Spatial Estimation of Gross Erosion in Shakkar River Watershed using Remote Sensing and GIS Techniques

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(SOIL AND WATER ENGINEERING)

By

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2015

CERTIFICATE – I

*This is certify that the thesis entitled "***Spatial Estimation of Gross Erosion in Shakkar River Watershed using Remote Sensing and GIS Techniques.***" 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. Aribam Priya Mahanta Sharma*** *under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.*

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

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*This is certify that the thesis entitled “**Spatial Estimation of Gross Erosion in Shakkar River Watershed using Remote Sensing and GIS Techniques**” submitted by **Mr. Aribam Priya Mahanta Sharma** 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 evaluated, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination on the same.*

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DECLARATION AND UNDERTAKING BY THE CANDIDATE

I, **Aribam Priya mahanta Sharma, S/o Shri. Aribam Chandrakumar Sharma**, certify that the work embodied in thesis entitled, "**Spatial Estimation of Gross Erosion in Shakkar River Watershed using Remote Sensing and GIS Techniques**" is my own first hand bonafide work carried out by me under the guidance **of Dr. S. K. Sharma** at **Department of Soil and Water Engineering, College of Agricultural Engineering JNKVV, Jabalpur** during 2015

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INTRODUCTION

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard of modern times worldwide (Eswaran *et al.,* 2001). Soil erosion is a complex dynamic process by which productive surface soil is detached, transported and accumulated at a distant place resulting in exposure of sub surface soil and siltation in reservoirs and natural streams elsewhere (Kandrika and Venkataratnam, 2005). Globally, 1964.4 Mha of land is affected by human induced degradation (UNEP, 1997). Of this, 1,903 Mha land is subjected to water induced erosion and 543.3 Mha to wind erosion.

It is estimated that out of the total geographical area of 329 Mha of India, about 167 Mha is affected by serious water and wind erosion. This includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, water logging, salinity and alkalinity, shifting of river courses and desertification (Singh, 2000). Narayan and Babu (1983) estimated that in India about 5334 MT (16.4 t ha^{-1}) of soil is detached annually, about 29% is carried away by the rivers into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the storage capacity.

1.1 Effect of soil erosion on Environment and Agriculture

Soil erosion has been as a serious problem arising from agricultural intensification, land degradation and possibly due to global climatic change (Yang *et al*., 2003). Deposition of this sediment transported by river into the reservoir not only reduces the reservoirs' capacity, but sediment deposition on riverbed and banks causes widening of flood plains during floods. Soil erosion is the most significant contributor of off-site groundwater pollution on a global scale with most of the contaminants originating within an agricultural setting (Marsh and Grossa, 1996).

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard of modern times worldwide (Eswaran *et al*. 2001). Moreover, accelerated erosion due to human-induced environmental alterations at global scale is causing extravagant increase of geomorphic processes and sediment fluxes in many parts of the world (Turner *et al.* 1990; IGBP-BAHC 1997). It causes loss of fertile top soil cover and delivers millions of tonnes of sediments into reservoirs and lakes (Lal, 1998; Pimental *et al.* 1995). Not only the deposition of sediment transported by river into a reservoir reduces the reservoir capacity, but also sediment deposition on river bed and banks causes widening of flood plains during floods (Marsh and Grossa, 1996).

This latter phenomenon has a great deal of importance in optimising policies for management of water resources, particularly when sediment is generated in such a way as to seriously reduce the capacity of reservoirs. Storage capacity of existing reservoirs is a valuable and non-renewable resource that must be protected from 'sediment danger' (Di Silvio, 1996), and can be restored only through costly periodic dredging. It is therefore desirable to predict distributions of soil loss, sediment yield, and sediment deposition upstream of a dam in order to plan structural works and other means for reducing the problem.

1.2 Need to assess the risk of soil erosion

The major threat for sustainable agriculture is indeed soil erosion and its assessment can be helpful for land evaluation of the region, as soil is the basis of agricultural production. Estimating the soil loss and its spatial distribution is one of the key factors for successful erosion assessment. Spatial and quantitative information on soil erosion on a regional scale contributes to conservation planning, erosion control and management of the environment. Identification of erosion prone areas and quantitative estimation of soil loss rates with sufficient accuracy are of extreme importance for designing and implementing appropriate erosion control or soil and water conservation practices. Researchers have developed many predictive models that estimate soil loss and identify areas where conservation measures will have the greatest impact on reducing soil loss for soil erosion assessments. In case of the sediment yield monitored for the watershed at the outlet, draws quantitative result rather than the qualitative result. However, the origin and extent of the eroded sediments from the watershed remain unknown (Bhaware, 2006).

1.3 Soil Erosion Models

The estimation of soil erosion is a challenging task that has been undertaken through the development of numerous models. Various parametric models such as empirical (statistical/metric), conceptual (semi-empirical) and physical process based (deterministic) models are available to compute soil loss. In general, these models are categorized depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model. Empirical models are generally the simplest of all three model types. They are statistical in nature and based primarily on the analysis of observations and seek to characterize response from these data (Wheater *et al.,* 1993). 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 physics 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-parameterised.

Most of these models need information related with soil type, landuse, 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 agriculture fields. Modified Universal Soil Loss Equation (MUSLE) (Williams & Berndt, 1997; Meyer and Foster, 1975) a modified version of USLE is applicable to other conditions by introducing hydrological runoff factor for sediment yield estimation. Water Erosion Prediction Project (WEPP) (Nearing *et al*., 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) designed to compute soil erosion within a watershed. The European Soil Erosion Model (EUROSEM) (Morgan *et al.*, 1995, 1998) is a single process–based model for assessing and risk prediction of soil erosion from fields and small catchments. Morgan, Morgan and Finney (MMF) model is an empirical model developed for mean annual soil loss estimation from field-sized areas on hill slopes (Morgan *et al.,* 1984) having strong physical base.

1.4 Remote Sensing and GIS in Soil Erosion Assessment

Due to the spatial variation in rainfall and catchment heterogeneity, both soil erosion and sediment transport processes are spatially varied. Such variability has promoted the use of data intensive distributed approach for the estimation of catchment erosion and sediment yield by discretizing a catchment into sub-areas each having approximately homogeneous characteristics and uniform rainfall distribution (Young *et al*., 1987; Beven, 1989). To encapsulate the spatial variation of the parameters like topography, soil and land use in a watershed, the use of Geographical Information System (GIS) methodology is well suited.

