

Remote Sensing and GIS Approach for Estimation of Soil Erosion of Shakker River Watershed

THESIS

Submitted to the



Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

**In partial fulfillment of the requirements for
the degree of**

MASTER OF TECHNOLOGY

In

**AGRICULTURAL ENGINEERING
(SOIL AND WATER ENGINEERING)**

By

PATIL RUPESH JAYARAM

**Department of Soil and Water Engineering
Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur
College of Agricultural Engineering
Jabalpur (M.P.)**

2013

CERTIFICATE – I

*This is to certify that the thesis entitled “Remote Sensing and GIS Approach for Estimation of Soil Erosion of Shakker River Watershed” submitted in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY** in **AGRICULTURAL ENGINEERING (Soil and Water Engineering)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by Mr. **Patil Rupesh Jayaram** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.*

No part of the thesis has been submitted for any other Degree or Diploma (Certificate Awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigation have been duly acknowledged by him.

Dr. S. K. Sharma

Chairman of the Advisory Committee

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

Chairman (Dr. S. K. Sharma) -----

Member (Dr. M. K. Awasthi) -----

Member (Dr. K. S. Kushwaha) -----

CERTIFICATE-II

*This is to certify that the thesis entitled “Remote Sensing and GIS Approach for Estimation of Soil Erosion of Shakker River Watershed” submitted by **Mr. Patil Rupesh Jayaram** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfillment of the requirements for the degree of Master of Technology in **Agricultural Engineering** in the Department of **Soil and Water Engineering** has been, after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination on the same.*

Place : Jabalpur

Date : / /2013

(Dr. S. K. Sharma)

Chairman of the Advisory Committee

MEMBERS OF THE ADVISORY COMMITTEE

Chairman (Dr. S. K. Sharma) -----

Member (Dr. M. K. Awasthi) -----

Member (Dr. K. S. Kushwaha) -----

Head of the Department (Dr. Deva Kant) -----

Director of Instruction (Dr. P. K. Mishra) -----

ACKNOWLEDGEMENT

I would like to acknowledge my profound and heartfelt gratitude and sincere thanks to my research guide Dr. S. K. Sharma, Assistant Professor, Department of Soil and Water Engineering, College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur for his invaluable advice, continued guidance, constructive encouragement and sound support throughout the period of this research project work.

I am grateful to Dr. V. S. Tomar, Hon'ble Vice-Chancellor, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur for providing me an opportunity to work on this research topic and complete degree successfully.

I want to present my sincere thanks to Dr. P. K. Mishra, Director of Instruction, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur for providing me an opportunity to work on this challenging topic of research project.

I am grateful to Dr. T. K. Bhattacharya, Dean, College of Agricultural Engineering, Jabalpur for providing me an opportunity to work on this research topic and words of inspiration when needed most.

I am thankful to Dr. Dev Kant, Professor and Head, Department of soil and Water Engineering, College of Agricultural Engineering, Jabalpur for his encouragement during the research work.

I wish to thank Dr. M. K. Awasthi, Associate professor and Dr. R. K. Nema, Professor, Department of Soil and Water Engineering, College of Agricultural Engineering, Jabalpur for their expert opinions and valuable suggestions during the research work.

I wish to thank Dr. K. S. Kushwaha, Professor, Department of Mathematics and Statistics, College of Agricultural Engineering, Jabalpur for his valuable suggestions during the research work.

I am also thankful to Er. Subhash Thakur, Er. Renu Upadhyay and Er. Seema Suraiya, College of Agricultural Engineering, Jabalpur for their kind

cooperation during the period of this research work. I am also thankful to Shri. Shiv Murat for his sincere help during the research period.

I would like to extend special thanks to my friends Er. Ashish Pitre, Er. Kumar Soni, Er. Rajiv Ranjan, Er. Swapnil Ganvir, Er. Deepak Chouhan and Er. Ajeet Kumar for their kind cooperation during this research project.

I would like to thank my parents Shri. Jayaram Patil and Smt. Jayashree, my brother Rohit and other family members without whose worthy encouragement and moral support I could not have achieved this stage.

I owe much to all who have directly and indirectly contributed to the success of this research project work.

Place : Jabalpur

Date : / /2013

Patil Rupesh Jayaram

List of Contents

Chapter No.	Title	Page
1.	Introduction	1
1.1	Soil Erosion threat to Environment and Agriculture	2
1.2	Need to Assess Soil Erosion Risk	3
1.3	Soil erosion modeling	4
1.4	Remote Sensing and GIS in Soil Erosion Assessment	5
1.5	Objectives of study	7
2.	Review of literature	8
2.1	Estimation of soil erosion using RS and GIS approach	8
2.2	Estimation of rainfall erosivity factor (R)	16
2.3	Estimation of soil erodibility factor (K)	19
2.4	Estimation of topographic factor (LS)	22
2.5	Estimation of crop/cover management factor (C)	27
2.6	Estimation of conservation/support practice factor (P)	30
3.	Material and Methods	34
3.1	Study area and data availability	34
3.1.1	About study area	34
3.1.2	Data availability	36
3.1.2.1	Rainfall data	36
3.1.2.2	Digital elevation model (DEM)	37
3.1.2.3	Soil	37
3.1.2.4	Satellite data	37
3.1.2.5	Observed sediment data	39
3.1.3	Software used for preparation of thematic maps	40
3.2	Introduction to Geographic Information Systems (GIS)	40
3.3	Methods of analysis	42
3.3.1	USLE based spatially distributed soil erosion estimation	42
3.3.2	The USLE	42
3.4	Development of model database for USLE	43
3.4.1	Rainfall erosivity factor (R)	43

3.4.2	Soil erodibility factor (K)	46
3.4.3	Topographic factor (LS)	47
3.4.3.1.	Slope length factor (L)	48
3.4.3.2	Slope gradient factor (S)	49
3.4.3.3	Description of C++ program's operation	50
3.4.4	Crop/cover management factor (C)	53
3.4.5	Conservation/Support practice factor (P)	56
3.5	Assessment of annual rate of soil erosion	57
3.6	Comparison of simulated and observed sediment loss	58
4.	Results and Discussions	60
4.1	Preparation of base map of the study area	60
4.2	USLE based spatially distributed soil erosion estimation	61
4.3	Development of data base for USLE	62
4.3.1	Rainfall erosivity factor (R)	62
4.3.2	Soil erodibility factor (K)	65
4.3.3	Topographic factor (LS)	67
4.3.4	Crop/cover management factor (C)	70
4.3.4.1	Land use/land cover classification of the study area	71
4.3.5	Conservation/support practice factor (P)	74
4.4	Assessment of annual rate of soil erosion	76
4.5	Comparison of simulated and observed sediment loss	84
5.	Summary, Conclusions and Suggestions for Further Work	88
5.1	Summary	88
5.2	Conclusions	89
5.3	Suggestions for further work	91
	References	92

List of Tables

Table No.	Title	Page
3.1	Showing annual rainfall (mm) at respective rain gauge stations	36
3.2	Showing details of satellite data	38
3.3	Showing annual sediment load and annual rate of sediment loss	39
3.4	Software used and their distinctive features	40
4.1	Showing the annual rainfall and annual rainfall erosivity factor (R)	62
4.2	Area of each soil class, percent of watershed area and K factor	66
4.3	Land use/land cover statistic of the study area	73
4.4	Crop/cover management factor for different land use/land cover classes	73
4.5	Comparison of observed and simulated sediment yields	84
4.6	Showing the priority scales for soil erosion	86

List of Figures

Figure No.	Title	Page
3.1	Location map of study area	35
3.2	False colour composite (FCC) of study area	38
3.3	Example of GIS data layers organized into separate themes	41
3.4	Field Estimation of the Slope Length on a side profile of a hill	48
3.5	Slope (degrees) illustrated with fundamental relationship of right triangle	49
3.6	Illustration of the LS factor algorithm (Van Remortel <i>et al.</i> , 2004)	52
3.7	Relation between NDVI and USLE C-factor	56
3.8	Illustration of the USLE layers and how they overlap	58
3.9	Flow chart for estimation of annual rate of soil loss using USLE with GIS	59
4.1	Drainage map of the study area	61
4.2	Thiessen polygon of the study area	64
4.3	Rainfall erosivity factor (R) map of year 1992	65
4.4	Soil erodibility factor (K) map of Shakker river watershed	67
4.5	Digital elevation model (DEM) of study area	68
4.6	Slope map of Shakker river watershed	69
4.7	Topographic factor (LS) map of study area	70
4.8	Land use/land cover map of the study area	72
4.9	Crop/cover management factor (C) map of study area	74
4.10	Conservation/support practice factor (P) map of study area.	75
4.11	Soil erosion map for year 1992	76
4.12	Soil erosion map for year 1993	77
4.13	Soil erosion map for year 1994	77
4.14	Soil erosion map for year 1995	78
4.15	Soil erosion map for year 1996	78
4.16	Soil erosion map for year 1997	79
4.17	Soil erosion map for year 1998	79
4.18	Soil erosion map for year 1999	80
4.19	Soil erosion map for year 2000	80

4.20	Soil erosion map for year 2001	81
4.21	Soil erosion map for year 2002	81
4.22	Soil erosion map for year 2003	82
4.23	Soil erosion map for year 2004	82
4.24	Soil erosion map for year 2005	83
4.25	Soil erosion map for year 2006	83
4.26	Comparison between observed and simulated sediment loss	85
4.27	Spatial distribution of sediment loss in Shakker river watershed	87

List of Abbreviations

Abbreviation/ Symbol	Stand for
A	Average annual rate of soil loss
C	Crop/cover management factor
CAE	College of Agricultural Engineering
cm	centimeter
CWC	Central Water Commission
DEM	Digital Elevation Model
E	East
EI ₃₀	Rainfall erosion index unit
eq	equation
ERDAS	Earth Resources Data Analysis Systems
et al.	and others
etc.	Etcetera (and so on)
FAO	Food and Agricultural Organization
FCC	False Color Composite
Fig.	Figure
ft	Foot
GIS	Geographic Information Systems
GLCF	Global Land Cover Facility
h	Hour
ha	hectare
I	Rainfall intensity
i.e.	id est (that is)
IRS	Indian Remote sensing Satellite
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya
K	Soil erodibility factor
KE	Kinetic energy
km	Kilometer
L	Slope length factor

LISS	Linear Imaging Self Scanner
m	meter
Mha	Million hectares
MJ	Mega Jules
mm	millimeter
MP	Madhya Pradesh
MPWSRP	Madhya Pradesh Water Sector Restructuring Project
MSL	Mean Sea Level
N	North
NBSSLUP	National Bureau of Soil Survey & Land Use Planning
NDVI	Normalized Difference Vegetation Index
NRSA	National Remote Sensing Agency
P	Conservation/support practice factor
pixel	Picture element
R	Rainfall erosivity factor
R ²	Coefficient of determination
RS	Remote Sensing
S	Slope gradient factor
SRTM	Shuttle Radar Topographic Mission
t	tones
TIFF	Tagged Information File Format
TIN	Triangular Irregular Network
USLE	Universal Soil Loss Equation
VI	Vegetation Index
yr	Year
°	degree
'	minute
%	percentage

INTRODUCTION

Soil erosion by water occurs throughout the world. It is the process of detachment or entrainment, transportation of surface soil particles from original location and accumulation of it to a new depositional area. Various human activities disturb the land surface of the earth and thereby induce the significant alteration of natural erosion rates. Soil erosion by running water has been recognized as the most severe hazard threatening about the protection of soil as it reduces soil productivity by removing the most fertile topsoil (FAO/UNEP, 1994). In the world map on the status of human-induced soil degradation, it is accounted that loss of topsoil and terrain deformation due to soil erosion are the consequence of deforestation, removal of natural vegetation and overgrazing in the mountainous regions (Shrestha, 1997).

In India out of 329 Mha of country's total geographical area 69 Mha of land is critically degraded and 106 Mha are severely eroded at an average rate of 16.4 tones per hectare per annum of soil detachment (Singh, 2000). In spite of this India shares only 2% of world's geographical area but supports around 17.5% of world's population. Thus soil erosion in India is one of the prime concerns of nation as agriculture is being adversely affected to great extent (Census, 2012). Thus India's land resources are under immense pressure as reflected looking to the above fact. Declining land availability for agriculture, which is expected to be only 0.15 ha per capita by 2035 AD, shows the severity of the problem (Singh, 2000).

Soil is considered as a non-renewable resource and sediment is largely responsible for compromising the amount and quality of the water and silting the water bodies (Desilva *et al.*, 2010). Apart from the serious loss of production due to soil erosion and land degradation on account of human activities and interferences, the other immediate reaction of this problem is seen through excessive and premature siltation of multipurpose reservoirs. Nearly 10 per cent of the soil detached annually is being deposited in surface reservoirs resulting in a loss of about 2 per cent of storage capacity annually. These reservoirs have been constructed in India for various purposes, such as hydro-electric power generation, irrigation, domestic water supply, soil

erosion control and flood mitigation involving high expenditure. Most of them have been designed to last at least 100 years but the excessive siltation due to accelerated erosion has considerably decreased the useful life of these structures. About 6000 MT of soil is eroded every year in India from about 80 Mha of culturable land losing 8.4 metric tones of nutrients. The nutrient losses in this way are much greater than the quantity that is presently used in the country (Singh, 2000). Out of 16 rivers of the world which experience severe erosion and carry heavy sediment load, three rivers namely Ganga, Brahmaputra and Kosi occupy 2nd, 3rd and 4th position respectively. Also a rise in amount spent on drought and flood relief programmes annually is an indication of the land degradation in the country (Mishra *et al.*, 2003).

1.1 Soil erosion threat to environment and agriculture

Soil erosion is a global environmental crisis today that threatens natural environment and also the agriculture. Accelerated soil erosion has adverse economic and environmental impacts (Lal, 1998). It creates on-site and off-site effects on productivity due to decline in land/soil quality (Lal, 2001). The current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreparable loss in productivity on about 6 million hectare of fertile land a year (Dudal, 1981). Asia has the highest soil erosion rate of 74 tones/acre/year and Asian rivers contribute about 80 % of the total sediments delivered to the world's oceans (EI-Swaify, 1997).

Soil resource is important for Livelihood of the human being. Sustainable use of land depends upon conservation and potential use of soil and water resources. It is severely affecting global food security due to ever-growing population and its dependency for livelihood on limited natural resources. Landslide, mudslides, collapse of man-made terraces, soil loss from steep slopes and decline of forest / pasture areas are the main reasons for land resource degradation. It has been observed that loss of fertile top soil because of surface and gully erosion is a common phenomenon and agricultural land has expanded to areas having marginal soil cover. Thus natural resources in mountainous terrain are profoundly afflicting from land degradation as a result of intensive deforestation, overgrazing and subsistence agriculture due to population pressure, large-scale road

construction and mining etc. along with anthropogenic activities. As a consequence of deforestation coupled with the influence of the high rainfall, the fragile terrains with steep slope have become prone to severe soil erosion (El-Swaify, 1997).

1.2 Need to assess soil erosion risk

The soil erosion risk assessment can be helpful for land evaluation in the region where soil erosion is the main threat for sustained agriculture, as soil is the basis of agricultural production. Soil erosion assessment and mapping of erosion prone area serve the knowledge for soil conservation and watershed management. Current huge investment in civil engineering works aiming to renovate the results of erosion is comparatively higher than investments in soil conservation effort. Therefore the need is not merely quantifying the erosion rate but such results of erosion assessment can be core of any decision making and supportive in policy formulation for sustaining the environment as a whole coupled with the land productivity. Consequently monitoring is essential in order to check the deterioration of the natural resources particularly those affecting agricultural practices. Hence, it is essential to assess soil erosion risk for soil conservation program. Further prediction of soil erosion rate is needed to evaluate soil losses. Various methodologies to assess soil erosion rate are available. Conventional techniques of field study for measurement of soil erosion and runoff are expensive and time consuming. Moreover, it is having limitations because of complexity of interactions and difficulty of generalizing from the results. The accuracy is likely to be poor and it is not known where the soil came from and when (Hudson, 1995). In the suspended sediment measurements, the discharge and sediment yield passing a point at the outlet of a catchment is monitored for quantitative indication of the amounts of soil lost from whole selected watersheds. But the origins and extent of the sediment load from the catchment itself remain unknown. Similarly, the eroded soil deposited at other locations without reaching the gauging station cannot be computed. Use of these experimental outputs for quantification of soil loss from wider area with a diversity of situational variation is still debatable. Land surveying using reconnaissance methods for soil loss

estimation considers the approximation of the amount of erosion by measuring change of surface level. But it has limitation for arable land because the surface level is affected by cultivation and settlement.

The hydrological studies including frequency analysis are very important in practice. The geomorphological parameters directly or indirectly reflect almost the entire watershed based causative factors affecting the rate of runoff and sediment loss. The surface features are the fundamental units of analysis prior to adopting any sophisticated tools to monitor watershed responses in connection to any of the hydrologic processes acting on it. The need for accurate information on runoff and sediment yield has grown rapidly during the past two decades along with the acceleration in watershed management programmes for conservation, development and beneficial use of these resources (Hakkim & Chandrakaran, 2005).

1.3 Soil erosion modeling

Erosion models are used to predict soil erosion. Soil erosion modeling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Various parametric models such as empirical (statistical/metric), conceptual (semi-empirical) and physical process based (deterministic) models are available to compute soil loss. In general, these models are categorized depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model. Empirical models are generally the simplest of all three model types. They are statistical in nature and based primarily on the analysis of observations and seek to characterize response from these data. The data requirements for such models are usually less as compared to conceptual and physical based models. Conceptual models play an intermediary role between empirical and physical process based models. Physical process based models take into account the combination of the individual components that affect erosion, including the complex interactions between various factors and their spatial and temporal variability. These models are comparatively over-parameterized.

Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. They are designed for specific set of conditions of particular area. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) was designed to predict soil loss from sheet and rill erosion in specific conditions from agricultural fields. Modified universal soil loss equation (MUSLE) (Williams & Berndt, 1972), a modified version of USLE is applicable to other conditions by introducing hydrological runoff factor for sediment yield estimation. Water erosion prediction project (WEPP) (Nearing and Lane, 1989) is process based continuous simulation model developed to replace USLE (Okoth, 2003). Areal non-point source watershed environment response simulation (ANSWERS) (Beasley *et al.*, 1980) was designed to compute soil erosion within a watershed. The European Soil Erosion Model (EUROSEM) is a single process based model for assessing and risk prediction of soil erosion from fields and small catchments. Morgan, Morgan and Finney (MMF) model is an empirical model developed for mean annual soil loss estimation from field-sized areas on hill slopes (Morgan *et al.*, 1999, 1984) having strong physical base.

1.4 Remote Sensing and GIS in soil erosion assessment

One of the major problems in testing these models is the generation of input data, which is too spatial. The conventional methods proved to be too costly and time consuming for generating this input data. With the advent of remote sensing technology, deriving the spatial information on input parameters has become more handy and cost-effective. Besides with the powerful spatial data processing capabilities of Geographic Information System (GIS) and its compatibility with remote sensing data, the soil erosion modeling approaches have become more comprehensive and robust (Bhaware, 2006). Remote Sensing can facilitate studying the factors enhancing the erosion process such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. Satellite data can be used for studying erosional features such as gullies, rainfall interception by vegetation and vegetation cover factor. DEM (Digital Elevation Model), one

of the vital inputs required for soil erosion modeling can be created by analysis of stereoscopic optical and microwave remote sensing data. Remote sensing provides significant source for real-time and accurate data related to land and soil. It enables homogeneous information over large regions, and can therefore greatly contribute to regional erosion assessment. As an account for seasonal variability, multi-temporal satellite images are useful to extract the valuable information associated to seasonal land use dynamics for mapping land use/land cover. It can be used to generate a cover and management factor (C-factor) (Morgan, 1995; Wischmeier and Smith, 1978) which is one of the input requirements of erosion modeling. The factors associated with soil classification such as soil properties, climate, vegetation, topography and lithology can be potentially mapped with satellite remote sensing to account for spatial differences in erodibility which serve as input data for erosion modeling. Especially optical satellite imagery can be used for soil mapping mainly through visual delineation of soil patterns (Dwivedi *et al.*, 1997). The basic requirement of any hydrologic or geomorphologic studies is a digital elevation model (DEM) and it enables to derive various topographic attributes such as elevation, slope and aspect etc. which are essential to analyze watershed physical characteristics. DEM data can be extracted from the satellite images of terrain such as stereo optical imagery (Kumar, 2003).

Geographic Information System (GIS) has emerged as a powerful tool for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output and for interaction with soil erosion models. There is considerable potential for the use of GIS technology as an aid to the soil erosion inventory with reference to soil erosion modeling and erosion risk assessment. A GIS can be used to scale up to regional levels and to quantify the differences in soil loss estimates produced by different scales of soil mapping used as a data layer in the model. The integrated use of remote sensing and GIS could help to assess quantitative soil loss at various scales and also to identify areas that are at potential risk of soil erosion (Saha *et al.*, 1992). Several studies showed the potential utility of GIS technique for quantitatively assessing soil erosion hazard is based on various soil erosion

models (Saha *et al.*, 1992; Shrestha, 1997). Considering the inaccessibility of the hilly terrain if it is extensive area, RS is essential to accommodate spatial variability and information. Spatial modeling involves the use of GIS for representation of the conceptual model and performance of simple mathematical computations on the stored GIS object attributes for displaying the results spatially (Kumar and Rastogi, 2005).

1.5 Objectives of study

Keeping the above perspectives in view, the objectives of present study are aimed at:

1. To assess annual rate of soil erosion from watershed using distributed information for topography, land use and soil etc. using RS and GIS techniques.
2. To compare the simulated sediment loss with observed sediment loss.

REVIEW OF LITERATURE

Controlling the soil loss from watersheds has been a challenging problem for the watershed managers and soil conservationists. The basic processes and factors that are responsible for inducing land degradation, particularly soil erosion and associated phenomena are critical to the conceptualization, design and implementation of productive, stable and sustainable agricultural systems. This is particularly on steep lands where the potential for soil erosion and runoff water losses is high. The productivity and degradation hazards on these lands are determined by the site's climate, soil and topography. However, their uniqueness lies more with their topographic constraints than with other factors. Use of steep lands is an increasingly common situation in the tropics because of high population pressures and continuing encroachment on hilly lands. Erosion potential and actual erosion in these settings may exceed even hundreds of tons of soil loss per hectare per year. Thus the selection and design of cropping systems, land management systems and water management systems must be tailored to attain effective erosion and runoff control in order to avoid their detrimental impacts both onsite and off-site. This chapter briefly deals with the review of the research work carried out in India and abroad in relation to the objectives under this study. A review of the literature related to this particular study is presented below:

2.1 Estimation of soil erosion using RS and GIS approach

Kothyari and Jain (1997) developed a method for the determination of the sediment yield from a catchment using GIS. The method involves spatial disaggregation of the catchment into cells having uniform soil erosion characteristics. The surface erosion from each of the discretized cells was 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 is 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 were

performed through a GIS technique using the Integrated Land and Water Information System (ILWIS) package.

Jain and Kothyari (2000) proposed a Geographical Information System (GIS) based method and was demonstrated for the identification of sediment source areas and the prediction of storm sediment yield from catchments. Data from the Nagwa and Karso catchments in Bihar (India) was used. The Integrated Land and Water Information System (ILWIS) GIS package was used for carrying out geographic analysis. An Earth Resources Data Analysis System (ERDAS) image processor was used for the digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments. The catchments were discretized into hydrologically homogeneous grid cells to capture the catchment heterogeneity. The cells thus formed were then differentiated into cells of overland flow regions and cells of channel flow regions based on the magnitude of their flow accumulation areas. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USLE) by carefully determining its various parameters. The concept of sediment delivery ratio (SDR) was used for determination of the total sediment yield of each catchment during isolated storm events.

Fernandez *et al.* (2002) stated that because of increasing concerns on water quality and aquatic habitat, the need to quantify and predict sediment yield at a watershed level has become important. Models for sediment yield provide invaluable information when applied to those areas lacking of data, for guiding data collection programs and for predicting future impacts of agricultural activities, land-use, stream stabilization and flood control practices. This study was conducted to develop a methodology using Geographic Information System (GIS) and computer modeling to estimate the spatial distribution of soil erosion and sediment yield in the Lawyers Creek Watershed located in western-central Idaho. Soil loss erosion and the sediment yield for the Lawyers Creek Watershed were estimated based on the Revised Universal Soil Loss Equation (RUSLE) and the Sediment Delivery Distributed (SEDD) Model integrated with GIS.

Sumathi and Bosu (2004) used Geographic Information System for facilitating sediment yield estimation. In this study the Geographic Information System (GIS) combined with the sediment yield model to enhance the evaluation of soil erosion estimation. Geographic Information System with the Modified Universal Soil Loss Equation (MUSLE) was used to estimate sediment yield of Ebbanad watershed of Lower Bhavani Catchment, Nilgiri District, India. Spatial data from different sources provided as input for the factors in the MUSLE and from 20 years (1981–2001) of rainfall records, the storms were identified for determining the sediment yield estimation. The drainage area, drainage network, slope and aspect were extracted from Digital Elevation Model (DEM) prepared from Survey of India toposheet at 1:50000 scale using IDRISI-32 GIS software. A sediment yield map of Ebbanad watershed from GIS predicts the degrees of erosion areas. The sediment yield was observed to be minimum in the range of 0 –2 tones on Reserve forest and Perennial crop areas for all the storm events and on an average between 4 to 20 tones from annual crop areas.

Hoshikawa *et al.* (2005) conducted study on estimation of potential sediment yield by integrating USLE with GIS. This study was attempted to estimate the sediment yield at eight sub-watersheds: Yokokawa, Katagiri, Matsukawa, Shintoyone, Minowa, Miwa, Koshibu and Misakubo watersheds of the Tenryu basin, Japan using USLE model incorporated with GIS techniques and validated the estimated sediment yield with the actual sedimentation measured from their corresponding reservoirs. From the study, it was found that the variation of observed annual sedimentation at reservoirs has showed similar trend with the estimated USLE values within the studied watershed. This outcome suggests the reliability and adaptability of the USLE method that was integrated with GIS in estimating annual potential sediment yield in the large watershed having complex topography and geology.

Lim *et al.* (2005) stated that accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. To effectively estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. The Revised Universal

Soil Loss Equation (RUSLE) has been used in many countries and input parameter data for RUSLE have been well established over the years. However, RUSLE cannot be used to estimate the sediment yield for a watershed. Thus, the GIS-based Sediment Assessment Tool for Effective Erosion Control (SATEEC) was developed to estimate soil loss and sediment yield for any location within a watershed using RUSLE and a spatially distributed sediment delivery ratio. SATEEC was enhanced in this study by developing new modules to: 1) simulate the effects of sediment retention basins on the receiving water bodies, 2) estimate the sediment yield from a single storm event and 3) prepare input parameters for the Web-based sediment decision support system using a GIS interface. The enhanced SATEEC system was applied to the study watershed to demonstrate how the enhanced system can be effectively used for soil erosion control. All the procedures were fully automated with the Avenue and database programming; thus the enhanced SATEEC system does not require experienced GIS.

Kim (2006) used RUSLE and GIS for soil erosion modeling in the Imha watershed, South Korea. The RUSLE model was combined with GIS techniques to analyze the gross soil loss rates caused by typhoon "Maemi" and the annual average soil loss and to evaluate the spatial distribution of soil loss rates under different land uses. The annual average soil loss rate and soil loss rate caused by typhoon "Maemi" were predicted as 3,450 tones/km²/year and 2,920 tones/km²/year "Maemi" respectively. In addition, the cover management factor for forested areas of the Imha watershed is calibrated using a "Trial and Error method" from the relationship between the annual soil losses and various sediment delivery ratio models. The determined C value for the forested area was 0.03 and is 3 times larger than that of the undisturbed forested area. The sediment delivery ratio was determined to be 25.8% from the annual average soil loss rate and the surveyed sediment deposits in the Imha.

