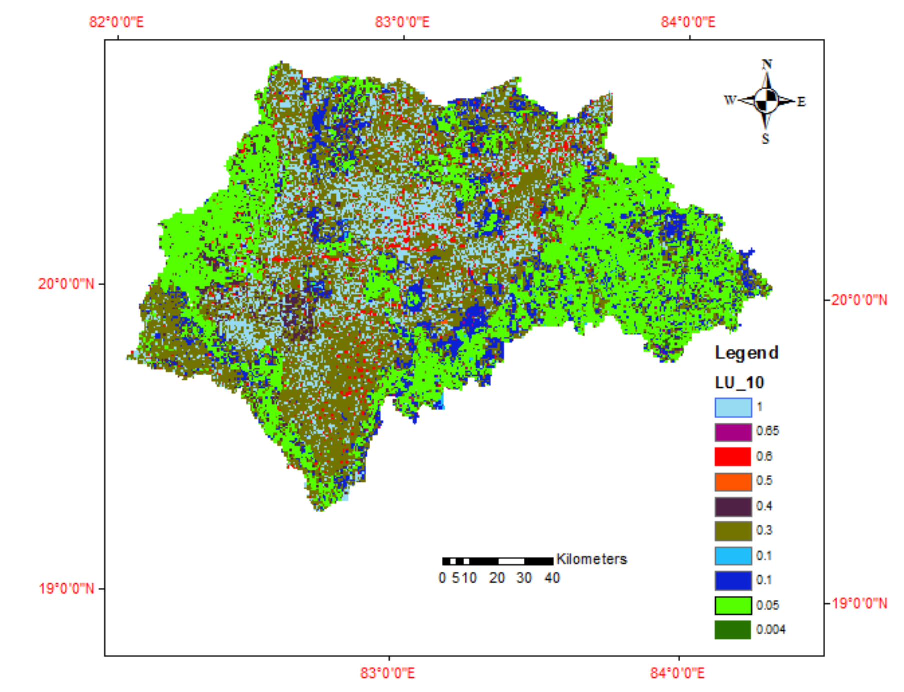
C value for the year 2007



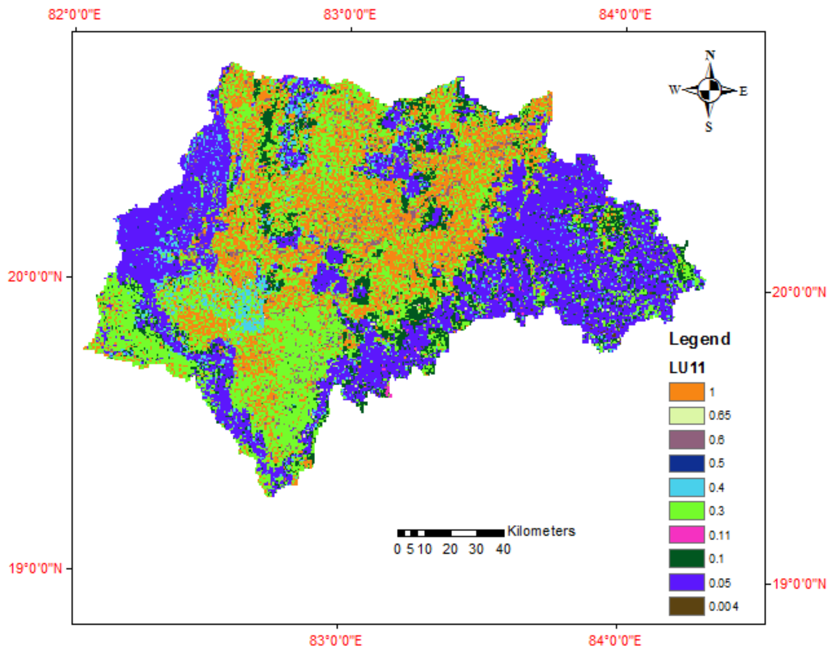
C value for the year 2008



C value for the year 2009



C value for the year 2010

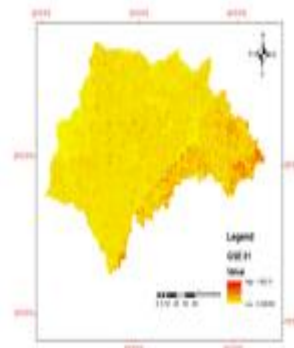


C value for the year 2011

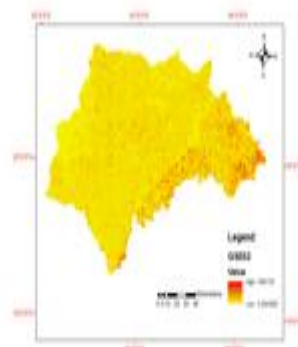
APPENDIX -III: Figures showing gross soil erosion of the study catchment from the year 1999 to 2011.

