APPLICATION OF UNIVERSAL SOIL LOSS EQUATION IN ESTIMATION OF SEDIMENT YIELD
(Case study: Upper Mahanadi Catchment, India)

A Thesis submitted in partial fulfillment of the requirements for the award of the Degree of

Master of Technology

in

Water Resources Engineering

by

SOBHAN MISHRA
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DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "**APPLICATION OF UNIVERSAL SOIL LOSS EQUATION IN ESTIMATION OF SEDIMENT YIELD (Case study: Upper Mahanadi Catchment, India)**" submitted by **Mr. SOBHAN MISHRA** in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Water Resources Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:
Place:

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ACKNOWLEDGEMENTS

First and foremost I offer my sincere gratitude and respect to my project supervisor, **Prof. K.C Patra,** Department of Civil Engineering, for his invaluable guidance and suggestions to me during my study and project work. I consider myself extremely fortunate to have had the opportunity of associating myself with him for one year. This thesis was made possible by his patience and persistence.

I express my sincere thanks to **Prof. Ramakar Jha, Prof. K.K. Khatua** and **Prof. A.Kumar** of Civil Engineering Department, NIT Rourkela for providing valuable co-operation and advice all along my M.Tech study. I also express my thanks to **Mr. Janaki Ballav Swain (Ph.D scholar),** and all my friends of Water Resources Engineering Specialization who helped me to learn many things about my project.

Also I would like to extend my gratefulness to the Head of Department, **Prof. S.K. Sahu** and to all the Professors and staff members of Civil Engineering Department for helping and providing me the necessary facilities for my research work.

Lastly, I want to thank my parents and almighty God whose blessings have always helped me achieving my goals of life.

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ABSTRACT

Soil erosion in the upstream river basins, its transport and deposition play a major role in understanding many activities of global significance. In recent activities of man like interfering with nature, like changing of river course by construction of dams, weirs and barrages have affected the sediment yield. At first the watershed is generated in Arc GIs on spatial data of upper Mahanadi basin by using Raijm as controlling station. Spatial data from upstream of Mahanadi catchment are analyzed for computation of sediment yield. The factor responsible for this variation are also analyzed. Universal Soil Loss Equation is used for computation of sediment yield in Raijm gauging station present in Raipur district of Chhattisgarh. Analysis of data indicated that the distribution of rainfall and topographical characteristics are the major factors influencing the variation of sediment flux in upper Mahanadi Basin. Data collected from India Wris are used for computation of observed sediment yield. The maximum erosion found per hector is less than 47 tons per year. The location for maximum erosion prone area was also found out. It was observed that sediment yield was maximum in monsoon. The maximum error obtained between observed and computed sediment yield is less than 30%.

Keyword: Watershed, Spatial Data, Sediment Flux, sediment yield, Topographical Characteristics

CONTENTS

List of Figures

List of Tables

List of Abbreviations

USLE	Universal Soil Loss Equation
DEM	Digital Elevation Model

R	Rainfall erosibility factor
K	Soil erodibility factor
C	Cover management factor
P	Support practice factor
A	Average annual soil loss rate
GIS	Geographical Information System

CHAPTER 01

INTRODUCTION

1.1 General

Soil disintegration is the procedure in which it incorporates separation, transport and ensuing affidavit. By the raindrop effect and the shearing power of streaming water the residue is isolatesd from soil surface. By the streaming of water the uprooted dregs is transported to down incline in principally, albeit there is a little measure of downslope transport by raindrop sprinkle too. Soil disintegration is a fundamental component of thought in the arranging of watershed change lives up to expectations. It has been acknowledged as a basic issue emerging from farming reinforcing, area debasement and potentially because of overall climatic change. Soil disintegration diminishes not just the stockpiling limit of the downstream bowls additionally falls apart the proficiency of the watershed. Precise estimation of residue transport sums, when all is said in done, relies on upon an exact from the earlier estimation of overland streams .Sediment yield.is shield as the measure of dregs load passing the outlet of a watershed is known as silt yield. Subsequently, any errors in the estimation of overland streams would be amplified over absolutely wrong disintegration estimations. Around the world, more than 50% of pasturelands and around 80% of cultivating terrains experience the ill effects of soil disintegration. (Pimentel et al. 1995).It is educated (Dudal 1981) that, widespread, around 6,000,000 ha of prolific area is being lost consistently because of simply soil disintegration and related elements. In this sum, it is evaluated that as of now around 1,964.4 MH of aggregate area region has been presently corrupted (UNEP 1997). Of this, around 1,903 and 548.3 MH are influenced with water and wind disintegration issues, separately. In India, Land corruption by soil disintegration is a significant issue happens. Water and soil misfortunes are the fundamental driver for residue inflowing the bowl, and these procedures possibly diminishing water quality. Soil disintegration around there emphatically impacts the living soundness of the city. Consequently, it got to be key to compute soil disintegration all the more widely, with the point of giving an instrument to anticipating soil preservation strategies on watershed premise. The correct detailing of watershed administration programs for feasible development essentials data on watershed dregs yield. Definite figuring of disintegration from watershed zones is genuinely subject to their spatial, monetary, natural, and social connection. The data on wellsprings of residue yield inside of a watershed can be utilized as viewpoint on the measure of soil disintegration happening inside that watershed. In spite of the change of a scope of physically based soil disintegration and silt transport mathematical statements, residue yield gauges at a watershed or local scale are at present accomplished fundamentally through straightforward exploratory models as the point by point information needed for utilization of physically based models are not accessible at this scale. To gauge soil disintegration and residue yield some straightforward observational models are generally utilized for their effortlessness, which makes them pertinent regardless of the possibility that just a constrained measure of info information is accessible. For example, the straightforward technique are Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978), Modified Universal Soil Loss Equation (MUSLE; Williams 1975) or Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1991), are frequently utilized for estimation of gross measure of surface disintegration in watershed zones. (e.g.Williams and Berndt 1972; Griffin et al. 1988; Ferro et al. 1998; Jain and Kothyari 2000; Kothyari et al. 2002; are regularly utilized for the estimation of surface disintegration and silt yield from catchment territories (Ferro and Minacapilli, 1995 Ferro, 1997; Kothyari and Jain, 1997) on the grounds that basic structure and simplicity of utilization. There are a portion of the cases generally utilized watershed models taking into account USLE technique to figure soil disintegration, for example, Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984) and Agricultural Non-Point Source Pollution Model (AGNPS) (Young et al., 1987). While USLE/RUSLE may not duplicate the genuine picture of disintegration process as they are in light of variables figured or balanced on the premise of perceptions, it has been generally connected everywhere throughout the world essentially because of the effectiveness in the model plan and effortlessly accessible information set (Bartsch et al., 2002; Jain and Kothyari, 2001; Jain et al., 2001). In appraisal of good soil disintegration at plot scale USLE has been demonstrated better result among them. (Wischmeier and Smith, 1978). If there should be an occurrence of catchment, some piece of dissolved soil is saved inside catchment before it spreads the catchment outlet. In any case, soil disintegration computed by USLE can be coordinated to catchment outlet utilizing the hypothesis of dregs conveyance proportion by applying suitable method .In precipitation and catchment heterogeneity, both soil disintegration and silt transport procedures are spatially fluctuated because of the spatial variety. Such irregularity has animated the utilization of information concentrated dispersed technique for the estimation of catchment disintegration and residue yield by discretizing a catchment into sub-ranges every having around homogeneous attributes and steady precipitation dissemination (Young et al., 1987; Beven, 1989).To outline the spatial contrast of the parameters like geography, soil and area use in a watershed, the utilization of Geographical Information System (GIS) system is well suitable. The discretization of the catchment into little matrix cells and for the calculation of such physical attributes of these cells as slant, area utilize and soil sort, by utilization of GIS methods, the all of which influence the courses of soil disintegration and testimony in the diverse sub-ranges of a catchment. Various distinctive models (both test and procedure based) have been built up to decipher soil misfortune information in light of GIS. Utilizing the USLE parameter to gauge the precipitation based disintegration and the vehicle of non-point source contamination stacks on upper Mahanadi catchment in Raijm gaging station. They have utilized exact relationship between Delivery Ratio (DR) and catchment region keeping in mind the end goal to register residue load. Jain et al. (2003) made a count of dregs yield for the upper Mahanadi stream bowl at Raijm gaging station: (I) relationship between suspended residue load and release and (II) exact relationship. The sediment–discharge relationship was produced utilizing day by day information. For estimation of the silt yield utilizing the test relationship, different land parameters, for example, area utilization and geology were produced utilizing Geographic Information System (GIS) system. They likewise used trial comparison to gauge residue conveyance proportion keeping in mind the end goal to compute dregs yield at catchment outlet. By utilizing. GIS, Remote Sensing (RS) with Universal Soil Loss Equation (USLE) to distinguish the basic disintegration inclined ranges of watershed for positioning reasons.

Mainland disintegration and ensuing exchange of the dissolved material to sea play an essential part in the comprehension of numerous exercises of worldwide biological community. Disintegration, entrainment, transportation, testimony, and compaction of soil particles are normal also, complex procedures that have been dynamic all through the geographical ages and molded the present scene of our reality. The essential disintegration forms that happen on upland ranges are soil separation, transport, and statement. Separation happens when strengths applied by precipitation and streaming water surpasses the dirt's imperviousness to those strengths. Separated particles can be transported both by raindrop sprinkle and stream. Statement happens when the amount of separated particles surpasses transport limit. Interrelationships between the different wellsprings of disintegration and their related conveyance framework bring about conceptualizing the aggregate catchment or bowl conveyance framework. Enhanced information of all periods of the conveyance framework gives linkages among the procedures. Advancement of disintegration forecast innovation is needed for a progressive at the field level, to look at the effect of different administration systems on soil misfortune and to anticipate ideal utilization of area (Flanagan et aI., 2002). It likewise permits strategy producers to evaluate the present status of the area assets and the potential requirement for improved then again new arrangements to secure soil and water assets. The estimation of silt yield is an indispensable piece of studies intended to survey mainland disintegration or to oversee water assets. There have been various advances connected with systems for measuring residue yields lately (Hadley et aI., 1985). Photoelectric turbidity meters, ultrasonic and atomic dregs gages, programmed molecule size analyzer, and so forth are the most recent advances.

1.2 Soil Erosion

Soil erosion is the process in which, the removal of the soil surface material is carried out by wind or water. Water is the major factor for soil erosion where the process includes detachment, transportation and deposition of individual soil particles (sediment) by raindrop effect and flowing water (Foster and Meyer 1977; Wischmeier and Smith 1978; Julien 2002). Erosion is one of the main problems in agriculture and natural resources management. It reduces soil productivity, pollutes the streams and fills the reservoirs (Fangmeier et al. 2006). Human activity such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization usually accelerate the process of erosion, transport, and sedimentation (Julien 2010)

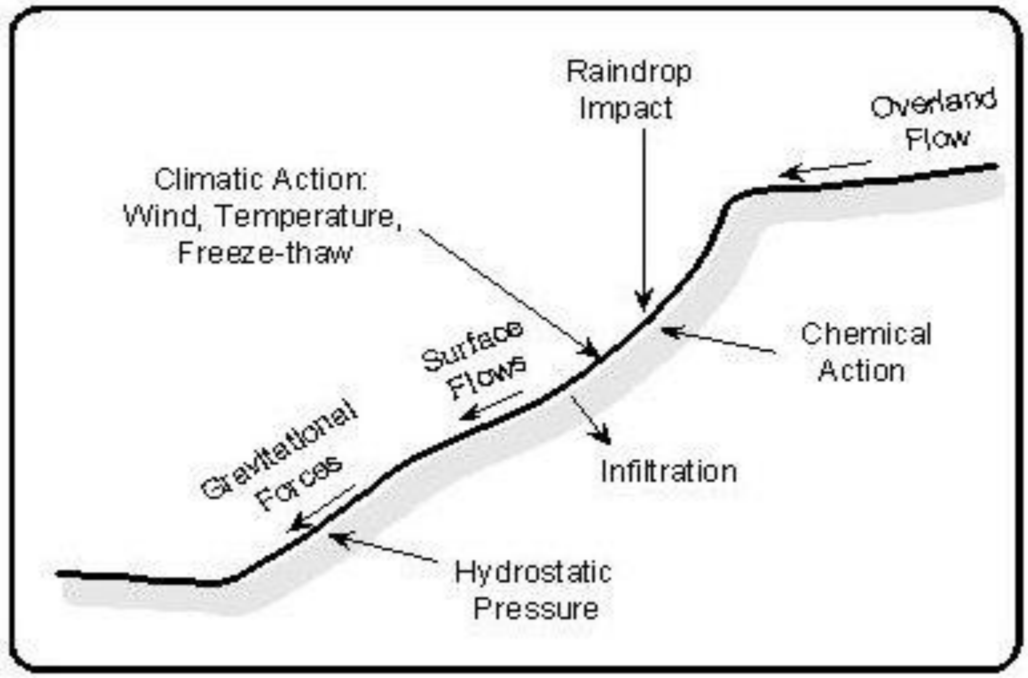

Figure 1.1 - Soil Erosion Processes

Disintegration and sedimentation procedure is indicated in Figure 1.1. Disintegration procedure begins when raindrops hit the ground surface and uproot soil particles by sprinkle. Uprooted particles are along the side transported to the rills by a slight overland stream and this procedure is called sheet disintegration or interrill disintegration. Most downslope silt transport is brought through stream in the rills. Rill disintegration happens when water from sheet disintegration joins to shape thought little channels. This kind of disintegration is the predominant type of surface disintegration. It is indicated in this figure rills steadily join together to shape bigger directs and this outcomes in ravine disintegration which is like rill disintegration, with the exception of bigger in scale. Distinctive rill disintegration, chasm disintegration can't be decimated by culturing.

Stream channel disintegration results from concentrated water which shapes from rills and chasms, and contains dregs expulsion from streambed and stream banks. Bank disintegration in stream channels lead to shape direct winding which brings about exorbitant disintegration and testimony inside of the floodplain. It ought to be noted, if the measure of disconnected soil is more than the vehicle limit, just the transportable sum will be conveyed downslope and the rest will be stored on the portion.

1.3 Soil Erosion Models

The Universal Soil Loss Equation (USLE) model is one of the real advancements in soil and water protection in the 20th century. This exact model has been connected far and wide to gauge soil disintegration by raindrop effect and surface spillover. USLE model is the consequence of many years of soil disintegration experimentation directed by college resources and government researchers over the U.S. It was at first proposed by Wischmeier and Smith (1965) taking into account the idea of separation and transportation of particles from precipitation to gauge soil disintegration rates in farming regions.

1.4 Geographic Information System (GIS)

Geographic Information System (GIS) is an electronic database administration framework which empowers the client to catch, store, recover, investigate, oversee, and imagine the spatial information that are connected to this present reality coordinates (ESRI 2005). GIS is enhanced with a situated of geospatial devices that can perform measurable investigation, recognize connections, and focus examples and patterns.

Notwithstanding, when all is said in done utilization of GIS in natural field especially in hydrologic and water driven demonstrating, surge mapping, and watershed administration and so on.

1.5 Objectives of the study

The overall objective is to determine the soil erosion rates using the USLE model and ArcGIS 10.2 at the Upper Mahanadi river basin in Raijm gauging station. The specific objectives are:

1. To study on different mathematical models used for sediment yield estimation.
2. To calculate the annual average soil loss rate using the Rainfall data, Digital Elevation Model (DEM), Soil Type Map, and Land Cover Map data.
3. To identify the erosion prone area using unique value accumulation of an image in ARC GIS.

1.6 Thesis outline

Chapter 1: Gives a general view about soil erosion. It describes the procedure for rill and inter rill soil erosion. In this chapter a brief idea is given about which type of erosion model to be used for my study area.

Chapter 2: It gives a brief details about the work done by previous researchers on that field. Use of various types of software like mat lab, arc gis, ilwis and wepp on the calculation of sediment yield on catchment basis was done.

Chapter 3: This chapter gives a brief idea about the location and climatic condition of the study area. Type of soil, cultivation and land cover pattern are discussed briefly.

Chapter 4: This chapter gives a detail description about the procedure of obtaining of study area. It gives a brief idea about the types of parameters used for obtaining sediment yield. The values of the parameters obtained are also given

Chapter 5: the final sediment yield obtained on catchment basis and pixel basis are described briefly. The maximum soil erosion prone areas are obtained for each year and given in tabular form.

Chapter 6: this chapter presents the detailed summary and conclusion of my work.

Chapter 7: this chapter presents the future scope for my work. What other improvements can be added.

CHAPTER 2

LITERATURE REVIEW

2.1 INTROUCTION

The sediment yield calculation can be done by various method like universal soil loss equation, modified universal soil loss equation and revised universal soil loss equation. Some other models like water erosion prediction model and unit sediment hydrograph can also be used for calculation of sediment yield on catchment basis.

2.2 GEOGRAPHIC INFORMATION SYSTEM OF SOIL EROSION MODELLING

Many scientists have come out with procedure and methods of generating the sediment loss zone maps by identifying remote sensing based spatial layers of sediment yield controlling parameters using GIS.

Narayana and Babu *et al.,* (1983) carried out work on Soil erosion problems of India. In the absence of accurate process of soil erosion an empirical method was developed for calculation of soil erosion on reservoir and catchment basis. In the given analysis, existing annual soil loss data for 20 diverse land resource regions for a country, sediment loads of major rivers, and rainfall erosivity for 36 river basins and 17 catchments of major reservoirs are utilized and statistical regression equations are developed for forecasting of sediment yield. Using these terminologies and conforming values for the area, rainfall, rainfall erosivity and surface runoff, annual values of total sediment loads of streams, sediment deposition in reservoirs, and sediment lost permanently into the sea are estimated. Allowing to this estimate, which is treated as a first approximation, 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. Ten percent of it is deposited in reservoirs. The remaining 61% is interrupted from one place to the other.