Various erosion models are available, with which the major problem is the generation of input data, which are 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 capability with remote sensing data, the soil erosion modelling approaches have become more comprehensive and robust (Bhaware, 2006). Satellite data can be used for studying erosional features, such as gullies, rainfall interception by vegetation and vegetation cover factor. Utilization of multi-temporal satellite images provides the opportunities to extract valuable information associated to seasonal land use change. Digital Elevation Model (DEM), one of the vital inputs required for soil erosion modelling 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 can be used to generate a cover and management factor (C- factor) (Morgan, 1995; Wischmeier and Smith,

1978) which is one of the input required for soil erosion modelling. Especially optical satellite imagery can be used for erosion mapping, mainly through visual delineation of soil patterns (Dwivedi *et al.,* 1997)

Geographic Information System (GIS), a technology designed to store, manipulate, and display spatial and non-spatial data, has become an important tool in the spatial analysis of factors such as topography, soil, land use/land cover etc. GIS provides a digital representation of the catchment, which can be used in hydrologic modelling. GIS can be used for the discretization of the catchment into small grid cells and for the computation of such physical characteristics of these cells as slope, land use and soil type, all of which affect the processes of soil erosion and deposition in the different sub-areas of a catchment (Marshringni and Cruise, 1997; Rewarts and Engel, 1991; Srinivasan and Engel, 1994).

GIS can be used to scale up to regional levels and to quantify the difference in soil loss estimation produces by different scale of soil mapping used as a data layer in the model. The integrated use of RS and GIS could help to assess quantitative soil loss at various scales and identify areas that are at potential risk of soil erosion (Saha *et al.,* 1992). Considering the inaccessibility of the terrain if it is extensive area, Remote Sensing is essential to accommodate spatial variability and information. Spatial modelling involves the use of GIS for representation of the conceptual model and performance of simple mathematical computations on the stores GIS object attributes for displaying the results spatially (Kumar and Rastogi, 2005).

1.5 " Why estimate soil erosion at variable scale"

Accurate or precise assessment of soil erosion has been a complicated task, due to complex nature of soil erosion variables. The outcome of soil erosion assessments depends greatly on the spatial scale (cell/grid resolution) and structure of the data used. Recognition of the importance of scale in erosion assessments has grown considerably over the past decade (Wilbanks, 2003), but research on the effects of scale on water resources variables is conspicuously lacking. Recently developed macro-scale hydrologic models estimate the spatial variability of hydrological phenomena over large areas at a spatial resolution finer than can be provided by observed data alone. This has led to focus on scale issues and concern with the nature of spatial variability in remote sensing, geomorphology, hydrology, etc.

The availability of high-resolution geospatial datasets provides an empirical basis for study. Recent availability of tools like GIS has also facilitated better multivariable and multi-scale analysis and integration of spatial datasets (Atkinson and Tate, 2000) to explore interrelations between and across scales (Bunnell and Coe, 2001). It also helps in identification of erosion prone areas and provides data inputs to many of the soil erosion models (Rawat *et al.*, 2014). 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 became more comprehensive and robust (Saha *et al.*, 1992; Shrestha, 1997).

Depending on the application and spatial heterogeneity of the geographic phenomenon, it has often been argued that there should be a “specific” scale that will generalize the spatial pattern of a specific feature to be discovered, yet retain the important spatial variations (Levin, 1992). Moving to a coarser scale (e.g. larger grid-cell sizes) involves moving away from the basic processes (Meentemeyer and Box, 1987). The number of variables that are reliably depicted generally becomes smaller at coarser scales. Multi-scale analyses evaluate spatial phenomenon at a variety of spatial scales. Some researchers maintain that a geographic analysis is not complete without a multiple scale approach which is essential to integrated environmental assessments (Stone, 1972). Multi-scale studies are motivated by several factors.

1.6 Objective of Study

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

1. To estimate gross erosion at variable spatial scales using distributed information for rainfall, soil, topography and land use using RS and GIS techniques.
2. To analyze effect of variable spatial scales on simulated gross soil loss.

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List of Abbreviations

Abbreviation/ Symbol	**Stand for**
A	Average annual rate of soil loss
ASTER	Advance Spaceborne Thermal Emission and Reflection
C	Crop/cover management factor
CAE	College of Agricultural Engineering
cm	Centimetre
CWC	Central Water Commission
DEM	Digital Elevation Model
E	East
EI_{30}	Rainfall erosion index unit
eq	Equation
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
et al.	and others
etc.	Etcetera (so on)
FAO	Food and Agricultural Organisation
FCC	False Colour Composition
FVC	Fractional Vegetation
Fig	Figure
ft	Foot
GIS	Geographic Information System
GLCF	Global Land Cover Facility
h	Hour
ha	Hectare
I	Rainfall intensity
i.e.	Id est (that is)
IRS	Indian Remote Sensing Satellite
JNKVV	Jawarharlal Nehru Krishi Vishwa Vidyalaya
K	Soil erodibility
KE	Kinetic energy
km	Kilometer

L	Slope length factor
LISS	Linear Imaging Self Scanner
m	Meter
Mha	Million hectares
MJ	Mega Joules
mm	Millimetre
MP	Madhya Pradesh
MPWSRP	Madhya Pradesh Water Sector Restructuring Project
MSL	Mean sea level
MT	Million Tonnes
N	North
NBSSLUP	National Bureau of Soil Survey & Land Use Planning
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NRSA	National Remote Sensing Agency
NSCL	Non-Cumulative Slope Length
P	Conservation/support practice factor
pixel	Picture element
R	Rainfall erosivity
R^2	Coefficient of determination
RS	Remote Sensing
S	Slope gradient factor
t	Tones
TIFF	Tagged Information File Format
USLE	Universal Soil Loss Equation
^{o}	Degree
‘	Minute
%	Percentage

REVIEW OF LITERATURE

Soil erosion has become a serious global issue and will become an even greater issue in the future as population growth continues to expand and land resources are more intensively used. Controlling the soil erosion has been a problematic task for watershed researchers and soil conservationist. Conceptualization, design and implementation of measures to avoid the hazard of soil erosion have become must. Potential of soil erosion increases with the physical and topographical condition of the watershed. Particularly, on steep lands the potential of soil erosion is high. The investigation on the subject of soil erosion has a long time scientific history and the fundamentals of erosion process have been investigated for many decades. But still research focusing on review on the process of soil erosion processes as well as its modelling is going on. In this chapter reviews in relation to the above considered objective will be discussed; moreover, the literature review is primarily focusing on the literature of last several years.