1999

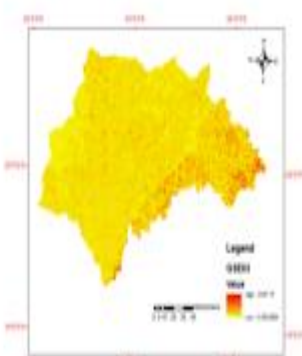
2000



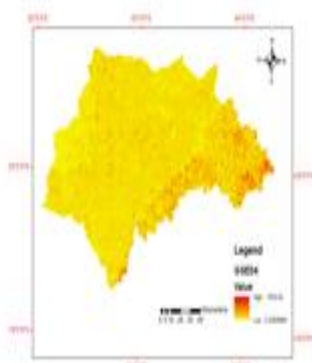
2001



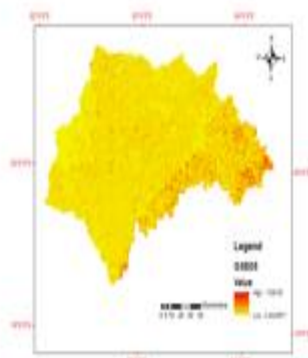
2002



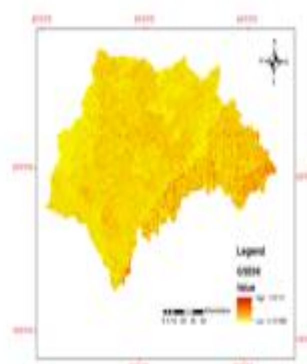
2003



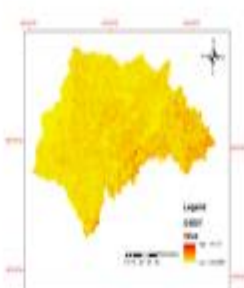
2004



2005

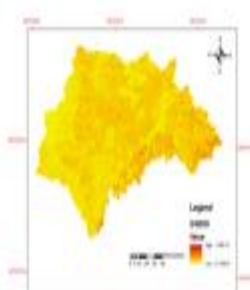


2006

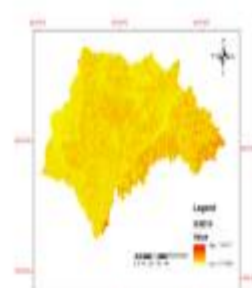


2007

2008



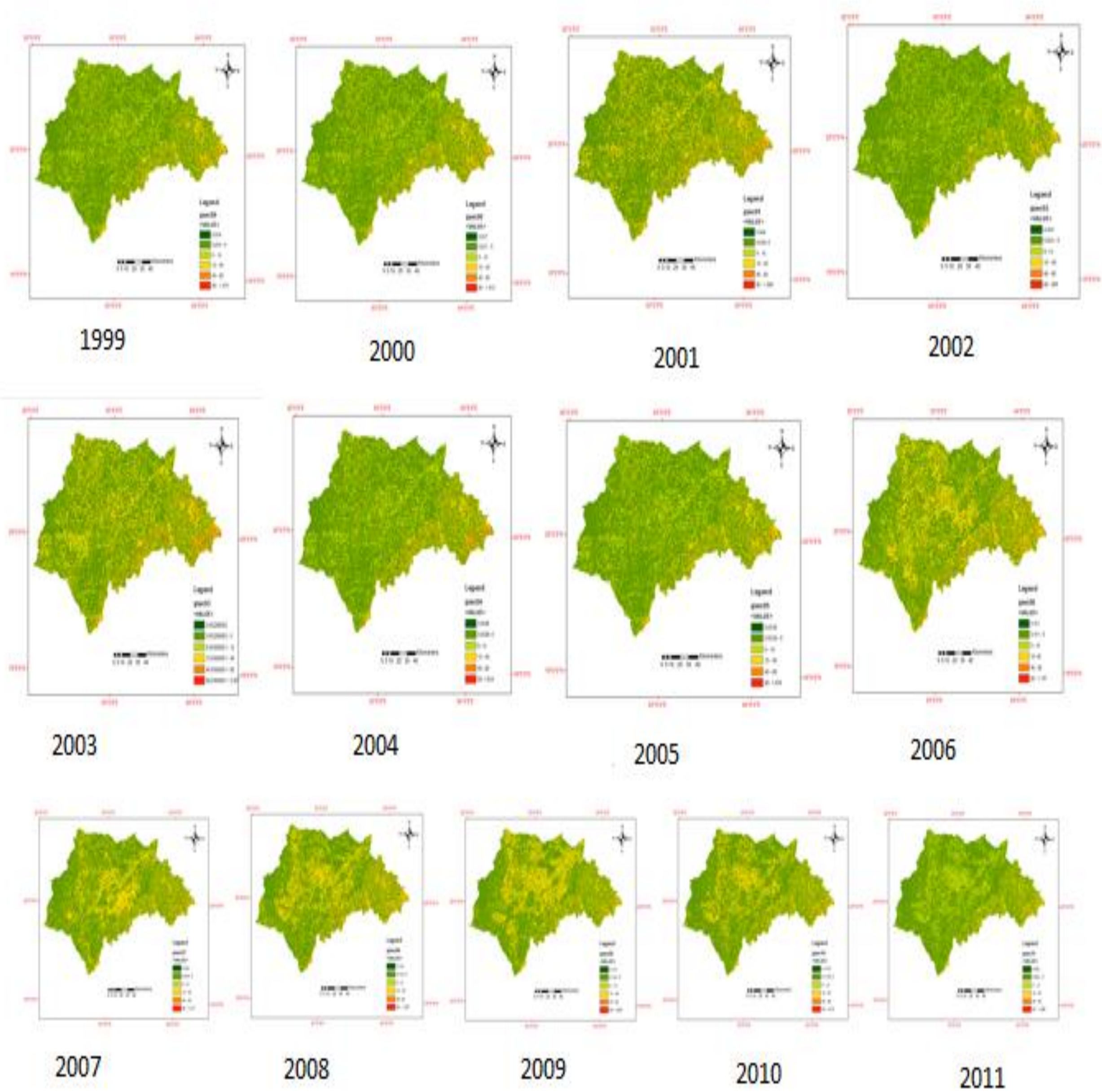
2009



2010

2011

APPENDIX-IV Classified Soil Zone Area of the Study Catchment



APPENDIX-V Soil Loss Zones of the Study Area and the Percentage of Area That Belongs to the Specified Soil Loss Zone From the year 1999 to 2011.

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1418214	70.8057
Moderate	5 to 10	404982	20.21912
High	10 to 40	152748	7.626091
Severe	40 to 80	14863	0.74205
Very severe	>80	12159	0.60705

Area under various soil loss zones of the study area for the year 1999

Soil zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1406953	70.24348
Moderate	5 to 10	398072	19.87413
High	10 to 40	166307	8.303037
Severe	40 to 80	17962	0.89677
Very severe	>80	13672	0.682588

Area under various soil loss zones of the study area for the year 2000

Soil zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1363534	68.07574
Moderate	5 to 10	144686	7.223587
High	10 to 40	447070	22.3204
Severe	40 to 80	30569	1.526187
Very severe	>80	17107	0.854083

Area under various soil loss zones of the study area for the year 2001

Soil zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1483725	74.07639
Moderate	5 to 10	388176	19.38006
High	10 to 40	113143	5.648773
Severe	40 to 80	10068	0.502655
Very severe	>80	7854	0.392118

Area under various soil loss zones of the study area for the year 2002

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1300686	64.938
Moderate	5 to 10	182864	9.129661
High	10 to 40	467226	23.32671
Severe	40 to 80	32039	1.599578
Very severe	>80	20151	1.006058

Area under various soil loss zones of the study area for the year 2003

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1406949	70.24328
Moderate	5 to 10	397984	19.86973