Htun *et al.* (2007) carried out spatial pattern analysis of land degradation using satellite remote sensing data and GIS in Mandalay watershed, Central Myanmar. This study explored the influence of major

socioeconomic factors on erosion processes and conservation measures in a Dry Zone Farming context for producing Erosion Risk Map of the study area. It also put forward a way of studying soil Erosion and relations of soil erosion factors by integrating GIS and RS. Firstly, satellite images (ETM) and the real ground conditions were rectified. Secondly, according to the ecological environmental factors, the spatial database and Digital Elevation Model of the study area was built. Finally, referring to Universal Soil Loss Equation, the quantization and distribution of the soil erosion, risks and changes was obtained. The result of this assessment showed spatial distribution of different land degradation severity across the area in watershed basis. Soil erosion susceptibility was estimated through Universal Soil Loss Equation USLE. This study was intended to develop a model based on spatial information and demographic data.

Alejandra (2008) used remote sensing and GIS techniques for estimation of soil erosion from Grande De watershed of Puerto Rico. This work has used the USLE to calculate soil erosion rate. Model inputs such as cover factor and conservation practice factor were successfully derived from remotely sensed data. The LS factor map was generated from slope map. The K factor map was prepared from soil map which was obtained from SURGO data. Maps covering each parameter (R, K, LS, C and P) were integrated to generate a composite map of potential erosion intensity based on advanced GIS functionality.

Avanzi *et al.* (2009) conducted a study on soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. They stated that mapping and assessment of erosion risk is an important tool for planning of natural resources management, allowing researchers to modify land-use properly and implement management strategies more sustainable in the long-term. The objective of this study was to apply the Universal Soil Loss Equation (USLE) with GIS PC Raster in order to estimate potential soil loss from the Grande River Basin, allowing identification of the susceptible areas to water erosion and estimation of sediment delivery ratio for the adoption of land management practices so that further soil loss could be minimized. For the USLE model, the following factors were used: rainfall–runoff erosivity (R),

erodibility (K), topographic (LS), cover-management (C) and support practice (P). The Fournier Index was applied to estimate R for the basin using six pluviometric stations. Maps of the K, LS, C and P factors were derived from the soil map, digital elevation model (DEM) and land-use maps, taking into account information available in the literature. In order to validate the simulation process, Sediment Delivery Ratio (SDR) was estimated which is based on transported sediment (TS) to basin outlet and mean soil loss in the basin (MSL). The SDR calculation included data (total solids in the water and respective discharge) between 1996 and 2003 which were measured at a gauging station located on the Grande River and a daily flow data set was obtained from the Brazilian National Water Agency (ANA). They found that it was possible to validate the erosion process based on the USLE and SDR application for the basin conditions, since absolute errors of estimate were low.

Dengiz *et al.* (2009) employed geographical information system (GIS) and remote sensing (RS) techniques for soil erosion assessment in Ankara-Guvenc basin, Turkey. The objective of this research was to assess vulnerable soil erosion risk with qualitative approach using GIS in Ankara-Guvenc Basin. The selected theme layers of this model include topographic factor, soil factors (depth, texture, impermeable horizon) and land use. Slope layer and land use-land cover data were prepared by using DEM and Landsat-TM satellite image. After combination of the layers, soil erosion risk map was produced. The results showed that 44.4% of the study area was at high soil erosion risk, whereas 42% of the study area was insignificantly and slightly susceptible to erosion risk. In addition, it was found that only 12.6% of the total area was moderately susceptible to erosion risk. Furthermore, conservation land management measures were also suggested for moderate, high and very high erosion risk areas in Ankara-Guvenc Basin.

Esther (2009) used GIS techniques to determine RUSLE's 'R' and 'LS' factors for Kapingazi river catchment in Kenya. The purpose of this study was to use GIS techniques to determine some of the soil erosion factors including rainfall runoff erosivity (R) and slope length/steepness factor (LS). This was done successfully and thematic maps of these parameters were

generated. In order to establish the effects of these factors especially topography, a preliminary assessment of potential soil erosion was carried out. The factors were calculated using the local data that was collected specifically for Kapingazi River Catchment.

Said and Svoray (2009) conducted a multi-criteria analytical study on soil loss, water ponding and sediment deposition variations as a consequence of rainfall intensity and land use. They stated that, prediction of areas prone to land degradation in agricultural catchments is a complex task. This is due to the difficulties encountered in data gathering over wide regions and in the translation of existing scientific knowledge to a quantitative and spatially explicit risk assessment system. This study incorporated the use of remotely sensed data, terrain analysis and a multi-criteria mechanism for evaluating risks of soil loss, water ponding and sediment deposition in a mid-sized agricultural Mediterranean catchment. The research used simulations to study the effect of topographic attributes, soil characteristics, vegetation cover, rainfall intensity and human activities on the three above-mentioned processes. They stated that use of a simple weighted linear combination was more useful than the more sophisticated computerized programming technique. From the phenomenological point of view, the increase in rainfall intensity and land-use transformation from orchard to field-crops has led to a significant increase in soil loss and sediment yield, while extreme changes in tillage direction have only yielded minor changes in water ponding.

Arekhi *et al.* (2011) tested the Kinematic Wave-Geomorphologic Instantaneous Unit Hydrograph-Modified Universal Soil Loss Equation (KW-GIUH-MUSLE) model for its sediment yield estimation potential on the Kengir watershed in Iyvan city of Ilam Province, Iran. The runoff factor was calculated for six storms during year 2000. The spatial distribution of soil erodibility factor was taken from the attribute data pertaining to the soils of the study area. The topographic factor (LS) was calculated by multiplying the length (L) and slope (S) factor from the created maps. On the other hand, cropping management and erosion control practice factors for different land use were taken from the satellite based land use/land cover attribute data and geographic information system (GIS) respectively. Sediment yield at the

outlet of the study watershed was simulated for 6 storm events spread over the year 2000 and validated with the measured values. The percent deviations between the sediment yield measurements and observations vary in the range of - 22.50 to 5.83%. The high coefficient of determination value (0.99) indicates that model sediment yield predictions were satisfactory for practical purposes.

Mahmoodabadi (2011) used a semi-quantitative model and GIS-remote sensing data for sediment yield estimation. This study applied the Modified Pacific Southwest Inter-Agency Committee (MPSIAC) semi-quantitative model along with geographical information system and remote sensing techniques to estimate sediment yield in a semi-arid region in central Iran. Nine data layers of the model were generated from Landsat ETM+ imagery, adapted regional maps and field surveys. The GIS was applied to integrate the layers together and generate the sediment yield map. The results showed a range of sediment yield from 263.3 to 496.9 tones $\text{km}^{-2} \text{year}^{-1}$ with an average of 356.4 tones $\text{km}^{-2} \text{year}^{-1}$. However, it seems that descriptions of the model are sometimes too broad for making reliable scoring. They stated that this model is generally less data demanding and provides an efficient way to estimate sediment yield in un-gauged basins. It was found that hills are the most sensitive land types to sediment yield in the region.

Pal and Samanta (2011) used remote sensing and GIS techniques for estimation of soil erosion from Kaliaghai river basin, West Bengal. RUSLE (Revised Universal Soil Loss Equation) model was used for soil loss estimation. Different parameters, namely the rainfall and runoff factor (R), soil erodibility factor (K), slope length and steepness factor (LS), crop management factor (C) and conservation practice factor (P), that are the mandatory inputs to RUSLE, were obtained from monthly and annual rainfall data, soil map of the region, Digital Elevation Model (DEM), RS techniques (with use of Normalized Difference Vegetation Index) and land use/land cover map respectively.

2.2 Estimation of rainfall erosivity factor (R) for USLE

The factor R is the number of rainfall erosion index units (EI_{30}) in a given period at the study location. The rainfall erosion index unit (EI_{30}) of storm is defined as:

$$EI_{30} = (KE \times I_{30})/100$$

Where,

KE = Kinetic energy of the storm. The KE in metric tones/ha-cm is expressed as

$$KE = 210.3 + 89 \log I$$

Where,

I = rainfall intensity in cm/h and

I_{30} = maximum 30 minutes rainfall intensity of the storm.

The study period can be a week, month, season or year. The storm EI_{30} values for that length of period is summed up.

Annual EI_{30} values are usually computed from data available at various meteorological stations and equal EI_{30} lines (also known as Iso-erodent lines) are drawn for the region covered by the data stations for ready use in USLE (Subramanya, 2008).

Rompaey *et al.* (2005) conducted a study on modeling sediment yields in Italian catchments. Sediment yield observations derived from 40 long term sedimentation records in Italian reservoirs, were used to calibrate and validate the spatially distributed sediment delivery model WaTEM/SEDEM using the best data available at national scale. Mean annual soil erosion rates for the different catchments were assessed using the USLE-2D procedure. In this model the rainfall erosivity factor (R) found to play a key role and estimated by the following equation:

$$R_{\text{annual}} = \sum_{i=1}^{12} 1.3 P_{\text{monthly}}$$

Where,

R_{annual} = mean annual rainfall erosivity factor (in MJ mm/ha/h/year) and

P_{monthly} = the total monthly rainfall (in mm).

Pandey *et al.* (2007) employed universal soil loss equation (USLE) and GIS technique for identification of critical erosion prone areas in the small agricultural watersheds. In this study, Karso watershed of Hazaribagh, Jharkhand state was divided into 200 × 200 m grid cells and average annual sediment yields were estimated for each grid cell of the watershed to identify the critical erosion prone areas of watershed for prioritization purpose. A recent and emerging technology represented by geographic information system (GIS) was used as a tool to generate, manipulate and spatially organize disparate data for sediment yield modeling. USLE was used to predict the spatial distribution of the sediment yield on grid basis. In this study the rainfall erosivity factor (R), acts as the key factor of USLE was computed by using following formula:

$$KE = 210.3 + 89 \log_{10} I$$

$$R = \sum_{i=1}^n \text{Erosion index} = \sum_{i=1}^n (KE \times I_{30})$$

Where,

KE = kinetic energy of storm (in MJ/ha),

I_{30} = maximum rainfall intensity during a continuous period of 30 minutes
(in mm/h),

I = intensity of rainfall (in mm/h) and

R = annual erosivity (in MJ mm/ha/ h/year).

Dabral *et al.* (2008) carried a study on soil erosion assessment in a hilly catchment of north eastern India using USLE, GIS and Remote Sensing. This study was aimed at soil erosion assessment of Dikrong river basin of Arunachal Pradesh. The river basin was divided into 200 × 200 m grid cells. The Arc Info 7.2 GIS software and ERDAS IMAGINE 8.4 image processing software provided with spatial input data and USLE was used to predict the spatial distribution of average annual soil loss on grid basis. The watershed has no record of rainfall intensity as a result monthly rainfall data were used to calculate rainfall erosivity factor (R) annually using the following relationship developed by Wischmeier and Smith (1978):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{1(1.5 \log_{10} \left(\frac{Pi^2}{P}\right) - 0.08188)}$$

Where,

R = rainfall erosivity factor in MJ mm/ha/h/year,

P_i = monthly rainfall in mm and

P = annual rainfall in mm.

The term $\left(\frac{Pi^2}{P}\right)$ in above formula is popularly known as Fournier index. The above formula is used in annual rainfall erosivity factor (R) estimation when the record of rainfall intensity is not available.

Das (2008) used GIS and remote sensing approaches for identification of critical erosion prone areas for watershed prioritization. He stated that the major factors responsible for soil erosion include rainfall, soil type,

vegetation, topographic and morphological characteristics of the basin. Surface erosion and sediment yield quantities were found to have large variability due to the spatial variation of rainfall and catchment heterogeneity. To compute soil erosion and sediment outflow in GIS using universal soil loss equation (USLE) with transport limiting sediment delivery (TLSD) concept, the catchment was divided into smaller grid cells of 30 × 30 m to account for catchment heterogeneity by considering grid cell as hydrologically homogeneous area. In this study the USLE's rainfall erosivity factor (R) was calculated by using following formula:

Annual relationship:

$$R = 81.5 + 0.38R_N \quad (340 \leq R_N \leq 3500 \text{ mm})$$

Seasonal relationship:

$$R = 71.9 + 0.361R_S \quad (293 \leq R_S \leq 3190 \text{ mm})$$

Where,

R = average annual/ seasonal erosion index,

R_N = average annual rainfall (mm) and

R_S = average seasonal rainfall (mm).

2.3 Estimation of soil erodibility factor (K)

Aggarwal (2000) applied Remote Sensing and GIS techniques for soil erosion assessment at Bata river basin, India. They stated that soil erodibility factor K is key input for soil erosion estimation model like USLE. The K factor map was prepared from the soil map, which was obtained from the previous studies done at Geo-Science Division of Indian Institute of Remote Sensing (IIRS), Dehradun.

Phadke and Singh (2006) adopted universal soil loss equation (USLE) along with GIS approach for assessment of soil loss by water erosion in Jamni river basin, Bundelkhand, India. They stated that, effective control of soil erosion requires the ability to predict the amount of soil loss which would occur under alternative management strategies and practices. They stated that soil erodibility factor K is the key input for soil loss prediction models. In this study following equation was used for the estimation of K factor:

$$K = 0.01292 [(2.1w^{1.14}) (12 - x)] + [3.25 (y - z) + 2.5(z - 3)]$$

Where,

x = the organic matter (%),

w = the silt (%) = (100 – clay %),

y = the soil structure code and

z = the profile permeability class.

Bienes *et al.* (2007) worked on spatial variability of the soil erodibility parameters and their relation with the soil map at subgroup level. This study takes a look at the variation of the parameters related to soil erodibility (fractions of clay, silt, fine and coarse sand; organic matter, permeability, and structure) coming from soil pits from the Community of Madrid's soil map (Spain), according to Soil Taxonomy at subgroup level. It draws the conclusion that map erodibility shouldn't be estimated from a soil map because the K factor obtained did not present significant differences among the different types of soil. One or more key factors related with soil erodibility must be taken into account if erodibility maps are to be drawn. This research had shown that silt and structure could be considered key factors for erodibility maps of the area, but not significant differences have been found in important factors such as clay or organic matter due to the wide range of data variance. In order to elaborate erosion risk maps the use of the K factor

from the physiographical map is a good alternative. It was found that erodibility was greater in soils developed over gypsic material, with a value of 0.63 ± 0.28 than in high plateaus (locally know as alcarrias), with a value of 0.40 ± 0.18 . In order to adequately represent soil erodibility, a kriging geostatistic technique was used, which reduces the variation of the factors considered when they are found to correlate, as is the case with the parameters considered to calculate K factor. Following equation (Wischmeier and Smith, 1978) was used for estimation of K factor:

$$100 K = 10^{-4} 2.71M^{1.14}(12-a) + 4.2(b-2) + 3.23(c-3)$$

Where,

K = K-factor ($t m^2 h ha^{-1} hJ^{-1} cm^{-1}$),

M = texture from the first 15 cm of soil surface

$$= [(100-Ac) \cdot (L+Arm f)]$$

Where,

Ac = % of clay (< 0.002 mm),

L = % of silt (0.002–0.05 mm),

Arm f = % of very fine sand (0.05–0.1 mm),

a = % of organic matter content,

b = structure of soil (very fine granular: 1–2 mm; fine granular: 2–5 mm; med or coarse granular: 5–10 mm; blocky, platy or massive: > 10 mm) and

c = permeability (c=1, very rapid, c=2, mod. to rapid, c=3, moderate, c=4, slow to mod., c=5, slow, c=6, very slow).

Bahrami *et al.* (2011) had developed a nomograph for estimation of erodibility factor (K) of calcareous soils in North West of Iran. They stated that in USLE model the soil erodibility factor (K) is measured using the average rate of soil loss from the unit plot per the unit of rainfall erosivity factor. This factor can also be estimated by the USLE nomograph on the basis of some measurable soil properties. The USLE nomograph had been developed based on field measurements of soil loss in soils of the semi-humid regions in USA, where soils were uncalcareous with low values of carbonates (lime). Thus, the application of the USLE nomograph in semi-arid regions' soils may lead to inaccurate assessment of the K factor. The K factor was measured under natural rainfall events in 36 unit plots from March 2005 to March 2007 and estimated using the USLE nomograph based on soil properties. The results showed that the nomograph-based estimates were 8.77 times more than the measured values. Following multi-regression equation was applied for the estimation of K factor:

$$K=2.8 \times 10^{-7} M^{1.14} (12-a) + 4.3 \times 10^{-3} (b-2) + 3.3 \times 10^{-3} (c-3)$$

Where,

K = soil erodibility factor in $t \ h \ MJ^{-1} \ mm^{-1}$,

M = [(100 - % clay) × (% very fine sand + % silt)],

a = % organic matter,

b = is soil structure code and

c = profile permeability class.

2.4 Estimation of topographic factor (LS)

Topographic factor (LS) is basically the product of length of slope factor (L) and gradient of slope factor (S). The slope length factor (L) is ratio of soil loss from given length of slope to that from the land having 22.13 m length of slope if all other conditions remain unchanged. And slope gradient factor (S)

is ratio of soil loss from given gradient of slope to that from land having 9 % slope if all other conditions remains unchanged (Das, 2008).

Eiumnoh (2000) integrated geographic information system (GIS) and satellite remote sensing (SRS) for watershed management. The universal soil loss equation (USLE) was used for the estimation of soil loss. He stated that the topographic factor (LS) performs a key role in soil detachment down the slope. In this digital elevation model (DEM) was used for the estimation of LS factor. Topographic map was used for elevation data to generate the DEM. Contour lines at 20 m interval in hilly areas and at 10 m interval in the plains, were digitized from the topographic map, using Arc/info software. Following equation was used for estimation of LS factor for less than 8% slope gradient:

$$LS = \left(\frac{l}{22.13}\right)^n (0.0065 + 0.045s + 0.0065s^2)$$

Where,

l = slope length (meters),

s = slope gradient (%) and

n = slope length exponent whose maximum value is 0.5 (Morgan, 1996).

For greater than 8 % slope gradient following equation (Liengsakul *et al.*, 1993) was used:

$$LS = \left(\frac{l}{22.13}\right)^{0.5} (0.17s - 0.55)$$

Gallant *et al.* (2001) worked on prediction of sheet and rill erosion over the Australian Continent, by incorporating monthly soil loss distribution. They used revised universal soil loss equation (RUSLE) for soil loss estimation. They stated that the topographic factor (LS) which is the product of slope

length factor (L) and slope gradient factor (S) play a key role in soil erosion by water. It represents the increase in storm runoff volume with increasing hill-slope length. For cropping land L was evaluated by the equation used in RUSLE (Renard *et al.*, 1997) with:

$$L = (X_h/22.13)^m$$

Where,

X_h = the horizontal slope length (meters) and

m = is a variable slope length exponent and m is related to the ratio of rill erosion to inter-rill erosion.

The slope gradient factor (S) was calculated by the following equations:

$$S = 10.8 \times \sin \theta + 0.03 \quad \text{for slope percent} < 9\%$$

$$S = 16.8 \times \sin \theta - 0.50 \quad \text{for slope percent} \geq 9\%$$

Where,

θ = slope angle (degree).

Batistella *et al.* (2004) used remote sensing and GIS techniques for soil erosion risk mapping in Rondonia, Brazilian Amazonia, by applying the Revised Universal Soil Loss Equation (RUSLE). They stated that the LS factor accounts for the effect of topography on erosion in RUSLE. The slope length factor (L) represents the effect of slope length on erosion and the slope steepness factor (S) reflects the influence of slope gradient on erosion. Digital elevation model (DEM) was used to generate the topographic factor (LS). They used following equation for calculating LS factor and it is an empirical equation provided by the USDA Agriculture Handbook (Wischmeier and Smith, 1978):

$$LS = \left(\frac{\lambda}{22.13}\right)^m (65.41\sin^2\theta + 4.56\sin\theta + 0.065)$$

Where,

LS = topographic factor,

λ = slope length (meters),

m = an exponent (depends on slope) and

θ = slope angle (degree).

Singh *et al.* (2007) carried a research on soil erosion under simulated conditions for black soils of southern India. They used the universal soil loss equation (USLE) for estimation of soil loss from the area. They stated that the slope is important factor that enhances the process of the erosion. They used the following equation for estimation of slope gradient factor (S):

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613}$$

Where,

S = slope gradient factor and

s = slope (%).

In the next step they used the modified equation (Wischmeier and Smith, 1978) for estimation of slope gradient factor (S) as given below:

$$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$$

Where,

S = slope gradient factor and

θ = slope angle (degree).

Douros *et al.* (2009) used following relationship (Schmidt *et al.*, 2002) for calculation of length of slope factor (L) and gradient of slope factor (S):

$$L = 1.4 \left(\frac{A_s}{22.13} \right)^{0.4} \quad \text{and}$$

$$S = \left(\frac{\sin \beta}{0.0896} \right)^{1.3}$$

Where,

A_s = specific catchment area (m²/m) and

β = slope angle (degrees).

Bhunia *et al.* (2012) performed quantitative analysis of relief characteristics of Morobe province of Papua New Guinea. The study analyzed seven topographic parameters namely absolute relief, relative relief, dissection index, slope, aspect, drainage density and ruggedness index, for better understanding of local relief characteristics with some observation of structural landscape pattern. The advanced application of Remote Sensing (RS) and Geographic Information System (GIS) techniques have lead to estimation of above parameters based on Digital Elevation model and satellite imagery. Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) was downloaded from GLCF website (Global land Cover Facility, 2000) Maryland, which was in Tagged Information File Format (TIFF) with 90 meter ground resolution. Raster derived from USGS DEM was converted to Triangulated Irregular Network (TIN) surface model to remove points within an area of interest from one or more embedded feature classes.

2.5 Estimation of crop/cover management factor (C)

Corp management factor (C) is the ratio of soil loss from given cropping management to that from the land kept continuously fallow if all other conditions remained unchanged (Tamas, 2005).

Alejandro and Omasa (2007) estimated the vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data. Soil conservation planning often requires estimates of soil erosion at a catchment or regional scale. They stated that predictive models such as Universal Soil Loss Equation (USLE) and its subsequent Revised Universal Soil Loss Equation (RUSLE) are useful tools to generate the quantitative estimates necessary for designing sound conservation measures. However, large-scale soil erosion model factor parameterization and quantification is difficult due to the costs, labor and time involved. Among the soil erosion parameters, the vegetative cover or C factor has been one of the most difficult to estimate over broad geographic areas. The C factor represents the effects of vegetation canopy and ground covers in reducing soil loss. Traditional methods for the extraction of vegetation information from remote sensing data such as classification techniques and vegetation indices were found to be inaccurate. Thus, a new approach based on Spectral Mixture Analysis (SMA) of Landsat ETM data had developed to map the C factor for use in the modeling of soil erosion. A desirable feature of SMA is that it estimates the fractional abundance of ground cover and bare soils simultaneously, which is appropriate for soil erosion analysis. Hence, the C factor was estimated by utilizing the results of SMA on a pixel-by-pixel basis.

Hui *et al.* (2008) developed an approach to compute the C factor for universal soil loss equation using EOS-MODIS vegetation index (VI). The development of Earth Observing System (EOS) project has provided with imageries of high temporal & spatial resolutions. MODIS (Moderate Resolution Imaging Spectro-radiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites, which are viewing the entire earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. With this more scientific method for C factor estimation using MODIS VI product

by taking account of time variation nature of C factor had been developed. The aim of this study was to present a new methodology to compute the C factor for soil loss estimation using MODIS level 3 products, which consider the time variation nature of C factor by combining the VI of different periods in a year. Based on this vegetation index You (1999) suggested a method to identify the weights of vegetation cover of different periods contributed to the average annual vegetation cover is used in this study and represented as follows:

$$C_{year} = \left[\left(\sum_{i=AP}^{JL} r_i^2/P \right) \times C_1 + \left(\sum_{i=A}^N r_i^2/P \right) \times C_2 + \left(\sum_{i=D}^M r_i^2/P \right) \times C_3 \right] / \left(\sum_{i=J}^D r_i^2/P \right)$$

Where,

C_{year} = average annual vegetation cover,

r_i = rainfall amount in each month,

P = annual rainfall amount,

C_1, C_2 and C_3 = vegetation cover of April to July, August to November, and December to next March respectively and

Ap, JI, A, N, D, M and J = short of April, July, August, November, January.

Karaburun (2010) estimated crop management factor (C) for soil erosion modeling using NDVI in Buyukcekmece watershed. He stated that, in order to take measures in controlling soil erosion it is required to estimate soil loss over area of interest. Soil loss due to soil erosion can be estimated using predictive models such as Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE). The accuracy of these models depends on parameters that are used in these equations. One of the most important parameters used in both of models is C factor that represents effects of vegetation and other land covers. Estimating land cover by

interpretation of remote sensing imagery involves Normalized Difference Vegetation Index (NDVI), an indicator that shows vegetation cover. The C factor values for Buyukcekmece watershed using NDVI derived from 2007 Landsat 5 TM Image. The final C factor map was generated using the regression equation in Spatial Analyst tool of ArcGIS 9.3 software. It was found that north part of watershed had higher C factor values and almost 60% of watershed area had C factor classes between 0.2 and 0.4. The spectral reflectance difference between Near Infrared (NIR) and red was used to calculate NDVI. The formula can be expressed as (Jensen, 2000):

$$\text{NDVI} = (\text{NIR} - \text{red}) / (\text{NIR} + \text{red})$$

Relationship between C and NDVI values was found as:

$$\text{C factor} = \{1.02 - (1.21 \times \text{NDVI})\}$$

Saumer *et al.* (2010) assessed the USLE crop and management factor C for soil erosion modeling in a Large Mountainous Watershed in Central China. They stated that one of the key factors in soil erosion control is the vegetation cover and crop type. However, determining these factors adequately for the use in soil erosion modeling is very time-consuming especially for large areas. In this study, the crop and management factor C was calculated using the fractional vegetation cover (CFVC) based on Landsat-TM images from 2005, 2006 and 2007. The NDVI was computed for each of the Landsat-TM images preprocessed based on bands 3 (red band; R) and 4 (near infrared; NIR) using following equation (Rouse *et al.*, 1974):

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R})$$

Where,

NDVI = normalized difference vegetation index,

NIR = reflectance in near-infrared band and

R = reflectance in red band.

Then by using the above equation, the C factor values were calculated by using the correlation between the NDVI and C factor.

Zaeen (2012) employed Remote sensing technique for monitoring the risk of soil degradation using NDVI. He stated that one of the most important parameters in soil erosion prediction models is (C) factor that represents effects of vegetation and other land covers. In this study the crop management factor (C) was estimated with the help of NDVI which shows the effect of vegetation cover. The NDVI of the study area was derived from the Landsat ETM images of study period. Finally the C factor map of the area was prepared in spatial analyst toolbox of ArcGIS using following exponential equation:

$$C = e^{\left(-\alpha \frac{NDVI}{\beta - NDVI}\right)}$$

Where,

α and β are the parameters determining the shape of NDVI-C curve.

2.6 Estimation of conservation/support practice factor (P)

Conservation or support practice factor (P) is basically the ratio of soil loss from a land having specified conservation practices to that from a land ploughed in direction parallel to slope if all other conditions remain unchanged (Wischmeier & Smith, 1978).