2.1 Estimation of soil erosion using RS and GIS

Jain and Kothyari (2000) estimated soil erosion and sediment yield using GIS of the Nagwa and Karso catchments in Bihar, India. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USEE) by carefully determining its various parameters. An Earth Resources Data Analysis System (ERDAS) Imagine image processor was used for the digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments. Further, the databases were introduced to GIS and 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 concept of sediment delivery ratio (SDR) was used for determination of the total sediment yield of each catchment during isolated storm events.

Singh *et al.* (2002) carried out study on Prioritization of Bata river basin using Remote Sensing & GIS Techniques. Soil erosion assessment in the study was done using Morgan *et al.* (1984) model. The model encompasses some of the recent advances in understanding of soil erosion processes. By using this model, it was found that the average annual soil loss in the watershed was 17.22 t/ha. Detailed analysis showed that detachment limited soil erosion is higher in the agricultural & barren land, while transport limited erosion was higher in the forestland.

Chansheng (2003) integrated geographic information systems and simulation model for watershed. The agricultural nonpoint source pollution model (AGNPS) was employed to analyze the effect of land use change on nonpoint source pollution in the study watershed. ArcView nonpoint source pollution modeling (AVNPSM), an interface between ArcView GIS and AGNPS was developed to facilitate agricultural watershed modeling. It was applied to study the watershed to simulate the impact of land use change on runoff, sediment, and nutrient yields based on a 25-year, 24-h period of single storm event of 114 mm. The simulation results show that expansion of urban land was likely to lead to an increase in surface runoff, peak flow, and soil erosion

Amore et al. (2004) studied the scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. Each basin was subdivided into hillslopes, using three different classes of average area, in order to estimate the scale effect on the sediment yield evaluation. The first physically based model of the Water erosion Prediction Project (WEPP). A Geographical Information System was used as a tool to handle and manage data for application of the model computed sediment yields were compared with each other and with measurements of deposited sediment in the reservoir, and for these cases the WEPP estimates better approximated the measured volumes than did the USLE. The study suggested that a finer subdivision may better define the experimental conditions (plot or field areas) for calibration of model but may not result in a better estimate of erosion..

Bhattarai & Dutta (2007) estimated the soil erosion and sediment yield using GIS at Catchment Scale in a small watershed of Mun River basin, Thailand. The catchment was spatial disintegration into homogenous grid cells to capture the catchment heterogeneity. The gross soil erosion in each cell was calculated using Universal Soil Loss Equation (USLE) by carefully determining its various parameters. The concept of sediment delivery ratio was used to route surface erosion from each of the discritized cells to the catchment outlet. The process of sediment delivery from grid cells to the catchment outlet was represented by the topographical characteristics of the cells. The effect of DEM resolution on sediment yield was analyzed using two different resolutions of DEM. The spatial discretization of the catchment and derivation of the physical parameters related to erosion in the cell were performed through GIS techniques.

Erdogan (2007) used USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed in the Kazan watershed , Central Anatolia, Turkey. Rain erosivity (R), soil erodibility (K), and cover management factor (C) values of the model were calculated from erosivity map, soil map, and land use map of Turkey, respectively. R values were site specifically corrected using DEM and climatic data. The topographical and hydrological effects on the soil loss were characterized by LS factor evaluated by the flow accumulation tool using DEM and watershed delineation techniques. From simulated soil loss map of the watershed, the magnitude of the soil erosion was estimated in terms of the different soil units and land uses and the most erosion-prone areas where irreversible soil losses occurred were reasonably located in the Kazan watershed.

Alejandro (2008) calculated soil erosion using RS and GIS in Río Grande de Arecibo watershed, Puerto. Inputs of the model such as cover factor and conservation practice factor was successfully derived from remotely sensed data. The LS factor map was generated from the slope and aspect map derived from the DEM. The K factor map was prepared from the soil map, which was obtained from SURGO data and K factor values from a Soil Survey of United States and Virgin Islands (1998). Maps covering each parameter (R, K, LS, C and P) were integrated to generate a composite map

Ismail & Ravichandran (2008) applied RUSLE2 Model for Soil Erosion Assessment using Remote Sensing and GIS in the Veppanapalli sub watershed of Krishnagiri catchment located in Tamil Nadu, India. The soil erosion was estimated for each of the hillslope units in the study area. The factors considered were intensity of rainfall, type of soil, land use classification and the existing soil conservation practices. Detailed analysis of soil samples were done to assess the texture, structure, permeability and organic matter content of the soil samples of each hillslope unit. The required data for the other parameters were estimated by carrying out intense field investigations and by the analysis of the satellite imagery of 5.6 m resolution. A data base was created with all the subfactor values for the hillslope units.

Joshi and Nagare (2009) used remote sensing and GIS techniques fpr land use change detection along the Pravara River Basin in Maharashtra. The study area was a basin which was economically growing fast by converting the fallow lands, badlands and woodlands to agricultural land for the past few decades. IRS (Indian Remote sensing Satellites) 1 C – LISS III and IRS 1 C PAN and IRS P6 – LISS III and IRS 1 D PAN Images were merged to generate imageries with resolution matching to the landscape processes operating in the area. The images of the year 1997, 2000, 2004 and 2007 were analyzed to detect the changes in the landuse and landcover in the past ten years. The change of land use was observed from the analysis of satellite data of last ten years revealed that landuse was changing very rapidly in the region. The analysis revealed that there has been 20% increase in the agricultural area over the past ten years

Yaragal *et al.* (2009) applied Universal Soil Loss Equation (USLE) in Micro-Water Sheds of the Kudremukh National Park Area, Karnataka, India. The Universal Soil Loss Equation (USLE) was applied to 219 watersheds and the watershed prioritization for proper planning of conservation of water and land resources and their management for optimum productivity. Remote Sensing and GIS technique was employed for preparation of base map and thematic map of the study area. The factor R was calculated using the Isopleth map of Rain fall – Run-off erosivity factor (R), developed by Raghunath (1985). The factor LS was derived from toposheet using the equation given by Wischemeir and Smith (1965). The factor C is derived from LU/LC map. The factor K was obtained using the nomograph given by Wischmeier and Smith (1978). The factor P, which is a function of conservation practice, was set to 1 due to non-availabilty of data. Finally soil loss in 219 micro watersheds was calculated using the USLE.