Jinze et al., (1996) carried out work on the high sediment load transported by the Yellow River which was derived mainly from soil erosion on the loess plateau. The most severe erosion occured in the gullied rolling loess area and a primary sediment yield area is located in the Hekouzhen-Longmen reach on the middle Yellow River. The strong erosion and sediment yield are caused by rainstorms and heavy storms. In the 1980s, the average annual observed amount of sediment transport by the middle Yellow River was only 799 X 1061, the minimum value for a 10-year series since the beginning of records. The average annual sediment reduction through complete management of the catchment in the middle Yellow River in the 1980s was 252 x 106t, of which sediment reduction through soil conservation measures was 176 X 106 t, making up 69.8% of the average annual sediment reduction through catchment management. However, the increased sediment due to damage by human activities is about 47 X 106 t, counteracting the effect of sediment reduction through catchment management by 18.6%. Although the average annual sediment flowing into the Yellow River will be reduced about 500 X 1061 in the next 50 years, the Yellow River will still be a hyper-sediment concentrated river due to the influence of unfavorable factors of geology and climate.

Subramanian *et al.,* (1996) carried out work on information collected on sediment transport in Indian rivers. It shows the major contribution which Indian rivers make to the total amount of sediment delivered to the ocean at a global scale, but also highlights the large temporal and spatial variability of riverine sediment transport in the Indian sub-continent. This variability is evident not only in the quantity of the sediment transported but also in the size and mineralogical features of the sediment loads.

Erskine and Saynor *et al.,* (1996) carried out work on soil loss rates for erosion plots and sediment yields for small and large drainage basins, which have been treated to varying degrees by soil conservation and land management practices in the same climatic zone of central eastern Australia, shows remarkably similar but highly variable values (3-233.51 km^{-2} $year^{-1}$) for land areas which range through 9 orders of magnitude (from 0.01 ha to 27 720 km^{-2}). Soil erosion and sediment transport are storm-dominated due to the large variability of rainfall and runoff throughout most of Australia. In such an environment, it is vital to judiciously design the research program to ensure that there is an adequate number of replicate treatments for the same basin area to unequivocally identify the effects of the treatment. As this has not been done to any important degree for land areas greater than 0.88 km^{-2} in size, it can be concluded that soil conservation works are only successful in reducing on-site soil erosion rates and off-site sediment yields in small drainage basins.

Kothyari and Jain *et al.*, (1997) carried out work on method which was developed in the present study for the determination of the sediment yield from a catchment using a GIS. The method involves spatial disaggregation of the catchment into cells having uniform soil erosion features. The surface erosion from each of the discretized cells is routed to the catchment outlet using the concept of sediment delivery ratio, which is defined as a function of the area of a cell covered by forest. The sediment yield of the catchment was defined as the sum of the sediments delivered by each of the cells. The spatial discretization of the catchment and the derivation of the physical parameters related to erosion in the cells are performed through a GIS method using the Integrated Land and Water Information Systems (ILWIS) package.

Jain and Kumar and Varghese et al., (2001) carried out work on the fragile ecosystem of the Himalayas has been an increasing cause of worry to ecologists and water resources designers. The steep slopes in the Himalayas along with exhausted forest cover, as well as high seismicity have been main factors in soil erosion and sedimentation in river reaches. Estimation of soil erosion is a must if adequate provision is to be made in the design for conservation of structures to offset the ill effects of sedimentation during their generation. In the present study, two diverse soil erosion models, i.e. the Morgan model and Universal Soil Loss Equation (USLE) model, have been used to estimate soil erosion from a Himalayan watershed. Parameters essential for both models were generated using remote sensing and subsidiary data in GIS mode. The soil erosion assessed by Morgan model is in the order of 2200 t km−2 yr−1 and is within the limits reported for this region. The soil erosion assessed by USLE gives a higher rate. Therefore, for the current study the Morgan model stretches, for area located in hilly terrain, fairly good results.

Hyeon *et al.,* (2006) carried out work on Imha watershed, located in the north eastern part of Nakdong river basin. It has also less forest cover about 40% of the watershed has steep slopes. Due to topographical characteristics most of the watershed is vulnerable to severe erosion. Soil erosion from steep upland areas has caused sedimentation of Imha reservoir. It has also deteriorated the water quality and has caused negative effect of aquatic ecosystem.

Chandramohan *et al.,* (2006) carried out work on modeling of suspended sediment dynamics in tropical river basins. He proposed to analyse the sediment transport characterstics of 16 river basins of kerala, using the data collected from CWC and to study the seasonal and sptial distribution of sediment load carried by these rivers. Pamba river was selected as the representative hydrologic regime for detailed studies of modelling of sediment hydrodynamics. Emperical sediment rating curve , modified universal soil loss equation, conceptual unit hydrograph and distributed water prediction project models were tested using field data by monitoring rainfall, discharge and suspended concentration for selected micro-watershed in the river basin.

Raghuwanshi, Singh and Reddy *et al.,* (2006) carried out work on precise estimation of both runoff and sediment yield for correct watershed management. Artificial neural network (ANN) models were established, to predict both runoff and sediment yield on a daily and weekly basis, for a small agricultural watershed. A total of five models were designed for forecasting runoff and sediment yield, out of which three models were based on a daily interval and the other two were based on a weekly interval. All five models were developed both with one and two hidden layers. Each model was designed with five different network architectures by selecting a different number of hidden neurons.

Gebhardt and Jackson *et al.,* (2007) carried out work on the Modified Universal Soil Loss Equation (MUSLE), which was related to average annual sediment yield on 14 small rangeland drainage basins by substituting average annual runoff and a calibrated design discharge for the runoff and peak flow terms respectively in MUSLE. The objective was to determine if a design discharge could be prescribed which would enable MUSLE, in this form, to be used for annual sediment yield estimates on small rangeland drainage basins.

Carolina,Joris de Vente and Castillo et al., (2008) carried out work on Extensive land use changes that had occurred in many areas of SE Spain as a result of reforestation and the abandonment of agricultural activities. Similar to this the Spanish Administration spends large funds on hydrological control works to reduce erosion and sediment transport. Though, it remains untested how these large land use variation affect the erosion processes at the catchment scale and if the hydrological control works efficiently reduce sediment export. A mixture of field work, mapping and modelling was used to test the impact of land use scenarios with and without sediment control structures (check-dams) on sediment yield at the catchment scale. The study catchment is located in SE Spain and suffered important land use changes, increasing the forest cover 3-fold and decreasing the agricultural land 2D5-fold from 1956 to 1997. In addition 58 check-dams were built in the catchment in the 1970s accompanying reforestation works. The erosion model WATEM-SEDEM was applied using six land use scenarios: land use in 1956, 1981 and 1997, each with and without check-dams. Adjustment of the model provided a model efficiency of 0D84 for absolute sediment yield. Model use showed that in a scenario without check dams, the land use changes between 1956 and 1997 caused a progressive decrease in sediment yield of 54%. In a scenario without land use changes but with check-dams, about 77% of the sediment yield was reserved behind the dams. Check-dams can be effective sediment control measures, but with a short-lived result. They have significant side-effects, such as encouraging channel erosion downstream. While also having side-effects, land use changes can have important long-term effects on sediment yield. The application of either land use changes (i.e. reforestation) or check-dams to control sediment yield depends on the basis of the management and the specific environmental conditions of each area.

Chadin and Tetsuya *et al.,* (2008) carried out work on sediment yield and transportation analysis of managawa river basin. In this study, the Geographic Information System (GIS) combined with sediment yield model can be ornamental for the evaluation of soil erosion assessment. Surface erosion on Managawa river basin is computed with the Modified Universal Soil Loss Equation (MUSLE) and it is verified to reflect the hydrological processes be able to estimate soil losses. In the sediment conveyance routing module, total load equation is applied to transmit sediment from soil surface erosion to deposit in Managawa dam.

Arekhi and Shabani *et al.,* (2010) carried out work on Modified Universal Soil Loss Equation (MUSLE) application study in order to estimate the sediment yield of the Kengir watershed in Iyvan City, Ilam Province, Iran. The runoff factor of MUSLE was computed using the measured values of runoff and peak rate of runoff at outlet of the watershed. Topographic factor (LS) and crop management factor(C) are determined using geographic information system (GIS) and field-based survey of land use/land cover. The conservation practice factor (P) was obtained from the literature. Sediment yield at the outlet of the study watershed is simulated for six storm events spread over the year 2000 and validated with the measured values. The high coefficient was used for determination value (0.99), which indicates that MUSLE model sediment yield predictions are satisfactory for practical purposes.

Arekhi and Rostamizad *et al.,* (2011) carried out work on accurate estimation of water and soil losses from agro-ecologically diverse areas was extremely important for designing appropriate resource management or soil/ water preservation measures. The advanced KW-GIUH-MUSLE(Kinematic wave- Geomorphological Instantaneous Unit Hydrograph-Modified universal Soil loss equation) model is tested for its sediment yield estimation potential on three agro-ecologically diverse micro-watersheds in Almora district of Uttaranchal. It was observed that estimates are associated with about 49% mean relative errors and mean DV value of about 0.51 in Salla Rautella and Naula micro-watersheds. This presented that point forecasts of annual sediment yields are of moderate quality. However, root mean square error assessments and comparison of mean and standard deviation values for the observed and simulated sediment yields showed that long term sediment yields could be estimated quite realistically. The analysis thus clearly showed that the developed KW-GIUH-MUSLE model could indeed be utilized for obtaining reasonable sediment yield estimates for un-gauged/ inadequately gauged micro-watersheds.

Corina and Viorel et al., (2011) carried out work on a quantitative estimate of the current annual rate of soil surface erosion in the Codrului Ridge and Piedmont (due to the pluvial denudation and sheet erosion) and a spatial representation of the results by implementing GIS techniques. The database used for the application of the ROMSEM model (Romanian Soil Erosion Model) consist of Digital Elevation Model (DEM) with a resolution of 10 m, for computing the topographic factor (LS), soil map (with information about the type, texture, structure and degree of soil erosion), land use map, based on Corine Land Cover 2000 and corrected according to ortophotos dating from 2005, with a 0.5 m resolution, and the rainfall erosivity index map in Romania. The assessment of the surface erosion in the Codrului and Piedmont Ridge was achieved in two stages: first was assessed the potential erosion (the peak value of the erosion in an area devoid of vegetation) based on the climatic, topographic and soil factors. The actual surface erosion map was obtained in the second stage of the mathematical modeling erosion, by mixing the effect of natural or crop vegetation.

CHAPTER 3
SITE DESCRIPTION AND DATA SET

3.1 Introduction

This chapter describes the Upper Mahanadi site, along with the various data needed to analyze sediment erosion in the upper Mahanadi catchment. The catchment, topography, soil types, land use types, runoff, and precipitation are illustrated for the application of soil erosion modeling. Precipitation data will be used to estimate the rainfall-runoff erosivity factor and soil and land use type data will be used to predict the soil erodibility factor and cover management factor, respectively. In order to calculate the slope length and slope steepness factor, DEM will be used. Surveyed sediment data will be used to analyze the SDR in the upper Mahanadi catchment.

3.2 Upper Mahanadi Catchment

The Mahanadi basin extends over states of Chhattisgarh and Odisha and comparatively smaller portions of Jharkhand, Maharashtra and Madhya Pradesh, draining an area of 1, 41,589 Sq.km which is nearly 4.3% of the total geographical area of the country. The geographical extent of the basin lies between 80°28' and 86°43' east longitudes and 19°8' and 23°32' north latitudes. The basin has maximum length and width of 587 km and 400 km. It is bounded by the Central India hills on the north, by the Eastern Ghats on the south and east and by the Maikala range on the west. The total length of the river from origin to its outfall into the Bay of Bengal is 851 km. It originates from a pool, 6 km from Farsiya village of Dhamtari district of Chhattisgarh. The Mahanadi is one of the major rivers of the country and among the peninsular rivers, in water potential and flood producing capacity, it ranks second to Godavari.

The Upper Mahanadi catchment is located in the northeastern part of the Mahanadi River basin, which is between 19° 59' 23" ~ 21° 02' 53"N and 81°09'39" ~ 82°25'09"E. It includes three districts dhamtari, kankar and Raipur. The net area of watershed is 8760 $km^{2.}$, And has a maximum height of 283.32m. It covers around 6.18% of total Mahanadi river basin. The study area also includes three major dams such as Ravi Shankar dam and Dudhawa dam in Raipur. Murrum silli dam near Kankar district.

Figure 3.1 sows the location of the upper Mahanadi river basin in Chhattisgarh, India. The main gauging station (Raijm) is also located in the given map.

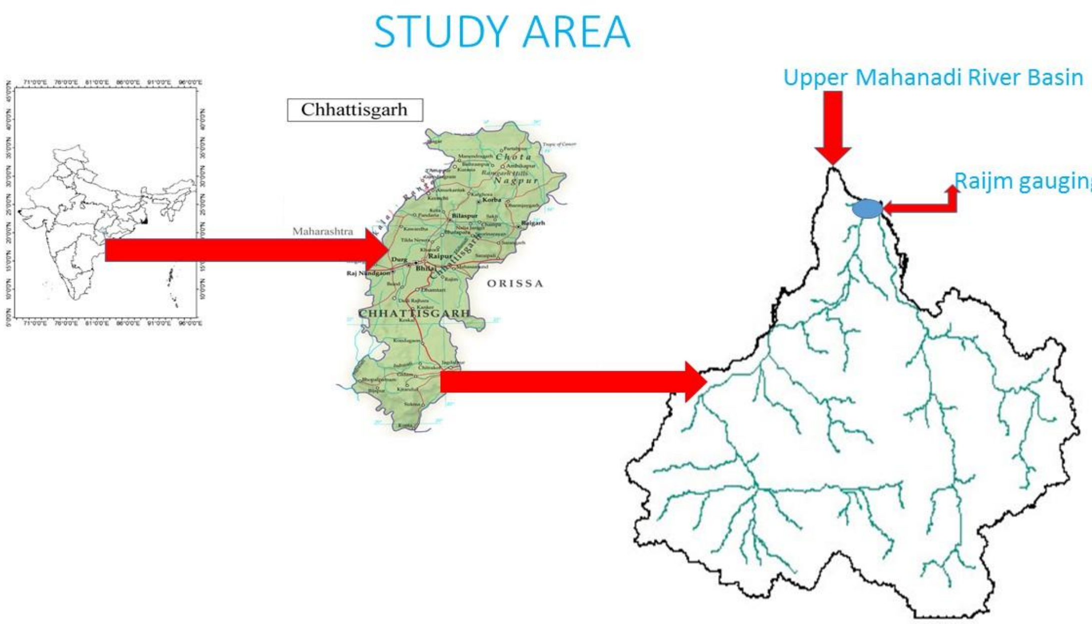

Figure 3.1 location of study area

Figure 3.1 represents the location of eight rainfall gauging station on Google map. Thiessen polygon of the upper Mahanadi catchment is obtained by proximity tool of ArcGIS, and coordinates was entered into the study area.

Figure 3.2 representing gauging station in upper Mahanadi catchment

3.3 Data Set of the Upper Mahanadi Catchment

Soil erosion is influenced by a variety of factors such as rainfall intensity and distribution, soil types, topography of watershed, land use types, etc. These factors are presented very well with the temporal and spatial type using GIS technique. GIS application is increasing more and more to predict soil erosion in the watershed. In order to predict the soil erosion, sediment delivery ratio, and trap efficiency in the upper Mahanadi catchment, the following spatial and temporal data are used:

Digital Elevation Model (Data source: Catrosat v1.1, Bhuvan: 30 by 30m, year-2009)

2) Soil types map (Data source: F.A.O, vectorized map, year-2003)

3) Land cover type map (Data source: AWiFS, Bhuvan, cell size: 30mby 30m, 2009)

4) Daily precipitation data (Data source: India Meteorological Department)

6) Sediment Transportation survey report in the Upper Mahanadi catchment (Data source: India Wris)

The India Wris has a database of suspended and runoff data from 1992 to 2010. It also has some thematic maps, including a hydrologic units map, land cover map, soil type map, population density map, etc. The precipitation data is available in Indian meteorological department from year 2004 to 2013 district wise on daily basis. This database is available at the web site; http://www.India-wris.nrsc.gov.in

3.3.1 Digital Elevation Model

The DEM of the upper Mahanadi catchment is presented in Figure 3.3. This DEM was newly created using the digital contour map (scale 1:5000). The watershed is delineated first for upper Mahanadi catchment. The shape file is obtained from the raster image. Using that shape file the DEM was extracted by mask extraction process. The terrain elevation of the upper Mahanadi catchment ranges from EL.211m to EL.886m, with average elevation EL.426m. Using the DEM, the following watershed and river characteristics can be predicted;

1) Watershed characteristics: drainage area, basin perimeter, effective basin width, form and shape factor, drainage density, channel segment frequency, basin average elevation, basin slope, etc.

2) River characteristics: basin length, total stream length, channel slope, stream order, stream length ratio, bifurcation ratio, etc.