Roslan and Tew (1997) used satellite imagery to determine the land use management factor of the USLE. The study was conducted at Cameron Highlands in Malaysia as it being threatened by landslips and flash floods due to numerous development projects and intensive agricultural activities. A study of the land use management factor (Cover and Management factor, C and Support Practice factor, P) of the Universal Soil Loss Equation (USLE)

has been undertaken, as this parameter reflects the land cover in the study area and its effect on soil erosion. Using remote sensing satellite imagery, the Ringlet area in the Cameron Highlands has been identified as having the highest erosion risk/loss based on the CP factor and this was confirmed by its highest ranking for residential and construction areas compared to other locations. The results of this study highlight the important land uses associated with erosion risk and provide guidance to ensure that development was carried out to ensure a quality environment for the future. They stated that with recent developments in remote sensing technology, color infrared imagery could be used to determine the combined land use management factor, C and P of the USLE.

Gallant *et al.* (2001) worked on prediction of sheet and rill erosion over the Australian Continent by incorporating monthly soil loss distribution. They stated that supporting practice factor (P) account for the effects of contour, strip cropping or terracing. It is defined as the ratio of soil loss with a specific supporting practice to the corresponding soil loss with certain cultivation. Due to a lack of spatial data on existing contour locations and tillage practices, it was assumed that the values of P factor were 1 everywhere. Given this scenario, the estimated soil loss rate reflects erosion potential under current conditions with no soil conservation support practices.

Desilva *et al.* (2010) worked on the water erosion modeling in a watershed under forest cultivation through the USLE model. They stated that modeling of erosion processes integrated with a Geographic Information System (GIS) had been an important tool to assess erosion by water. The objective of this study was to determine the spatial distribution of water erosion in forest ecosystems and generate soil loss prediction maps according to different land use scenarios. The study was conducted in a watershed occupied by Eucalyptus cultivation located in Belo Oriente in the Rio Doce river valley, Central-East region of Minas Gerais state, Brazil. For the spatial distribution modeling of soil loss for the watershed, the USLE model was applied coupled with Geographic Information System (GIS). The factor P which is showing effect of different land uses was assumed to be 0.5

for the scenario with conservationist Eucalyptus and 1.0 for the other scenarios.

Sheikh *et al.* (2011) integrated GIS and universal soil loss equation (USLE) for soil loss estimation in a Himalayan watershed. They stated that erosion calculation requires huge amount of information and data, usually coming from different sources and available in different formats and scales. Therefore GIS was used, which helped considerably in organizing the spatial data representing the effects of each factor affecting soil erosion. The factors that most influence soil erosion are linked to topography, vegetation type, soil properties and land use/cover. Average annual soil losses were calculated by multiplying five factors: R, K, LS, C and the conservation/support practice factor P. Support practice factor indicates the rate of soil loss according to the various cultivated lands on the earth. There are contour cropping and terrace as its methods and it is important factor that can control the erosion. P values generally range from 0 to 1, whereby the value 0 represents a very good manmade erosion resistance facility and the value 1 no manmade erosion resistance facility. In the study area there were some agricultural support practices such as contour farmland and terraced farmland. But P factor value was taken as 1 for simplicity purpose in this study.

Arekhi *et al.* (2012) used RUSLE, Remote Sensing and GIS for mapping soil erosion and sediment yield susceptibility in Cham Gardalan watershed, Iran. They stated, the P factor reflects the impact of support practices dealing with the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up and down slope. The lower the P value, more effective is the conservation practice and deemed to be at reducing soil erosion. As with the other factors, the P-factor differentiates between cropland and rangeland or permanent pasture. As the study of this research work to estimate soil erosion using RUSLE modeling was applied in the area of non-agriculture or on natural (geological) erosion, it was considered that there were no conservation practices(P) in non-agricultural areas. Therefore as the conservation practice factor (P) value ranges from 0 to 1 and highest value is assigned to areas

with no conservation practice. The maximum value for P, that is 1.0, was assigned to this research work area.

From the above mentioned review it is inferred that the predictive model like USLE is most widely used in prediction of erosion rates from an un-gauged watershed. The universal soil loss equation (USLE) also forms the basis of the soil erosion modeling which can be applied to any watershed as it is universally accepted. Several investigators reported that rate of soil erosion from a watershed is depends upon rainfall, soil, topography, cropping patterns and vegetation cover etc. Some of these factors are also responsible for sediment detachment and transportation processes. But collection of data regarding soil, topography, cropping pattern and ground cover by traditional methods is found to be much time consuming. After advent of the remote sensing (RS) technique the data collection process has become more handy and quick. Some researchers have reported that collection of data for distributed features like soil, topography, cropping pattern and ground cover have become much easy by integrating remote sensing with geographic information system (GIS). Now a day's investigators are using RS and GIS techniques along with predictive model like USLE for soil erosion modeling in watershed.

MATERIAL AND METHODS

The correctness of any prediction tool depends largely upon the accuracy of data sets with relevant information and the methodology adopted. In modeling the hydrologic process like soil erosion, the causative factors such as rainfall, soil type, topography, cropping pattern and vegetation or ground cover are to be known along with the hydrologic time series data. But, adequate data for a complete and comprehensive analysis are seldom available, leaving no other choice than to use only the available information. This chapter deals with the data collected and the methods used in analyzing the data for the estimation of annual rate of soil erosion of the Shakker river watershed lying in Narmada river basin situated in the Narsinghpur and Chhindwara districts of Madhya Pradesh.

3.1 Study area and data availability

3.1.1 About study area

The Shakkar River rises in the Satpura range, east of the Chhindi village, Chhindwara district, Madhya Pradesh. Area lies between 22°20'N to 23°00'N latitude and 78°40'E to 79°20'E longitudes with elevation range from 314 to 1154 m above MSL (mean sea level). The watershed covers 2223 km² of total geographical area up to the gauging point. The large portion of watershed lies in Narsinghpur district and some part in the Chhindwara district. The climate of the basin is generally dry except the southwest monsoon season. During the south-west monsoon season, the relative humidity generally exceeds 87% (August month) and rest of the year is drier. The driest part of the year is the summer season, when relative humidity is less than 33%. May is the driest month of the year. The normal maximum temperature during the month of May is 42.5⁰ C and minimum during the month of January is 8.2⁰ C. Soils are mainly clayey to loamy in texture with calcareous concretions invariably present. They are sticky and in summer, due to shrinkage, develop deep cracks. They generally predominate in montmorillonite and beidellite type of clays. In rest of alluvial areas, mixed clays, black to brown and reddish brown soil, derived from sandstones and traps is observed which is sandy clay in nature with calcareous concretions.

Near banks of the river and at the confluence, light yellow to yellowish brown soils are noticed which were deposited during the recent past .These soils are clayey to silt in nature.

The area receives the rainfall by south west monsoon. The southwest monsoon starts from middle of June and lasts till end of September. October and middle of November constitute the post monsoon or retreating monsoon season. The average annual rainfall of the area is 1245 mm where as normal annual rainfall of the area is 1192.1 mm. The location of study area is shown in following Fig. 3.1.

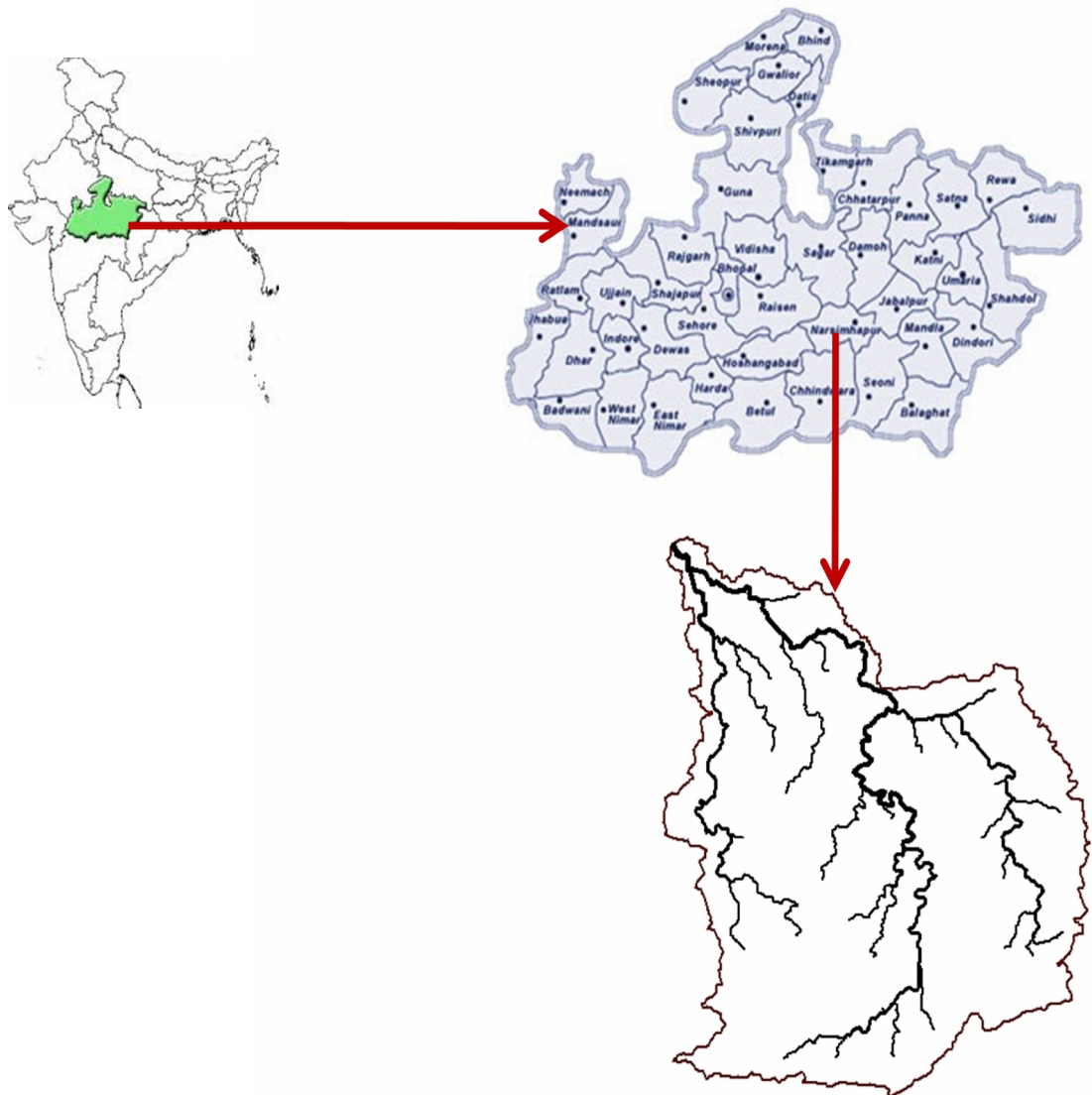


Fig. 3.1 Location map of study area.

3.1.2 Data availability

This study requires the data information regarding rainfall, topography, soil and vegetation or ground cover of the study area. The data of observed sediment loss at the outlet of the watershed is also required for validation of the estimation model.

3.1.2.1 Rainfall data

The rainfall data required for estimating the value of rainfall erosivity of the area. Three major rain gauge stations, namely Gadarwara and Harrai falling in the study area and Amarwara in the vicinity of the area, were selected. The 15 years 24-h rainfall data of these three stations was collected from the Department of Physics and Agro-meteorology, College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (MP). The annual rainfall of these stations was obtained by summing the daily rainfall data and it is presented in following Table 3.1.

Table 3.1 Showing annual rainfall (mm) at respective rain gauge stations.

Year	Station name		
	Gadarwara	Harrai	Amarwara
1992	909	1015	844
1993	1279	1276	1258
1994	860	1794	1532
1995	733	951	1085
1996	558	834	899
1997	951	1436	1907
1998	395	1011	1212
1999	2210	2023	1713
2000	928	1018	797
2001	993	1149	625
2002	1031	965	961
2003	1033	1357	938
2004	889	973	601
2005	1279	1202	1392

2006	684	1101	1351
Average	913.26	1207	1141

3.1.2.2 Digital elevation model (DEM)

For delineation of the Shakkar river watershed and preparation of drainage map the information regarding the topography was needed. In this study a geo-coded Digital Elevation Model (DEM) generated from Shuttle Radar Topographic Mission (SRTM) data has been used. The digital elevation model (DEM) was downloaded from GLCF website (Global Land Cover Facility, Maryland, 2000) which was in Tagged Information File Format (TIFF) with 30 meter ground resolution (Bhunia *et al.*, 2012).

3.1.2.3 Soil

In this study the soil data was used to have the sake of susceptibility of soil of study area to get eroded by the rainfall impact. For this purpose the soil map of Madhya Pradesh, sheet no. 5 was used. This map is generated by National Bureau of Soil Survey and Land Use Planning (NBSSLUP) using Soil Atlas of Madhya Pradesh. There are total 9 sheets in which the soil of Madhya Pradesh is covered. This map is available at the scale of 1:500000.

3.1.2.4 Satellite data

For getting information of the vegetation or ground cover, the land use land cover map of the study area was prepared with the help of ERDAS IMAGINE 9.2, which is well known image processing software. For preparation of land use/land cover map, satellite image of study area was used, which was obtained from National Remote Sensing Agency (NRSA, Hyderabad). The details of the satellite data are tabulated below in Table 3.2. False colour composite (FCC) of study area is shown in Fig. 3.2.

Table 3.2 Showing details of satellite data.

Satellite	Sensor	Spatial resolution	Band	Swath	Row/path	Acquired on
IRS-P6	LISS III	23.5 m	2,3,4,5	141 km	99/56	8 Jan 2011

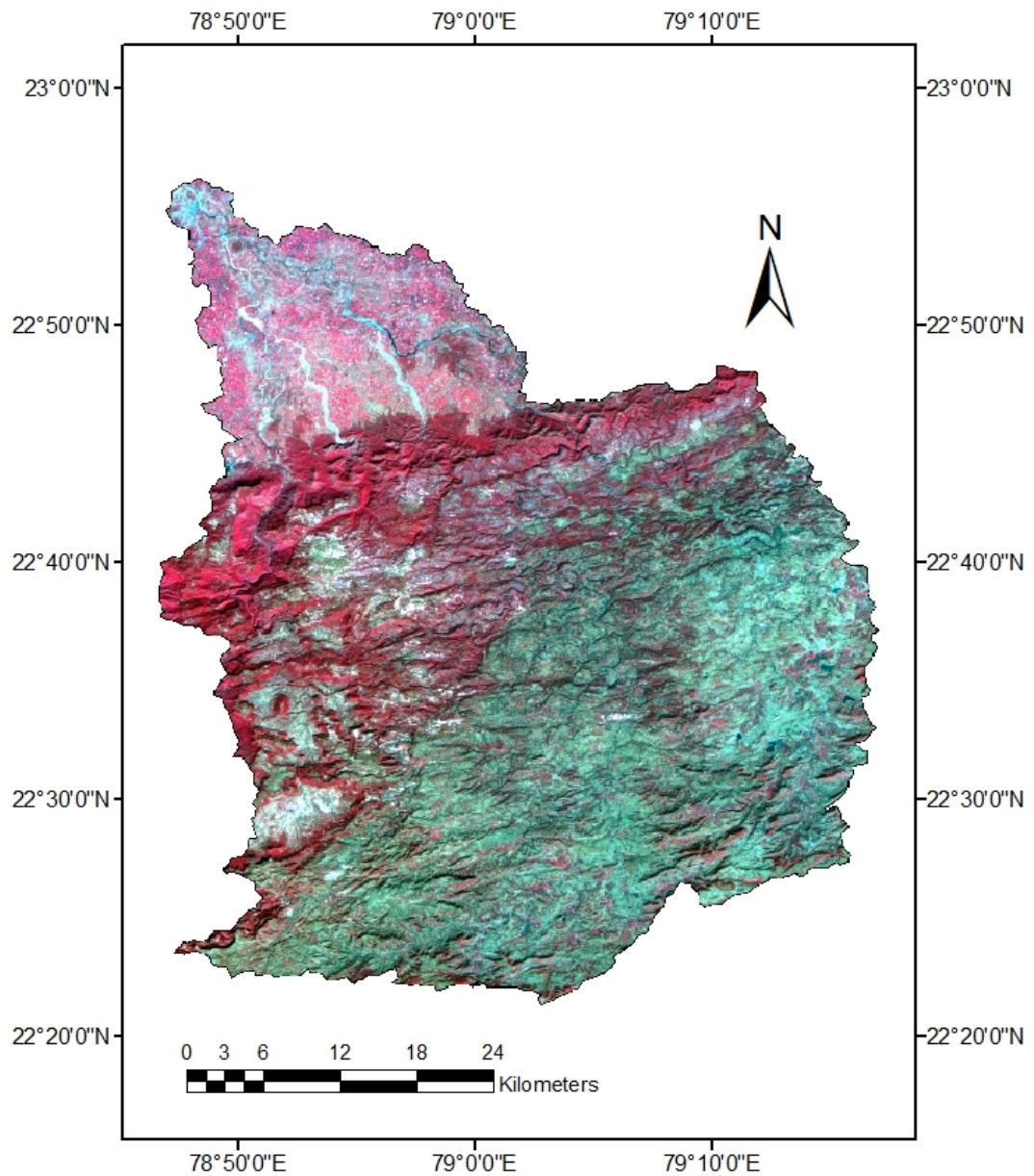


Fig. 3.2 False colour composite (FCC) of study area.

3.1.2.5 Observed sediment data

Observed sediment data of the stream gauging station at the outlet of watershed was collected from the “Integrated Hydrological Data Book for non classified river basins” published by Hydrological Data Directorate, Information Systems Organization, Water Planning & Projects Wing, Central Water Commission (CWC), New Delhi. The data books published in the years 2006 and 2012 were used. These data books contains statistics regarding annual sediment loss at outlet (at gauging point) expressed in MT (Million metric tones). The annual observed sediment load and annual rate of sediment loss is presented in following Table 3.3.

Table 3.3 Showing annual sediment load and annual rate of sediment loss.

Year	Observed annual sediment load (MT)	Annual rate of sediment loss (tones/ha/yr)
1992	1.417	6.37
1993	1.853	8.33
1994	2.391	10.75
1995	1.515	6.81
1996	1.314	5.91
1997	2.930	13.18
1998	2.150	9.67
1999	3.360	15.11
2000	1.576	7.09
2001	1.371	6.17
2002	1.460	6.57
2003	2.060	9.26
2004	1.318	5.93
2005	2.654	11.94
2006	1.745	7.85

3.1.3 Software used for preparation of thematic maps

Software available at well established GIS lab of Madhya Pradesh Water Sector Restructuring Project (MPWSRP), Department of Soil and Water Engineering, College of Agricultural Engineering, Jabalpur were used for preparation of thematic maps namely, drainage map, land use/land cover map and other datasets of the study area and for analysis of data. Detail of software used is given in following Table 3.4.

Table 3.4 Software used and their distinctive features.

Software	Description
ArcGIS 9.3	ArcGIS is the most complete and extensible GIS available. It includes all the functionality and adds advanced geoprocessing and data conversion capabilities. Professional GIS users use ArcMap (ArcInfo) for all aspects of data building, modeling, analysis, and map display for screen and output. ArcCatalog is mostly used for creating, deleting, and editing the spatial data files (ESRI).
ERDAS MAGINE 9.2	The ERDAS IMAGINE software provides the functions of both image processing and geographic information systems (GIS). These functions include importing, viewing, altering, and analyzing raster and vector data sets.
Other software	Window base software such as - MS office were used to build database and analyze them.

3.2 Introduction to Geographic Information Systems (GIS)

Development of Geographic Information Systems (GIS) closely follows advancements in computers. As computers are able to handle more data intensive operations, the use of GIS have also expanded to handle larger datasets. GIS are primarily used to process and display data which have a spatial component. The spatial information determines where the data model

is located at in the real world. The object's attributes or specific characteristics are also contained within the data model. Attributes such as length, area and count are important to distinguish between data models. Current GIS softwares are capable of storing complex spatial information into separate, thematic layers (Fig. 3.3).

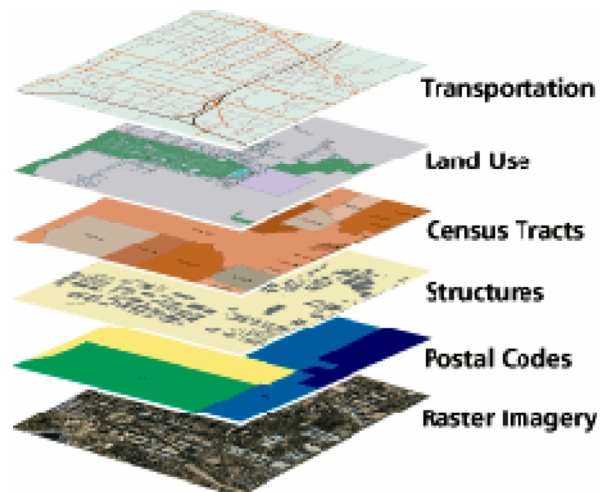


Fig. 3.3 Example of GIS data layers organized into separate themes.

The two spatial data types used in this research project are vector and raster files. Vector data contain features defined by a point, line or polygon. Vector data models are useful for storing and representing discrete features such as buildings and roads. ArcGIS implements vector data as a shape files. Raster data are composed of a rectangular matrix of cells. Each cell has a width and length and is a portion of the entire area represented by the raster. Each cell has a value which represents the phenomenon portrayed by the raster dataset, such as a category, magnitude, distance or spectral value. The category could refer to a land use class, such as grassland or urban. The cell size dimensions can be large or as small as necessary to accurately represent the area. The location of each cell is defined by either its reference system or projection. This research has used the Datum Indian 1975 (D_Indian_1975) and Indian Polyconic projection system for all data types. The use of the same projection system allows one raster layer to overlap over other layer.

3.3 Methods of analysis

For an accurate prediction the relevant data and methods of analysis are two important tools. This section includes the theory and procedure used for estimation of annual rate of soil erosion using universal soil loss equation (USLE) with Remote Sensing and GIS approaches. The detailed procedure for estimation of various USLE factors is given in further coming sub-sections.

3.3.1 USLE based spatially distributed soil erosion estimation

The rate of soil erosion from an area is strongly dependent upon rainfall, topographic characteristics, soil and vegetation. These characters are found to vary greatly within a watershed. Therefore a method which takes these factors in to account while estimating soil erosion is expected to produce realistic estimates of rates soil erosion (Das, 2008). The universal soil loss equation (USLE) (Wischmier and Smith, 1965) is one such equation that takes factors such as rainfall, topography, soil and land use into consideration while assessing soil erosion. The USLE is a simple empirical model used extensively to realistically estimate surface soil erosion over small areas (Wischmier and Smith, 1978; Jain and Kothiyari, 2000; Yusof and Baban, 2002; Jain and Goel, 2002; Mishra *et al.*, 2007; Pandey *et al.*, 2007).

3.3.2 The USLE

The Universal Soil Loss Equation (USLE) (Wischmier and Smith, 1965) for estimation of average annual rate of soil erosion can be expressed as:

$$A_i = R_i \cdot K_i \cdot L_i \cdot S_i \cdot C_i \cdot P_i \quad (3.1)$$

Where,

A_i = average annual rate of soil loss (t/ha/yr),

R_i = the rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{h}^{-1}$),

K_i = the soil erodibility factor ($\text{t ha h ha}^{-1} \text{MJ}^{-1} \text{mm}^{-1}$),

L_i = the slope length factor (Dimensionless),

S_i = the slope steepness/slope gradient factor (Dimensionless),

C_i = the crop/cover management factor (Dimensionless) and

P_i = conservation/support practice factor (Dimensionless) of the i^{th} cell.

In a large sized watershed, these factors (R, K, LS, C & P) show spatial variability. A watershed is needs to be discretized into smaller homogeneous areas to capture catchment heterogeneity (Jain and Kothyari, 2000). Several methods are available for discretization of watershed into smaller areas. The cell or grid approach is most commonly used due to its adoptability to raster based GIS and ease in the collection of input data using remotely sensed satellite data. A cell size of 30m x 30m is most widely used in distributed modeling and the same is adopted for representing the cell as hydrologically homogeneous area in the present study as well. Grid thus formed can be categorized as having lying on overland areas and those lying in channel areas. Such a differentiation is necessary because the process of sediment erosion and delivery in to them are widely different (Alejandra, 2008). The detailed procedure for estimation of USLE factors and preparation of thematic maps of these factors is given below:

3.4 Development of model database for USLE

3.4.1 Rainfall erosivity factor (R)

Erosion by fluvial process is generally believed to be the single most important factor shaping the earth's sub-aerial landscape. The general factors influencing erosion are well known but erosive properties of rain play a key role in soil detachment by impact action (Phillips, 1990).

Rainfall erosivity (R- factor) is the basic and important factor in the assessment of soil erosion in the mathematical model like Universal Soil Loss Equation (USLE). Erosivity is the potential capacity of the raindrops to cause detachment of the soil particles from its location and it depends on rainfall intensity and its recurrence. Hence it is important to accurately estimate erosivity for realistic and quantitative estimation of soil erosion. The

R-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} values, continuous rainfall intensity data are needed (Elangovan and Seetharaman, 2011).

Wischmeier and Smith (1978) states that the factor R is the number of rainfall erosion index units (EI_{30}) in a given period at the study location. The rainfall erosion index unit (EI_{30}) of storm is defined as

$$EI_{30} = (KE \times I_{30})/100 \quad (3.2)$$

Where,

KE = Kinetic energy of the storm. The KE in metric tones/ha-cm is expressed as

$$KE = 210.3 + 89 \log I \quad (3.3)$$

Where,

I = rainfall intensity in cm/h and

I_{30} = maximum 30 minutes rainfall intensity of the storm.

The study period can be a week, month, season or a year. The storm EI_{30} values for that length of period is summed up.

Annual EI_{30} values are usually computed from data available at various meteorological stations and lines of equal EI_{30} lines (also known as Iso-erodent lines) are drawn for the region covered by the data stations for ready use in USLE (Das, 2010).

Realistic estimation of monthly or annual rainfall erosivity (EI_{30}) value requires long term pluviographic data at 15 min interval or less (Wischmeier

and Smith, 1978). In many parts of the world, especially in developing countries, spatial coverage of pluviographic data is often difficult to obtain (Yu *et al.*, 2001; Cohen *et al.*, 2005). Monthly, seasonal and annual rainfall data are usually available for long periods are generally used to calculate R factor (Mati *et al.*, 2000; Babu *et al.*, 2004). In India, Babu *et al.* (2004), computed EI_{30} values using the data for storms greater than 12.5 mm of 123 rain gauge stations located in different zones of India using equations (3.2 & 3.3). Linear relationships were established between average annual and seasonal (June – September) rainfall with computed EI_{30} values for different zones of India. Derived relationships were as follows:

Annual relationship:

$$R = 81.5 + 0.38R_N \quad (340 \leq R_N \leq 3500 \text{ mm}) \quad (3.4)$$

Seasonal relationship:

$$R = 71.9 + 0.36R_S \quad (293 \leq R_S \leq 3190 \text{ mm}) \quad (3.5)$$

Where,

R = average annual/seasonal erosion index,

R_N = average annual rainfall (mm) and

R_S = average seasonal rainfall (mm).

The relationships are valid within the indicated rainfall range (equations 3.4 & 3.5). The above derived regression equations and average annual/seasonal (June to September) rainfall data were used to approximate the erosion index values of 500 locations fairly distributed all over India and iso-erodent maps were drawn for annual and seasonal EI_{30} values. For the present study equation (3.4) was used to compute annual values of rainfall erosivity (R) factor by replacing R_N with actual rainfall in a year in the watershed.