Jain and Das (2010) used GIS and Remote Sensing for estimation of sediment yield and areas of soil erosion and deposition for watershed prioritization in the Upper Damodar Valley in Jharkhand, India. Due to availability of gauged data at multiple locations within watershed area, the watershed was discretized into hydrologically homogeneous grid cells to capture the watershed heterogeneity. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USLE). The parameters of the USLE were evaluated using digital elevation model, soil and landuse information on cell basis. The concept of transport limited sediment delivery (TLSD) was formulated and used in ArcGIS for generating the transport capacity maps. An empirical relation was proposed and demonstrated for its usefulness for computation of land vegetation dependent transport capacity factor used in TLSD approach by linking it with normalized difference vegetation index (NDVI) derived from satellite data. Using these maps, the gross soil erosion was routed to the watershed outlet using hydrological drainage paths, for derivation of transport capacity limited sediment outflow maps.

Sakthivel *et al.* (2011) used Remote Sensing and GIS for Soil Erosion Prone areas Assessment in Kalrayan hills, Part of Eastern Ghats, Tamil Nadu, India. used. The geocoded digital data of IRS P6 LISS – III (P101-R65 of 2001) and Survey of India toposheets (1971) were interpreted and various thematic maps such as drainage, lineaments, geomorphology, land use/land cover and slope maps have been prepared. After assigning the weightage factors for each of the parameters they were overlayed and integrated it one another and various soil erosion prone areas were demarcated. GIS integration was carried out using ArcGIS to assess the soil erosion by overlaying the following maps such as lineament density, drainage density, geomorphology, slopes and land use / land cover.

Pal and Samanta (2011) estimated soil loss using remote sensing and geographic information system techniques in the Kaliaghai River basin, Purba

& Paschim Medinipur District, West Bengal, India. 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, had been either derived from remote sensing data or through conventional data collection systems. These parameters 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. The experiential study resulted with Soil loss is very high in the river basin area, calculated as 1927779 tons/year using RUSLE model.

Praveen and Kumar (2012) conducted a study on integrated approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. The soil erosion rate was determined as a function of land topography, soil texture, land use/land cover, rainfall erosivity, and crop management and practice in the watershed using the Universal Soil Loss Equation (for Indian conditions), remote sensing imagery, and GIS techniques. The rainfall erosivity R-factor of USLE was found as 546 MJ mm/ha/hr/yr and the soil erodibility *K*-factor varied from 0.23 - 0.37. Slopes in the catchment varied between 0% and 42% having *LS* factor values ranging from 0 - 21. The *C* factor was computed from *NDVI* (Normalized Difference Vegetative Index) values derived from Landsat-TM data. The *P* value was computed from existing cropping patterns in the catchment. The annual soil loss estimated in the watershed using USLE is 12.2 ton/ha/yr.

Ahmad and Verma (2013) applied USLE model and GIS, for soil loss estimation has been presented for the Tandula reservoir catchment area on Tanudula River at Balod Tehsil of Durg district of Chhattisgarh State, India. The result obtained from USLE model has been compared with existing model , Nayak and Khosla;s method, it was observed that USLE with GIS gave better result as compared to other two methods.

Laosuwan *et al.* (2013) used GIS and a well known parametric equation, the Universal Soil Loss Equation (USLE), to evaluate the risk area of soil erosion in the Maha Sarakham province in Thailand for the year 2010. In this study five parameters of USLE were evaluated for the study area using remotely sensed ground observation and existing map data. Remotely sensed data was the main source of information for the establishment of land-use/land-cover, geology, geomorphology, and soil map, as well as for deriving a scheme of watershed distribution using both digital image processing and visual interpretation. Each of the USLE factors with associated attribute data was digitally encoded in a GIS database to eventually produce five thematic layers. These were then spatially overlaid to produce a resultant polygonal layer. Further these encoded layers were employed with the USLE model to estimate soil erosion.

Patil *et al.* (2014) assessed the annual rate of soil erosion from the Shakkar River watershed using distributed information for topography, land use, soil, etc. using remote sensing (RS) and geographic information system (GIS) techniques and compared the simulated sediment loss with observed sediment loss. The study area, the Shakkar River watershed, lies in Narmada river basin is situated in Narsinghpur and Chhindwara districts of Madhya Pradesh, India. The universal soil loss equation (USLE) integrated with RS and GIS approach was used to predict the spatial distribution of the soil erosion on a cell basis occurring in the study area. 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) were prepared by using annual rainfall data, soil map, digital elevation model (DEM) and executable C++ program, and satellite image of the area, respectively, in the GIS environment. The annual rate of soil erosion was estimated for 10 years (1997 to 2006).

Machiwal *et al.* (2015) conducted estimation of soil erosion potential and identification of critical areas for soil conservation measures in an ungauged catchment situated in Aravalli hills of Udaipur district, Rajasthan (India). The soil erosion was estimated for 10 year period (2001–2010) by Universal Soil Loss Equation (USLE) model using Geographical information system (GIS) and remote sensing techniques. Thematic maps of six USLE model parameters, i.e., rainfall erosivity (R-factor), soil erodibility (K-factor), slope length (L-factor), slope steepness (S-factor), crop and management (C-factor), and support practice (P-factor), were prepared in GIS platform.

2.2 Estimation of soil erosion at variable spatial scale

The complex nature of spatially varying soil erosion variables leads to difficulties in measurement or prediction of erosion in a precise manner. As the outcome of soil erosion assessments depends greatly on the spatial scale, it plays a crucial role in soil erosion modeling. However, recognition of the importance of scale in erosion assessments has grown considerably over the past decade (Wilbanks 2003). Soil erosion estimation at variable spatial scale though is practiced rarely. Therefore, the knowledge for selection of optimum scale is conspicuously lacking. However, a few studies on spatial estimation of soil erosion with subject to variable spatial scale say (200 m, 100 m, 50 m, 30 m) are conducted appreciably and are reviewed for the present study.

Wu *et al.* (2005) studied the evaluation of grid size uncertainty in empirical soil loss modelling with digital elevation models. They studied on the effect of topographic variability on grid-based empirical estimation of soil erosion and sediment transport with raster geographic information systems (GIS). An original digital elevation model (DEM) of 10 m resolution for a case watershed was resampled to six realizations of greater grid sizes (30 m, 60 m, 100m, 150 m, 200 m and 250 m) for a comparative examination. The study resulted with the suggestion that the selection of the DEM gird size has considerable influence on the soil loss estimation with the empirical models. The estimate of total soil loss from the watershed was decreased significantly with the increasing DEM cell size as the spatial variability was reduced by the cell aggregation.