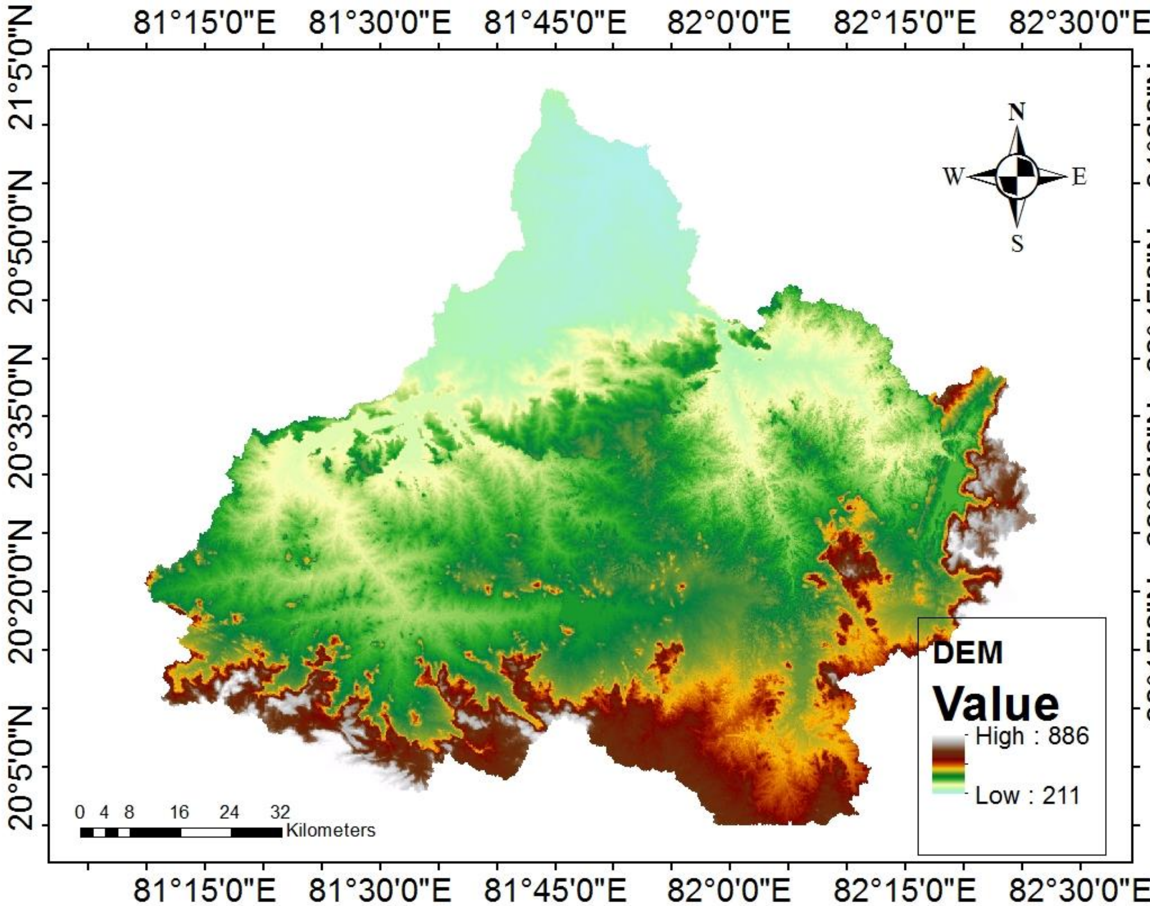

Figure 3.3 – The digital elevation model of the Upper Mahanadi Catchment

3.3.2 Soil Classification Map

Main type of soils found in the basin are red yellow soils. Mixed red and black soils also occurs in the catchment. This soils are reddish brown to yellowish in color. The color is developed mainly due to archean formation of gneiss and granities of gondwana system. Red soils are gravely, sandy and loamy in texture. They have low water retentive capacity. They are mainly rich in nitrogen, calcium, potassium and low in organic matter. The red color is due to low presence of iron oxide. They have low water holding capacity.

Soil classification of India is obtained from Land and Water Development Division, FAO, Rome' Version 3.6, completed in January 2003. Using the shape file of the catchment the attributes were extracted. Then using those attributes containing soil type. Value are assigned and then vector image is converted into raster image.

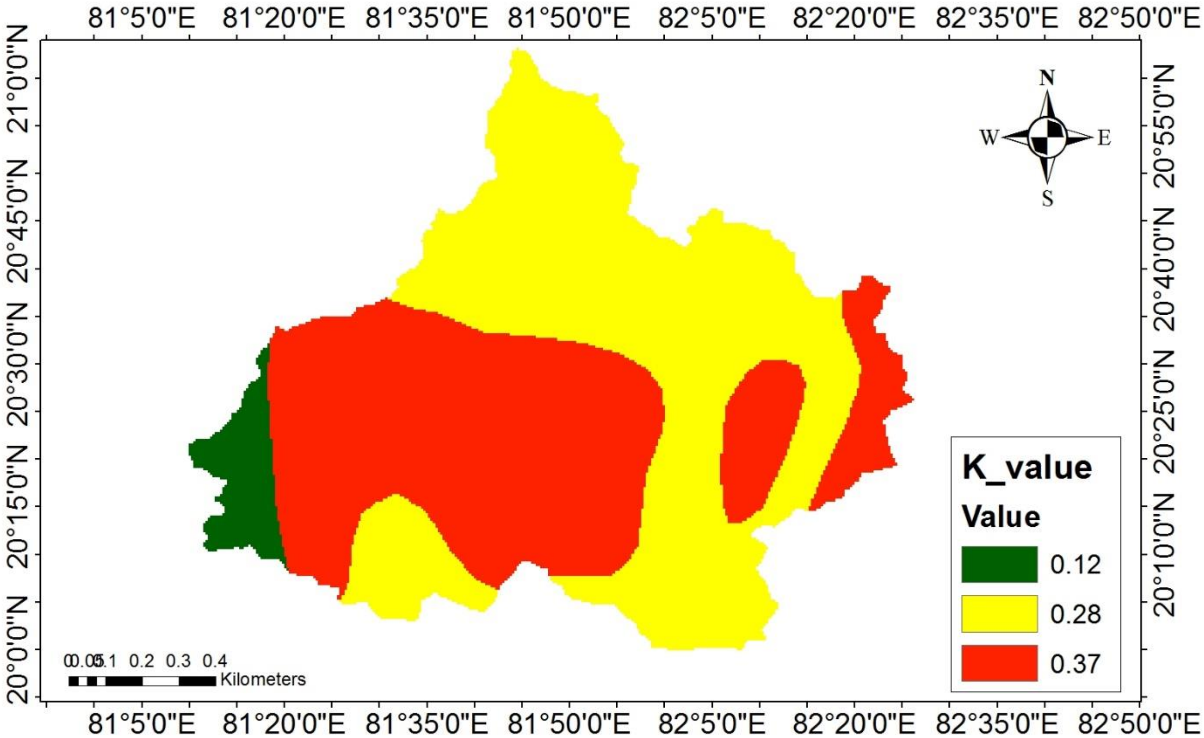

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Figure 3.4 – The soil classification map of Upper Mahanadi catchment

3.3.3 Land Cover Map

As per the study most of the catchment area is used for cultivation, domestic and industrial uses. Forest cover is only about 26.72% and barren land is about 15.14%. For pasture below 6% percent of land area is used. Net agricultural area is about 38.42%.

The land cover map is derived from AWiFS (advanced wide field sensor) satellite sensor. About 12 to 15 images with 30 m spatial resolution were used for the purpose of classification that included 6 main land classes with a number of mixed classes, which are as follows:

1. Urban Areas
2. Irrigated Agricultural land, with 3 sub-classes
3. Rain Fed Agricultural Lands, with 2 sub-classes

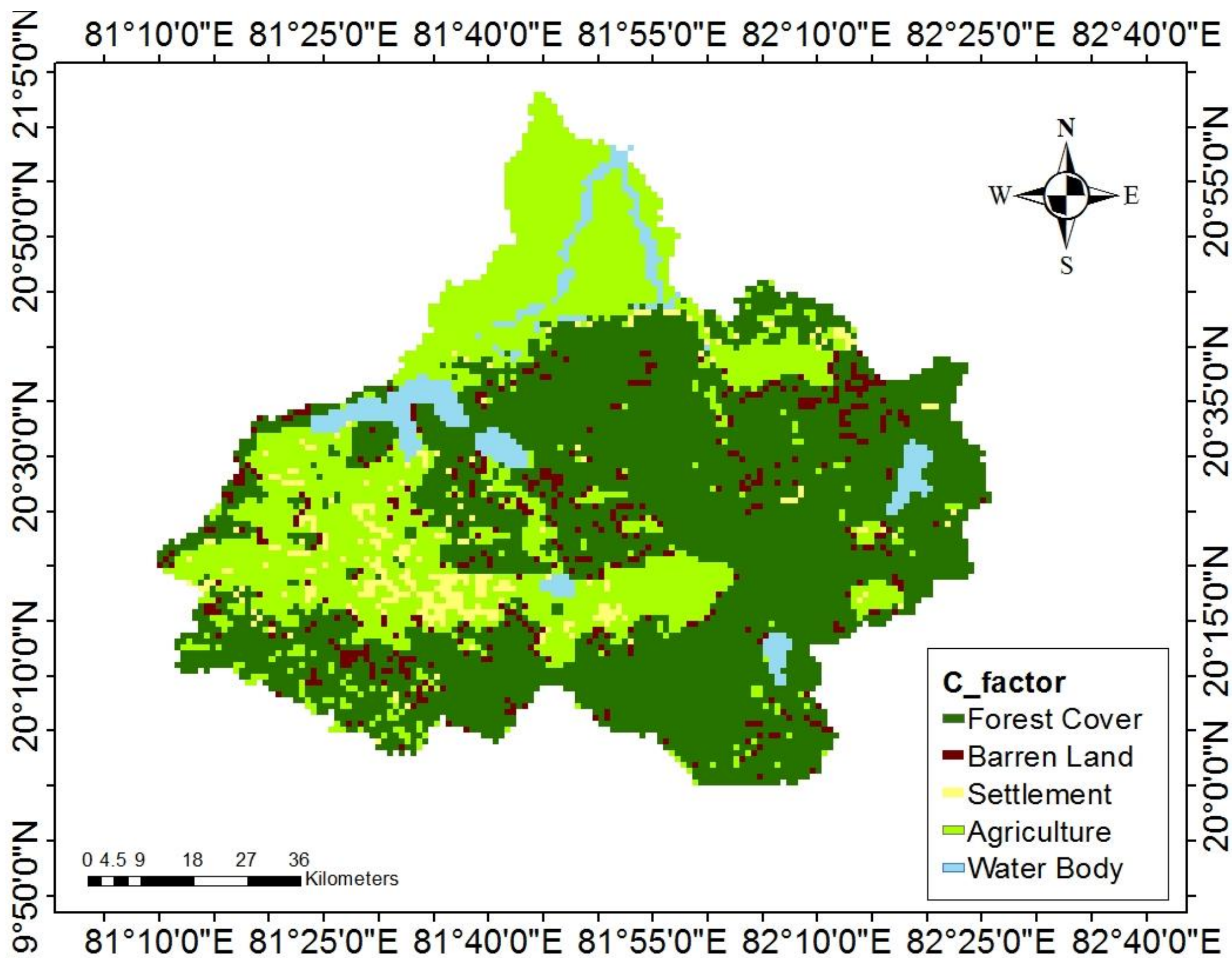
4. Natural Forests, with 2 sub-classes

5. Barren lands

6. Water Bodies

The developed map by AWiFS is used for the determination of this study. Figure 3.5 represents land cover classification map of the upper Mahanadi catchment. Land cover assessment and observing are essential for sustainability of natural resources.

Figure 3.5 shows the land classification of upper Mahanadi catchment derived by supervised image classification. The areas having all the parameters are classified on the basis of color as presented by NRS (national remote sensing institute)



3.5 Cover management factor of upper Mahanadi catchment

Table 3.2 presents station name, location, and beginning of observation of 8 rainfall gauging stations in the upper Mahanadi catchment. All of them are managed by central water commission. Daily rainfall and runoff records are available for 7 years of data from 2004 to 2014. Wischmeier and Smith (1978) recommended that at least 20 years of rainfall data should be used to accommodate natural climatic variation. Therefore, the upper Mahanadi catchment has a kind of limitation to calculate the rainfall runoff erosivity factor of USLE.

Table 3.1 – Rainfall Gauging Stations

no	Stations	District	Location		Beginning of observation	End of observation
			Latitude	Longitude		
1	Charma	Kankar	20.48450	81.373361	1.1.2004	30.12.2010
2	Gattasilli	Raipur	20.450361	81.803306	1.1.2004	30.12.2010
3	Raijm	Raipur	20.965	81.881667	1.1.2004	30.12.2010
4	Rudri	Raipur	20.664481	81.552787	1.1.2004	30.12.2010
5	Kankar	Kankar	20.270	81.490	1.1.2004	30.12.2010
6	Garibund	Raipur	20.633	82.0667	1.1.2004	30.12.2010
7	Narharpur	Kankar	20.4489	81.62036	1.1.2004	30.12.2010
8	Kurd	Dhamtari	20.830	81.720	1.1.2004	30.12.2010

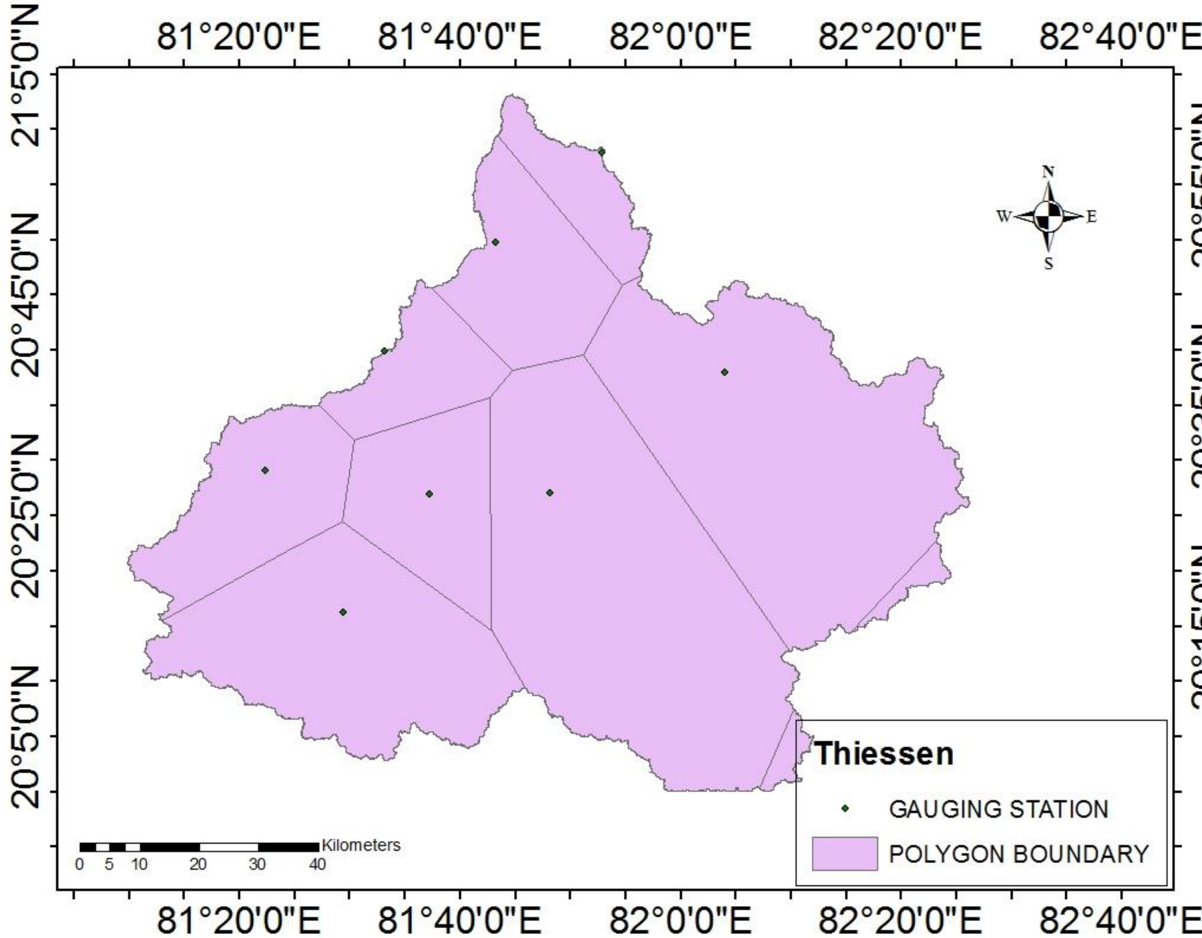


Figure 3.6 represent the thiessen polygon in upper Mahanadi catchment

Table 3.2 – Annual precipitation records

Station Year	Charma	Gattasilli	Raijm	Rudri	Kankar	Garibund	Narharpur	Kurd
2004	1037.8	939.2	9.932	939.2	1037.8	939.2	1037.8	916
2005	1245.7	1348	1348	1348	1245.7	1348	1245.7	1100.3
2006	1571.7	1206.7	1206.7	1206.7	1571.7	1206.7	1571.7	1320.4
2007	1235.7	1434.2	1434.2	1434.2	1235.7	1434.2	1235.7	1007.2

2008	652.2	1114.5	1114.5	1114.5	652.2	1114.5	652.2	901
2009	868.8	948.3	948.3	948.3	868.8	948.3	868.8	1113
2010	1480.8	1109.1	1109.1	1109.1	1480.8	1109.1	1480.8	1211.1

3.3.4 Discharge data

Average monthly flow data is collected from India-wris version 4.0 on upper Mahanadi Catchment basin at Raijm gauging station. From the June to October (2004-2010).

Table 3.3 Represent the Discharge data

year	Discharge data cumec
2004	100.562
2005	88.2
2006	181.81
2007	141.17
2008	89.4485
2009	101.07
2010	111.9295

3.3.5 Sediment Survey Data

The most important study of sediment yield in the upper Mahanadi catchment was performed by India-Wris. This study estimated sediment yields at proposed gauging station on the upper Mahanadi catchment. The study was based on annually sediment yield estimated at the Raijm gauging station. The observed sediment yield data is collected from India-wris during the period 2004 to 2010. The study did not exactly state how bed load amounts were accounted for the sediment yield. Figure 3.3 shows location of the sediment gauge station along the basin and Table 3.3 presents sediment yield for the stations located in the upper Mahanadi catchment. The unit for sediment yield for the river is given in ton of sediments per square kilometer of the catchment area per year

Table 3.1 gives sediment yield in tons per year. This value is computed from suspended sediment and discharge observed at the Raijm gauging station

Table 3.4 – Sediment Transportation data

Year	Sediment Yield in Tons/year
2004	3106.11
2005	3926.56
2006	4556.96
2007	6983.956
2008	5943.56

2009	5429.28
2010	6071.266

3.4 Summary

Chapter 3 demonstrates the upper Mahanadi catchment site description and data set: topography, soil and land use characteristics, precipitation, runoff, and sediment survey data. Precipitation and runoff data are needed to estimate the rainfall runoff erosivity factor (R). DEM, with 30m grid cell size, is needed to analyze the slope length (L) and slope steepness (S). A soil map based on vectorized feature data is used to estimate the soil erodibility (K) and transformed into the raster data file with 30m grid cell size. A land cover map, extracted from AWiFS images, is used to predict the cover management factor (C), which is one of the most sensitive factors in analyzing the soil loss rates of the USLE model.