Finally thematic map of rainfall erosivity factor (R) was prepared in the GIS environment. For this Thiessen polygon of the study area was prepared using spatial analyst tool box of the ArcGIS 9.3. Thiessen polygon gives fair distribution of the rainfall in surrounding area of a rain gauge station (Aggarwal *et al.*, 2000). Three rain gauge stations namely Gadarwara, Harrai and Amarwara were used for preparation of Thiessen polygon. The annual R factor values at individual stations were estimated using above equation (3.4). After attributing these values to the Thiessen polygons, raster maps of R factor for individual years were prepared using conversion tool box of ArcGIS 9.3.

3.4.2 Soil erodibility factor (K)

The soil-erodibility factor (K) is the rate of soil loss per rainfall erosion index unit as measured on a unit plot (Wischmeier and Smith, 1978). The soil-erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss. In practical terms, the soil-erodibility factor is the average long-term soil and soil-profile response to the erosive powers of rainstorms; i.e. the soil-erodibility factor is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes. These processes consist of soil detachment and transport by raindrop impact and surface flow, localized deposition due to topography and tillage-induced roughness, and rainwater infiltration into the soil profile (Young *et al.*, 1987).

Wischmeier and Smith (1978) suggest following equation for the estimation of soil erodibility factor (K):

$$100 K = 10^{-4} 2.7 1M^{1.14}(12-a) + 4.2(b-2) + 3.23(c-3) \quad (3.6)$$

Where,

K = K-factor ($t m^2 h ha^{-1} hJ^{-1} cm^{-1}$),

M = texture from the first 15 cm of soil surface

$$= [(100 - A_c) (L + A_{rmf})]$$

Where,

A_c = % of clay (< 0.002 mm),

L = % of silt (0.002–0.05 mm),

A_{rmf} = % of very fine sand (0.05–0.1 mm),

a = % of organic matter content,

b = structure of soil (very fine granular: 1–2 mm; fine granular: 2–5 mm; med or coarse granular: 5–10 mm; blocky, platy or massive: >10 mm) and

c = permeability ($c=1$, very rapid, $c=2$, mod. to rapid, $c=3$, moderate, $c=4$, slow to mod., $c=5$, slow, $c=6$, very slow).

Bienes *et al.* (2007) suggested that the variation of the parameters related to soil erodibility coming from soil map, according to soil taxonomy at subgroup level. Thus map erodibility shouldn't be estimated from a soil map because the K factor obtained does not present significant differences among the different types of soil.

For the present study K values for different soil groups falling in the area were assigned based on soil textural and related information taken from soil survey report of NBSSLUP (1996). For this purpose Soils of Madhya Pradesh published by NBSSLUP was used. The individual soil map unit was digitized in the Arc map extension of ArcGIS 9.3. Then the respective values of K factor for each soil map units were attributed to the digitized feature and raster map of K factor was prepared using Conversion tool box of ArcGIS 9.3.

3.4.3 Topographic factor (LS)

Topographic factor (LS) is the product of slope length factor (L) and slope steepness/slope gradient factor (S).

3.4.3.1 Slope length factor (L)

Slope length may be defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the run-off water enters a well defined channel (Wischmeier and Smith, 1958) as shown in Fig. 3.4.

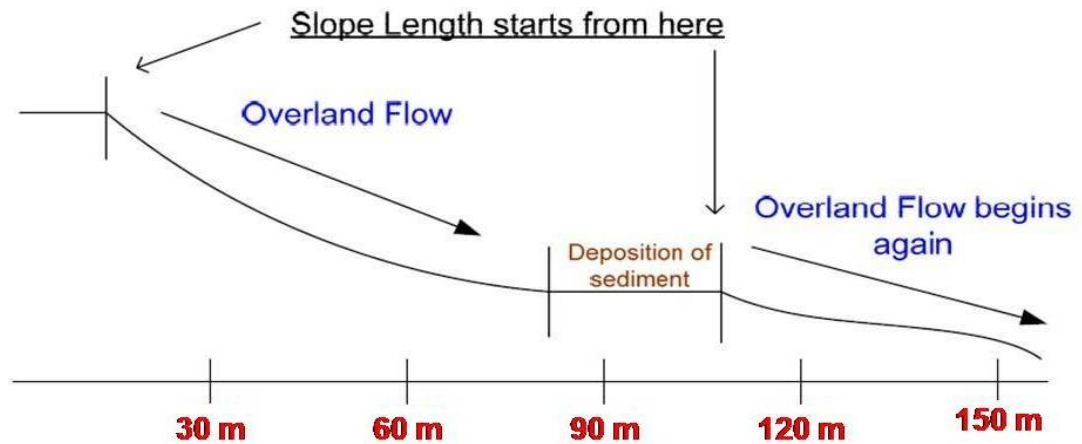


Fig. 3.4 Field Estimation of the Slope Length on a side profile of a hill.

Slope length factor (L) is the ratio of soil loss from given length of slope to that from land having 22.13 m length of slope; its value is generally expressed as (Wischmeier and Smith, 1978):

$$L = \left(\frac{\lambda}{22.13} \right)^m \quad (3.7)$$

Where,

λ = field slope length in meters and

m = an exponent having value ranging from 0.2 to 0.5.

3.4.3.2 Slope gradient factor (S)

Slope gradient factor (S) is ratio of the soil loss from given gradient of slope to that from land having 9 % slope. The slope gradient factor can be expressed mathematically as (Wischmeier and Smith, 1978):

$$S = (65.4\sin^2\theta + 4.56\sin\theta + 0.065) \quad (3.8)$$

Where,

θ is the angle of slope in degree, which is illustrated in Fig. 3.5.

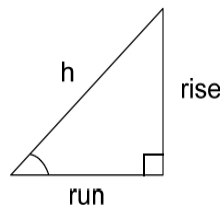


Fig. 3.5 Slope (degrees) illustrated with fundamental relationship of right triangle.

Then from above Fig. 3.5,

$$\text{Slope (degree)} = \tan^{-1} (\text{rise/run}).$$

Combining the above two factors the topographic factor (LS) is calculated. So topographic factor (LS) is expected ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9 % slope under otherwise identical conditions.

In present study the LS factor was calculated by an executable C++ program (Khosrowpanah *et al.*, 2007). The program is provided by International Association of Mathematical Geosciences (IAMG). The C++ program can be downloaded from the website: <http://www.iamg.org>. A link to

published program code is located on the right hand side of the website under “Computers & Geosciences”.

After downloading and uncompressing the package, the C++ executable program along with the source code files are accessible. To run the program, the DEM input needs to be in text format called ASCII. ArcMap has the function to do this located under the Conversion toolbox extension. After the conversion, double-click on the C++ executable program to run it. A series of command lines appears. The first line asks for the user to enter the path and filename for the DEM data, which must be in ASCII text format. Enter in the full path to the text file in the form of “E:\Folder name\ name of file with .txt suffix”. A second line then asks for the path where all the output files should be placed. Specify this path to lead to the appropriate folder. The third line asks the user to enter a short prefix for the output files. The prefix should not be longer than four letters. The fourth line asks if intermediate files should be produced during the computation process. Select “YES” to see each intermediate output file. The final line then asks if cells with no data should be fixed. The user should select “YES”. The program then begins its computation of the DEM text file.

The output of program consist 16 total files with the .dat file suffix. To convert the output files back to a raster format, the file suffix must be .txt in order for ArcMap to recognize it. Open ArcMap and select the Conversion toolbox. Individually convert the output files to import the *LS* factor as a raster layer.

3.4.3.3 Description of C++ program’s operation

A brief description of the C++ executable program’s operation is given. The program begins with a fill function on any depressions or sinks found on the DEM input. The highest elevation points on the DEM are then identified by the program and the flow direction is determined. Conceptually, if rainfall lands on a high point, the direction of flow can be in either one of the cardinal directions (ie. N, S, E and W) or in the diagonal directions (ie. NE, SE, SW, NW). In situations of converging flow, the flow direction of steepest descent takes precedence. The distance between the centers of one grid cell to the

next grid cell is then calculated by the C++ program as the non-cumulative slope length (NCSL). The logic of the program's method for calculating the L factor is summarized below (Hickey, 2000).

If the cell being calculated is a high point

Then $NCSL = 0.5$ (cell resolution size)

If the input cell's flow direction is in a cardinal (N,S,E,W) direction

Then $NCSL =$ (cell resolution size)

Otherwise (flow is in diagonal direction: NE, NW, SE, SW) and

$NCSL = 1.4142$ (cell resolution size)

A cumulative slope length is then computed by summing the NCSL from each grid cell, beginning at a high point and moving down along the direction of steepest descent. One important part of the C++ program is to recognize the areas where deposition is the dominant process instead of erosion. The assumption is that deposition would begin in areas where the slope angle decreases sufficiently enough so that overland flow can no longer transport sediment. The program has a function called the cutoff slope angle and is defined as the ratio of change in slope angle from one grid cell to the next along the flow direction. The default values for the slope cutoff angle are 0.5 for slope gradients greater than 5 % and 0.7 for slope gradients of less than 5%. These values are based on observations that deposition are easier to initiate on slopes with low gradients (Van Remortel *et al.*, 2004). When the slope angle decreases sufficiently, the cumulative slope length calculation stops. If the land surface extends further downhill, the calculations begin again. The C++ executable program applies the LS factor equations (3.7 and 3.8) to each grid cell of the DEM input. As an illustration, Fig. 3.6 shows a

square mesh of a hill slope with the flow path length colored in grey with a sketch of the side profile.

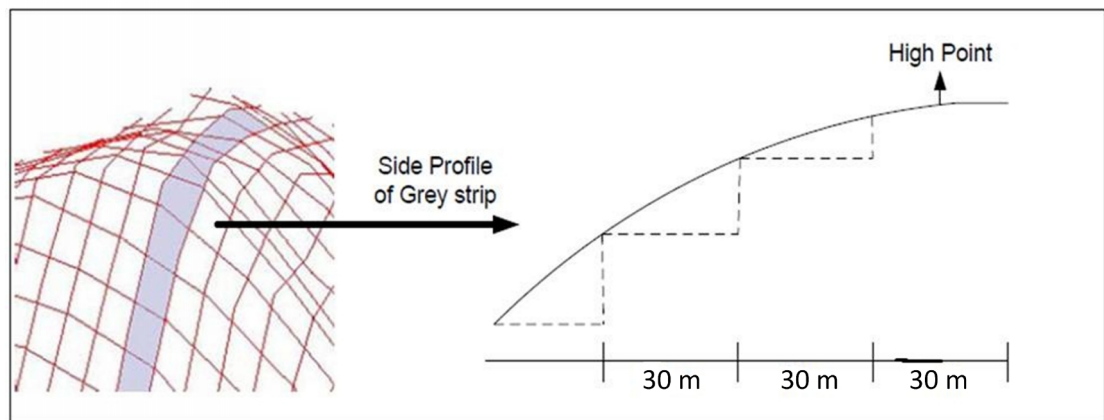


Fig. 3.6 Illustration of the LS factor algorithm (Van Remortel *et al.*, 2004).

The primary files used in the computation of the *LS* factors have the following file suffixes: *slp_ang* for the slope angle of each grid cell, *slp_len* for the cumulative slope lengths, and *slp_exp* which contain the slope dependant exponent *m* that each grid cell is raised to in the *L* factor equation. Recall that equation (3.7) for calculating the *L* factor is:

$$L = \left(\frac{\lambda}{22.13} \right)^m$$

Where,

λ is the horizontal projected slope length (meter) and *m* is the slope length exponent.

The C++ executable program computes the cumulative slope lengths as illustrated in Fig. 3.6 and substitutes this value as λ . After dividing by the reference slope length (22.13 meters or 72.6 ft) the expression is raised to the exponent *m*. The slope length exponent *m* is related to the variable λ ; which is a ratio of rill erosion (defined as erosion caused by overland flow) to interrill erosion (defined as erosion caused by rainfall). The method to

calculate the exponent m is given by equation (3.9) and (3.10) (McCool *et al.*, 1987). This equation determines the m exponent for areas with a moderate rill / interrill ratio. The low and high rill / interrill ratios are obtained by either halving or doubling the value of β respectively and substituting into the m equation. The C++ executable program uses a low rill / interrill ratio in its computation for the m exponent (Van Remortel *et al.*, 2004).

$$m = \frac{\beta}{(\beta + 1)} \quad (3.9)$$

Where,

m = exponent and value of β can be estimated as

$$= \frac{\left(\frac{\sin\theta}{0.0896}\right)}{[3.0 \times (\sin\theta)^{0.8} + 0.56]} \quad (3.10)$$

Where,

θ = slope angle (degree).

The calculated slope angle of each cell is first examined by the C++ program, and a sub-routine calls for a table lookup function. The range in which the slope angle falls within is identified and the corresponding m exponent value is assigned to that cell.

3.4.4 Crop/cover management factor (C)

The C factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow. It measures the effect of canopy and ground cover on the hydraulics of raindrop impact and runoff; of cover and management on the amount and rate of runoff; of coverage and management on soil structure, organic matter, soil tilth, evapo-transpiration and other soil characteristics; of carryover from

previous land use when land use changes; and of roughness from tillage or other disturbances. The C factor represents the effect of plants, soil cover, below-ground biomass, and soil-disturbing activities on soil erosion (Jones *et al.*, 1996).

According to the current demands, in terms of sustainable production, erosion by water should be considered a priority, since it is the consequence of inappropriate land use (Desilva *et al.*, 2010). At the same time, the vegetative soil cover highly contributes to a protection of top soils against erosive processes (Saumer *et al.*, 2010). On the landscape scale, quantities of soil erosion can be modeled with the well-established and worldwide-applied empirical Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; Renard *et al.*, 1997). Expressed as crop and management factor C, the soil vegetative cover is considered in the USLE. Its values range between 0 (very high crop cover protecting the topsoil against soil erosion) and 1 (no effect of the crop cover and high soil loss that is comparable to that of bare soil) (Saumer *et al.*, 2010).

However, the assessment of this factor in order to calculate the given soil loss rates is very time-consuming especially in mountainous areas, where access to terrain is often limited. Thus, large effort has been made on calculating and mapping the C factors for use in soil erosion modeling by means of Geographic Information System, remote sensing data and spectral indices (Suriyaprasit and Shrestha, 2008; Asis and Omasa, 2007).

Remote sensing techniques are generally employed for monitoring and mapping the condition of ecosystems of any part of earth. Vegetation cover is one of the most important biophysical indicators to soil erosion. Vegetation cover can be estimated using vegetation indices derived from satellite images. Vegetation indices allow us to delineate the distribution of vegetation and soil based on the characteristic reflectance patterns of green vegetation. The Normalized Difference Vegetation Index (NDVI), one of the vegetation indices, measures the amount of green vegetation. Now a day the Normalized Difference Vegetation Index is effectively used for the estimation of crop management factor (C) (Karaburun, 2010). The spectral reflectance

difference between Near Infrared (NIR) and red is used to calculate NDVI. The equation can be expressed as (Jensen, 2000):

$$\text{NDVI} = (\text{NIR} - \text{red}) / (\text{NIR} + \text{red}) \quad (3.11)$$

The NDVI has been used widely in remote sensing studies since its development (Jensen, 2005). NDVI values generally range from -1.0 to 1.0, where higher values are for green vegetation and low values for other common surface materials. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values (Lillesand *et al.*, 2004). More than 20 vegetation indices have been proposed and used at present. Since NDVI provides useful information for detecting and interpreting vegetation land cover it has been widely used in remote sensing studies (Gao, 1996; Myneni and Asrar, 1994; Sesnie *et al.*, 2008).

The value of C depends on vegetation type, stage of growth and cover percentage (Gitas *et al.*, 2009). Since NDVI values have correlation with C factor (De Jong, 1994; Tweddales *et al.*, 2000; De Jong and Riezebos, 1997). Many researchers used regression analysis to estimate C factor values for land cover classes in soil erosion assessment (Lin *et al.*, 2002; Symeonakis and Drake, 2004; Van der Knijff *et al.*, 2002).

The various studies assume that there exists a linear correlation between NDVI and C factor. Since C factor values range from 0 for well-protected soil to 1 for bare soil (Pierce *et al.*, 1986; Vicenta *et al.*, 2007) the C factor values for bare soil and forest land cover were set to 1 and 0, respectively in the regression analysis. Fig. 3.7 shows the graphical representation of the regression equation. The regression line that describes relationship between C and NDVI values and R shows the correlation coefficient of regression analysis.

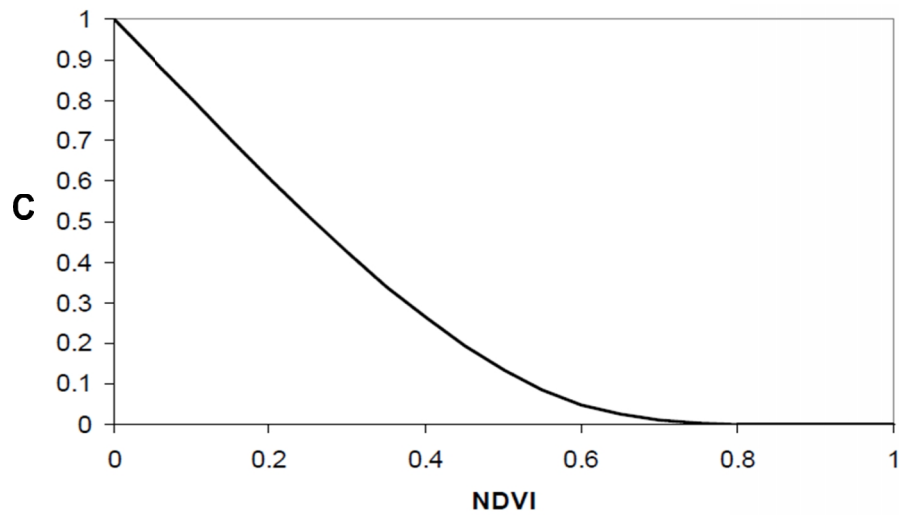


Fig. 3.7 Relation between NDVI and USLE C-factor.

The regression equation was found as:

$$\text{C factor} = 1.02 - 1.21 \times \text{NDVI} \quad (3.12)$$

In the present study land use/land cover map of the study was prepared with the help of ERDAS IMAGINE 9.2 software. For preparation of land use/land cover map, IRS P6 LISS III image of study area of January 2011 was used. In this Google Earth was used as means of verification of satellite image throughout the study. Then the values of C factor as suggested by Pandey *et al.* (2007) were attributed to the land use/land cover map and raster map of crop management factor (C) was prepared by using Conversion tool box of ArcGIS 9.3.

3.4.5 Conservation/Support practice factor (P)

Conservation or support practice factor (P) is basically the ratio of soil loss from a land having specified conservation practices to that from a land ploughed in direction parallel to slope if all other conditions remain unchanged (Wischmeier & Smith, 1978).

Support practice factor indicates the rate of soil loss according to the various cultivated lands on the earth. There are contour, cropping and terrace as its methods and it is important factor that can control the erosion (Shin, 1999). P values range from 0 to 1, whereby the value 0 represents a very good manmade erosion resistance facility and the value 1 no manmade resistance erosion facility (Sheikh *et al.*, 2011).

In this study land use/land cover map was also used for the preparation of P factor map. The values of conservation/support practice factor P as suggested by Dabral *et al.* (2008) and Aggarwal *et al.* (2000) were attributed to the land use/land cover map and a raster map of the P factor was prepared by using Conversion tool box of ArcGIS 9.3.

3.5 Assessment of annual rate of soil erosion

The USLE (Wischmeier and Smith, 1965) was combined with the ArcGIS 9.3 to calculate the average annual rate of soil loss (A) occurring within the Shakker River Watershed. Raster layers corresponding to each of the six USLE factors were created, stored and analyzed within the ArcGIS 9.3. This combination computes the simulated soil erosion potential for the entire watershed and areas of high soil erosion potential were identified. The grid cells in each layer overlap and the USLE computations were done by multiplying all the USLE factors together. Using USLE, annual rate of soil erosion was estimated for 15 years (1992 to 2006). Subsequently, annual rate of soil loss was estimated for each grid cell of the watershed, so that spatial distribution of annual rate of soil loss can be presented (Fig. 3.8).

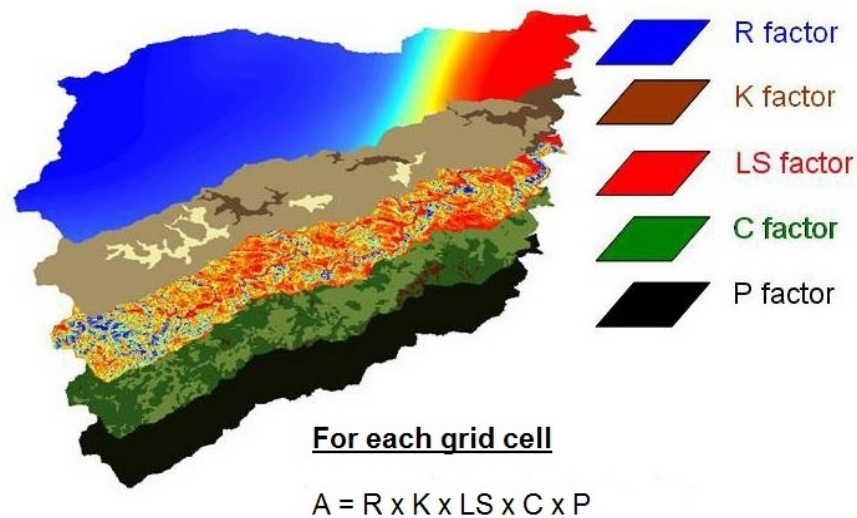


Fig. 3.8 Illustration of the USLE layers and how they overlap.

3.6 Comparison of simulated and observed sediment loss

The sediment loss estimated by the USLE was compared with observed sediment loss data of stream gauging station located at outlet of watershed. The data was collected from the Integrated Hydrological Data Book for non classified river basins published by Hydrological Data Directorate, Information Systems Organization, Water Planning & Projects Wing, Central Water Commission. The USLE model was validated with the data collected (Pandey *et al.*, 2007). The validation was done for 15 years (1992 to 2006) and percent deviation of the simulated sediment yield from the observed values was estimated. The under-prediction or over-prediction limits for the USLE model simulation are within 20 percent from the measured values and are considered as the acceptable levels of accuracy for the simulations (Bingner *et al.*, 1989). The USLE model was also validated by plotting the simulated values with observed values and the line of best fit with the above data and high coefficient of determination was obtained.

The detailed methodology, as discussed above for the estimation of average annual rate of soil loss using the Universal Soil Loss Equation (USLE) model and its validation with observed data is summarized and presented in following Fig. 3.9.

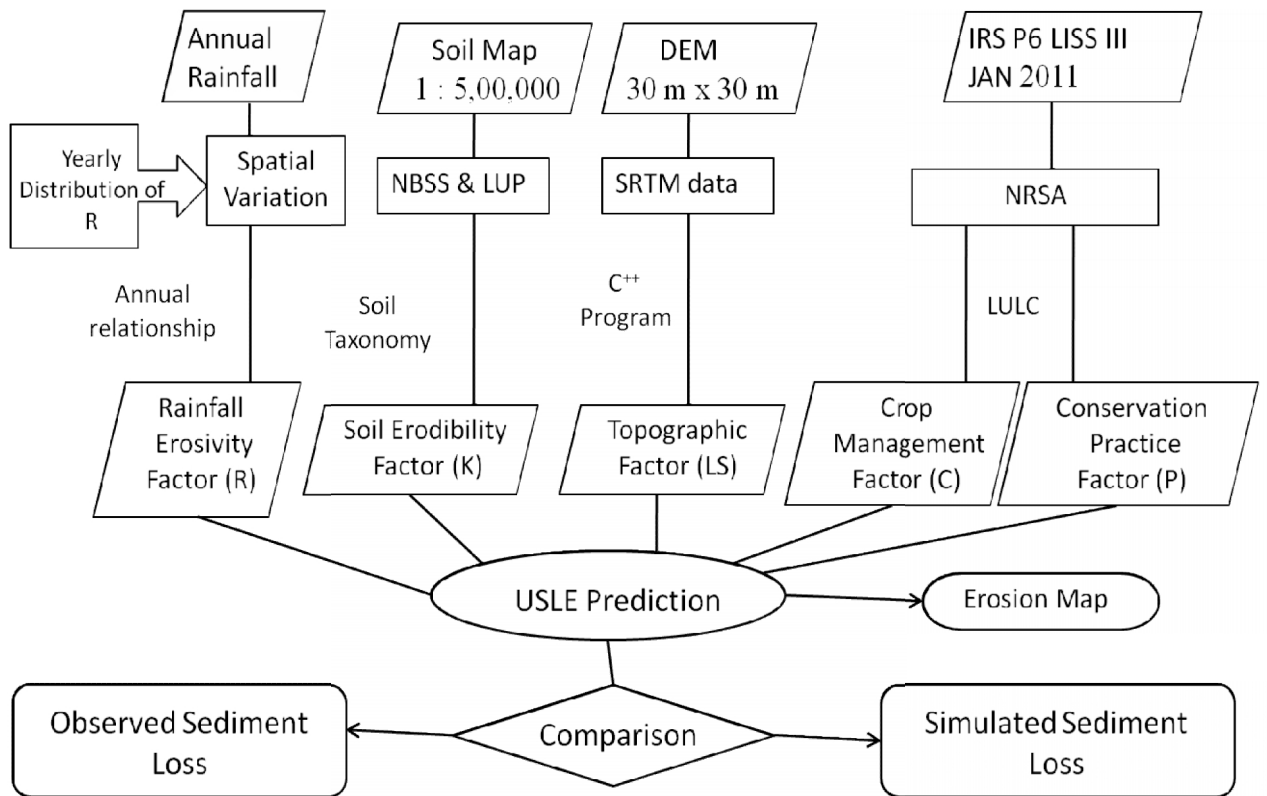


Fig. 3.9 Flow chart for estimation of annual rate of soil loss using USLE with GIS.

The results obtained by adoption of above discussed methodology are discussed in details in the next chapter.

RESULTS AND DISCUSSION

Using Remote Sensing and GIS, spatial erosion modeling by making use of universal soil loss equation (USLE) model was performed to predict annual rate of soil loss. Model estimated soil loss was validated with observed soil loss at watershed outlet. The results obtained in the study are presented as below:

4.1 Preparation of base map of the study area

For delineation of the Shakkar river watershed and preparation of drainage map a geo-coded Digital Elevation Model (DEM) generated from Shuttle Radar Topographic Mission (SRTM) data has been used. The digital elevation model (DEM) was downloaded from GLCF website (Global Land Cover Facility, Maryland, 2000) which was in Tagged Information File Format (TIFF) format with 30 meter ground resolution (Bhunia *et al.*, 2012). The drainage map of study area was prepared by processing this DEM and shown in following Fig. 4.1.