Rosalia *et al.* (2008) carried out grid scale effect on watershed soil erosion model. The model CASC2D-SED used for the Goodwin Creek experimental watershed in Mississippi to define erosion mode' response to raster-based grid cell sizes. The model was parameterized at 30 m, 90 m and 150m grid sizes and validated to three representative thunderstorms. At coarser grid sizes, the sediment source area became less appropriately depicted and the calculated sediment delivery ratio became unrealistically high. Grid sizes smaller than 150 m were recommended from the study for proper watershed simulation of erosion and sediment yield.

Prasannakumar *et al.* (2012) carried out estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. The spatial pattern of annual soil erosion rate was obtained through 30 m spatial erosion estimation over the entire study area. GIS data layers including, rainfall erosivity (R), soil erodability (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were computed to determine the average annual soil loss in the area.

Bagherzadeh (2014) conducted study for identification of spatial distributed different erosion prone areas by USLE model to determine the average annual soil losses at Mashhad plain, northeast of Iran. Soil losses were estimated on a 100×100 m cell basis resolution by overlaying the five digital parameter layers (R, K, LS, C, P). To determine the critical soil loss regions at the plain, cell-based USLE parameters were multiplied by Arc-GIS ver.9.3. The estimated annual soil losses values were subsequently grouped into five classes.

From the above reviews, it is obvious that few research works has been conducted on multiscale soil erosion modelling. Keeping in view the importance of spatial scale on hydrologic modelling the present study is taken up to incorporate the different spatial resolution in soil erosion estimation.

2.3 Estimation of rainfall erosivity factor (R) for USLE

Bhattarai and Dutta (2007) applied a GIS-based method for the determination of soil erosion and sediment yield in a small watershed in Mun River basin, Thailand. The method involves spatial disintegration of the catchment into homogenous grid cells to capture the catchment heterogeneity. The gross soil erosion in each cell was calculated using Universal Soil Loss Equation (USLE) by carefully determining its various parameters. In the study special considered was made for spatial variability of rainfall. Rainfall Erosivity Index (R) was calculated from an annual summation of rainfall data using rainfall energy over 30-min duration. The relative fall velocity of the single droplet and the overall rainfall intensity determines the erosive properties of rain droplets

$$R = \frac{1}{n}\sum_{i=1}^{m}\left(\sum\nolimits_{j=1}^{m} E_j (I_{30})_j\right)$$

Where,

n = Total number of years,

m = Total number of rainfall storms in ith year,

I_{30} = Maximum 30 min intensity (mm hr –1),

E_j = Total kinetic energy (MJ ha–1)

Pandey *et al.* (2007) estimated average annual sediment yield on grid basis (200 x 200) using Universal Soil Loss Equation (USLE). According to the sediment data yield simulated the watershed area were prioritized to critical erosion prone areas. Remote sensing (RS) technology provided the vital spatial and temporal information on some of these parameters. A recent and emerging technology represented by Geographic Information System (GIS) was used as the tool to generate, manipulate and spatially organize disparate data for sediment yield modeling. The rainfall erosivity factor was computed by the following formula

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

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

Where,

KE = Kinetic energy of the storm (MJ/ha)

Dabral *et al.* (2008) conducted study on soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and Remote Sensing. The study was aimed to assess the annual soil loss of the Dikrong river basin of Arunachal Pradesh, India. The river basin was divided into 200×200 m grid cells. The Arc Info 7.2 GIS software and RS (ERDAS IMAGINE 8.4 image processing software) provided spatial input data and the USLE was used to predict the spatial distribution of the 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 R-factor annually using the following relationship developed by Wischmeier and Smith (1978):

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

Where,

R = Rainfall erositivity factor in MJ mm/ha/h/year,

P_i = Monthly rainfall in mm and

P = Annual rainfall in mm

Jain and Das (2010) conducted study on estimation of sediment yield and areas of soil erosion and deposition for Watershed Prioritization using GIS and Remote Sensing in the Upper Damodar Valley in Jharkhand State, India. The study proposed and demonstrated a Geographical Information System (GIS) based method for the identification of sediment source and sink areas and the prediction of sediment yield from watersheds The watershed was discretized into hydrologically homogeneous grid cells to capture the watershed 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). The parameters of the USLE were evaluated using digital elevation model, soil and landuse information on cell basis. The concept of transport limited sediment delivery (TLSD) was formulated and used in ArcGIS for generating the transport capacity maps. Rainfall erosivity was estimated on annual basis using the data for storms from several rain gauge stations located in different zones. Following equation was used in the study

$$R = 81.5 + 0.38\, R_n (340 \leq R_n \leq 3500\, mm)$$

Where,

R_n is the average annual rainfall in mm.

Elangovan and Seetharaman (2011) proposed a Simplified relationship for estimating the erosivity in Krishnagiri watershed area. Data from three locations were used to develop the relationship and one additional station across the watershed is used to validate the developed relationship. It was established that the relationship between the erosivity and rainfall depth can be expressed in a potential form. The regression model and the erosivity map here provided represent a helpful mean for soil erosion assessment and mapping, both at watershed and at regional scale. The simple power function developed to estimate the R factor from the depth of rainfall is given as

$$R = 0.193\, P^{1.895}$$

where

R is the rainfall erosivity factor and

P is the depth of rainfall.

2.4 Estimation of soil erodibility factor (K)

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 the 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:

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

Where,

x = the organic matter (%)

w = the silt (%) = (100 – clay %),

y = the soil structure code and

z = the profile permeability class

Chen (2011) performed sssessment of spatial distribution of soil loss over the upper basin of Miyun reservoir in China based on RS and GIS techniques. For the study the soil data on soil properties and maps of soil type distribution were collected and derived from the Second Soil Investigation in China. He stated that the soil erodibility factor (K) represents both susceptibility of soil to erosion and the amount and rate of runoff, as measured under standard plot conditions. Information on soil surface texture was derived from Chinese Soil Taxonomy (Chinese Soil Taxonomy Research Group 1995), and was catagories into mountain meadow soil, brown forest soil, and cinnamon soil. In the study, for each soil type, percentages of clay, silt, and sand were used to estimate K based on the class descriptions. K was estimated using following equation (Wischmeier and Smith 1978):

$$K= [2.1\times10^{-4}(12-a)][Ss\times(100-Sc)]\,[1.14+3.25\times(b-2)+2.5\times(c-3)]$$

where

K = soil erodibility factor (t h MJ–1mm–1),

Ss & Sc = products of the dominant size component and the percentage of the clay respectively

. α = percentage of organic matter in %,

b = soil structural and

c = soil saturation capability

Tania (2013) conducted assessment of Soil Erosion Risk in Fizes River Catchment Using USLE Model and GIS. In the study, the K was determined by the mathematical method, the data regarding the physical and mechanical soil characteristics being taken from the pedological studies undertaken in the Fizes watershed by the Bureau for Pedological and Agrochemical Studies Cluj. He stated that K factor reflects the effect of the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff. He highlighted the main soil properties affecting K are soil texture, organic matter, structure and permeability of the soil profile.