CHAPTER 4

METHODOLOGY AND PARAMETER ESTIMATION

4.1 INTRODUCTION

This chapter describes the basic concepts, and the procedure for USLE model, in addition to the methodology to estimate these six parameters, and prediction of the USLE model. Based on the annual rainfall data, DEM, soil type map, and land cover map, six parameters of the USLE model will be estimated and verified.

4.2 Watershed Delineation Process

It is a process of creating boundary of a watershed that represents the contributing area for particular control point.

Step 1: cartosat image for required area is downloaded of 30m*30m resolution. Generally all the files adjacent to upper Mahanadi river basin is downloaded.

Step 2: All the fill, flow direction and flow accumulation function was carried out by using hydrology option of spatial analysis tool box.

Step 3: After carrying the above function, the pour point was selected. Pour point is a control point for a particular watershed or a catchment. Coordinates of Raijm were selected and added to the flow accumulation data.

Step 5: the pour point was snapped and using that snapped point and flow accumulation data a watershed was generated.

Step 6: Similarly the above procedure unless a desired watershed was obtained.

4.3 USLE Parameter Estimation

The degree of erosion, specific degradation, and sediment yield from watersheds are related to a complex interaction between topography, geology, climate, soil, vegetation, land use, and man-made developments (Shen and Julien, 1993). The USLE is the method most widely used around the world to predict long-term rates of inter rill and rill erosion from field or farm size units subjected to different practices. Wischmeier and Smith (1965) developed the USLE based on many years of data from about 10,000 small test plots throughout the U.S. Each test plot had about 22.13m flow lengths and they were all operated in a similar manner, allowing the soil loss measurements to be combined into a predictive tool. Modified USLE (MUSLE) is an improvement upon USLE (Williams, 1975) where by the soil loss from an isolated rainfall event can be estimated. In MUSLE the rainfall energy term is replaced by a runoff energy factor. Sediment yield for a rainfall event is given by: K, L, S, C, P factors remain the same as that for USLE.

The USLE model groups numerous physical and management parameters that influence erosion under six factors, which can be expressed numerically. Interrelation between the variables involved in erosion processes is represented in the flowchart shown in Figure 4.1.

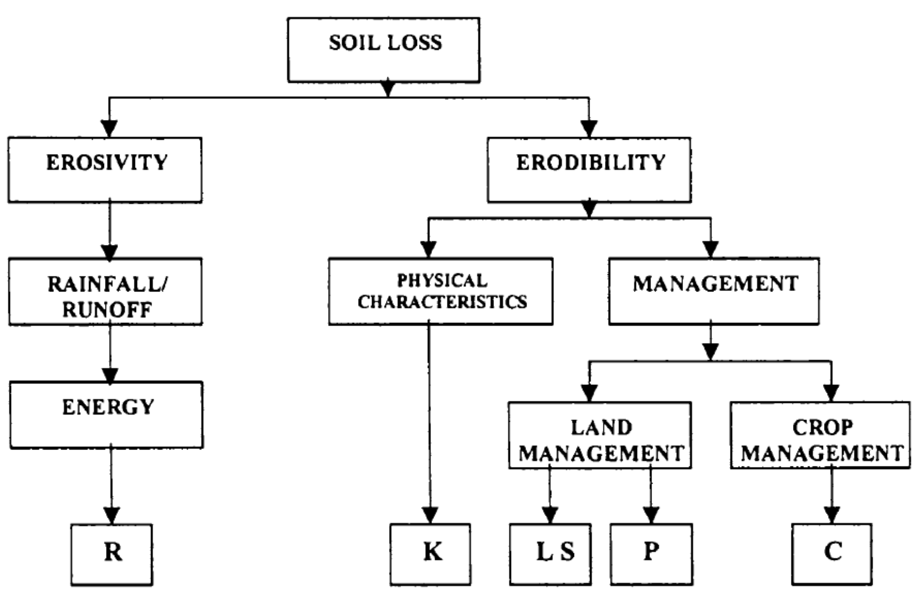


Figure 4.1: Schematic Representation of USLE Components

Equation for Universal Soil Loss Equation is described below.

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(Eqn 4.1)}$$

Where:

A = calculated average annual soil loss predicted and temporal average soil loss per unit of area. A is expressed in unit tons/ (acre× yr.), but other units can be selected (that is, tons / (ha× yr.))

R= Rainfall-runoff erosivity factor (MJ mm ha $^{-1}$ hr^{-1});

Erosivity factor is determined by both rainfall and the energy imparted to the land surface by the rain drop effect.

K = Soil erodibility factor: It is defined as soil loss per unit of area for unit plot.

L = Slope length factor: It is the ratio of soil loss from field slope length to that from 22.13 m length plot under identical conditions.

S = Slope steepness factor: It is the ratio of soil loss from the field slope gradient to that from 9 % slope under otherwise identical conditions

C = Cover management factor : It is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean, tilled fallow or identical soil and slope and under the same rainfall.

P = Support practice factor: It is expressed as a ratio, which compares the soil loss from investigated plot cultivated up and down the slope. P ranges from 1.0 for up and down cultivation to 0.25 for contour strip cropping of gentle slope.

L and S factors are dimensionless parameters which represent the impact of topographic effects on soil erosion rates. C and P factors stand for dimensionless impacts of cropping and management systems on soil erosion control practices. L and S factors stand for the dimensionless impact of slope length and steepness, and C and P represent the dimensionless impacts of cropping and management systems and of erosion control practices. All dimensionless parameters are normalized relative to the Unit Plot conditions, as described in Agriculture Handbook 703. Over the years, the USLE and RUSLE became the standard tool for predicting soil erosion not only in the U.S., but also throughout the world (Meyer, 1984). Widespread use has substantiated the usefulness and validity of USLE for this purpose.

4.3.1 Rainfall-Runoff Erosivity Factor (R)

Wischmeier and Smith (1958) derived the rainfall and runoff erosivity factor from research data from many sources. The rainfall – runoff erosivity factor is defined as the mean annual sum of individual storm erosion index values, EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum rainfall intensity in 30 minutes. To compute storm EI_{30}, continuous rainfall intensity data are needed. Wishmeier and Smith (1978) recommended that at least 20 years of rainfall data be used to accommodate natural climatic variation. Renard et al. (1997) states that the numerical value used for R in USLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain. The rainfall runoff erosivity factor (R) derived by Wischmeier appears to meet these requirements better than any of the many other rainfall parameters and groups of parameters tested against the plot data. Wischmeier and Smith (1965) found that the best predictor of rainfall erosivity factor (R) was:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right]$$

Where:

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff ($100m \times tonf \times hect^{-1} \times yr^{-1}$)

E = the total storm kinetic energy in hundreds of m-tons per hect;

I_{30} = the maximum 30-minute rainfall intensity;

j= the counter for each year used to produce the average;

k= the counter for the number of storms in a year;

m= the number of storms n each year;

n= the number of years used to obtain the average R.

The calculated erosion potential for an individual storm is usually designated EI. The total annual R is therefore the sum of the individual EI values for each rainfall storm event. The energy of a rainfall storm is a function of the amount of rain and of all the storm's intensity components. The median raindrop size generally increases with greater rain intensity (Wischmeier et al., 1958), and the terminal velocity of free-falling water drops increases with larger drop size (Gunn and Kinzer, 1949). To calculate the R-factor generally we used monthly, seasonal and annual rainfall data. Rainfall erosivity estimation using rainfall data for different rain gauge station in Upper Mahanadi catchment such as charma, gattasailli, Raijm, kankar, rudri, garibund, naraharpur, kurd.

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 (Ram Babu et al. 2004). Following equation was developed for upper Mahanadi river basin area in Chhattisgarh India by Ram Babu et al. (2004) and used in the present study

$R = 81.5 + 0.38RN\ (340 \leq RN \leq 3500 \text{ mm})$ …. (Eq. 2)

Where RN is the annual rainfall in mm. For the present study, Eq. 2 is used to compute annual values of R-factor by replacing RN with actual observed annual rainfall in a year Figure 4.1 present thiessen polygon maps of the Upper Mahanadi Catchment. The catchment boundaries and rain gauge station are shown with the help of boundary lines and points.

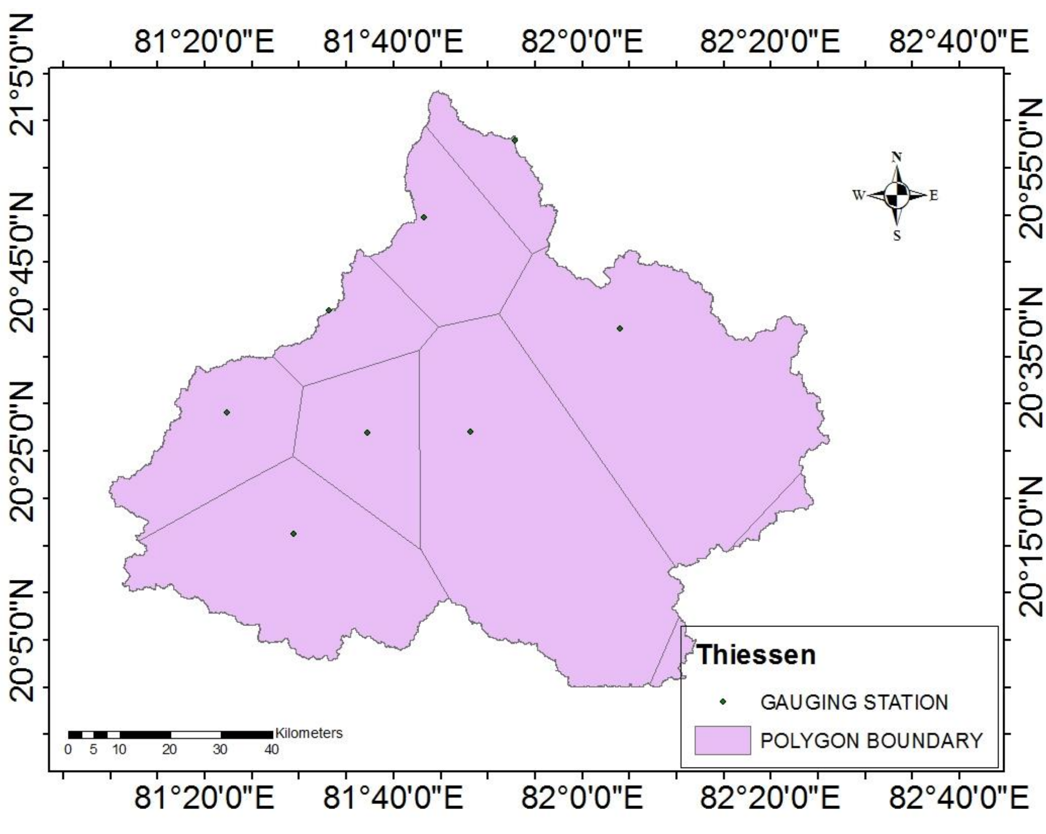


Figure 4.2 showing thiessen polygon

In ARC GIS R factor is computed by putting the Coordinates of the gauging station for upper Mahanadi catchment was obtained from Google. Then these longitude, latitude value are written in excel and then imported into ARC GIS. These coordinates were super imposed on the shape file of the upper Mahanadi catchment. Using Thiessen polygon command in proximity tool in analysis tool box and excel latitude, longitude coordinates as input file, and thiessen polygon is drawn. In the attribute of that polygon, gauging station name are entered corresponding to their coordinates. Then weightage factor are derived, finally total rainfall values for each gauging station are inserted. Then isoerodent value is computed for each field by using field calculator. Based on those isoerodent value the polygon file was converted into raster image. Similarly these steps are repeated for rainfall value of different year. A raster image of isoerodent value for upper Mahanadi catchment for year 2009 is shown below.

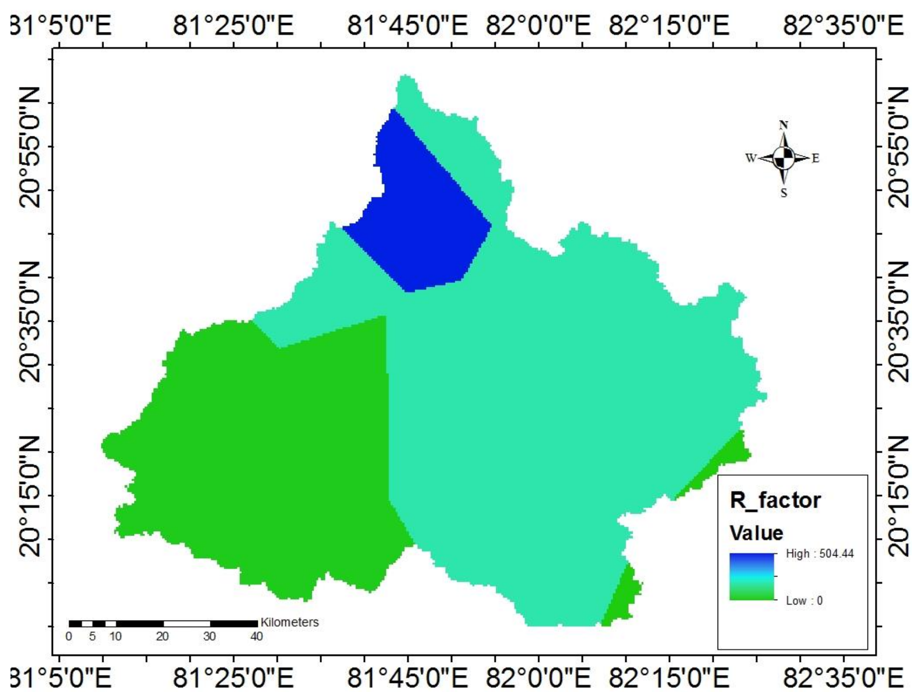


Figure 4.3 showing R_factor variation

4.3.2 Soil Erodibility Factor (K)

Soil erodibility (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input,

as measured under a standard condition. The standard condition is the unit plot, 22.13m long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hill slope (Weesies, 1998). K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil erodibility factors (K) are best obtained from direct measurements on natural runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Romkens 1985). For satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years (Loch et al., 1998). Therefore, considerable attention has been paid to estimating soil erodibility from soil attributes such as particle size distribution, organic matter content and density of eroded soil (Wischmeier et al., 1971). Figure 4.4 represents the nomograph used to determine the K factor for a soil, based on
its texture; % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability.

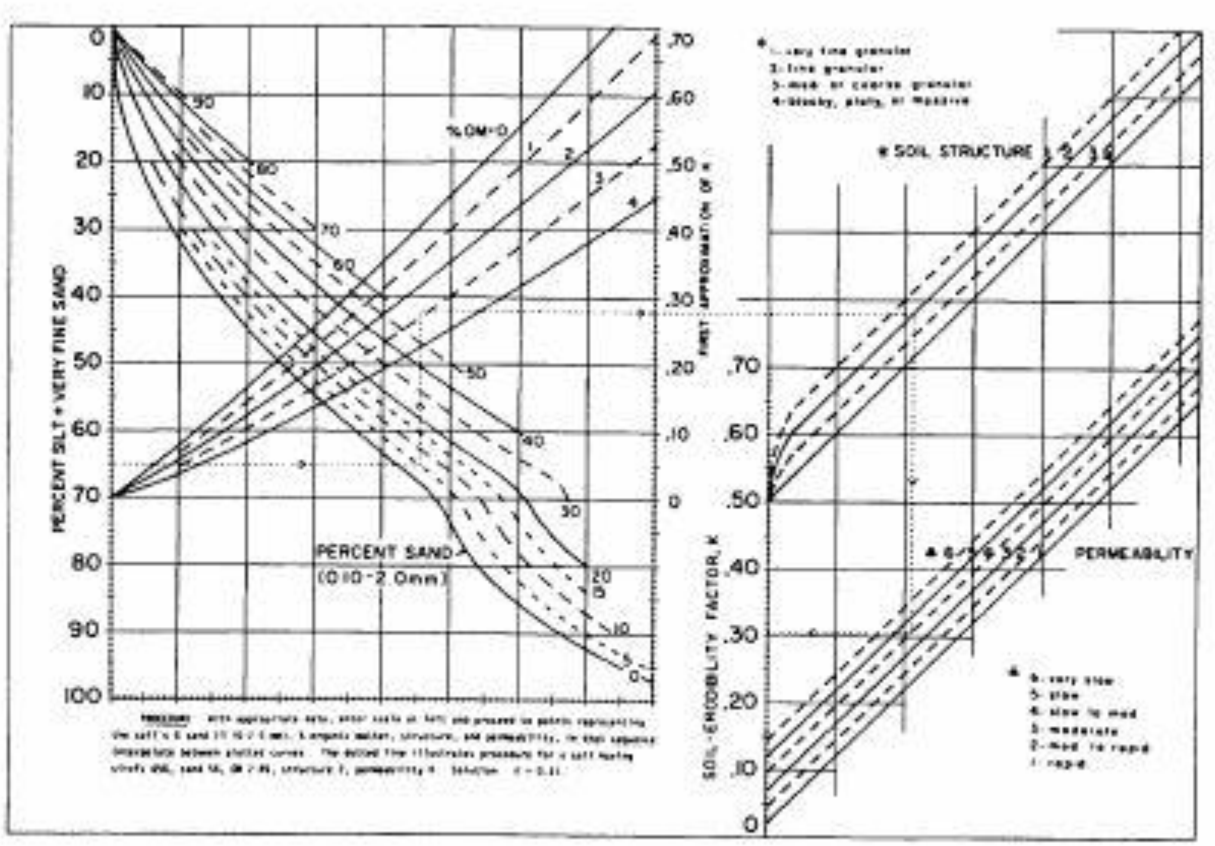


Figure 4.4 – Soil erodibility nomograph (after Wischmeier and Smith, 1978).