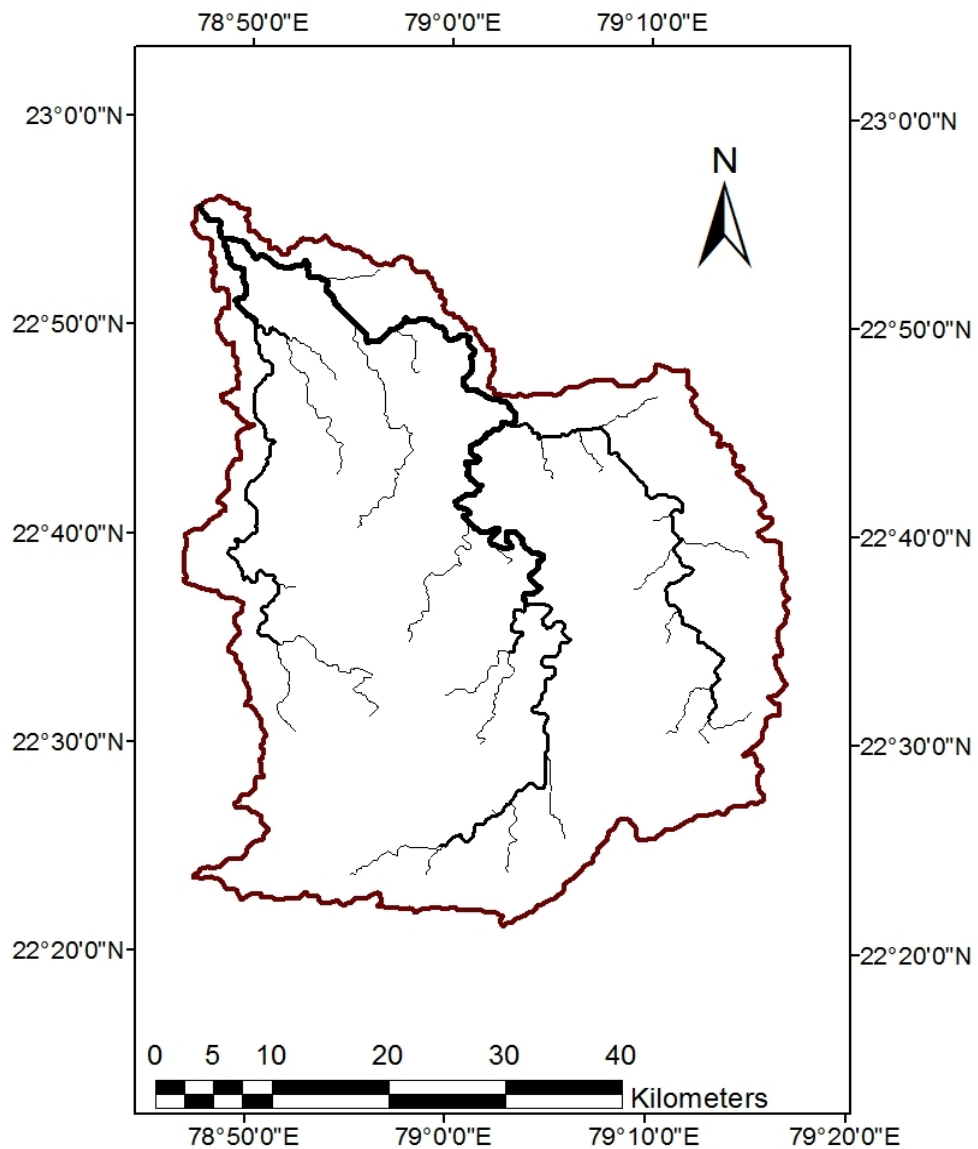


Fig. 4.1 Drainage map of the study area.

4.2 USLE based spatially distributed soil erosion estimation

The rate of soil erosion from an area is strongly dependent upon rainfall, topographic characteristics, soil and vegetation. These characters are found to vary greatly within a watershed. Therefore a method which takes these factors in to account while estimating soil erosion is expected to produce realistic estimates of soil erosion (Das, 2008). The universal soil loss equation (USLE) (Wischmeier and Smith, 1965) is one such equation that takes factors such as rainfall, topography, soil and land use into consideration while assessing soil erosion.

4.3 Development of data base for USLE

4.3.1 Rainfall erosivity factor (R)

Erosion by fluvial process is generally believed to be the single most important factor shaping the earth's sub-aerial landscape. The general factors influencing erosion are well known but erosive properties of rain play a key role in soil detachment by impact action (Phillips, 1990).

The rainfall erosivity factor (R) values for the study area were calculated using regression equation 3.4 following Babu *et al.* (2004) for Indian catchment. The R factor values calculated for three rain gauge stations falling in the study area are presented in following Table 4.1.

Table 4.1 Showing the annual rainfall and annual rainfall erosivity factor (R)

Station name	Year	Annual rainfall (mm)	Average annual rainfall (mm)	Annual rainfall erosivity factor (R)	Average annual rainfall erosivity factor (R)
Gadarwara	1992	909	913.26	426.77	428.54
	1993	1279		567.48	
	1994	860		408.41	
	1995	733		359.85	
	1996	558		293.62	
	1997	951		442.69	
	1998	395		231.60	
	1999	2210		921.45	
	2000	928		434.22	
	2001	993		458.80	
	2002	1031		473.28	
	2003	1033		474.00	
	2004	889		419.32	
	2005	1279		567.41	
	2006	684	341.42		
	1992	1015		467.28	
	1993	1276		566.42	

Harrai	1994	1794	1207	763.37	540.16
	1995	951		442.73	
	1996	834		398.31	
	1997	1436		627.18	
	1998	1011		465.49	
	1999	2023		850.32	
	2000	1018		468.23	
	2001	1149		517.97	
	2002	965		448.20	
	2003	1357		597.05	
	2004	973		451.20	
	2005	1202		538.11	
2006	1101	499.92			
Amarwara	1992	844	1141	402.30	515.08
	1993	1258		559.43	
	1994	1532		663.81	
	1995	1085		493.80	
	1996	899		423.27	
	1997	1907		805.97	
	1998	1212		541.91	
	1999	1713		732.55	
	2000	797		384.21	
	2001	625		319.15	
	2002	961		446.53	
	2003	938		437.98	
	2004	601		309.88	
	2005	1392		610.42	
2006	1351	594.69			

For preparation of R factor map the Thiessen polygon of the area was generated as stated earlier, by considering three rain gauge stations namely Gadarwara, Harrai and Amarwara falling in the study area. The Thiessen polygon of the area is presented in following Fig. 4.2.

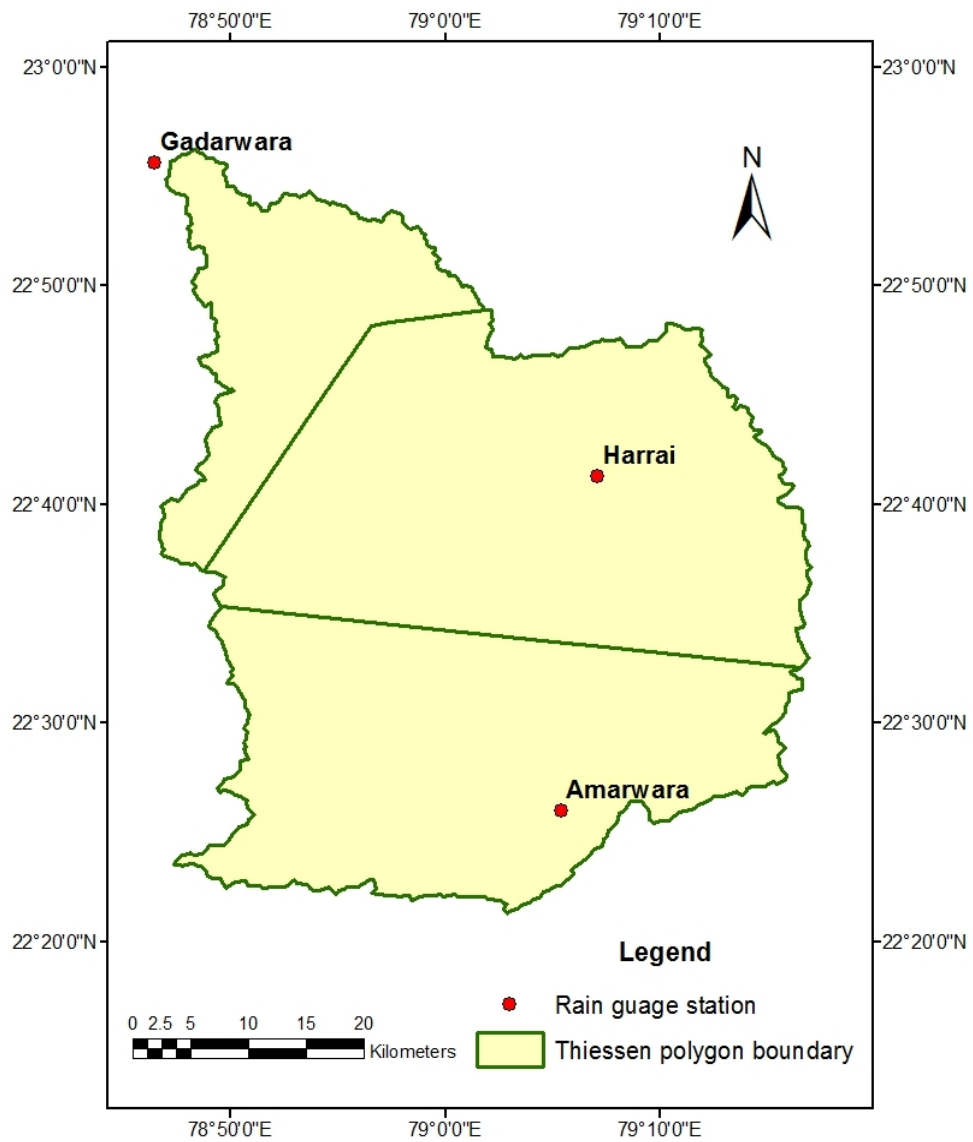


Fig. 4.2 Thiessen polygon of the study area.

Then the above estimated values of R factor were attributed to the respective polygon of rain gauge station. Then the raster maps of R factor were generated for individual year. The R factor map of the year 1992 is only shown for representation purpose in following Fig. 4.3.

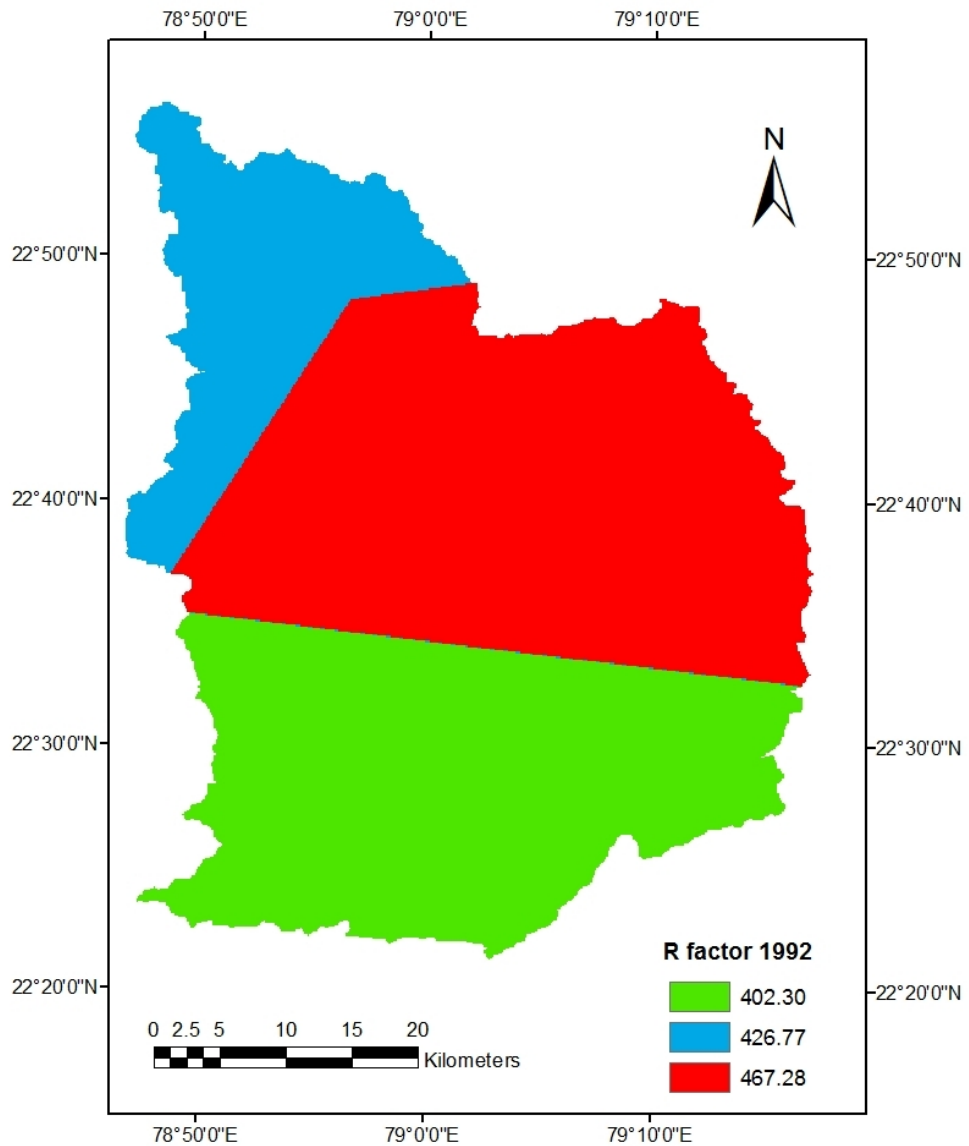


Fig. 4.3 Rainfall erosivity factor (R) map of year 1992.

4.3.2 Soil erodibility factor (K)

The soil-erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss. In practical terms, the soil-erodibility factor is the average long-term soil and soil-profile response to the erosive powers of rainstorms; i.e. the soil-erodibility factor is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes (Young *et al.*, 1987).

Using the methodology described earlier, map of K factor was generated. Areal extent of the different soil types present in the watershed and assigned value of K factor for each soil category is given in Table 4.2. Fig. 4.4 depicts spatial distribution of different soil types of Shakker river watershed.

Table 4.2 Area of each soil class, percent of watershed area and K factor.

Soil type	Soil class area (km²)	% of total watershed area	K factor
Clayey soil	840.12	37.79	0.04
Loamy skeletal soil	95.50	4.29	0.06
Silt loam soil	939.31	42.25	0.07
Loamy soil	318.61	14.33	0.08
Clay loam soil	29.56	1.32	0.11

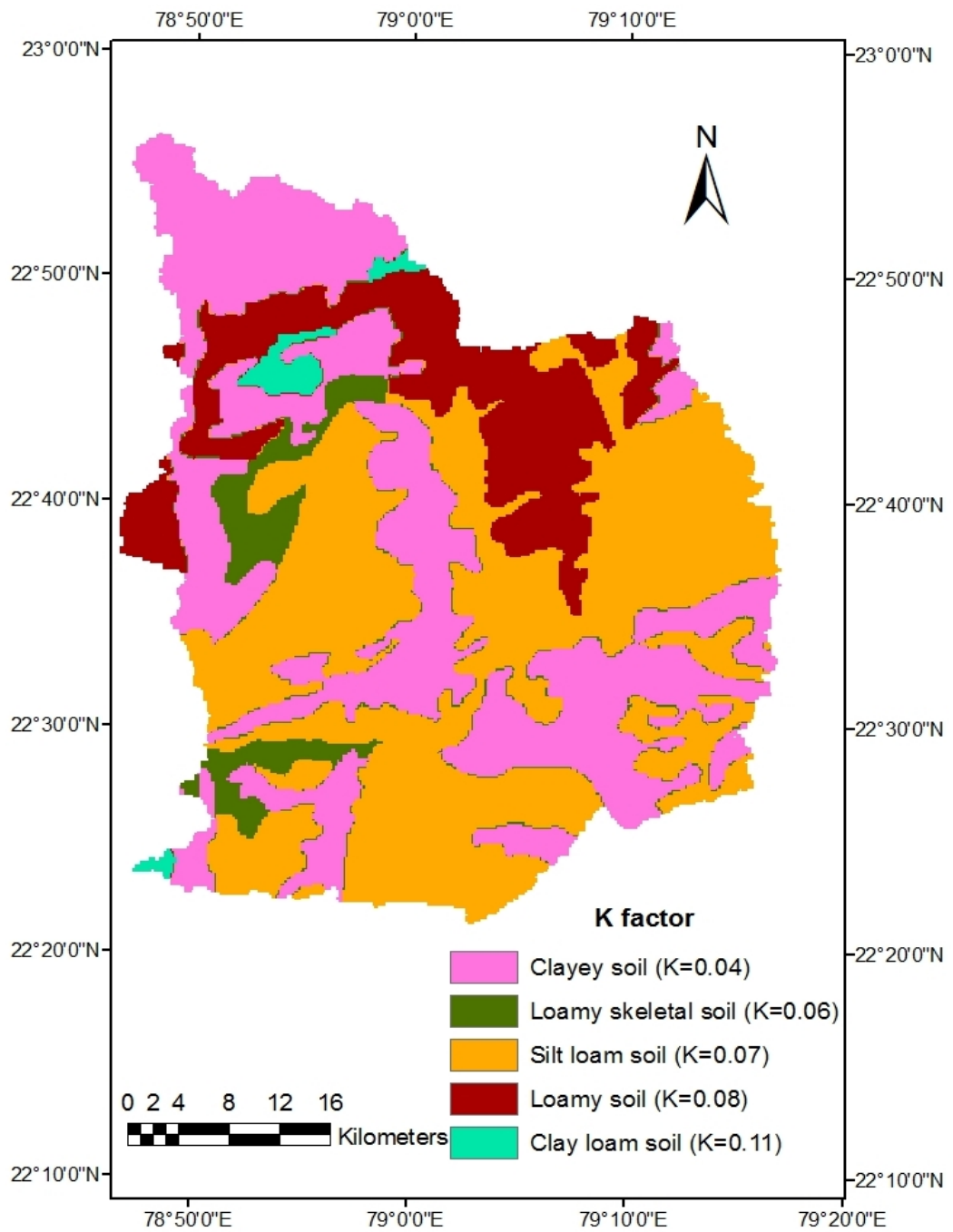


Fig. 4.4 Soil erodibility factor (K) map of Shaker river watershed.

4.3.3 Topographic factor (LS)

For computation of LS factor, the digital elevation model (DEM) of the area was used. The digital elevation model (DEM) of the study area was clipped from the downloaded SRTM data, after filling the sinks in the area is presented below in Fig. 4.5.

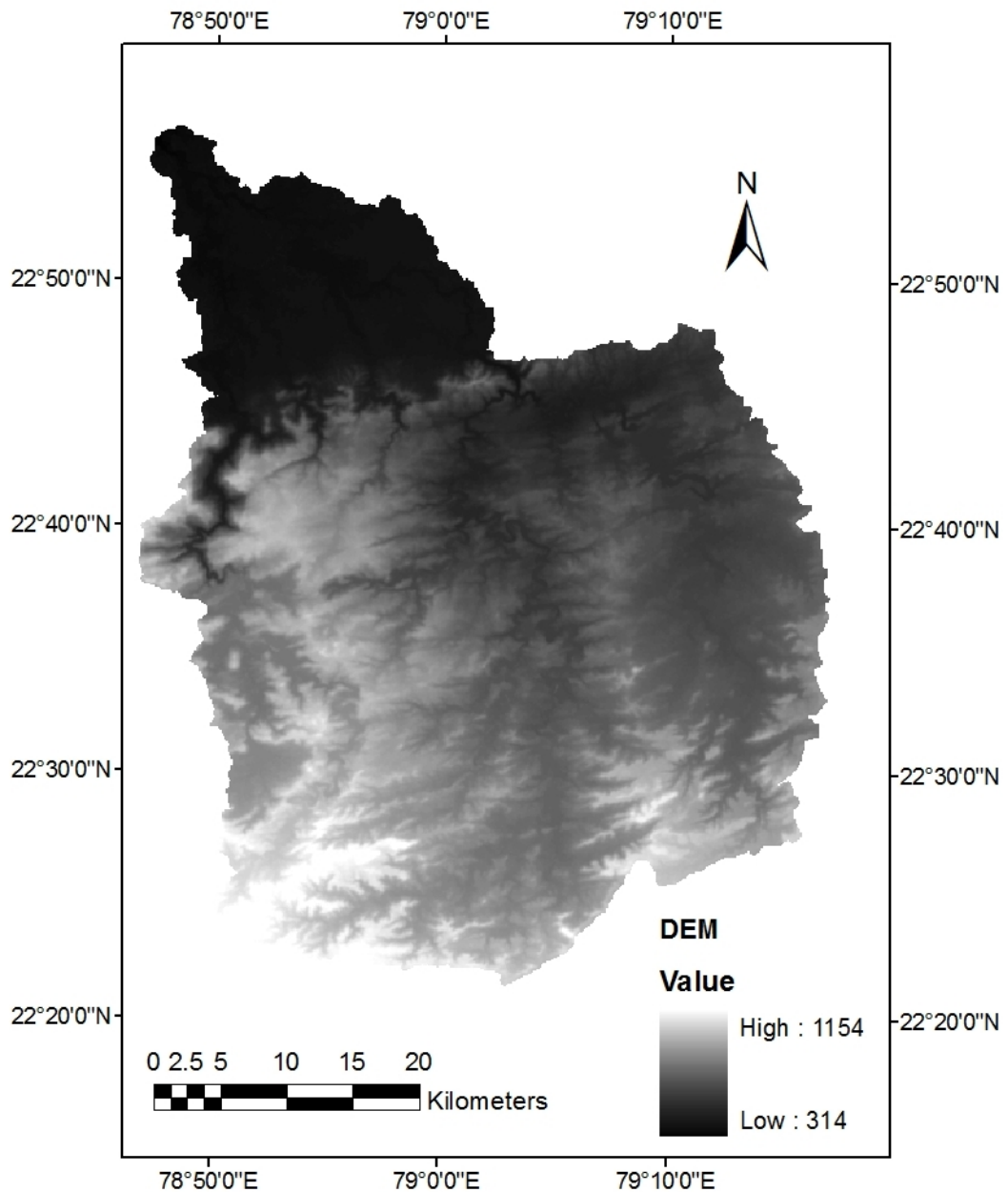


Fig. 4.5 Digital elevation model (DEM) of study area.

The topographic factor (LS) was calculated by using an executable C++ program following Khosrowpanah *et al.* (2007). For this first the slope map of area was prepared and using this map gradient of slope factor (S) and length of slope factor (L) map were prepared. The LS factor map was obtained by multiplying L factor and S factor maps in GIS environment. The LS factor for the watershed was found to be in the range of 0.1 to 90.98. The slope map of the watershed is presented in following Fig. 4.6 and LS factor map is presented in Fig. 4.7.

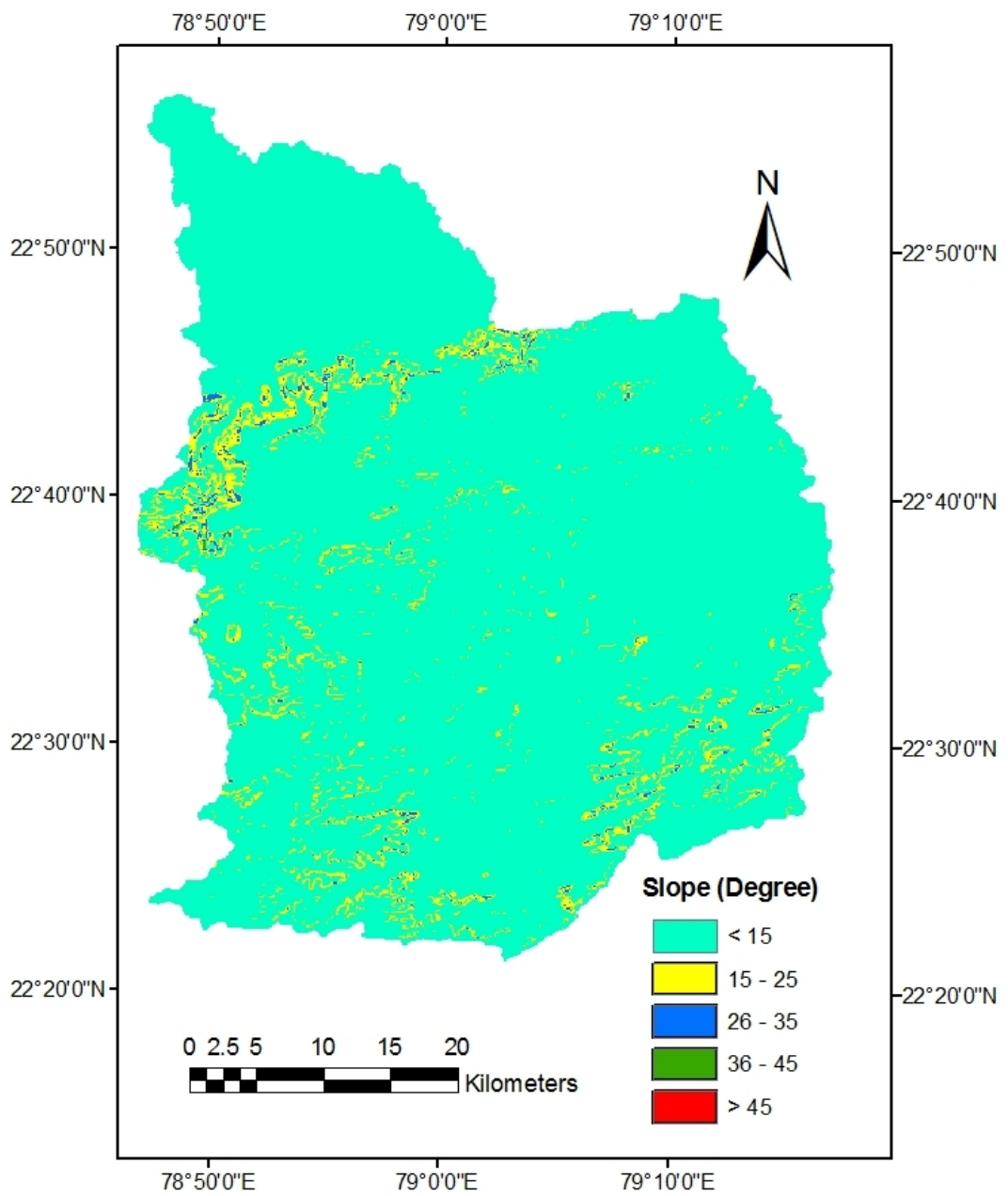


Fig. 4.6 Slope map of Shakker river watershed.