Shabani *et al.* (2014) conducted study on improvement to the prediction of the USLE K factor. This study evaluated the sensitivity of K to lime content (%lime) in the soil and slope (%slope) of the site. To evaluate the appropriateness of the USLE nomograph and other methods for estimating K and to develop a K estimation method for limy soils, a set of K values were measured in northern Iran using standard plots and natural precipitation events, for four different land uses (forest, rangeland, irrigated farming, and dry farming) and three slope categories (3–8%, 8–18% and 18–40%). Results indicated that there was considerable association between K and soil properties including the contents of sand, silt, very fine sand, organic matter and particularly lime, as well as slope inclination. A strong linear relationship was observed between the K values estimated from our model and the measured K was observed indicating that considering lime and slope gives a better estimate of K.

2.5 Estimation of topographic factor (LS)

Blevins, B. A. (2012) performed modelling of erosion potential in the Muskingum Watershed using a Geographic Information System. In the study RUSLE model was employed to assess the soil erosion from the study area. The LS factor for this study was computed using a widely accepted program that requires a digital elevation input. The program, executed using C++ programming language (Khosrowpanah *et al.,* 2007) .The LS program was to provide with a filled DEM input. In the study an unfilled, 30 meters DEM was clipped to the Muskingum Watershed boundary using the Data Management Tool, Clip. The program called for the DEM input in ASCII format, so the Conversion Tool, Raster to ASCII, was executed to the DEM raster. Once the DEM raster was in ASCII format, the file was provided to the C++ program, and the process was started. The completion of the program gave output consisting of 16 total files with the .dat extension. These files were then converted to raster format to get the LS map.

Kamaludin *et al.* (2013) performed integration of remote sensing with RUSLE and GIS to model potential soil loss and sediment yield (SY) in the catchment area of Pahang River, Malaysia. The study employed DEM for the catchment area of Pahang River involved digitizing 10m interval contour lines provided by the Department of Survey and Mapping Malaysia (JUPEM). The spatial elevations were derived from the contour lines 25 data using interpolation method in GIS. The DEM was derived from the spatial elevation data and projected to the Kertau RSO Malaya Meters. Length and slope factor (LS) was calculated through the equations that can be used in single index and which expresses the ratio of soil loss as following

$$LS = \frac{X}{22.1} m (0.065+0.045S +0.0065S^2)$$

Where,

X = slope length (m),

S = slope gradient (%), and

m = 0.5 to 0.2

Junakovaa *et al.* (2014) conducted study on the Influence of Topographical Factor Calculation on the Estimation of Water Erosion Intensity Using Geographical Information Systems. In the study Mitasova methodology was used for determination of the LS factor. The topographic factor for USLE was improved by incorporation of the influence of profile convexity/concavity using segmentation of irregular slopes and by improving the empirical equations for the computation of LS. A simpler, continuous form of the equation for computation of the LS factor at a point r = (x,y) on a hill slope, is given by

$$LS (r) = (m +1) \text{ x } \{A \text{®} /a_0\}^m \text{ x } \{\sin b (r)/b \}^n$$

Where A[m] is upslope contributing area per unit contour width, b [deg] is the slope, m = 0.2 and n = 1.2 are parameters for a specific prevailing type of flow and soil conditions, and a_0 = 22.1 m = 72.6ft is the length and b_0 = 0.09 = 9% = 5.16 deg is the slope of the standard USLE plot.

2.6 Estimation of crop/cover management factor (C)

Karaburun (2010) estimated C factor for soil erosion modelling using NDVI in Buyukcekmece watershed . The accuracy of the soil erosion prediction model, USLE and RUSLE depends on one of the most important parameters used in both of models 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 cove. The study employed NDVI derived from 2007 Landsat 5 TM Image. Since NDVI values have correlation with C factor (De Jong, 1994; Tweddales *et al.*, 2000; De Jong *et al.*, 1999; De Jong and Riezebos, 1997). The linear or non-linear regression equations was constructed using correlation analysis between NDVI values obtained from remotely sensed image and corresponding C factor values obtained from USLE/RUSLE computed using field observation. The study assumed that there exists a linear correlation between NDVI and C factor and uses bare soil and forest NDVI values as reference values. Sample NDVI values were collected for bare soil and forest land cover classes from average NDVI image. Since C factor values range from 0 for well-protected soil to 1 for bare soil (Pierce et al.,1986; Vicente *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. The regression line that describes relationship between C and NDVI values and R shows the correlation coefficient of regression analysis.

The regression equation was found as;

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

The final C factor map was generated using the regression equation in Spatial Analyst tool of ArcGIS 9.3 software.

Schönbrodt *et al.* (2010) assessed the USLE Crop and Management factor C for Soil Erosion Modelling in a Large Mountainous Watershed in Central China. The crop and management factor C was calculated using the fractional vegetation cover (C_{FVC}) based on Landsat-TM images from 2005, 2006, and 2007 and on literature studies (C_{LIT}). The NDVI was computed for each of the Landsat-TM images pre-processed based on bands 3(red band; R) and 4 (near infrared; NIR) using equation, according to Rouse et al. (1974)

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

Based on the three NDVI images derived the FVC was calculated. Therefore, the NDVI values were renormalized, providing an estimated value of vegetation cover (Boettinger *et al.*, 2008).Taking into account the NDVI of uncovered, bare ground (minNDVI) and of ground completely covered by vegetation (max NDVI), the percentage of the FVC was computed using equation

$$\mathrm{FVC}\ (\%) = (\mathrm{NDVI} - \mathrm{minNDVI}) / (\mathrm{maxNDVI} + \mathrm{minNDVI}) \times 100$$

C factor values were then calculated taking the logarithm of the percentage of FVC (c) using the regression function, according to Shi *et al.* (2004) and Zhou *et al.* (2008), using equation

$$C = 0.650\,8 - 0.343 \log c$$

The c values range between 0 and 78.3%. Thus, a C of 1 refers to a c of 0 and C of 0 equals to a c of 78.3%.