The soil type's map was extracted from the digital soil map of the world by food and agriculture organization of the United Nations, Version 3.6, completed January 2005. Soil classification of the upper Mahanadi Mahanadi is divided into 3 types of soil with varying soil characteristics. In this study, Soil erodibility (K) of the upper Mahanadi catchment can be defined using the relationship between soil texture class and organic matter content proposed by Schwab et al. (1981).

Table 4.1 – Soil Erodibility Factor (K) (Schwab et al., 1981)

	Organic Matter Content (%)	
Textural Class	**0.5**	**2**
Fine sand	**0.16**	**0.14**
Very fine sand	**0.42**	**0.36**
Loamy sand	**0.12**	**0.10**
Loamy very fine sand	**0.44**	**0.38**
Sandy loam	**0.27**	**0.24**
Very fine sandy loam	**0.47**	**0.41**
Silt loam	**0.48**	**0.42**
Clay loam	**0.28**	**0.25**
Silty clay loam	**0.37**	**0.32**
Silty clay	**0.25**	**0.23**

Table 4.2 type of soil with its erodibility value and area covered

Soil type	K_value	Area covered in km^2
Clay loam	0.28	1725.72

Silty clay loam	0.37	6464.88
Loamy sand	0.12	551.88

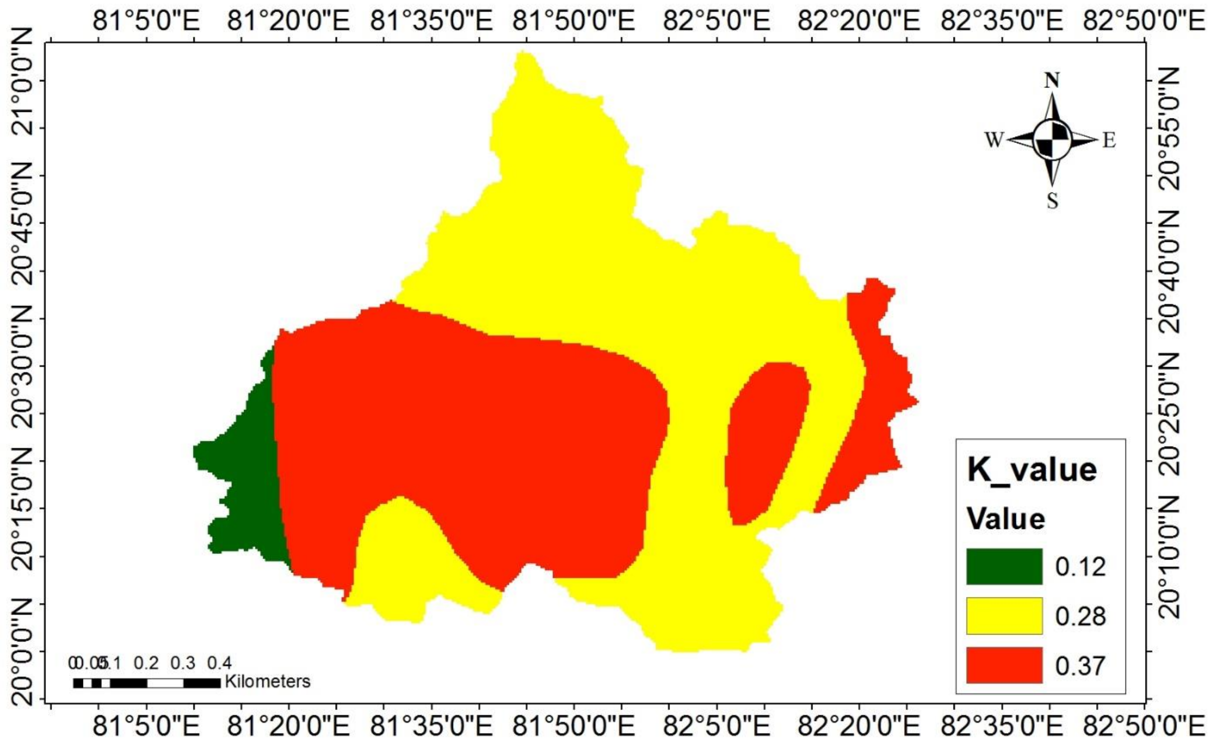


Figure 4.5 showing k map for upper Mahanadi catchment

4.3.3 Slope Length and Steepness Factor (LS)

The effect of topography on soil erosion is accounted for by the LS factor in USLE, which combines the effects of a slope length factor, L, and a slope steepness factor, S. In general, as slope length (L) increases, total soil erosion and soil erosion per unit area increase due to the progressive accumulation of runoff in the downslope direction. As the slope steepness (S) increases, the velocity and erosivity of runoff increase. The LS factor is computed by simple formula as suggested by (Wischmeier and Smith, 1978) $LS_i = (A_{si}/22.13)^n * (\sin\alpha_i/0.0896)^m$.

Where Asi is the specific area at a shell I (=Aup/wn),

Aup: area of overland grid per unit width normal to direction of flow Wn.

$\alpha_{i=}$ slope gradient in degrees for cell i. ,n=0.6 , m=1.3, gives consistent results in usle for slope length <100m and angles <14 degrees.

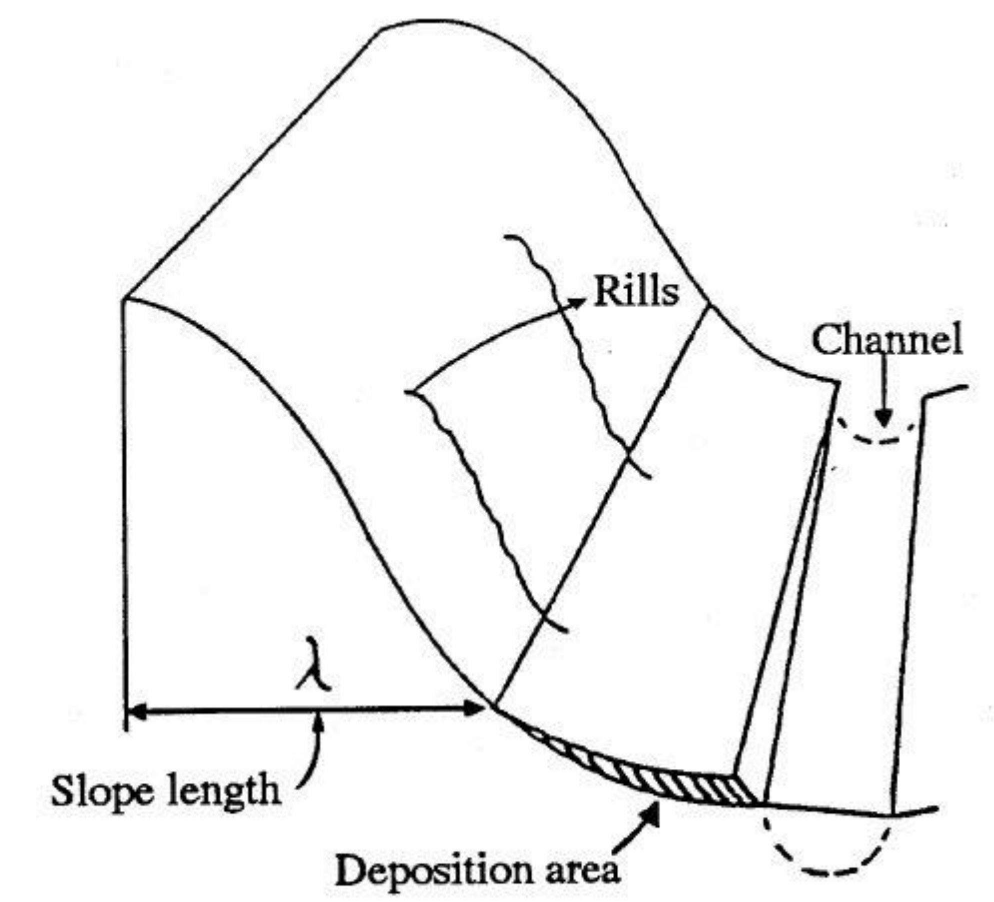


Figure 4.6 – Schematic slope profiles of USLE applications (Renard et al., 1997)

LS Factor: This is Topological factor consisting of two sub-factors: slope gradient and slope length factor; determined from DEM. These factors significantly influence soil erosion by surface water movement. Slope length in meters (L) is calculated from the flow accumulation and slope steepness in radian values. The LS factor is calculated using modification of the empirical equation of Wischmeier and Smith, 1978 by Moore and Wilson (1992) using Spatial Analyst tool of ArcGIS from equation 4:

[LS= power (“flow_accu”* cell size/22.1, 0.4) *power (sin (“slope_deg”*0.01745)/0.09, 1.4)*1.4]

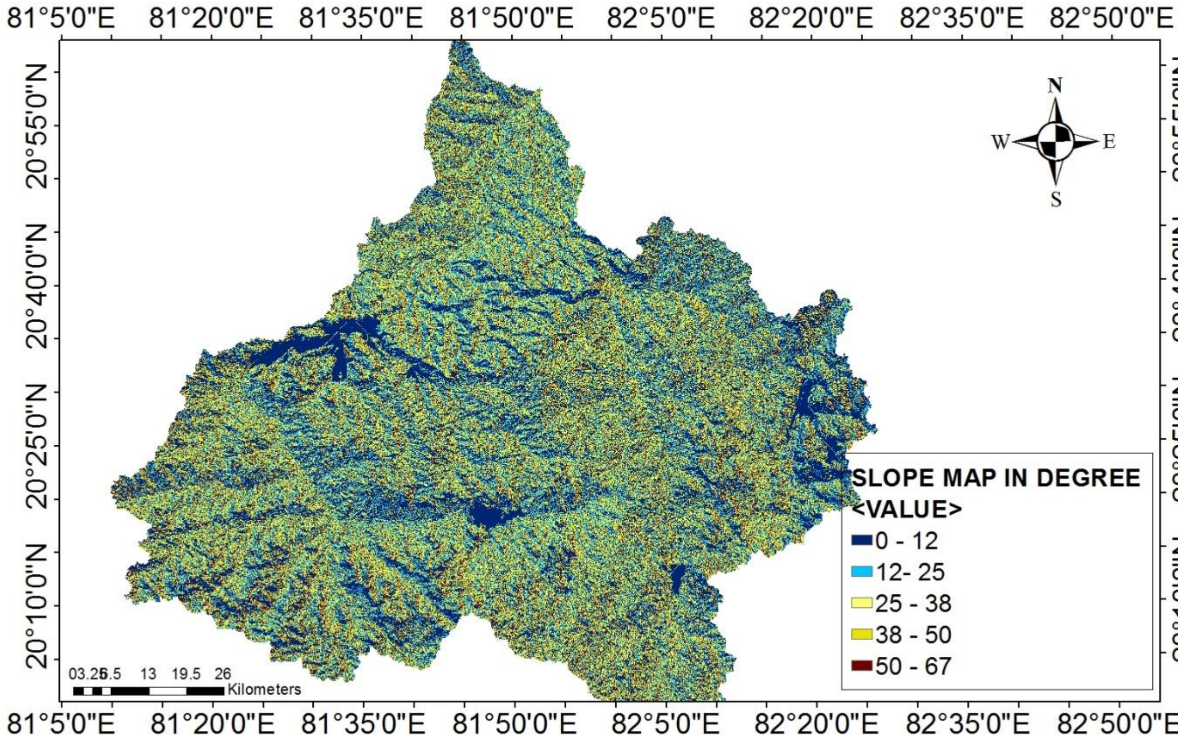


Figure 4.7 slope map of upper Mahanadi in degree

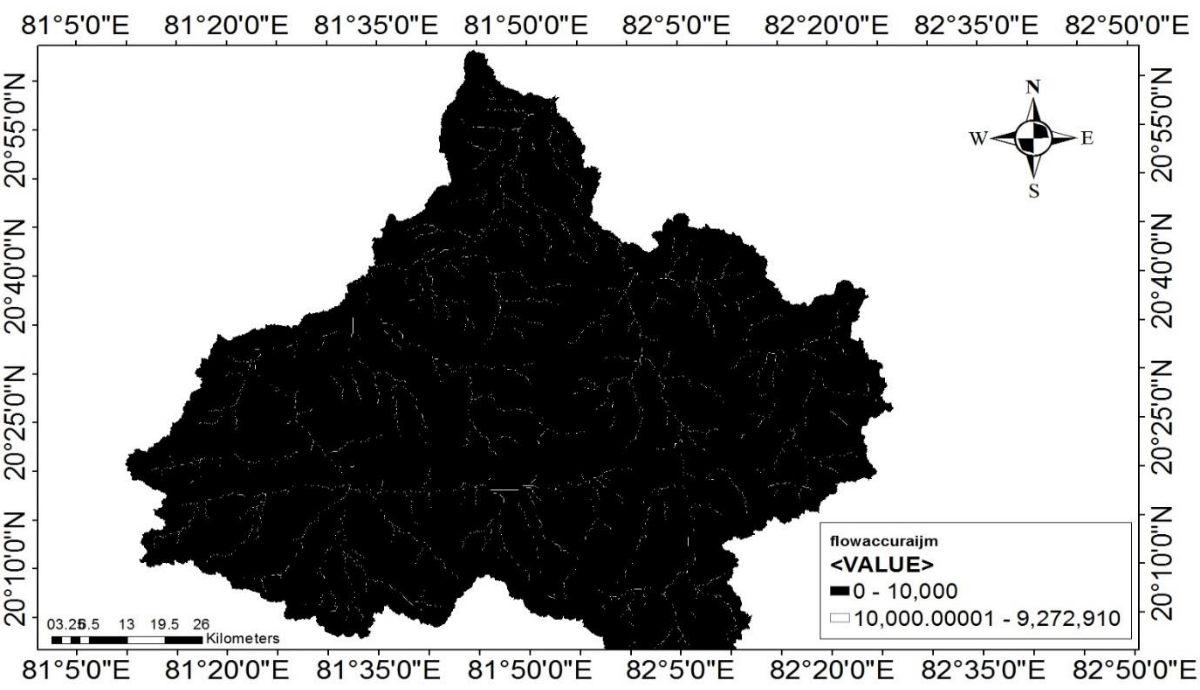


Figure 4.8 shows flow accumulation of upper Mahanadi

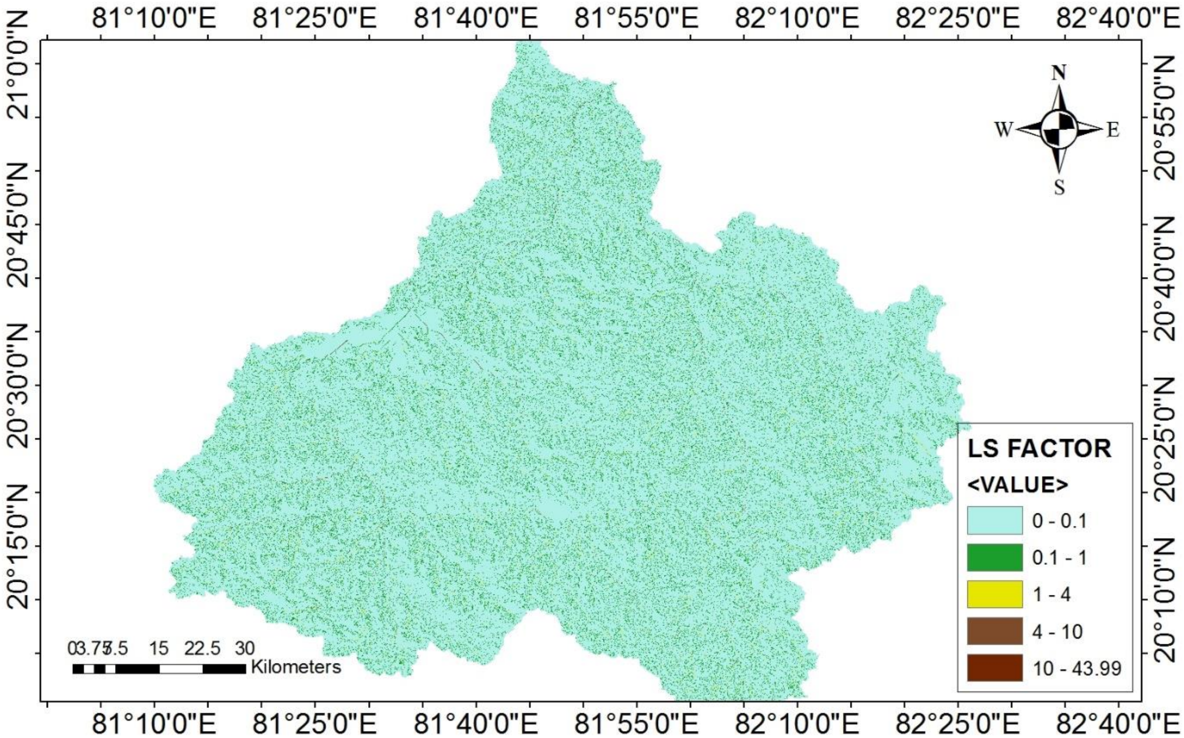


Figure 4.9 LS factor computed for upper Mahanadi catchment

4.3.4 Cover Management Factor (C)

The cover management factor (C) represents the effects of vegetation, management, and erosion control practices on soil loss. As with other USLE factors, the C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot as defined in earlier chapters.

USLE uses a sub factor method to compute soil loss ratios (SLR), which are the ratios of soil loss at any given time in the cover management sequence to soil loss from the standard condition. The sub factors used to compute a soil loss ratio value are prior land use, forest cover, surface cover, surface roughness, and soil moisture.

There are two C factor options in USLE, a time invariant option and a time variant option (Kuenstler, 1998). In the case of Chhattisgarh, India, about two thirds of annual precipitation is concentrated in the summer season, between July and September due to Monsoon effects. Due to the precipitation pattern of India, a time invariant option is applied to the upper Mahanadi catchment catchment.