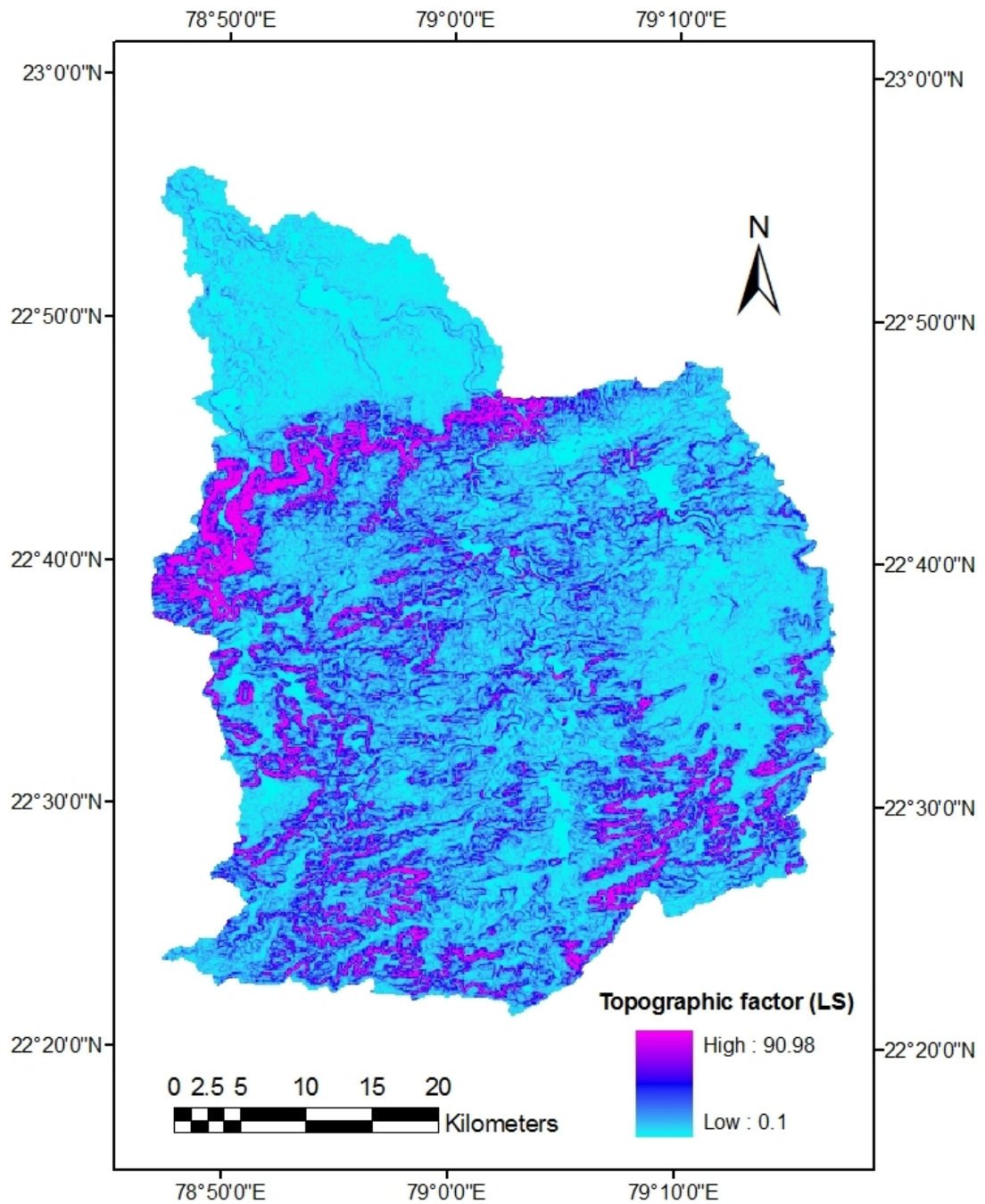


Fig. 4.7 Topographic factor (LS) map of study area.

4.3.4 Crop/cover management factor (C)

The C factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow. The C factor represents the effect of plants, soil cover, below-ground biomass and soil-disturbing activities on soil erosion (Jones *et al.*, 1996). In present study, the land use/land cover map was derived from the satellite

image as discussed earlier. It served as a guiding tool in the allocation of C and P factors for different land use classes (Dabral *et al.*, 2008). The C factor values were the representative values for allocating the USLE land cover and management factors corresponding to each crop/vegetation condition.

4.3.4.1 Land use/land cover classification of the study area

For getting information of the vegetation or ground cover, the land use land cover map of the study area was prepared with the help of ERDAS IMAGINE 9.2 software. As per this map the study area has been classified into seven land use/land cover classes namely; (1) agriculture and other vegetation, (2) fallow land, (3) waste land, (4) forest, (5) Habitation, (6) River and (7) water body. The land use/land cover map of the area is presented in following Fig. 4.8. The land use/land cover statistics of the study area is presented in Table 4.3.

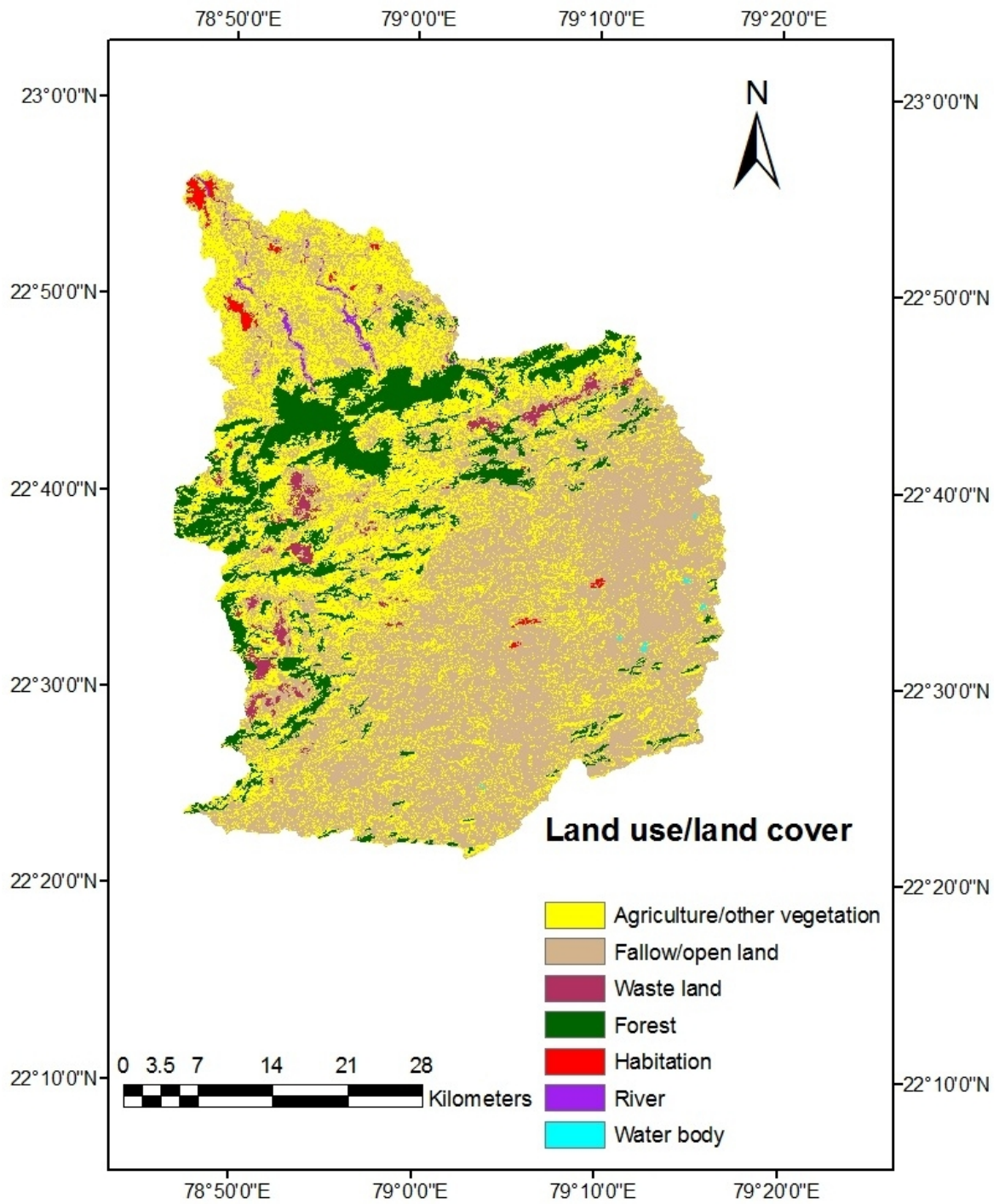


Fig 4.8 Land use/land cover map of the study area.

Table 4.3 Land use/land cover statistic of the study area.

Sr. No.	Land use/land cover class	Area (km²)	Percent of total watershed area
1	Agriculture/other vegetation	723.43	32.54
2	Fallow land	1184.42	53.28
3	Waste land	32.84	1.47
4	Forest	260.81	11.73
5	Habitation	11.50	0.51
6	River	9.53	0.42
7	Water body	1.10	0.049

Finally crop management factor was assigned for different land use patterns as suggested by Pandey *et al.* (2007) and shown in Table 4.4. The magnitude and spatial distribution of crop management factor are given in Fig. 4.9. Crop management factor was found to be in the range of 0.004 and 1.00.

Table 4.4 Crop/cover management factor for different land use/land cover classes.

Land use/land cover class	C factor
Agriculture/other vegetation	0.28
Fallow land	0.18
Waste land	1
Forest	0.004
Habitation	1
River	0.28
Water body	0.28

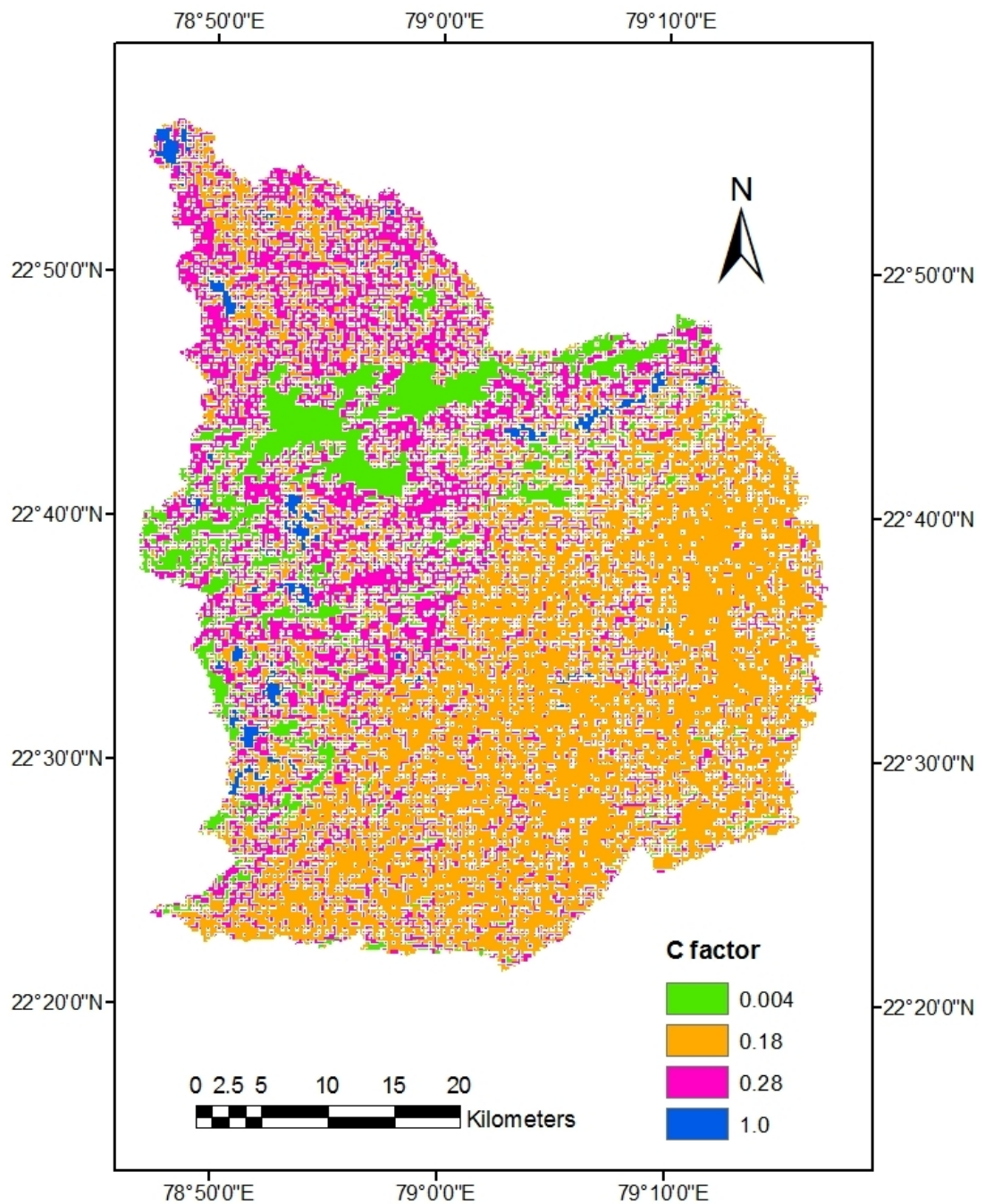


Fig. 4.9 Crop/cover management factor (C) map of study area.

4.3.5 Conservation/support practice factor (P)

Conservation or support practice factor (P) is basically the ratio of soil loss from a land having specified conservation practices to that from a land ploughed in direction parallel to slope if all other conditions remain unchanged (Wischmeier & Smith, 1978). In the study area, no major conservation practices are followed. Thus values for P factor assigned were

0.12 for agricultural area as sugarcane is the major crop in the study area and 1.0 for other area of the land use/land cover map. These values were based on the values suggested by Aggarwal *et al.* (2000) and Dabral *et al.* (2008). The magnitude and spatial distribution are shown in Fig. 4.10. The conservation/support practice factor was found to be 0.12 and 1.00.

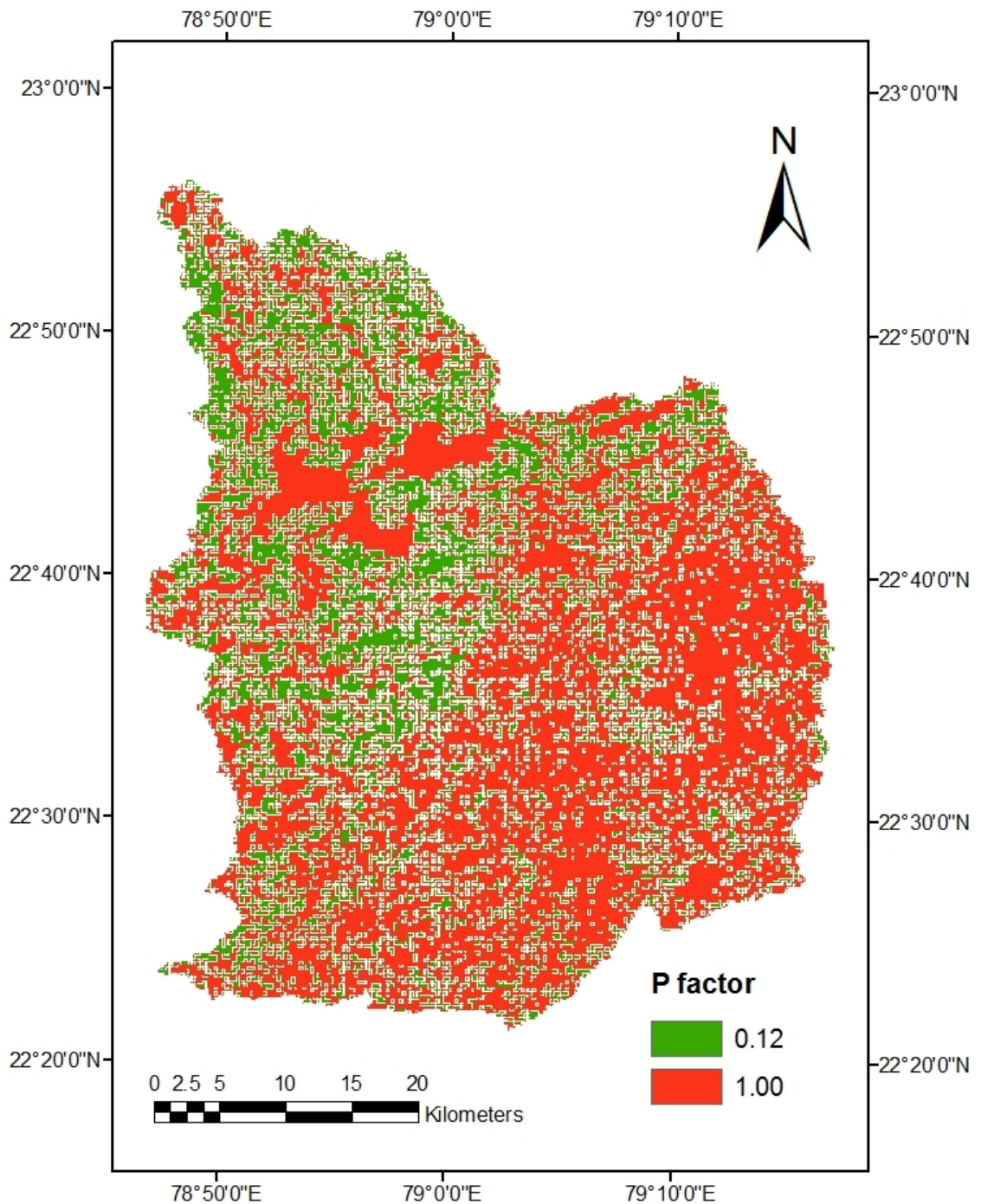


Fig. 4.10 Conservation/support practice factor (P) map of study area.

4.4 Assessment of annual rate of soil erosion

The USLE (Wischmeier and Smith, 1965) was combined with the ArcGIS 9.3 to calculate the average annual rate of soil loss (A) occurring within the Shakker River Watershed. Raster layers of rainfall erodibility factor (R), soil erodibility factor (K), topographic factor (LS), crop/cover management factor (C) and conservation/support practice factor (P) were created, stored and analyzed within the ArcGIS 9.3. This combination computes the simulated soil erosion potential for the entire watershed. Using USLE, annual rate of soil erosion was estimated for 15 years (1992 to 2006). The annual soil loss rates as estimated are presented in Table 4.5. The maps generated, showing annual rate of soil erosion are presented below from Fig. 4.11 to Fig. 4.25:

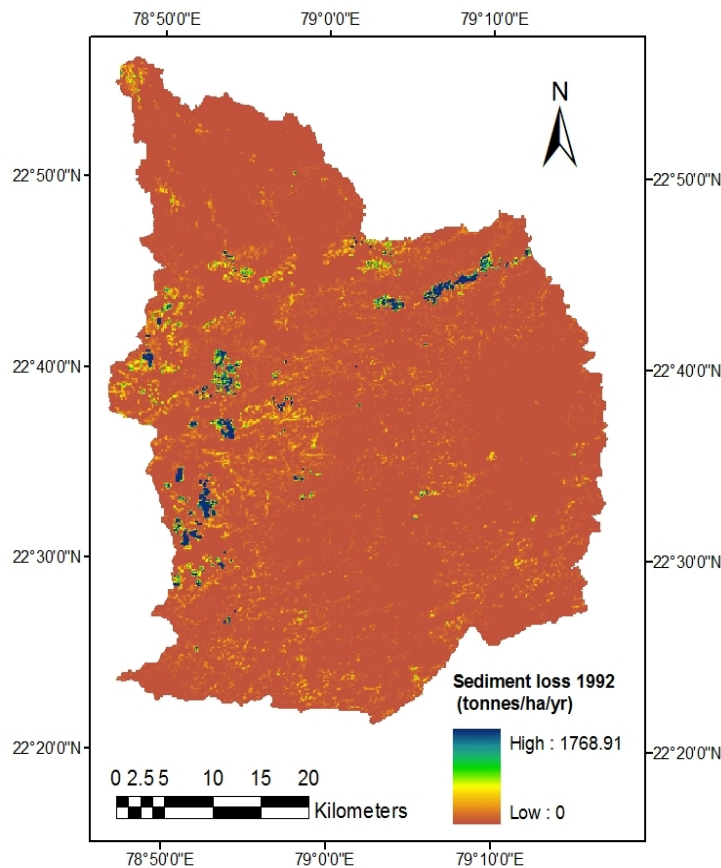


Fig. 4.11 Soil erosion map for year 1992.

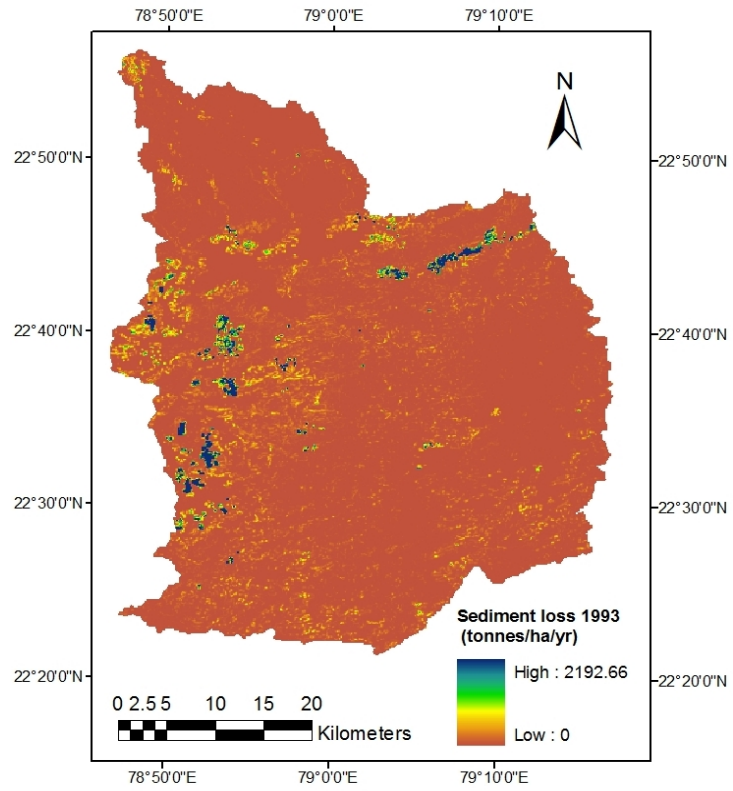


Fig. 4.12 Soil erosion map for year 1993.

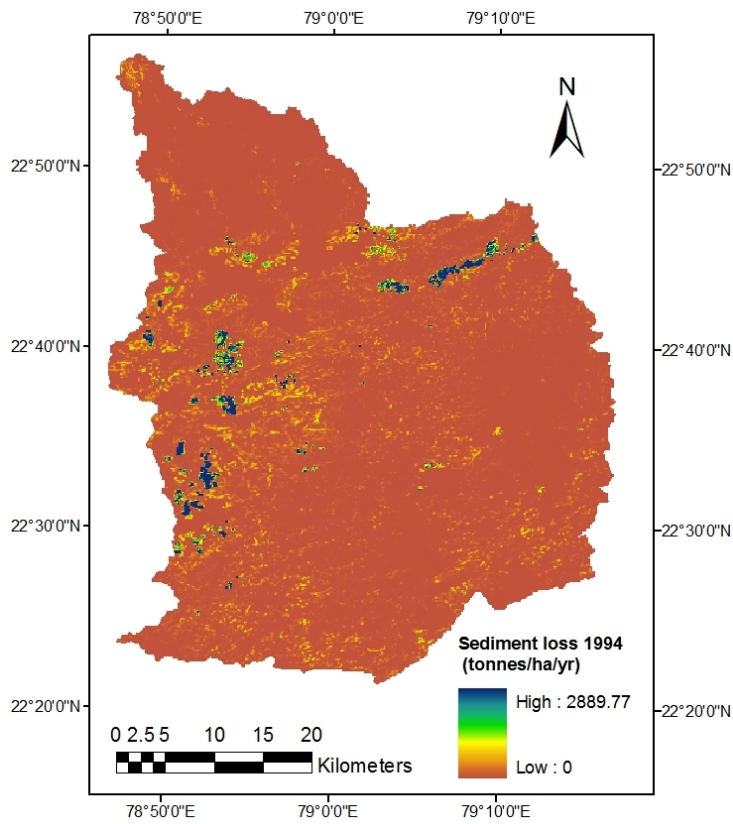


Fig. 4.13 Soil erosion map for year 1994.

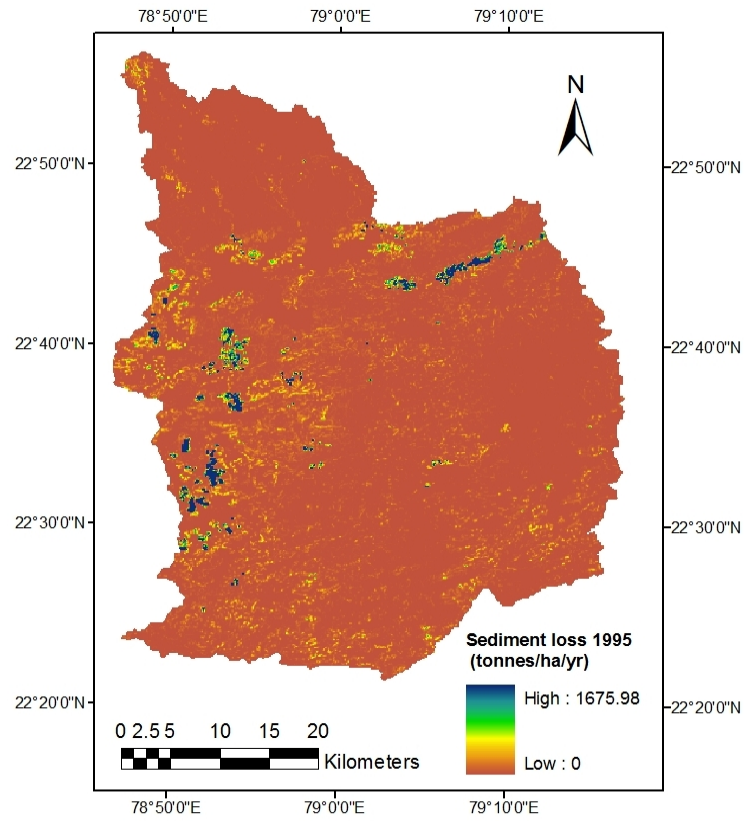


Fig. 4.14 Soil erosion map for year 1995.

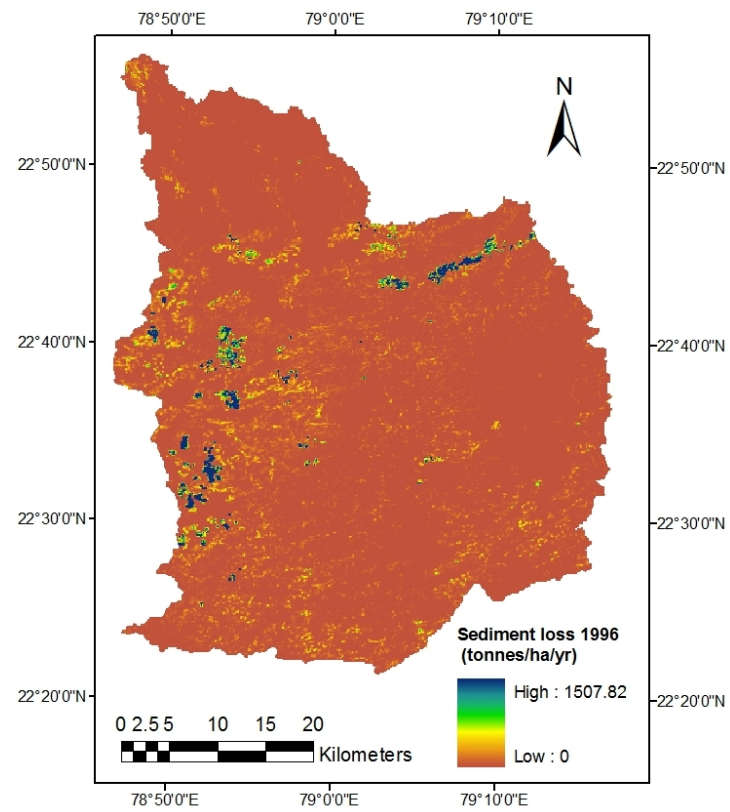


Fig. 4.15 Soil erosion map for year 1996.