Jamshidi *et al.* (2011) conducted study on native forest *c* factor determination using satellite imagery in four sub-catchments. The cover management (*C*) factor in RUSLE represents the significance of changes in cropping, forest cover, and vegetation growth stages on soil loss rate. The *C* factor is one of the most important parameters in a number of hydrological models. This study was carried out to evaluate the performance and accuracy of two recently developed approaches in mapping raster-based *C* values against traditional methods in subtropical forest catchments in New South Wales, Australia. A raster-based Normalised Difference Vegetation Index (NDVI) map was calculated from the biomass spectral data of SPOT 5 imagery acquired in January 2011 when vegetation cover sampling was conducted. A regression relationship was developed between the vegetation index of NDVI values for individual sampled locations and their corresponding *C* factor values obtained from RUSLE look-up tables. The stochastic method of Sequential Gaussian Simulation (SGS), which has the ability to evaluate single- and multi-location uncertainties of predictions, was also used to estimate the spatial distribution of *C* values using 100 realisations. *C* values were estimated for non-sample locations at the cell level based on 41 sampled locations and an additional 40 NDVI values extracted from the image on bare soil. Those values were then extended to all pixels in the sub-catchments using regression analysis and the SGS approach.

Loh (2012) conducted study on estimation of USLE's C-factor using vegetation indices for soil erosion modelling in lake Bosumtwi basin, Ghana. The study compared the NDVI to the EVI to map land cover types, to be applied in *C*-factor estimation. The study developed a model for C factor calculation and is given as

$$\mathrm{C}= e^{\left(-\propto\left(\frac{VI}{\beta-VI}\right)\right)}$$

Where

$\propto$ = 2

β = 1

VI = vegetation indices (NDVI and EVI)

2.7 Estimation of conservation practice factor (P)

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 support practise factor (P) accounts for the effects of contour, strip cropping or terracing. It is defined as the ratio of soil loss with certain cultivation. Due to the 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.

FU *et al.* (2005) conducted Assessment of Soil Erosion at Large Watershed Scale using RUSLE and GIS: A Case Study in the Loess Plateau of China. They stated that at the large watershed scale, the differences in support practices, such as terracing, contour tillage, and so on, cannot be reflected from a land-use map. However accurate P-factors are good indicators for support practice. In this study, because of the difficulty in identifying different support practices at large watershed scales, P-factor value for the Yanhe watershed was calculated using the Wener method (Lufafa et al., 2003).

$$P = 0.2 + 0.03\,S$$

Where,

S = slope grade (%)

Christos *et al.* (2008) conducted study on Quantification and site-specification of the support practice factor when mapping soil erosion risk associated with olive plantations in the Mediterranean island of Crete. In this study, the Revised Universal Soil Loss Equation (RUSLE) was implemented in the spatial domain using GIS. The P factor was derived with object-oriented analysis (classification) of the Quick- bird image, resulting in the quantification of support practices through a thematic map (instead of assigning a uniform P value for the entire study area or assigning different values by expertise, as usual). In technical terms, the terraces were mapped with object oriented image analysis (OOA), a buffer zone of 60m was delineated around them considering that this distance was the mean positive influence range of the terraces as means for preventing erosion; then, different P values were assigned to the buffers according to the local slope. Regarding the rural roads, only objects lying across the slope direction were mapped, considering only these as the roads having a protective character to erosion; then, a buffer zone of 30m was delineated around them and a P value of 0.6 was assigned to the buffers. The specific ranges for buffer zones and their P values were selected based on the literature, the knowledge of the study site, and teams' domain expertise.

MATERIAL AND METHODS

The modelling of hydrological process is one of the challenging assignments for the hydrologist around the world. Scientists have been conducting research to develop models for achieving the accurate prediction of soil erosion using empirical models like USLE and RUSLE. The complexity and limitations of the variables and also unavailability of data sets with relevant information for use in these models had led to be unpopular for adoption. Particularly in developing countries, like India often have insufficient data to support these empirical based models. Thus, the choice remains only to use the available data which however are not adequate for complete and comprehensive analysis. This chapter gives an overview of the physical characteristics of the study area, data collection and data analysis processes for estimation of annual gross soil erosion of the Shakkar River watershed lying in Narmada River basin situated in the Narsinghpur and Chhindwara districts of Madhya Pradesh.

3.1 Description of Study area

The study area i.e. Shakker river rises in the Satpura range, east of the Chhindi village, Chhindwara district, Madhya Pradesh. The large portion of the watershed lies in Narsinghpur district and some part in the Chhindwara district. The Shakkar River, after covering initial reaches on basalts takes turn from its westerly direction to north and cuts across the Satpura Mountain south of the Narmada River.

3.1.1 Geographical location

Area lies between $22^o20'$ N to $23^o00'$ N latitudes and $78^o\ 40'$ E and $79^o\ 20'$ E longitudes with an elevation ranging from 314 to 1154 m above MSL (mean sea level). It covers 2223 km^2 of the total geographical area up to the gauging point and is shown in Fig. 3.1.

3.1.2 Climate

The climate of the area is generally characterized by dry climate except the southwest monsoon season. During the southwest monsoon season, the relative humidity generally exceeds 87% (August month) and rest of the year is drier. The climate of the basin is generally dry except the southwest monsoon season. 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 whereas normal annual rainfall is 1192.1 mm. The normal maximum temperature during the month of May is 42.5^0 C and minimum during the month of January is 8.2^0 C.

3.1.3 Soil and topology

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 to reddish brown, derived from sandstones and traps is observed which sandy clay in nature with calcareous concretions is. Near the banks of the rivers 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.