High	10 to 40	159345	7.955452
Severe	40 to 80	24361	1.216246
Very severe	>80	14327	0.715289

Area under various soil loss zones of the study area for the year 2004

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	1418214	0 to 5	70.8057
Moderate	412580	5 to 10	20.59845
High	145921	10 to 40	7.285246
Severe	14611	40 to 80	0.729468
Very severe	11640	>80	0.581138

Area under various soil loss zones of the study area for the year 2005

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1253116	62.56302
Moderate	5 to 10	203485	10.15918
High	10 to 40	503588	25.14211
Severe	40 to 80	27386	1.367272
Very severe	>80	14013	0.699612

Area under various soil loss zones of the study area for the year 2006

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1309002	65.33778
Moderate	5 to 10	162439	8.108012
High	10 to 40	498132	24.86386
Severe	40 to 80	22182	1.107197
Very severe	>80	11683	0.583148

Area under various soil loss zones of the study area for the year 2007

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1281820	64.02669
Moderate	5 to 10	143799	7.182735
High	10 to 40	539493	26.94758
Severe	40 to 80	24232	1.210384
Very severe	>80	12665	0.632615

Area under various soil loss zones of the study area for the year 2008

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1243788	62.16609
Moderate	5 to 10	162159	8.104911
High	10 to 40	565908	28.28479
Severe	40 to 80	18658	0.93255
Very severe	>80	10237	0.511658

Area under various soil loss zones of the study area for the year 2009

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1350107	67.40579
Moderate	5 to 10	162136	8.094844
High	10 to 40	461632	23.04756
Severe	40 to 80	18715	0.93437
Very severe	>80	10364	0.517436

Area under various soil loss zones of the study area for the year 2010

Soil loss zone	range(in ton/ha/yr)	Area (in ha)	Area (%)
Slight	0 to 5	1368193	68.30876
Moderate	5 to 10	489007	24.41429
High	10 to 40	126323	6.306835
Severe	40 to 80	12283	0.613244
Very severe	>80	7148	0.356873

Area under various soil loss zones of the study area for the year 2011