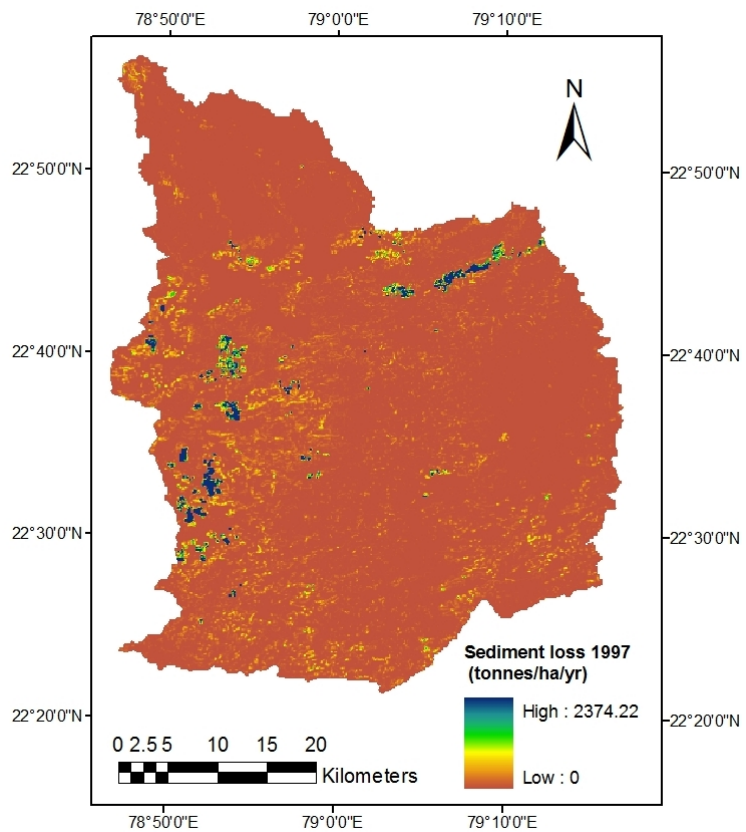


Fig. 4.16 Soil erosion map for year 1997.

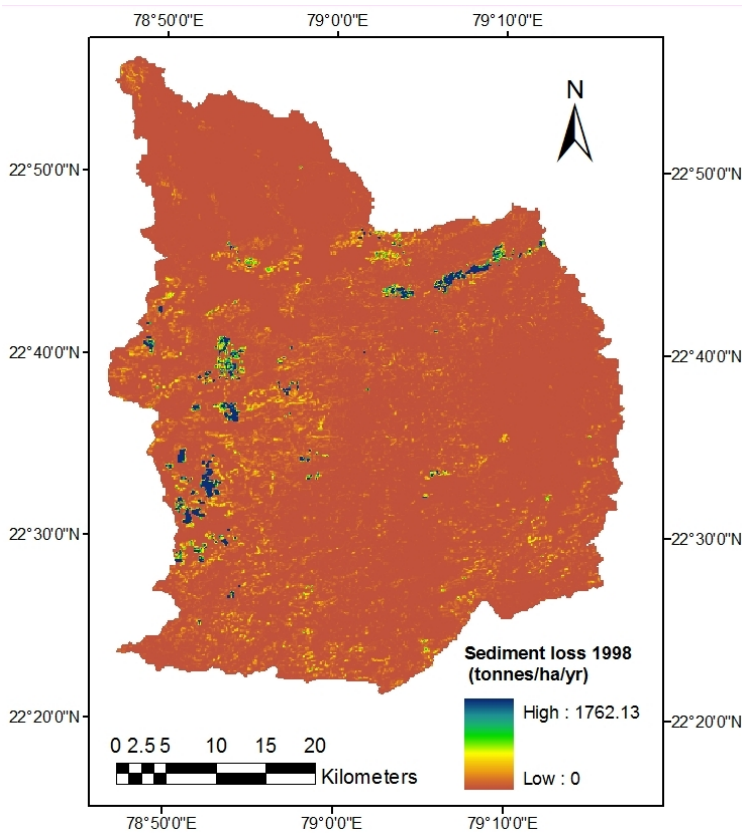


Fig. 4.17 Soil erosion map for year 1998.

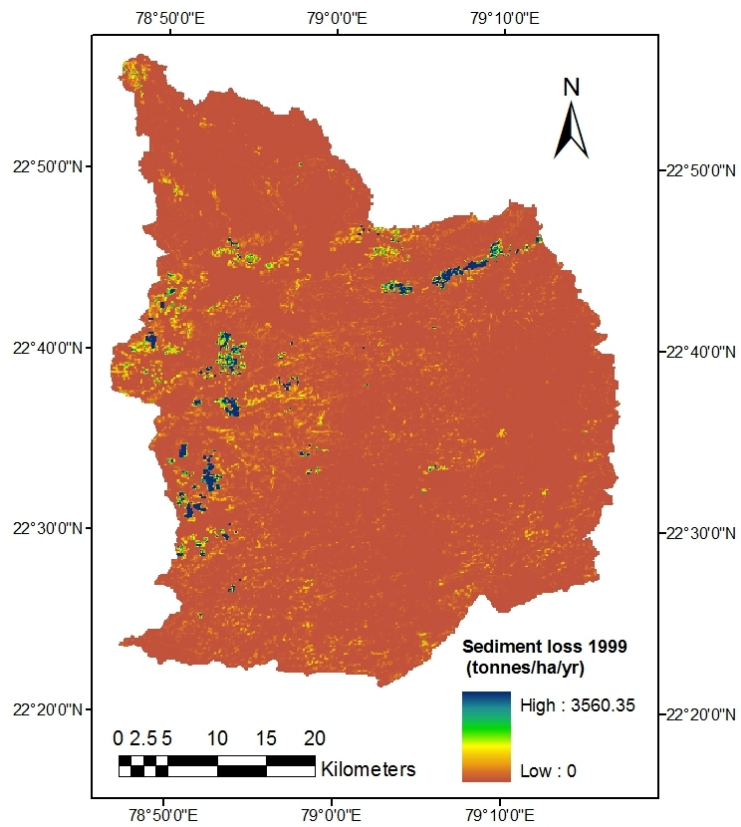


Fig. 4.18 Soil erosion map for year 1999.

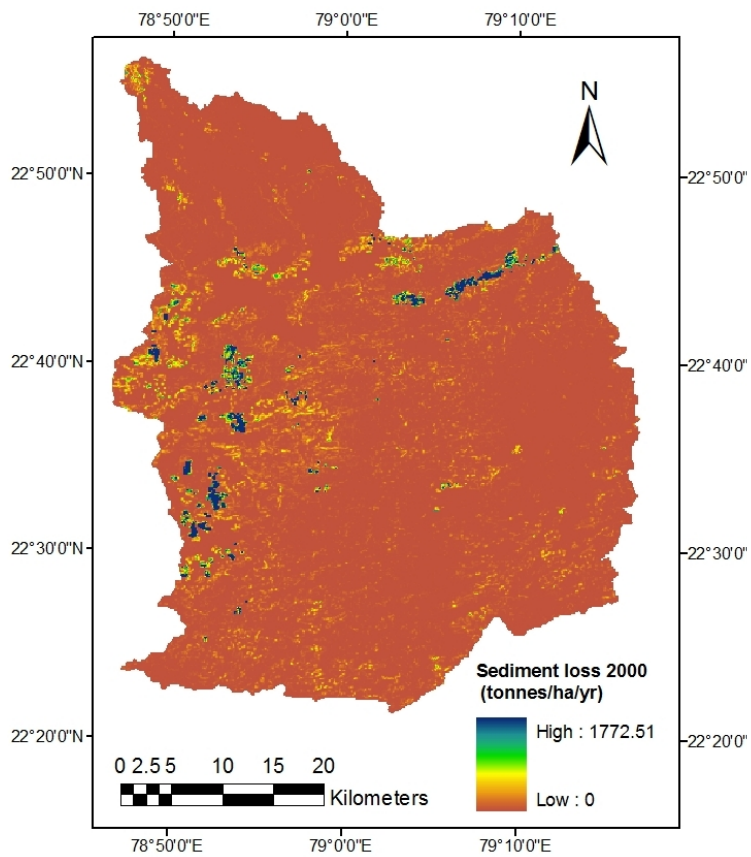


Fig. 4.19 Soil erosion map for year 2000.

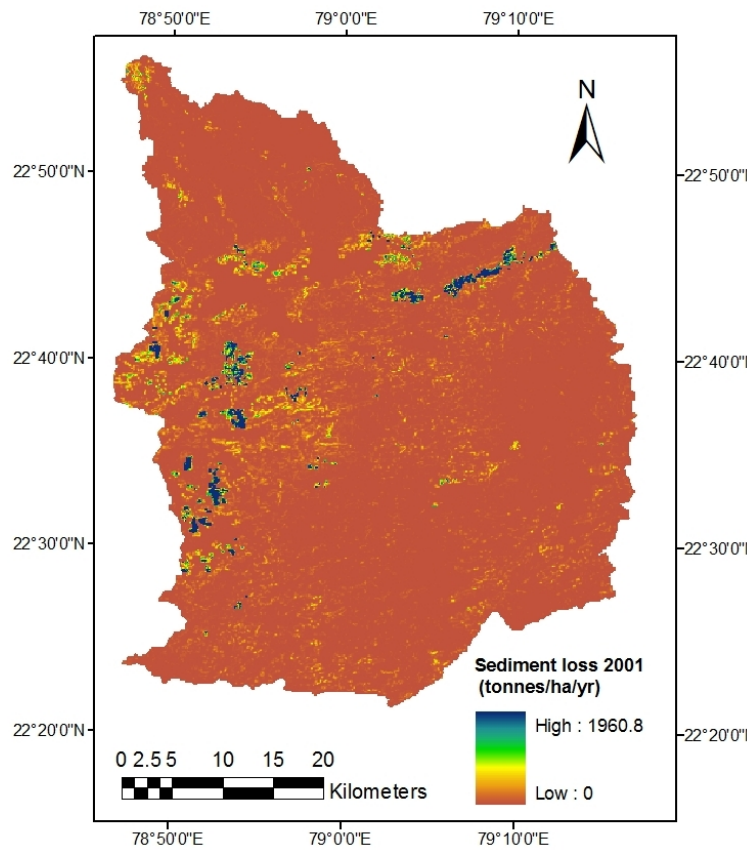


Fig. 4.20 Soil erosion map for year 2001.

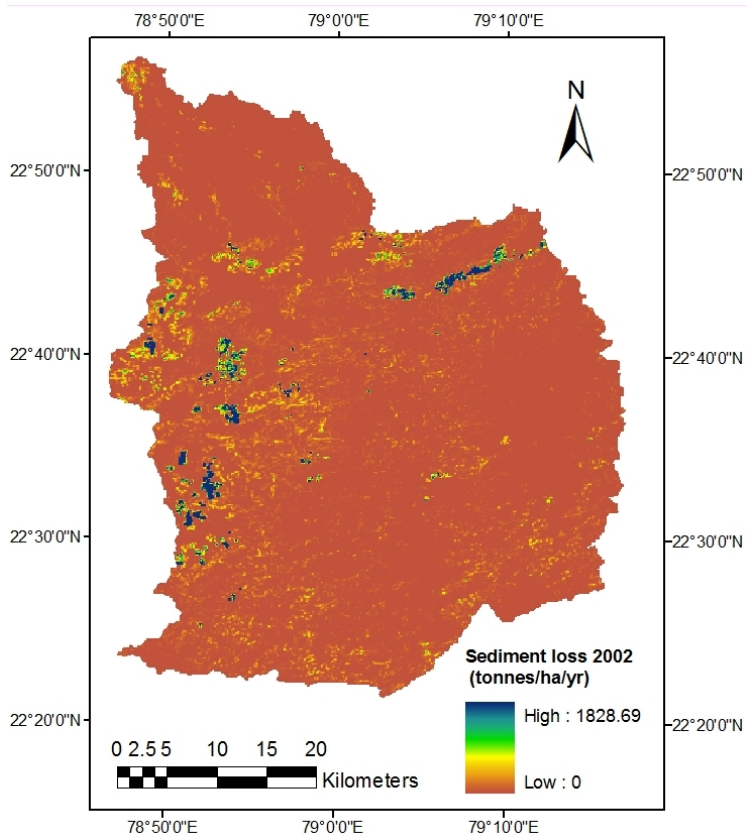


Fig. 4.21 Soil erosion map for year 2002.

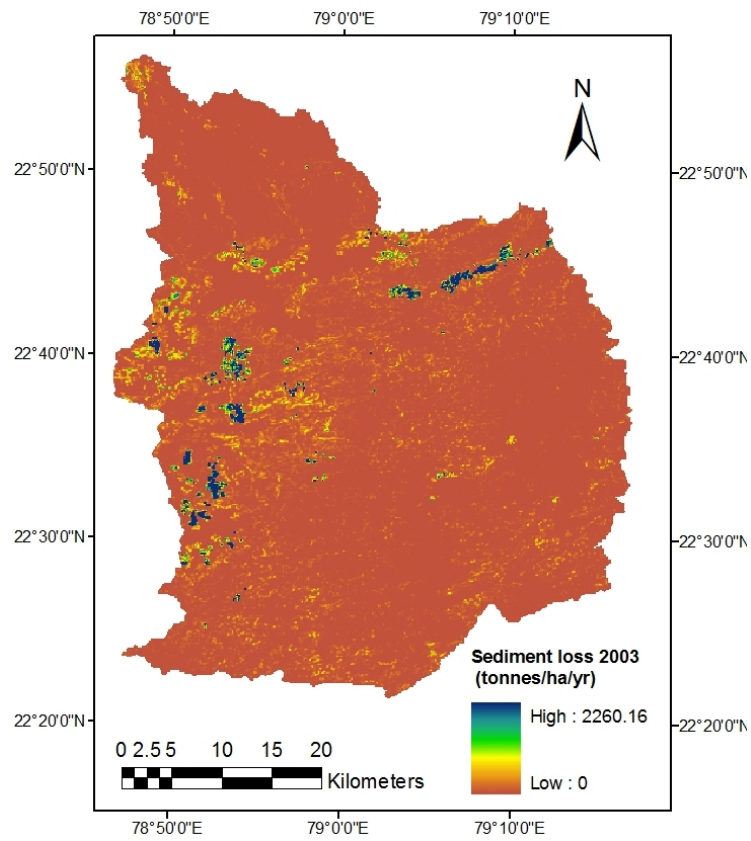


Fig. 4.22 Soil erosion map for year 2003.

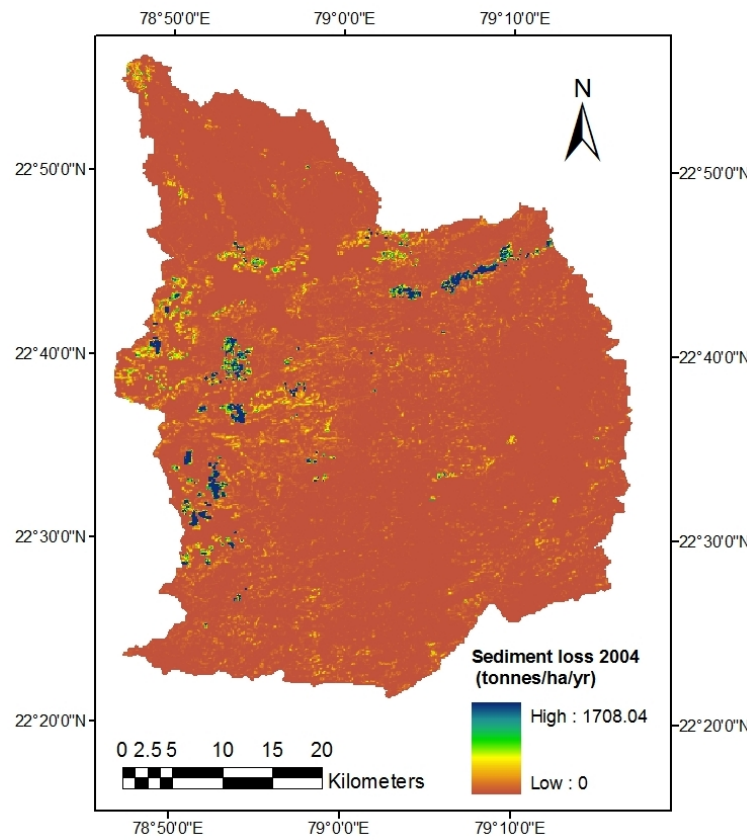


Fig. 4.23 Soil erosion map for year 2004.

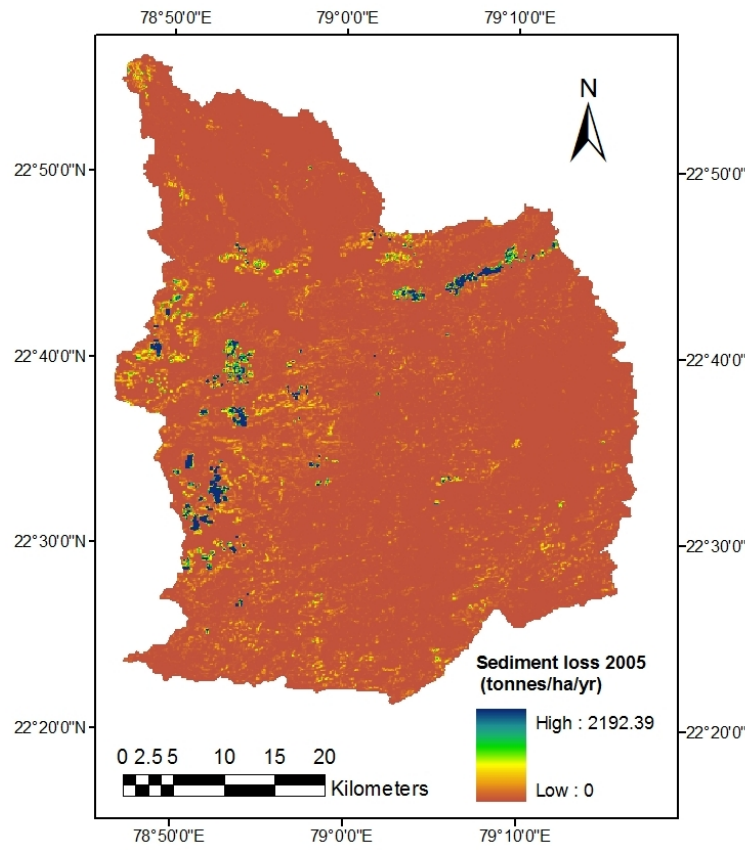


Fig. 4.24 Soil erosion map for year 2005.

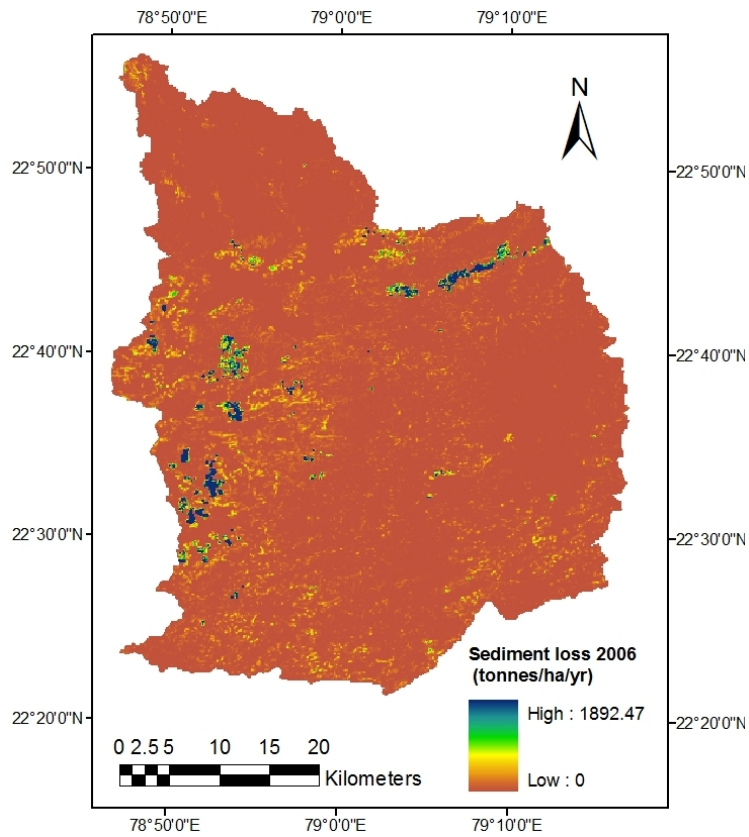


Fig. 4.25 Soil erosion map for year 2006.

4.5 Comparison of simulated and observed sediment loss

The simulated sediment yields and observed sediment yields are presented in Table 4.5

Table 4.5 Comparison of observed and simulated sediment yields.

Year	Observed sediment loss (tones/ha/yr)	Simulated sediment loss (tones/ha/yr)	Percent deviation
1992	6.37	7.43	16.64
1993	8.33	9.75	17.05
1994	10.75	11.79	9.67
1995	6.81	8.03	17.91
1996	5.91	6.98	18.10
1997	13.18	12.28	6.83
1998	9.67	8.45	12.62
1999	15.11	13.74	9.07
2000	7.09	7.28	2.68
2001	6.17	7.03	13.94
2002	6.57	7.79	18.57
2003	9.26	8.68	6.26
2004	5.93	6.45	8.77
2005	11.94	10.05	15.83
2006	7.85	9.32	18.73

It is evident from Table 4.5 that the percent deviation of the simulated sediment loss from the observed values varies in the range of 2.68 to 18.73 percent. The under prediction or over prediction limits for the USLE model simulation are within 20 percent from measured values and are considered as the acceptable levels of accuracy for the simulations (Pandey *et al.*, 2007). The USLE model was also validated by plotting the simulated sediment loss with observed sediment loss values as shown in Fig. 4.26. It can be seen from Fig. 4.26 that the points obtained by plotting the simulated values against observed values are very close to a line indicate that the differences between them are not significant. The best fit line between the

above data have high coefficient of determination (R^2) of 0.874 which shows that they are related by a straight line.

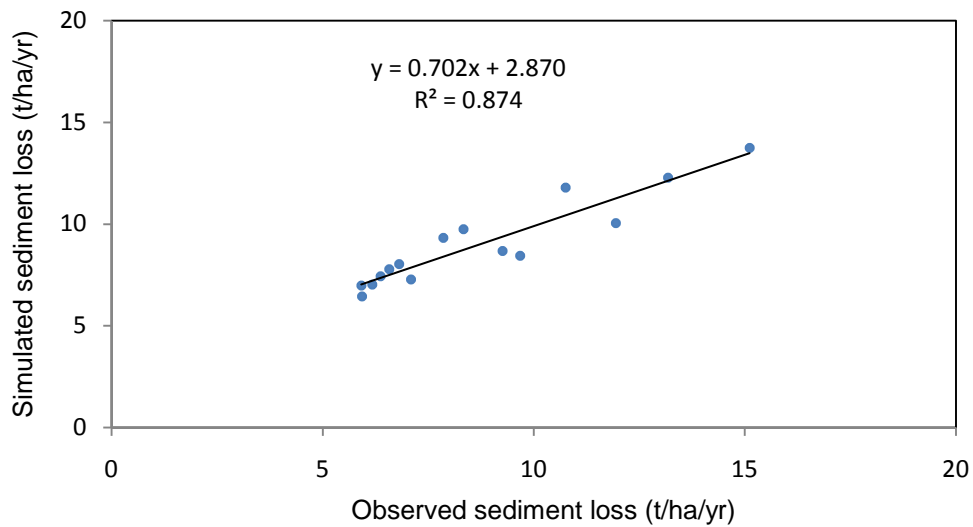


Fig. 4.26 Comparison between observed and simulated sediment loss.

The differences between the simulated and observed sediment yields from the USLE model are reinforcement of the knowledge that the erosion predictions in general contain large factors of error. Thus USLE can be successfully used for estimation of sediment loss from Shakker river watershed. The wide variation in sediment loss is mainly due to the variation in R factor. Minimum sediment loss in the range of 6.45 t/ha/yr was found in the year 2004, when the rainfall was less. Similarly highest value of sediment loss in the range of 13.74 t/ha/yr was found in the year 1999, when the rainfall was high. From this study the potential soil erosion for Shakker river watershed was found to be 9.84 t/ha/yr, on an average. It was found that there is a correlation between the rainfall characteristics and soil loss. An increase in rainfall intensity and amount is generally accompanied by an increase in soil loss.

Finally, average annual sediment loss was estimated on a cell basis and all the grid cells of watershed were grouped in to following scales of priority as given in Table 4.6.

Table 4.6 Showing the priority scales for soil erosion.

Sediment loss (t/ha/yr)	Soil erosion class
0 – 5	Slight
5 – 10	Moderate
10 – 20	High
20 – 40	Very high
40 – 80	Severe
>80	Very severe

These erosion classes are as per the guidelines adopted by Pandey *et al.* (2007) for Indian conditions. Thus Fig. 4.27 shows the magnitude and the spatial distribution of potential rates soil erosion in the Shakker river watershed on a cell basis.

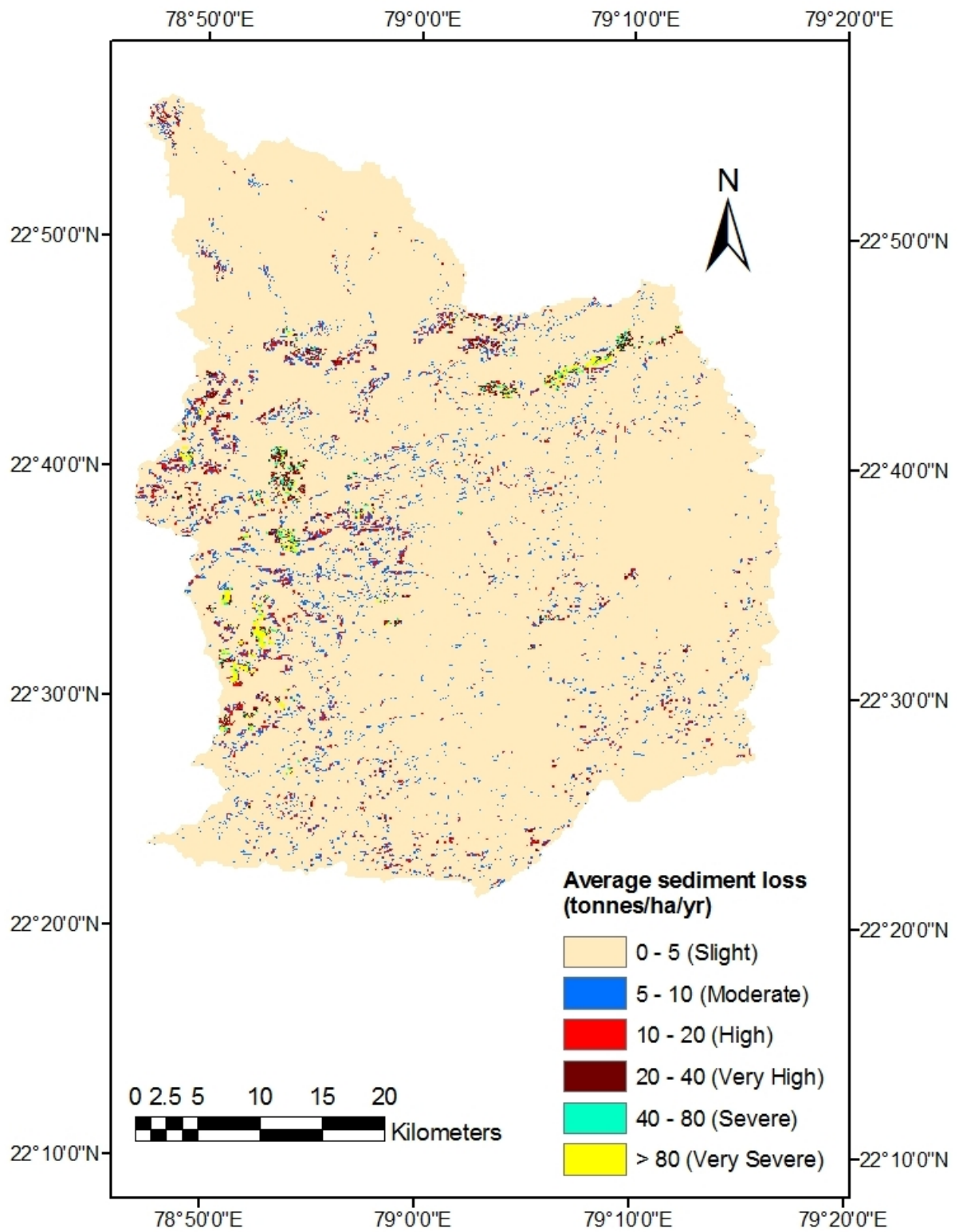


Fig. 4.27 Spatial distribution of sediment loss in Shaker river watershed.