Based on the "Advanced wide field sensor study by bhuvan (AWiFS), 2009", the land cover of the upper Mahanadi catchment is classified with six land cover classifications: Water, Urban, Wetland, Forest, barren land, and Paddy field. The National Institute of Agricultural Science and Technology (NIAST) had studied the cover management factor with crop coverage based on the Lysimeter experiments from 1977 to 2001 and proposed the cover management factor about the Crop land. Basically, Wischmeier and Smith (1978) proposed that the cover management factor (C) which ranges from 0.0001 to 0.9. The cover management factor was basically computed by using supervised classification of option in image classification tool of ARC GIS. At first the 3 bands from AWiFS (collected from bhuvan) is converted into composite band using image analysis tool. The raster image was extracted by mask from the composite image. Then sample color for each file was obtained by using image classification tool. Similar color sample file was merged and names were assigned to different sample file and a signature file was made. Supervised image classification was carried out using maximum likelihood classification in image classification tool. Then the classified raster image was converted into polygon file. Then the attributes having same grid code was merged using editor tool. After merging all the polygons having same grid code values were assigned to these grid codes. Area and perimeter were calculated for these polygons. Based on these assigned values the polygon file was again converted into raster image. The value of c factor must varies from -1 to 1.

Table 4.3 assigns cover management factor to the type of land use as obtained by above process.

Type of land	Cover management factor (c)
Barren land	0.9
urban	0.003
water	0
agriculture	0.09

forest	0.03

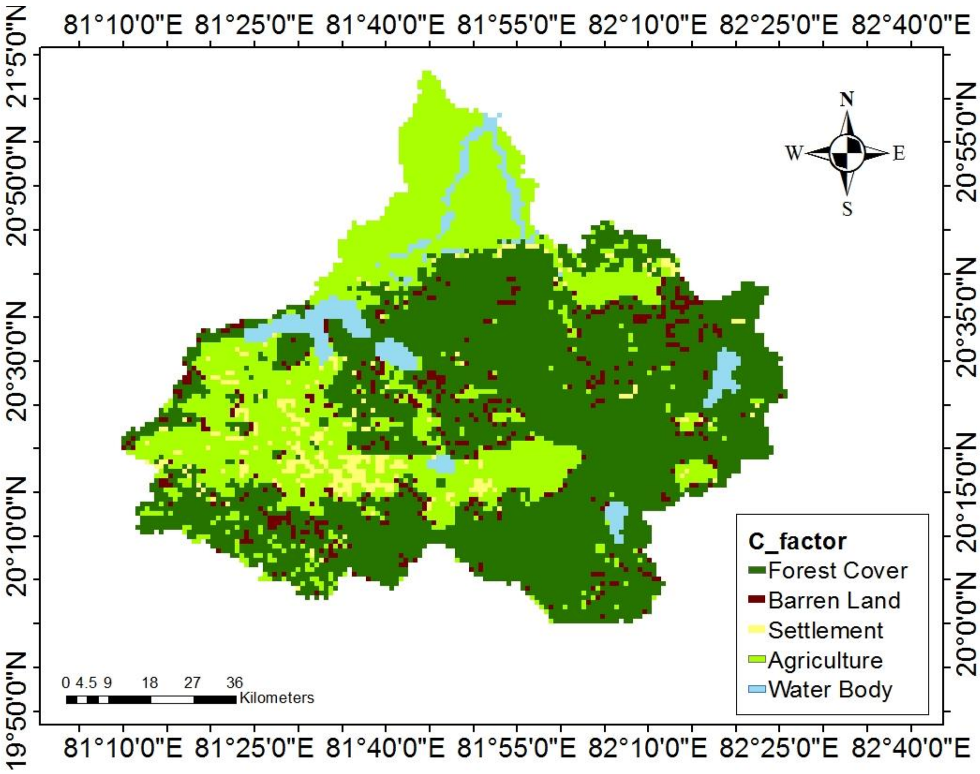


Figure 4.10 showing land classification map of upper Mahanadi catchment

However, forested area of upper Mahanadi catchment has been already disturbed due to the Multi-purpose dam construction and the development of the surrounding area such as road construction, restaurant and hotel construction, and agricultural area development.

4.3.5 Support Practice Factor (P)

Support Practice Factor (P) in RUSLE model is account for the ratio of soil loss with a specific support practice to corresponding soil loss with upslope and downslope tillage. These practices essentially effect erosion by adjusting the flow pattern, steepness, or direction of surface runoff and by reducing the amount and rate of runoff (Reynard and Foster 1983). The support practices for cultivable lands are including contouring, strip-cropping, terracing, and subsurface drainage. While on dry land or rangeland area, soil disturbing practices to result storage of moisture and reduction of runoff considered to be as support practices mechanisms.

Support Practice Factor (P) is ranged from 0 to 1. It is equal to 1 when the land is directly plowed on the slope and less than 1 when the adopted conservation practice reduces soil erosion. Terracing and contouring are common and effective support practices on the field level. The effects of terracing are reflected in the hill slope length and gradient, because it reduces the length of the hill slope. Contouring changes the flow direction and cause runoff to flow around the hill slope rather than directly downslope.

Currently there are no support practices in place within the study site. The common practice is to assign a value of 1 for the P factor. For future use, after calculating the estimated soil loss by USLE, the P factor values can be adjusted to forecast various prevention measures.

4.4 Summary

Chapter 4 presents the procedure and methodology of the USLE parameter estimation. USLE has six parameters, which are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice factor (P). In the upper Mahanadi catchment, the annual average R values range from 164 to 504.44 based on the location of rainfall stations. Kurd, Dhamitri located in the southeastern part of the watershed presents the maximum R value of 504.44. Based on the soil classification and organic matter, soil erodibility (K) is estimated and varies from 0.13 to 0.38. Slope length and steepness (LS) is predicted using the DEM and Arc info AML developed by Van Remortel et al. (2001). LS values range from 0 to 44. The cover management factor (C) is calculated from AWiFS data obtained from bhuvan. Forested area C value is estimated using a “Trial and Error method” from the relationship between the annual soil losses and various sediment delivery ratio models. As most of the land area is covered by forest and agriculture the cover management factor varies from 0.003 to 0.9. Since no support practice factor is like strip cropping, contour cropping is practiced in that area so support practice factor is taken as 1.

Chapter 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter deals with the application and results of the USLE model; the annual average soil loss rate, upper Mahanadi catchment. The results of these cases will be analyzed and compared based on the spatial and temporal variation. Based on the land cover in upper Mahanadi, the spatial distribution pattern of soil loss rate will be analyzed. The basic concept of the Sediment Delivery Ratio (SDR) will be described and total soil loss rate in the upper Mahanadi catchments are analyzed.

5.2 Events Simulation of Soil Loss Rate

In order to simulate upland erosion at upper Mahanadi catchment, three cases will be modeled. In performing this analysis, each thematic map, which is the same grid cell size and coordination, will be used. The rainfall runoff erosivity factor (R) varies spatially and temporally throughout the upper Mahanadi catchment. In contrast, the soil erosivity factor (K), the slope length and steepness factor (LS), the cover management factor (C), and support practice factor (P) are considered to be constant throughout the upper Mahanadi catchment. Computed annual average soil loss rate will be used to estimate the SDR at the upper Mahanadi catchment as representing the relationship between annual average soil loss rate and surveyed sediment deposits.

5.3 The Annual Average Soil Loss Rate

The occurrence of soil erosion has a close relationship with the status of land use and the situation of farmland management along with topographical characteristics such as slope length and steepness. As mentioned previously in chapter 4.3.4, the cover management factor of forested area is calculated by the method of supervised classification in ARC GIS.

Table 5.1 presents the results of the annual soil loss rate and SDR estimated according to the variable C values of forested area. Figure 5.1 represents the relationship graph between the annual average soil loss rate and SDR including the observed sediment deposits and SDR values estimated using the basin characteristics. Based on the SDR values estimated by Renfro (1975), Williams (1977), and Roehl (1962), and surrounding development situations of the upper Mahanadi catchment, the appropriate C value range for forested area can be chosen as 0.03 in this study.

5.3.1 Computed pixel wise sediment yield for year 2004

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 418.72 ~ 475.84 MJ mm ha^{-1} hr^{-1}
2) Soil erodibility factor (K): 0.12 ~ 0.37
3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99
4) Cover management factor (C): 0 ~ 1
5) Support practice factor (P): 1

Figure 5.3.1.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 33.1033 per hector per year.

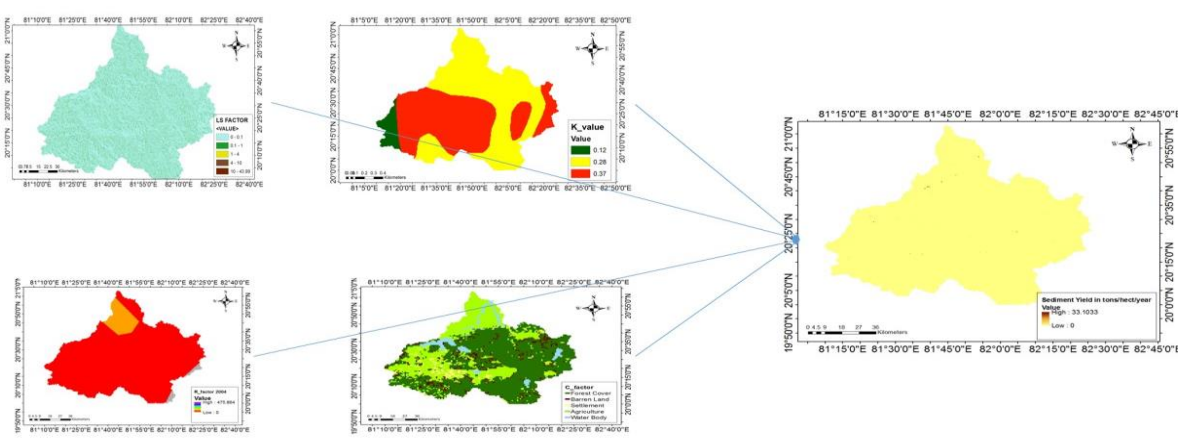


Figure 5.3.1.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2004

5.3.1.b the figure below represents the product of all four factors of USLE. After adding all the unique values of the pixel, the net sediment yield in tons per year is 4297.36. Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wiris is 3106.11 in tons per year. The error obtained is 22.4%

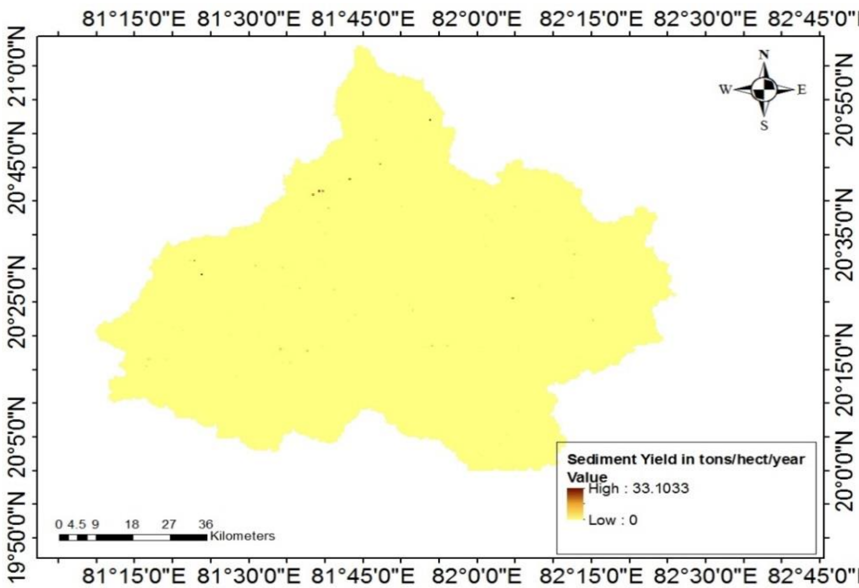


Figure 5.3.1.b sediment yield in tons per hect per year 2004

Table 5.3.1.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.1.a shows the maximum erosion prone area in the catchment area in the year 2004 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.485658	81.396527	Nawagaon Saradui	Chhattisgarh
20.519208	81.381536	Charama, Kanker	Chhattisgarh
20.691957	81.652081	Dhamtari	Chhattisgarh
20.684818	81.641374	Dhamtari	Chhattisgarh
20.429264	82.678243	Lambipani	Chhattisgarh

5.3.2 Computed pixel wise sediment yield for year 2005

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 480.94 ~ 593.74 MJ mm ha^{-1} hr^{-1}

2) Soil erodibility factor (K): 0.12 ~ 0.37

3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99

4) Cover management factor (C): 0 ~ 1

5) Support practice factor (P): 1

Figure 5.3.2.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 24.132 per hector per year.

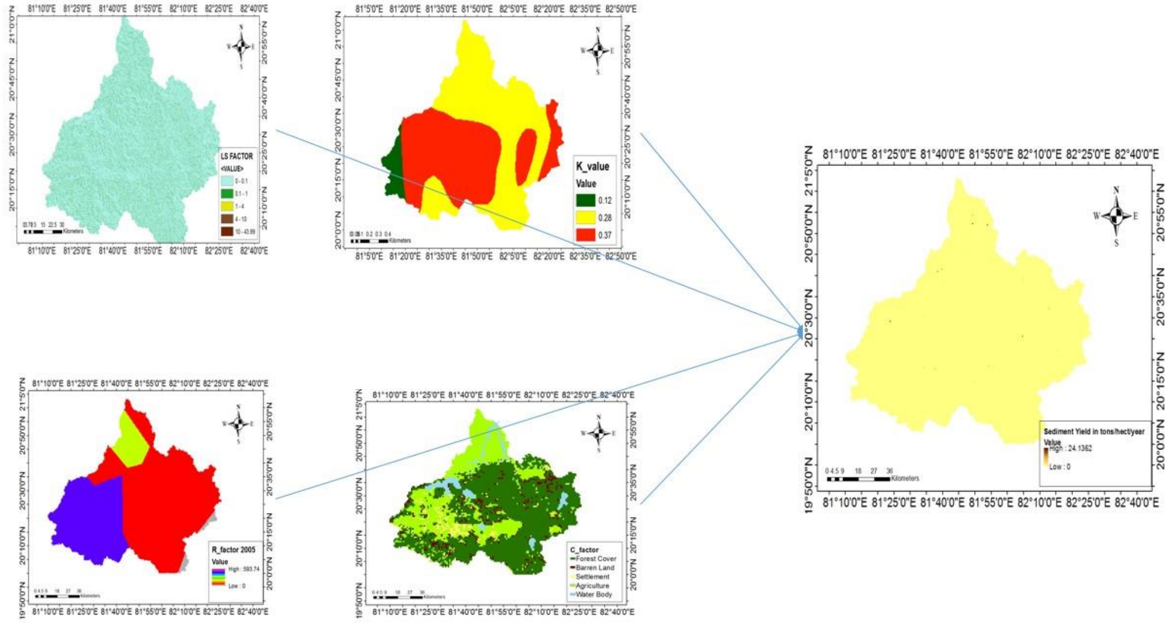


Figure 5.3.2.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2005

5.3.2.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 33.1033. After adding all the pixel values the net sediment yield in tons per year is 5065.26 Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wiris is 3926.56 in tons per year. The error obtained is 29.7%.

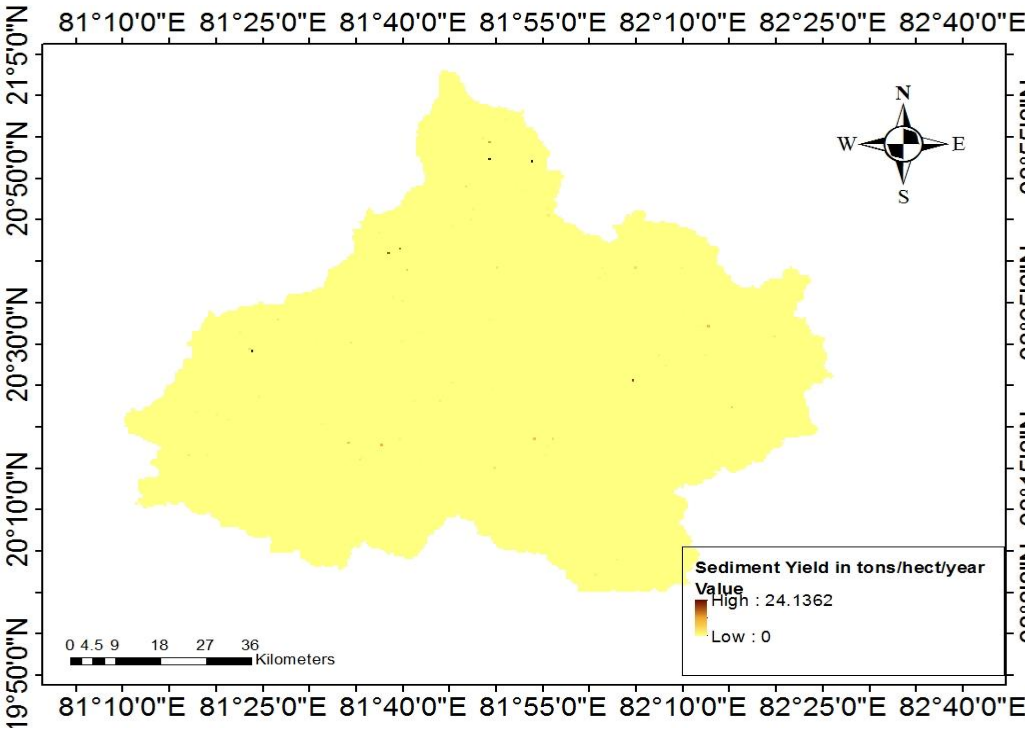


Figure 5.3.2.b sediment yield in tons per hect per year 2005

Table 5.3.2.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.2.a shows the maximum erosion prone area in the catchment area in the year 2005 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.536340	82.213158	Chikhli	Chhattisgarh
20.427837	82.077529	Gariaband	Chhattisgarh
20.311841	81.901211	Bhiterras	Chhattisgarh

20.266133	81.628881	Saranda	Chhattisgarh
20.486728	81.397598	Nawagaon Saradui	Chhattisgarh

5.3.3 Computed pixel wise sediment yield for year 2006

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 540.046 ~ 678.746 MJ mm ha^{-1} hr^{-1}

2) Soil erodibility factor (K): 0.12 ~ 0.37

3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99

4) Cover management factor (C): 0 ~ 1

5) Support practice factor (P): 1

Figure 5.3.3.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 28.1768 per hector per year.