SUMMARY AND CONCLUSIONS

5.1 Summary

Soil resource is important for Livelihood of the human being. Sustainable use of land depends upon conservation and potential use of soil and water resources. It is severely affecting global food security due to ever-growing population and its dependency for livelihood on limited natural resources. Landslide, mudslides, collapse of man-made terraces, soil loss from steep slopes and decline of forest/ pasture areas are the main reasons for land resource degradation. Soil erosion by water is the process of detachment or entrainment, transportation of surface soil particles from original location and accumulation of it to new depositional area.

Soil erosion is a global environmental crisis in the world today that threatens natural environment and also the agriculture. Soil erosion in India is one of the prime concerns of nation as agriculture is being adversely affected to great extent. Sediment is largely responsible for compromising the amount and quality of the water and silting the water bodies.

The soil erosion risk assessment can be helpful for land evaluation in region where soil erosion is the main threat for sustained agriculture, as soil is the basis of agricultural production. Erosion models are used to predict rates of soil erosion. Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. One of the major problems in testing these models is the generation of input data, that too spatially and conventional methods proved to be too costly and time consuming for generating this input data. With the advent of remote sensing technology, deriving the spatial information on input parameters has become more handy and cost-effective. Besides with the powerful spatial processing capabilities of Geographic Information System (GIS) and its compatibility with remote sensing data, the soil erosion modeling approaches have become more comprehensive and robust.

Keeping above perspectives in view the present study was undertaken with the specific objectives to assess annual rate of soil erosion from

watershed using distributed information for topography, land use and soil etc. using RS and GIS techniques and to compare the simulated sediment loss with observed sediment loss.

In present study the Shakker river watershed, lying in Narmada basin situated in Narsinghpur and Chhindwara districts of Madhya Pradesh was selected. The study area lies between 22°20'N to 23°00'N latitude and 78°40'E to 79°20'E longitudes with elevation range from 314 to 1154 m above MSL (mean sea level). The watershed covers 2223 km² of total geographical area up to the gauging point. Methodology adopted in this study involves the preparation of thematic maps of USLE factors like rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS), crop/cover management factor (C) and conservation/support practice factor (P) and multiplying these all maps/layers in GIS environment to assess the annual rate of soil erosion. Finally the simulated sediment loss values were compared with observed values.

5.2 Conclusions

On the basis of this study, following conclusions can be drawn:

1. The annual rate of soil erosion that occurs in the study area have been estimated by integrating remote sensing (RS) and geographic information system (GIS) with soil erosion prediction model universal soil loss equation (USLE). The rate of soil erosion was estimated for 15 years (1992 to 2006). In this period minimum sediment loss in the range of 6.45 t/ha/yr was found in the year 2004, when the rainfall was less. Similarly highest value of sediment loss in the range of 13.74 t/ha/yr was found in the year 1999, when the rainfall was high. The wide variation in sediment loss is mainly due to the variation in R factor. From this study the potential soil erosion for Shakker river watershed was found to be 9.84 t/ha/yr, on an average. It is found that there is a correlation between the rainfall characteristics and soil loss.
2. The simulated sediment loss as obtained from USLE was compared with observed values and it is found that the percent deviation of the

simulated sediment loss from the observed values varies in the range of 2.68 to 18.91 percent. The USLE model was also validated by plotting the simulated sediment loss versus observed values and it was observed that the points obtained by plotting the simulated values against observed values are very close to a line indicating that their differences are not significant. The best fit line between the above data have high coefficient of determination of 0.873 which shows that they are related by a straight line. Thus USLE can be successfully used for estimation of sediment loss from Shakker river watershed.

SUGGESTION FOR FURTHER WORK

The elaborative study on the runoff estimation from the watershed should be done in order to validate sediment and runoff estimation models after being integrated with RS and GIS techniques in the area.

REFERENCES

- Aggarwal, S. P., R. P. Desilva and M. H. Mohamed Rinos (2000). Application of Remote Sensing and GIS on soil erosion assessment at Bata River Basin, India. Natural Hazard Management Booklet.
- Alejandra, M. R. (2008). Soil erosion calculation using remote sensing and GIS in Río Grande De Arecibo watershed, Puerto Rico. ASPRS, Annual Conference Portland, Oregon.
- Alejandro, M. A. and K. Omasa (2007). Estimation of vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data. ISPRS, Journal of Photogrammetry & Remote Sensing, 62: 309–324.
- Arekhi, S., A. Shabani and S. K. Alavipanah (2011). Evaluation of integrated KW-GIUH and MUSLE models to predict sediment yield using geographic information system (GIS) (Case study: Kengir watershed, Iran). African Journal of Agricultural Research Vol. 6(18): 4185-4198.
- Arekhi, S., A. D. Bolourani, A. Shabani, H. Fathizad and S. Ahamdyasbchin (2012). Mapping Soil Erosion and Sediment Yield Susceptibility using RUSLE, Remote Sensing and GIS (Case study: Cham Gardalan Watershed, Iran). Advances in Environmental Biology, 6(1): 109-124.
- Asis, A. M. and K. Omasa (2007). Estimation of Vegetation Parameter for Modeling Soil Erosion Using Linear Spectral Mixture Analysis of Landsat ETM Data. ISPRS Journal of Photogrammetry and Remote Sensing, 62(4): 309–324.
- Avanzi, J. C., S. Beskow, N. Curi, C. R. Mello, L. D. Norto and M. R. Viola (2009). Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. Catena 79: 49–59.

- Babu, R., B. L. Dhyani and N. Kumar (2004). Assessment of erodibility status and refined Iso-erodent map of India. *Indian Journal of Soil Conservation*, 32 (3): 171-177.
- Bahrami, H. A., A. R. Vaezi, S. H. R. Sadeghi and M. H. Mahdian (2011). Developing A Nomograph For Estimating Erodibility Factor Of Calcareous Soils In North West Of Iran. *International Journal of Geology*, 4 (5).
- Batistella, M., D. Lu, G. Li and G. S. Valladares (2004). Mapping soil erosion risk in Rondo Nia, Brazilian Amazonia: using RUSLE, Remote Sensing and GIS. *Land Degradation. Develop.* 15: 499–512.
- Beasley, D. B., L. F. Huggins and E. J. Monke (1980). ANSWERS: A model for watershed planning. *Trans. ASAE*, 23: 938-944.
- Bhaware, K. O. (2006). Soil erosion risk modeling and current erosion damage assessment using remote sensing and GIS techniques. Published Master's thesis, Andhra University, India.
- Bhunia, G. S., B. Pal and S. Samanta (2012). Quantitative analysis of relief characteristics using space technology. *International Journal of Physical and Social Sciences*, 2(8).
- Bienes, R., R. P. Rodriguez and M. J. Marques (2007). Spatial variability of the soil erodibility parameters and their relation with the soil map at subgroup level. *Science of the Total Environment*, 378: 166–173.
- Bingner, R. L., C. E. Murphee and C. K. Mutchler (1989). Comparison of sediment yield models on various watersheds in Mississippi. *Trans. ASAE*, 32(2): 529-534.
- Cohen, M. J., K. D. Shepherd and M. G. Walsh (2005). Empirical formulation of the USLE for erosion risk assessment in a tropical watershed. *Gesderma*, 124: 235-252.

- Dabral, P. P., N. Baithuri and A. Pandey (2008). Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. *Water Resources Management* 22: 1783–1798.
- Das, D. J. (2008). Identification of critical erosion prone areas for watershed prioritization using GIS and remote sensing. Master's Dissertation, Indian Institute of Technology, Roorkee.
- Das, G. S. (2010). Hydrology and Soil Conservation Engineering including Watershed Management. 2nd edition (Eastern Economy Edition), PHI Learning, Private Limited, New Delhi.
- De Jong, S. M. (1994). Application of Reflective Remote Sensing for Land Degradation Studies in a Mediterranean Environment. University of Utrecht.
- De Jong, S. M. and H. T. Riezebos (1997). SEMMED: a distributed approach to soil erosion modelling. In: Spiteri, A. (Ed.), *Integrated Applications for Risk Assessment and Disaster Prevention for the Mediterranean*. Balkema, Rotterdam, pp. 199–204.
- Dengiz, O., T. Yakupoglu and O. Baskan (2009). Soil erosion assessment using geographical information system (GIS) and remote sensing (RS) study from Ankara-Guvenc Basin, Turkey. *Journal of Environmental Biology*, 30(3): 339-344.
- Desilva, R. P., N. D. K. Dayawansa and K. D. B. L. Jayarathne (2010). GIS Based Analysis of Biophysical and Socio - Economic Factors for Land Degradation in Kandaketiya DS Division. *Tropical Agricultural Research* Vol. 21(4): 361–367.
- Douros, K., I. Z. Gitas, C. G. Karydas, C. Minakou and G. N. Silleos (2009). Multi-temporal soil erosion risk assessment in North Chalkidiki using a Modified USLE raster model. *EARSeL, e-Proceedings*, 8(1).
- Dudal, R. (1981). An evaluation of conservation needs. *Soil Conservation: Problems and Prospects*. Wiley, New York.

- Dwivedi, R. S., T. Ravi Sankar, L. Venkataratnam, R. L. Karale, S. P. Gawande, K. V. Seshagin Rao, S. Senchaudhary, K. R. Bhaumik and K. K. Mukharjee (1997). The inventory and monitoring of eroded lands using remote sensing data. *International Journal of Remote Sensing* 18(1): 107–119.
- Eiumnoh, A. (2000). Integration of Geographic Information System (GIS) and Satellite Remote Sensing (SRS) for watershed management. School of Environment, Resources and Development, Asian Institute of Technology, Thailand.
- Elangovan, A. B. and R. Seetharaman (2011). Estimating Rainfall Erosivity of the Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu, India. *International Conference on Environmental and Computer Science*, Singapore, Vol. 19.
- El-Swaify, S. A. (1997). Factors affecting soil erosion hazards and conservation needs for tropical steep lands, *Soil Technology*, 11(1): 3-16.
- ERDAS IMAGINE Tour Guides, ERDAS IMAGINE Field Guides, ERDAS IMAGINE V 8.5 (2001). Inc. Atlanta, Georgia, USA.
- ESRI (Environmental Systems Research Institute) (1994). Cell based modeling with grid. Environmental Systems Research Institute Inc., Redlands, California, USA.
- Esther, M. W. (2009). Using GIS techniques to determine RUSLE's 'R' and 'LS' factors for Kapingazi River Catchment. Published Master's research, Jomo Kenyatta University of Agriculture.
- FAO/UNEP (1994). Land degradation in south Asia: its severity causes and effects upon the people. FAO and UNEP project, Rome.
- Fernandez, C. C., O. Stockle, J. Q. Wu and D. K. McCool (2002). Predicting erosion and sediment yield using geographic information systems:

application to the Lawyers Creek Watershed. Research & Extension Regional Water Quality Conference, Washington.

- Gallant, J., H. Lu, C. Moran, G. Priestley and I. P. Prosser (2001). Prediction of Sheet and Rill Erosion over the Australian Continent, Incorporating Monthly Soil Loss Distribution. CSIRO, Land and Water, Canberra, Australia, Technical Report 13(01).
- Gao, B. C. (1996). NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, 58: 257–266.
- Gitas, I. Z., K. Douros, C. Minakou, G. N. Silleos and C. G. Karydas (2009). Multi-Temporal Soil Erosion Risk Assessment in North Chalkidiki Using A Modified Usle Raster Model. *Earsel Eproceedings*, 8: 40-52.
- Global Land Cover Facility (GLCF, 2000). <http://glcfapp.umiacs.umd.edu>, visited on August 10th, 2012.
- Hakim, A. V. M. and S. Chandrakaran (2005). Hydrology of high and mid land watersheds of Kerala. Edi. book; *Hydrology and Watershed Management*, Himanshu Publications, Udaipur, pp. 224-233.
- Hickey, R. (2000). Slope Angle and Slope Length Solutions for GIS. *Cartography*, 29 (1): 1–8.
- Hoshikawa, K., M. Kawabata, M. B. Shrestha and J. Suzuki (2005). Estimation of Potential Sediment Yield by integrating USLE with GIS -A case study at Tenryu Watershed in Central Japan. Shinshu University, Nagano, Japan.
- Htun, K. Z., S. S. Aye and L. Samarakoon (2007). Spatial Pattern Analysis of Land Degradation Using Satellite Remote Sensing Data and GIS in Mandalay Watershed, Central Myanmar. Mandalay Technological University, Myanmar.

- Hudson, N. (1995). Runoff, erosion and sedimentation: prediction and measurement. In: FAO (Ed.), Land and Water Integration and River Basin Management, FAO Land and Water Bulletin, 1(85).
- Hui, L., H. Huizhong, C. Xiaoling and Z. Lihua (2008). An Approach to Compute the C Factor for Universal Soil Loss Equation Using EOS-MODIS Vegetation Index (VI). SPIE Digital Library, Vol. 7285.
- IAMG (International Association of Mathematical Geosciences), <http://www.iamg.org>, visited on September 15th, 2012.
- Integrated Hydrological Data Book (Non-classified river basins) (2006). Published by Hydrological Data Directorate, Information Systems Organization, Water Planning & Projects Wing, Central Water Commission, New Delhi.
- Integrated Hydrological Data Book (Non-classified river basins) (2012). Published by Hydrological Data Directorate, Information Systems Organization, Water Planning & Projects Wing, Central Water Commission, New Delhi.
- Jain, M. K. and U. C. Kothyari (2000). Estimation of soil erosion and sediment yield using GIS. Hydrological Sciences Journal, 45(5): 771-786.
- Jain, S. K. and M. K. Goel (2002). Assessing the vulnerability to soil erosion of the Ukai Dam catchment using remote sensing and GIS. Hydrological Sciences Journal, 47(1): 31-40.
- Jensen, J. R. (2000). Remote Sensing of the Environment: An Earth Resource Perspective Prentice Hall, New Jersey.
- Jensen, J. R. (2005). Introductory Digital Image Processing: A Remote Sensing Perspective Pearson Prentice Hall, New Jersey.
- Jones, R. J. A., L. Montanarella and J. M. van der Knijff (1996). Soil Erosion Risk Assessment in Italy. Space Applications Institute, European Soil Bureau.

- Karaburun, A. (2010). Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. *Ozean Journal of Applied Sciences* 3(1).
- Khosrowpanah, S., L. F. Heitz, Y. Wen and M. Park (2007). Developing a GIS-based soil erosion potential model of the Ugum watershed. Water & Environmental Research Institute, Western Pacific UOG Station, Guam, Technical Report No. 117.
- Kim, H. S. (2006). Soil erosion modeling using RUSLE and GIS on the Imha Watershed, South Korea. Published Master's thesis, Colorado State University, Fort Collins, Colorado.
- Kothyari, U. C. and S. K. Jain (1997). Sediment yield estimation using GIS. *Hydrological Sciences Journal*, 42(6).
- Kumar, V. (2003). Rainfall characteristics of Shimla district (H.P.). *Journal of Indian Water Resources Society*, 23(1): 1-10.
- Kumar, V. and R. A. Rastogi (2005). Sub area routing model for estimation of sediment yield from a mountainous watershed. Edi. book: *Hydrology and Watershed Management*, Himanshu Publications, Udaipur pp. 98-105.
- Lal, R. (1998). Soil erosion impact on agronomic productivity and environment quality: critical reviews. *Plant Sciences*, 17: 319–464.
- Lal, R. (2001). Soil degradation by erosion. *Land Degradation & Development*, 12: 519–539.
- Liengsakul, M., S. Mekpaiboonwatana and P. Pramjane. (1993). Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland: A case study in the highlands of northern Thailand. *Geoderma*, 60: 293- 307.
- Lillesand, T. M., R. W. Kiefer and J. W. Chipman (2004). *Remote Sensing and Image Interpretation*. 5th edition, New York: John Wiley & Sons, Inc.

- Lim, K. J., M. Sagong, B. A. Engel, Z. Tang, J. Choi and K. S. Kim (2005). GIS-based sediment assessment tool. *Catena*, 64: 61–80.
- Lin, C. Y., W. T. Lin and W. C. Chou (2002). Soil erosion prediction and sediment yield estimation: the Taiwan experience. *Soil and Tillage Research* 68 (2): 143–152.
- Mahmoodabadi, M. (2011). Sediment yield estimation using a semi-quantitative model and GIS-remote sensing data. *International Agrophysics*, 25: 241-247.
- Mati, B. M., R. P. C. Morgan, F. N. Gichuki, J. N. Quinton, T. R. Brewer and H. P. Liniger (2000). Assessment of erosion hazard with the USLE and GIS: A case study of the Upper Ewaso Ngiro North basin of Kenya. *JAG*, 2(2): 78– 86.
- McCool, D. K., L. C. Brown and G. R. Foster (1987). Revised slope steepness factor for the USLE. *Trans. ASAE*, 30: 1387-1396.
- Mishra, R.N., S. S. Bhist and M. Chandra Sekhar (2003). *Watershed Management - A Perspective*, Edi. book, Allied Publishers Limited, New Delhi pp. 151-163.
- Mishra, P. K., A. K. Singh, M. Kothari, , V. Kumar, G. V. Srinivasa Reddy and R. C. Purohit (2007). Soil erosion research under simulated conditions for black soils of Southern India - A review. *Agricultural Reviews*, 28(11): 63-68.
- Morgan, R. P. C. (1995). *Soil Erosion and Conservation (Second Edition)*, Longman Group, U. K. Limited.
- Morgan, R. P. C., D. D. V. Morgan and H. J. Finney (1984). A predictive model for the assessment of soil erosion risk. *Journal of Agricultural Engineering Research*, 30 (1): 245–253.
- Morgan, R. P. C., D. D. V. Morgan and H. J. Finney (1999). A predictive model for the assessment of soil erosion risk. *Canadian Journal of Remote Sensing*, 25(4): 367-380.

- Myneni, R. B. and G. Asrar (1994). Atmospheric effects and spectral vegetation indices. *Remote Sensing of Environment*, 47: 390–402.
- NBSSLUP (1996). *Soils of Madhya Pradesh for Optimizing Land Use*. Publication, 50(b).
- Nearing, M. A. and L. J. Lane (1989). A process based soil erosion model for USDA water erosion prediction project technology. *Trans. ASCE*, 32(5): 1587-1593.
- Okoth, P. F. (2003). *A Hierarchical Method for Soil Erosion Assessment and Spatial Risk Modeling (A Case Study of Kiambu District in Kenya)*. Wageningen University, Ph. D. thesis, 3344.
- Pal, B. and S. Samanta (2011). Estimation of soil loss using remote sensing and geographic information system techniques (Case study of Kaliaghai River basin, Purba & Paschim Medinipur District, West Bengal, India). *Indian Journal of Science and Technology*, 4(10).
- Pandey, A., V. M. Chowdary and B. C. Mal (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. *Water Resources Management*, 21(4): 729-746.
- Phadke, V. S., and R. Singh (2006). Assessing soil loss by water erosion in Jamni River Basin, Bundelkhand region, India, adopting universal soil loss equation using GIS. *Current Science*, 90(10).
- Phillips, J. D. (1990). Relative importance of factors influencing fluvial soil loss at global scale. *American Journal of Science*, 290: 547-568.
- Pierce, F. J., W. E. Larson and R. H. Dowdy (1986). *Soil Conservation: An Assessment of the National Resources Inventory*, Vol. 2. National Academy Press, Washington (D. C.)
- Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool and D. C. Yoder (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*.

Handbook, 703, US Department of Agriculture: Washington (DC), 404.

- Rompaey, A. V., P. Bazzoffi, R. J. A. Jones and L. Montanarella (2005). Modeling sediment yields in Italian catchments. *Geomorphology*, 65: 157-169.
- Roslan, Z. A. and K. H. Tew (1997). Use of satellite imagery to determine the land use management factors of the USLE. *Human Impact on Erosion and Sedimentation (Proceedings of Rabat Symposium S6)*, IAHS, Publication no. 245.
- Rouse, J. W., R. W. Haas and J. A. Schell (1974). Monitoring the Vernal Advancement and Retrogradation (Greenwave Effect) of Natural Vegetation. NASA/GSFCT, Type-III Final Report, Greenbelt, MD, USA.
- Saha, S. K., M. Kudarat and S. K. Bhan (1992). Erosion soil loss prediction using digital satellite data and Universal soil loss equation – soil loss mapping in Siwalik Hills in India. In book on “Application of Remote Sensing in Asia and Oceanic- Environmental change monitoring” (Ed. Shunji mural): Phb. Asian Association on Remote Sensing, 369-372.
- Said, B. S., and T. Svoray (2009). Soil loss, water ponding and sediment deposition variations as a consequence of rainfall intensity and land use: a multi-criteria analysis. *Earth Surface Processes and Landforms*, 102(10).
- Saumer, P., S. Schonbrodt, T. Behrens, C. Seeber and T. Scholten (2010). Assessing the USLE Crop and Management Factor C for Soil Erosion Modeling in a Large Mountainous Watershed in Central China. *Journal of Earth Science*, Vol. 21(6): 835–845.
- Schmidt, L., S. Rasemann, J. Schrott and R. Dikau (2002). Geomorphometry in mountain terrain. In: Bishop, M. and J. J. Shroder (Eds.),

Geographic Information Science (GIScience) and Mountain Geomorphology. Praxis Scientific Publishing, Springer, Berlin.

- Sesnie, S. E., P. E. Gessler and B. Finegan (2008). Integrating Landsat TM and SRTM-DEM derived variables with decision trees for habitat classification and change detection in complex neotropical environments. *Remote Sensing of Environment*, 112: 2145-2159.
- Sheikh, A. H., S. Palria and A. Alam (2011). Integration of GIS and universal soil loss equation (USLE) for soil loss estimation in a Himalayan watershed. *Recent Research in Science and Technology*, 3(3): 51-57.
- Shin, G. J. (1999). "The analysis of soil erosion analysis in watershed using GIS". Ph. D. thesis, Department of Civil Engineering, Gang-won National University.
- Shrestha, D. P. (1997). Assessment of soil erosion in the Nepalese Himalaya - A case study in Likhu Khola valley, middle mountain Region. *Land Husbandry*, 2 (1): 59-80.
- Singh, P. K. (2000). *Watershed Management (Design and Practices)*. e-media publications, Udaipur.
- Singh, A. K., M. Kothari, P. K. Mishra, V. Kumar, G. V. Srinivasa Reddy and R.C.Purohit (2007). Soil erosion research under simulated conditions for black soils of Southern India – A review. *Agricultural Review*, 28 (I): 63-68.
- Subramanya, K. (2008). *Engineering Hydrology*. Third Edition, Tata McGraw-Hill Education Private Ltd., New Delhi.
- Sumathi, I. and S. S. Bosu (2004). Using GIS for facilitating Sediment Yield Estimation. Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.
- Suriyaprasit, M. and D. P. Shrestha (2008). Deriving Land Use and Canopy Cover Factor from Remote Sensing and Field Data in Inaccessible

Mountainous Terrain for Use in Soil Erosion Modelling. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37(Part B7): 1747–1750.

- Symeonakis, E. and N. Drake (2004). Monitoring desertification and land degradation over sub-Saharan Africa. *International Journal of Remote Sensing* 25 (3): 573–592.
- Tamas, J., P. Kardevan, E. Kovacs, E. Kovacs and P. Takacs (2005). Evaluation of environmental risks of non point source heavy metal contamination using DAIS sensor. Proceedings of 4th EARSeL Workshop on Imaging Spectroscopy, Warsaw University, Warsaw.
- Tweddles, S. C., C. R. Eschlaeger and W. F. Seybold (2000). An Improved Method for Spatial Extrapolation of Vegetative Cover Estimates (USLE/RUSLE C factor) using LCTA and Remotely Sensed Data.
- Van der Knijff, J., R. J. A. Jone and L. Montanarella (2002). Soil erosion risk assessment in Italy. European Soil Bureau, Joint Research Center of European Commission.
- Van Remortel, R., R. Maichle and R. Hickey (2004). Computing the RUSLE LS Factor based on Array-based Slope Length Processing of Digital Elevation Data Using a C++ Executable Programme. *Computers and Geosciences* Volume 30, 9(10): 1043-1053.
- Vicenta, M.L., A. Navas and J. Machin (2007). Identifying erosive periods by using RUSLE factors in mountain fields of the Central Spanish Pyrenees. *Hydrology, Earth System and Sciences Discussions*, (4): 2111-2142.
- Williams, R. and H. D. Berndt (1972). Sediment yield computed with universal equation. *Journal of Hydraulic Engineering*, ASCE, 98(HY12): 2087-2098.
- Wischmeier, W. H. and D. D. Smith (1958) Rainfall energy and its relationship to soil loss. *Trans American Geophysics Union*, 39(2).

- Wischmeier, W. H. and D. D. Smith (1965). Predicting rainfall-erosion losses from cropland east of Rocky Mountains: guide for selection of practices for soil and water conservation. U.S. Department of Agriculture, Agricultural Handbook, p. 282.
- Wischmeier, W. H. and D. D. Smith (1978). Predicting rainfall-erosion losses - a guide to conservation planning. AH-537. U. S. Department of Agriculture, Washington (D.C.)
- You, S. C. (1999). Estimation of soil erosion supported by GIS- A case study in Guanji township, Taihe, Jiangxi. *Journal of Natural Resources*, 14 (1): 63-68.
- Young, R. A., C. A. Onstad, D. D. Bosch and W. P. Anderson (1987). AGNPS: An agriculture nonpoint source pollution model. Conservation Research Report 35, USDA/ARS, Washington (D.C.), USA.
- Yu, B., G. M. Hashim and Z. Eusof (2001). Estimating the R-factor with limited rainfall data: A case study from Peninsular Malaysia. *Journal of Soil and Water Conservation*, 56(2): 101-105.
- Yusof, K. W. and S. M. J. Baban (2002). A preliminary attempt to develop an erosion risk map for Langkavi Island, Malaysia using the USLE, remote sensing and geographical information system. GIS development proceedings.
- Zaen, A. A. (2012). Remote sensing technique to monitoring the risk of soil degradation using NDVI. *International Journal of Geographical Information System Applications and Remote Sensing*, 3(1).

Vita

The author of this thesis is Er. Rupesh Jayaram Patil, S/o Shri. Jayaram Dhondu Patil, was born on 1st February 1990, at Khaniwali, Tal – Wada, Thane (M.S.). He passed his Secondary School



securing 73.60 and Higher Secondary School with 65.50 % in first class from Maharashtra State Board of Secondary and Higher Secondary Education, Mumbai Division (M.S.).

He admitted to B. Tech. degree programme in Agricultural Engineering at College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (M.S.) in the year 2007 and successfully completed the degree in the year 2011 with a CGPA of 8.10 at 10.00 point scale.

In the year 2011 he joined “Master of Technology” two years Post Graduation degree programme in the Department of Soil and Water Engineering at College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). After completing the entire prescribed course work successfully, he has submitted the thesis entitled “Remote Sensing and GIS Approach for Estimation of Soil Erosion of Shakker River Watershed” in partial fulfillment of the requirements for the award of degree of “Master of Technology”.