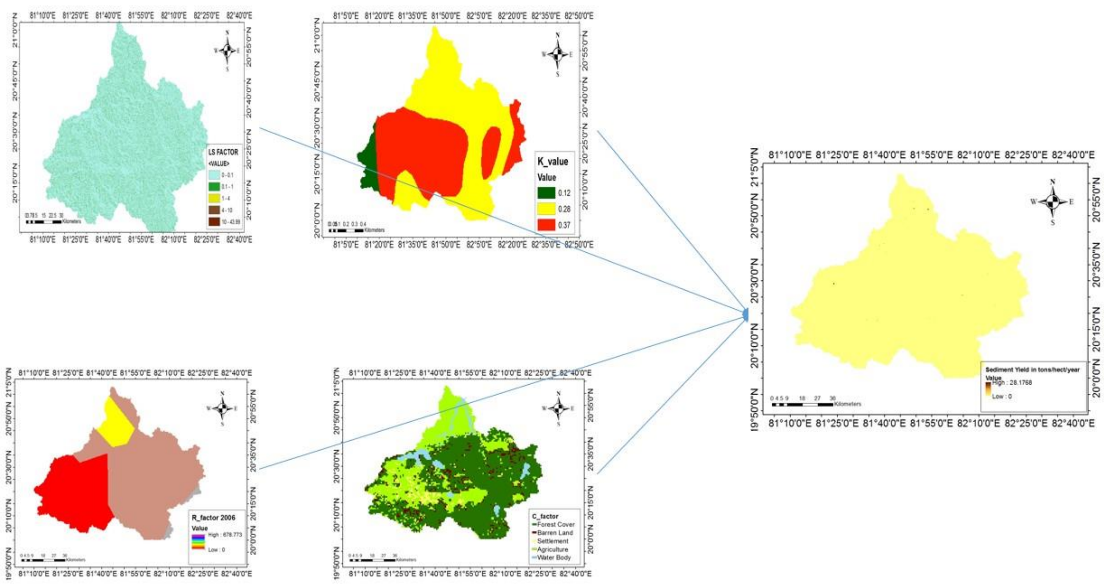


Figure 5.3.3.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2006

5.3.3.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 28.176. After adding all the pixel values the net sediment yield in tons per year is 5650.33 Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wiris is 4556.986 in tons per year. The error obtained is 24.22%.

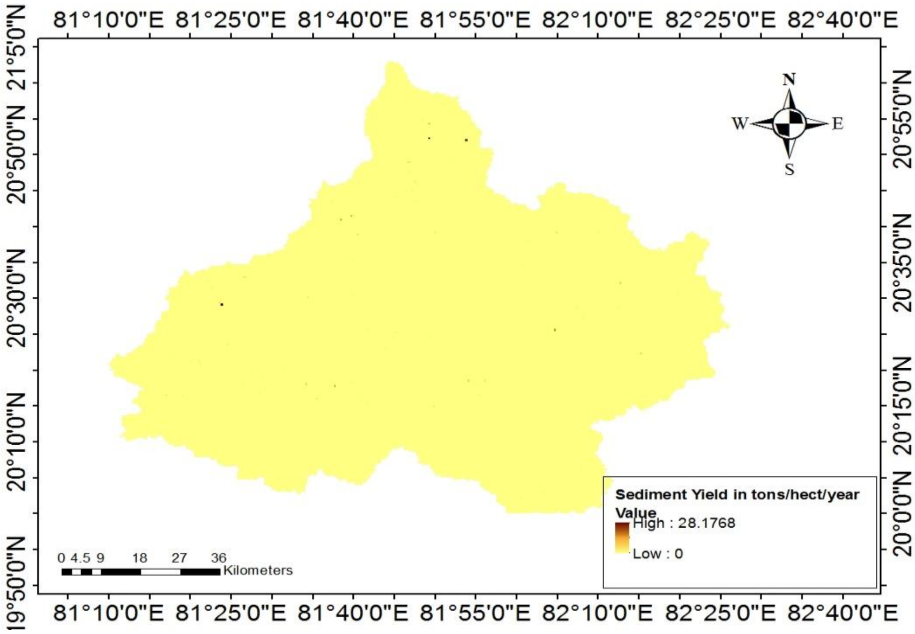


Figure 5.3.3.b sediment yield in tons per hect per year 2006

Table 5.3.3.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.3.a shows the maximum erosion prone area in the catchment area in the year 2006 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.489584	81.393315	Kanker	Chhattisgarh

20.503860	81.574630	Kariyapahad	Chhattisgarh
20.685175	81.641017	Dhamtari	Chhattisgarh
20.426766	82.077172	Gariaband	Chhattisgarh
20.872915	81.820190	Charbhatha	Chhattisgarh

5.3.4 Computed pixel wise sediment yield for year 2007

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 464.236 ~ 626.572 MJ mm ha^{-1} hr^{-1}

2) Soil erodibility factor (K): 0.12 ~ 0.37

3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99

4) Cover management factor (C): 0 ~ 1

5) Support practice factor (P): 1

Figure 5.3.4.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 47.3125 per hector per year.

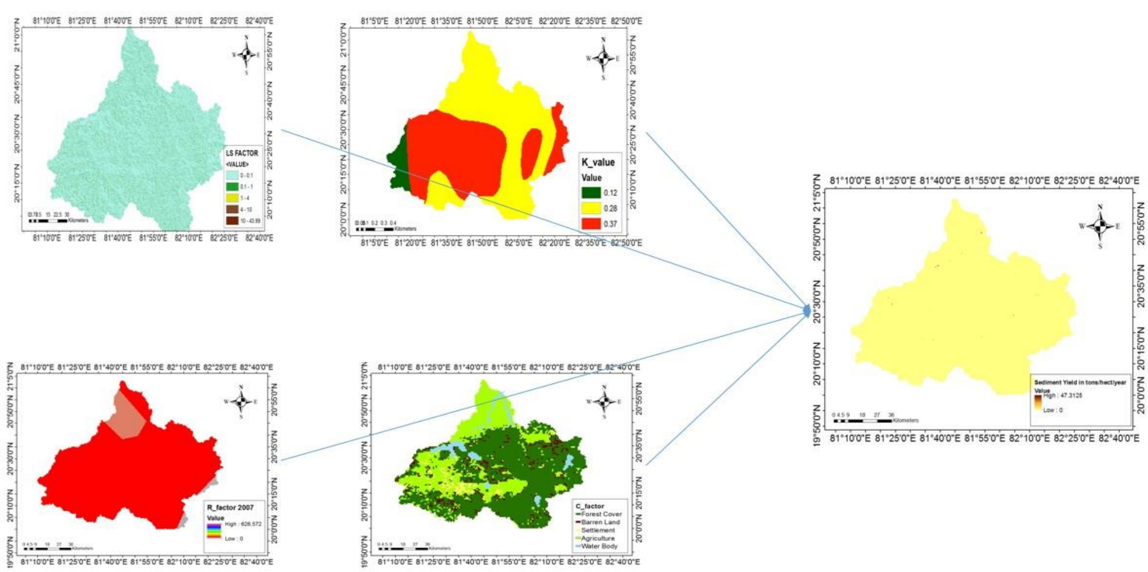


Figure 5.3.4.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2007

5.3.4.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 47.312. After adding all the pixel values the net sediment yield in tons per year is 8969.89. Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wiris is 6983.95 in tons per year. The error obtained is 22.14%.

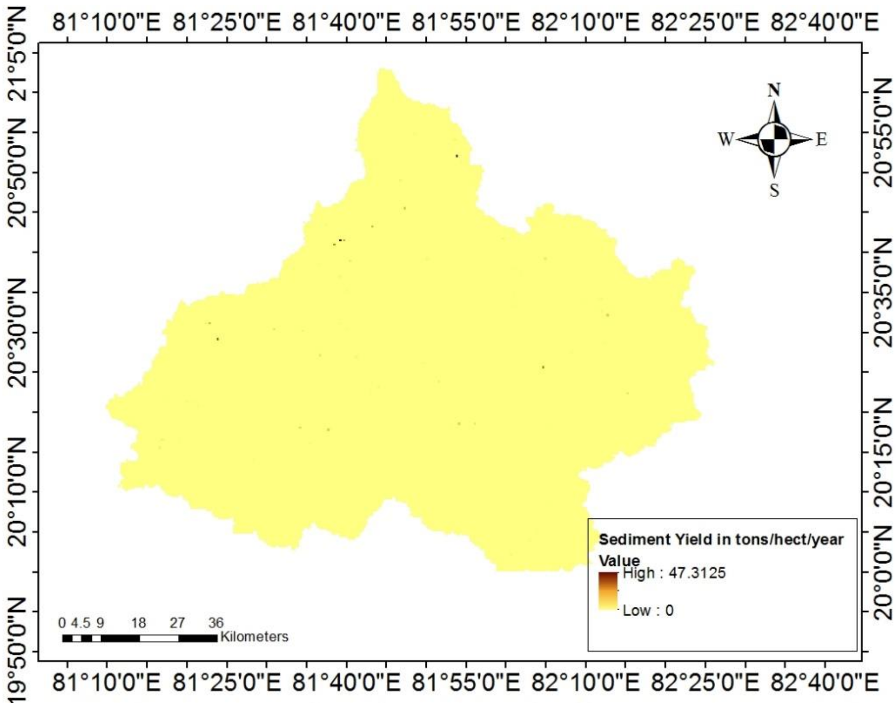


Figure 5.3.4.b sediment yield in tons per hect per year 2007

Table 5.3.4.a is a tabular representation of the coordinates obtained by estimation for highest erosion in the year 2007. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map. Then these coordinates were used in lat long.net website to find out name and district of the area.

Table 5.3.4.a shows the maximum erosion prone area in the catchment area in the year 2007 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.692314	81.653866	Dhamtari	Chhattisgarh
20.720867	81.722394	Donar	Chhattisgarh
20.868632	81.896571	Kuruskera	Chhattisgarh
20.296133	81.628881	Deoribalaji	Chhattisgarh
20.520993	81.379752	Bhelai	Chhattisgarh

5.3.5 Computed pixel wise sediment yield for year 2008

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 329.336 ~ 505.01 MJ mm ha^{-1} hr^{-1}

2) Soil erodibility factor (K): 0.12 ~ 0.37

3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99

4) Cover management factor (C): 0 ~ 1

5) Support practice factor (P): 1

Figure 5.3.5.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 38.133 per hector per year.

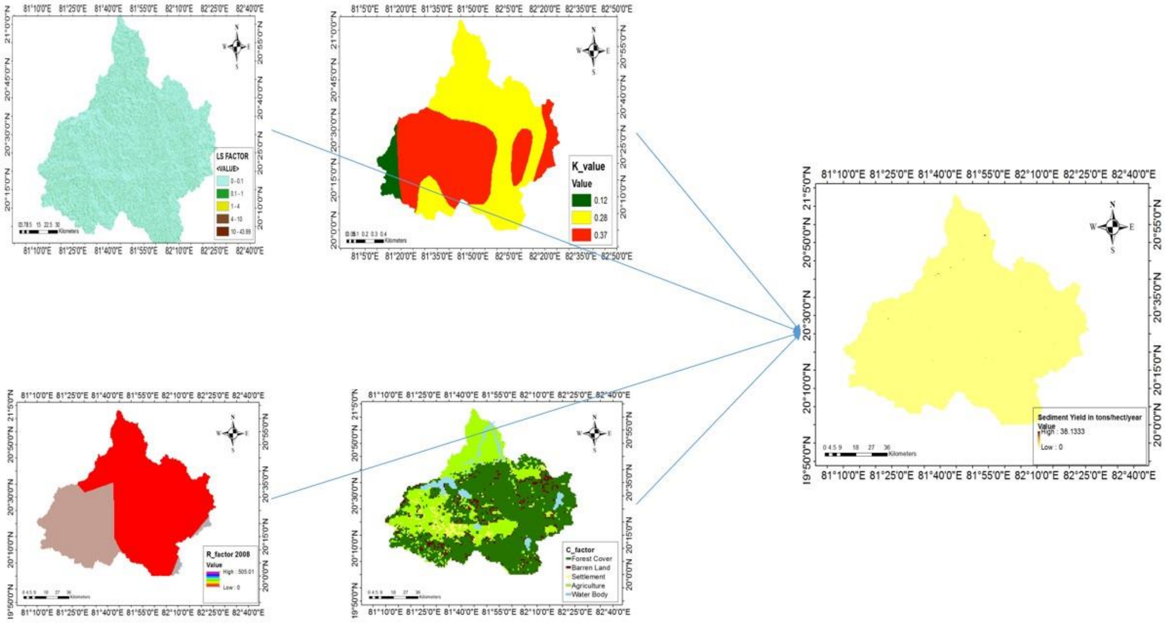


Figure 5.3.5.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2008

5.3.5.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 38.133. After adding all the pixel values the net sediment yield in tons per year is 6495.97. Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wris is

5943.56 in tons per year. The error obtained is 8.5%.

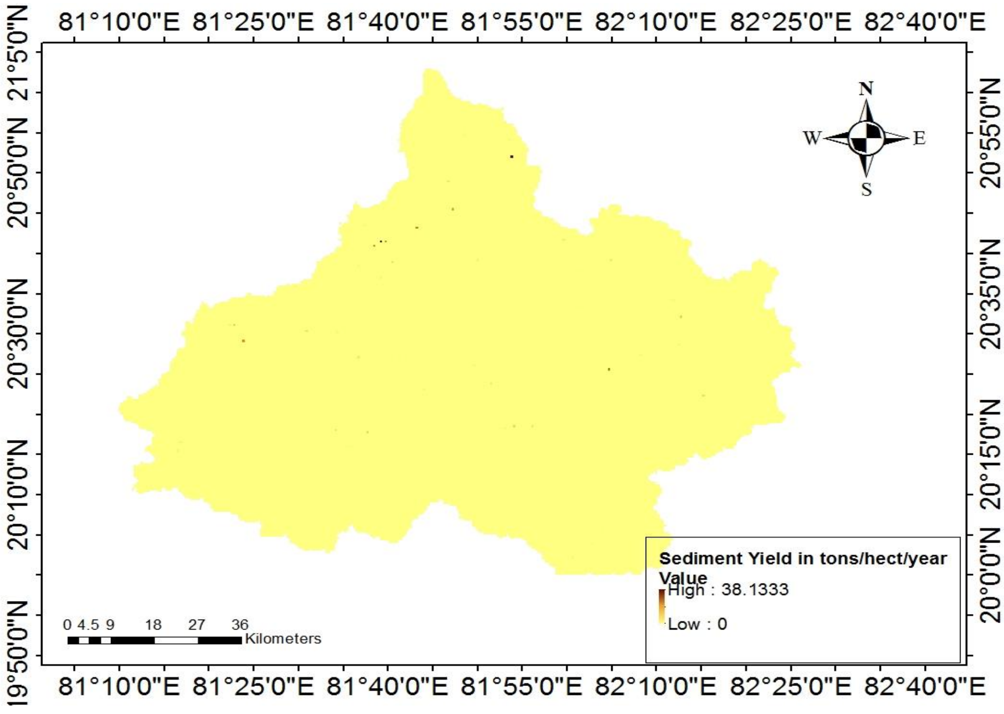


Figure 5.3.5.b sediment yield in tons per hect per year 2008

Table 5.3.5.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.5.a shows the maximum erosion prone area in the catchment area in the year 2008 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.485301	81.397598	Nawagaon Saradui	Chhattisgarh
20.426766	82.077172	Gariaband	Chhattisgarh
20.867918	81.896571	Kuruskera	Chhattisgarh

20.78701	81.787354	Dhamtari	Chhattisgarh
20.691600	81.653866	Dhamtari	Chhattisgarh

5.3.6 Computed pixel wise sediment yield for year 2009

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 411.56 ~ 504.44 MJ mm ha^{-1} hr^{-1}
2) Soil erodibility factor (K): 0.12 ~ 0.37
3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99
4) Cover management factor (C): 0 ~ 1
5) Support practice factor (P): 1

Figure 5.3.6.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 33.36 per hector per year.

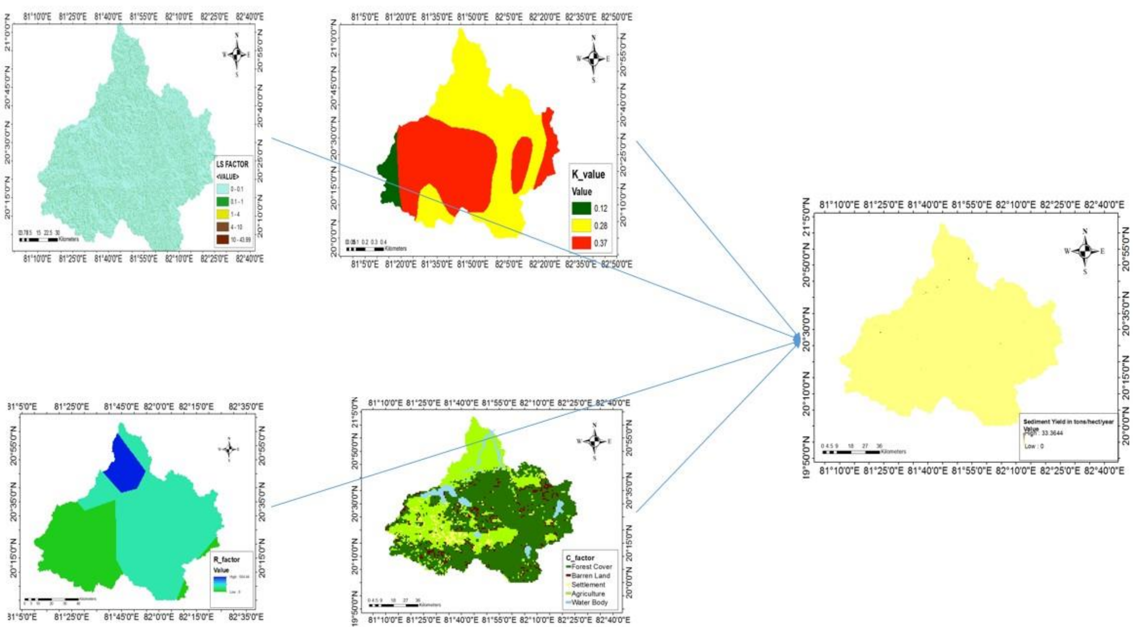


Figure 5.3.6.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2009

5.3.6.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 33.6. After adding all the pixel values the net sediment yield in tons per year is 6362.69. Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wris is 5429.28 in tons per year. The error obtained is 14.67%.

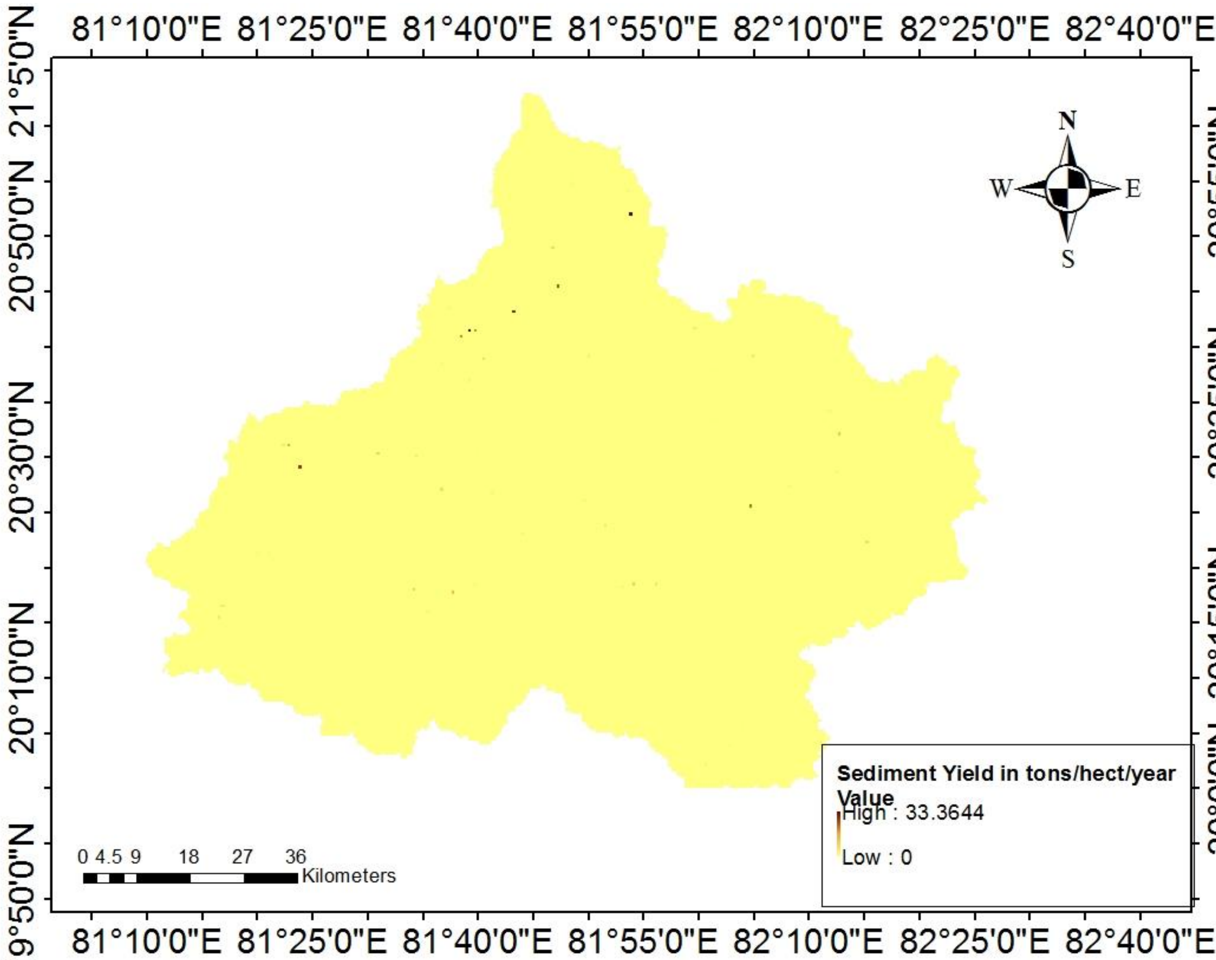


Figure 5.3.5.b sediment yield in tons per hect per year 2009

Table 5.3.6.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.6.a shows the maximum erosion prone area in the catchment area in the year 2009 (source field study)

LATITUDE	LONGITUDE	PLACE OF SEDIMENT EROSION	STATE
20.867918	81.897304	Kuruskera	Chhattisgarh
20.485746	81.397897	Nawagaon Saradui	Chhattisgarh
20.519535	81.380289	Kanker	Chhattisgarh
20.426974	82.078066	Gariaband	Chhattisgarh
20.535834	82.212268	Chikhli	Chhattisgarh

5.3.7 Computed pixel wise sediment yield for year 2010

Following are 5 parameters used for calculating sediment yield.

1) Rainfall runoff erosivity factor (R): 502.95 ~ 644.204 MJ mm ha^{-1} hr^{-1}
2) Soil erodibility factor (K): 0.12 ~ 0.37
3) Slope length factor & slope steepness factor (LS): 0 ~ 43.99
4) Cover management factor (C): 0 ~ 1
5) Support practice factor (P): 1

Figure 5.3.7.a shows multiplication of all four parameters of USLE. The images are multiplied pixel by pixel in raster calculator in arc map function of spatial analysis tool box. The maximum value obtained is 37.97 per hector per year.

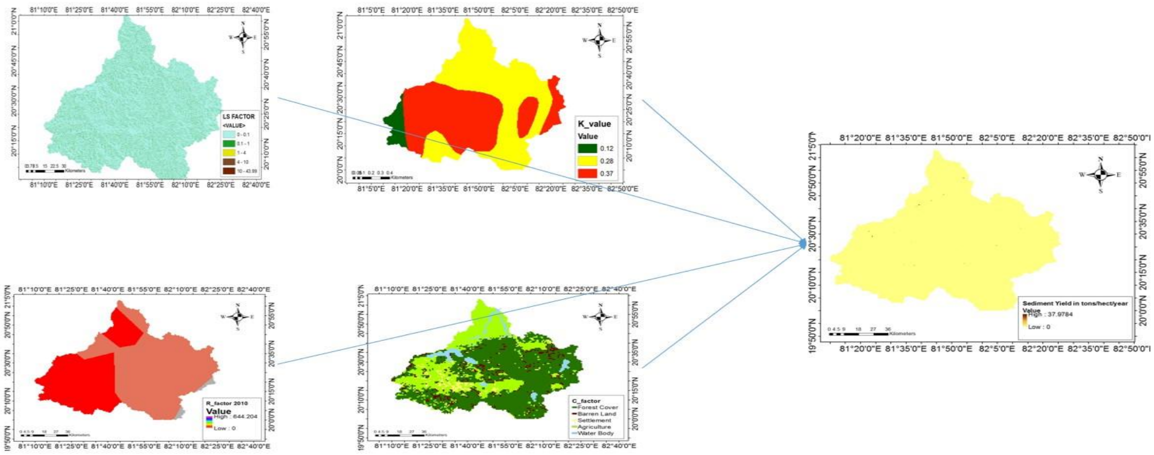


Figure 5.3.7.a Annual Average Soil loss rate map of the upper Mahanadi catchment in year 2010

5.3.7.b The below figure is product of all four parameters on pixel basis . The highest value of theoretical sediment yield in tons per hector per year is 37.97. After adding all the pixel values the net sediment yield in tons per year is 7218.09. Observed sediment yield at the gauging station computed from daily data of discharge and suspended sediment obtained from India Wris is 6071.26 in tons per year. The error obtained is 18.88%.

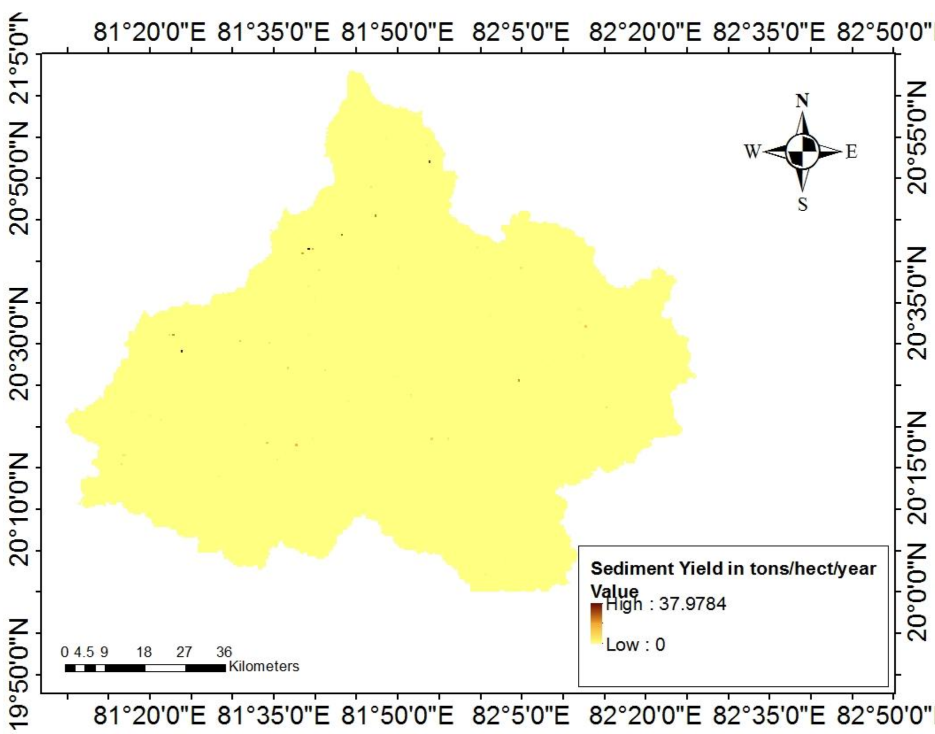


Figure 5.3.7.b sediment yield in tons per hect per year 2010

Table 5.3.6.a the coordinates obtained for highest soil erosion for a particular area is shown in table below. These coordinates are obtained by using identification tools of ARC GIS on the annual average soil loss rate map.

Table 5.3.7.a shows the maximum erosion prone area in the catchment area in the year 2010 (source field study)

LATITUDE	**LONGITUDE**	**PLACE OF SEDIMENT EROSION**	**STATE**
20.683717	81.640483	Dhamtari	Chhattisgarh
20.691332	81.655712	Rudari	Chhattisgarh
20.758432	81.789437	Kareli Chhoti	Chhattisgarh
20.868364	81.896037	Kuruskera	Chhattisgarh
20.426974	82.078066	Gariabanda	Chhattisgarh

5.4 Tabular representation of observed, computed sediment yield and sediment delivery ratio.

This table 5.4 represents gauging station wise observed and computed sediment yield. The sediment delivery ratio for the catchment area is also shown in the table. The sediment delivery ratio is the gross sediment yield at the outlet point of the gauging station. It is obtained by dividing the observed sediment by area of the basin.

Table: 5.4 Comparison between observed and computed values of sediment yield (source field study)

Year	Gauging station	Sediment delivery ratio	Observed sediment yield in tons/year	Computed sediment yield in tons/year	Percentage of error
2004	Raijm	0.35	3106.11	4297.36	22.4
2005	Raijm	0.448	3926.56	5065.26	29.7
2006	Raijm	0.52	4556.96	5650.63	24.22
2007	Raijm	0.43	6983.956	8969.89	22.14
2008	Raijm	0.304	5943.56	6495.97	8.5
2009	Raijm	0.44	5429.28	6362.69	14.67
2010	Raijm	0.69	6071.266	7218.09	18.88

CHAPTER 06

SUMMARY AND CONCLUSIONS

6.1 Summary and Conclusions

The fluvial system consisting of upland erosion zone, transportation zone and downstream sediment zone is an open system that is susceptible to modification by climate change and human activities. Changes of erosion pattern of upstream of Mahanadi river basin affect the sedimentation rate of downstream river basin. If a relationship between factors affecting the soil erosion can be established, then future scenarios can be predicted in response to global climate change and urban expansion. The present study has been formulated to understand these factors affecting the sedimentation of Mahanadi river basin. The discharge and suspended data collected from India Wris have been analyzed to study sediment carrying capacity of Mahanadi River Basin on annual basis.

6.2 Specific conclusions related to Upper Mahanadi catchment are

1. The annual average soil loss rate of the Upper Mahanadi catchment were estimated to be 8969.89 tons/hect/year of 2006 to 2010

2. In case of the spatial distribution of erosion rates at the Upper Mahanadi Catchment, the relationship between probability and annual average soil loss rates is analyzed. The analysis indicated that up to seventy percent of the mean annual soil loss rates are in the range of tolerable soil loss rate (0 – 5 tons/acre/year). Moreover, south western part of the basin is prone to extensive erosion than the eastern part.

3. Sediment yield of all seven years are compared and maximum erosion obtained is below 30%. Erosion prone areas are located in the catchment.

4. Type of soil found out is laterite soil, kankar and red yellow soil. Slope stiffness factor obtained is less than 40. Results obtained from the present study work are very good. Therefore, more study should be done to find out actual location of erosion prone areas and to follow different types of cultivation or forestation in order to prevent soil erosion

FUTURE SCOPE OF STUDY

• This study helps to calculate the change of cross section of the river basin due to sediment deposited.

• This study will help us to use better sediment prediction models like MUSLE and RUSLE to calculate more precise sediment yield.

• This study helps to predict suspended load concentration at the gauging site.

• This study helps to perform various hydrological operations like flood routing, determination of capacity and water spread corresponding to each elevation.

• This study helps in identifying the erosion prone areas of the river basin.

• This helps for taking measures for conservation of soil that can be implemented on those areas for checking of siltation of soil.

CHAPTER 8
REFERENCE

- Narayan, D. and Babu, R. (1983) **'estimation of soil erosion in India'** American society of civil engineering 0733-9437.
- Subramanian, V. (1996) **'The sediment load of Indian rivers, erosion and sediment yield',** Global and regional perspective IAHS publication number 236.
- Wayne, D.E. and Saynor, M.J. (1996) **'success of soil conservation work in reducing soil erosion rate and sediment yield in central eastern Australia',** global and regional perspectives IAHS publication number 236
- Kothyari, U, (1996) **'Erosion and sedimentation',** Erosion and Sedimentation, Global and Regional perspective IAHS publication number 236.
- Jinze, M. (1996) **' Recent studies of the role of soil conservation in reducing erosion and sediment yield in the loess plateau of yellow river basin',** Erosion and sediment yield IAHS publication number 236.
- Adinarayan, J. (1996) **'Prioritization of basins on a silt index –an integrated graph approach',** Eosion and sediment yield IAHS publication number 236.
- Kothyar, U.C and Jain, S.K. (1997) **'sediment yield estimation using GIS',** Hydrological since journal 42(6).
- Jain, S.K., Kumar, S. and Varghese, J. (2001) **'Estimation of soil erosion of Himalayan watershed using GIS technique',** water resource management vol-15.
- Singh, V.P. and Woolhiser, (2002) D.A**. 'Mathematical modelling of watershed hydrology',** American Society of Civil Engineering 10.1061.
- Erskine, D.W. , Mahamudzdeh, A. and Myers, C. (2002) '**land use effects of sediment yield and soil erosion rates in small basin of Trassic sandstone near Sydney , Australia',** Elsevier catena 49
- Ahmad, I. and Verma, M.K. (2003**) 'Application of USLE model And GIS in estimation of soil erosion of tandula reservoir',** International Journal of emerging Technology and advance engineering volume-3, issue 4.
- Bhattari, R. and Dutta, D. (2006) **' Estimation of soil erosion and sediment yield using GIS at catchment scale' ,** By springer since
- Raghuswanshi, N.S., Singh.R and Reddy L.S. (2006) **'Run off and sediment yield modelling using artificial neural network upper sewane river india',** American society of civil engineering 1084-1699.
- Pandey, A., Chowdary, V.M, and Mal, B.C, (2006**) 'Identification of Critical erosion prone areas in small agricultural watershed using USLE and remote sensing',** Springer since and business media.

- Jackson, W.L. and Gebharlt, K. (2007) **'Use of modified Universal Soil Loss Equation for average small sediment yield estimate of small range land drainage basin',** Hydrologist USDI Bureau Of land Management.
- Kate, C. and Sumi, T. (2008) **'Sedimentation yield and transportation analysis case study of managawa river basin',** Annual Hydraulic Engineering, JSCE volume.52.
- Dubral, P.P., Baithuri, N. and Pandey, A. (2008) **'soil erosion assessment in hilly catchment of eastern India using USLE and remote sensing',** Water Resource Manage , springer since -008-92539.
- Carolina B.F., Joris, D.V. and Castillo, V. (2008) **'The impact of land use change and check dams on catchment sediment yield',** hydrologic process wiley inter since.
- Jain, M.K. and Das, D. (2009) **'Estimation of sediment yield areas of soil erosion and deposition of watershed prioritization using GIS and remote sensing',** Water resource Mange Springer Since.
- Arekhi, S. and Shabani, A. (2010) **'Applcation of modified universal soil loss equation in prediction of sediment yield case study: kengir watershed Iran',** Saudi Society of Geo since.
- Arekhi, S. and Rostamizad, G. (2011) **'Sediment yield estimating from three micro-watersheds by integrated KWGIUH and MUSLE models',** Elixir Agriculture (36) 3190-3199.
- Cornia, A. and Viorel, A. (2011) **'The quantitate estimation of the soil erosion using USLE type Romsen model',** Carpathian journal of earth and environmental since, vol-6, page 59-66.
- Parveen, R. and Kumar, U. (2012) **' Integrated approach of universal soil loss equation and geographic information system for soil loss risk assessment in upper south koel basin',** journal by geographic information system, published by scientific research vol-4 .