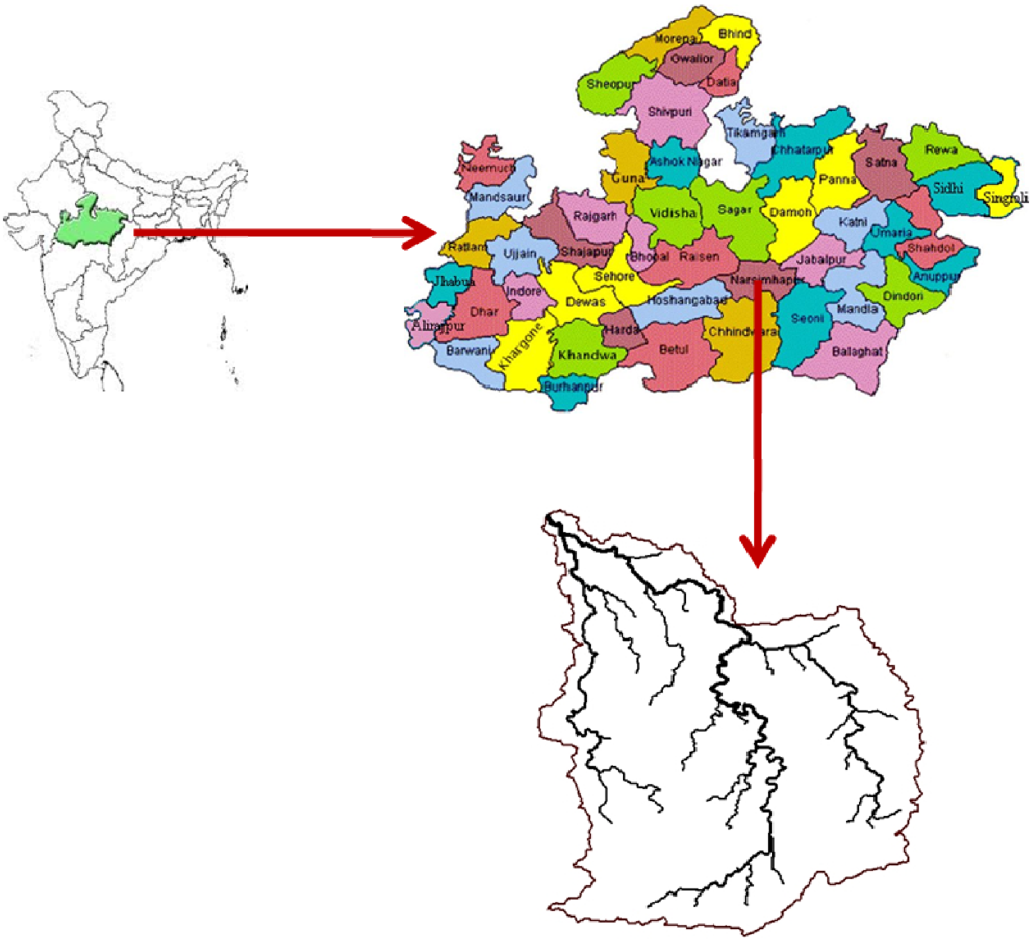

Fig 3.1 Location of the study area

3.2 Data Availability

3.2.1 Hydro-meteorological Data

The rainfall data are 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 study area were selected. The data of observed sediment loss at the outlet of the study area at Garadwara is required for validation of the estimation of USLE model. 20 years daily rainfall record of three stations was obtained 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 the following Table 3.1

Table 3.1 Annual rainfall (mm) at the selected raingauge 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
2007	597	1078	1017
2008	619	916	847
2009	1348	1384	1971
2010	907	535	373
2011	711	568	407
Average	945.735	1129.42	1086.62

Observed sediment data of the stream gauging station at the outlet of watershed was collected from the “Intergrated Hydrological Data book for non classified river basins” published by Hydrological Data Directorate, Information System Organization, Water Planning and Projects Wing, Central Water Commission (CWC), New Delhi. The data book published in the year 2006 and 2012 were used. These data books contains statistics regarding annual sediment loss at outlet (at gauging point) expressed in MT (Million metric tonnes). The annual observed sediment load and annual rate of sediment loss is presented in following Table 3.2.

Table 3.2 Observed sediment loss at the gauging stations.

Year	Observed sediment loss	
	(tones /ha/yr)	Million metric tones
1992	6.37	1.417
1993	8.33	1.853
1994	10.75	2.391
1995	6.81	1.515
1996	5.91	1.314
1997	13.18	2.930
1998	9.67	2.150
1999	15.11	3.360
2000	7.09	1.576
2001	6.17	1.371
2002	6.57	1.460
2003	9.26	2.060
2004	5.93	1.318
2005	11.94	2.254
2006	7.85	1.745
2007	6.75	1.501
2008	6.65	1.478
2009	12.14	2.699
2010	7.76	1.725
2011	7.84	1.743

3.2.2 Soil

Soil physical and chemical properties hold great roles to any erosion and hydrological model as well. Soil properties such as texture, structure, organic matter, nature of clay and the amount and kinds of salts characterise the detachability and transportability of soil. Soil of high detachability and transportability are highly erodible.

In this study, the soil data was used to assess/estimate susceptibility of soils in the study area to be eroded by the rainfall. To serve the purpose, soil map of Madhya Pradesh, sheet no. 5, generated by National Bureau of Soil Survey and Land Use Planning (NBSSLUP) was used. The map generated is at the scale of 1:500000. The NBSSLUP has assigned Soil Mapping Units (SMU) to different soils based on soil characteristics and the same has taken in this study for computation of soil erodibility factor (K).

3.2.3 Digital elevation model (DEM)

Topography is one of the prime inputs to any erosion and hydrological model, since it defines the effect of gravity on the movement and flow of water and sediments. Digital Elevation Model (DEM) consists of an array of uniformly spaced elevation data used to represent the topography. A number of DEMs are readily available today, with resolutions ranging from 1 arc second (30 m) to as high as 30 arc second (1 km). The elevation and derived topographical variables used in the baseline and present-day scenario evaluations were derived.

In this study, Digital Elevation Model (DEM) of the study area is required for watershed and stream network delineation and including slope for HRU (Hydrological Response Unit) definition. The DEM of the study area was obtained from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) elevation data, which is accessible at the website http://www.glcf.umd.edu. The data obtained was in Tagged Information File Format (TIFF) and has a ground resolution of 30 m.

3.2.4 Satellite data

For generating the land use/land cover information, satellite data of IRS-P6 LISS III and LANDSAT-7 ETM+ images was used. For getting information of the vegetation or ground cover, the land use land cover of the study area was prepared with the help of ERDAS IMAGINE 2011, which is popular image processing software. Of the satellite data used in this study, IRS-P6 LISS III was obtained from National Remote Sensing Agency (NRSA, Hyderabad) via MPWSRP Lab and LANDSAT-7 ETM+ was downloaded from GLCF (Global Land Cover Facility, Maryland) website (http://www.glcf.umd.edu.). The details of the satellite data are provided in Table 3.3 and False Colour Composite (FCC) of study area is shown in Fig. 3.2.

Table 3.3 Details of satellite images used

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	8th Jan 2011
LANDSAT-7	ETM+	30 m	2,3,4,5	185 km	144/44	14th Dec 2006
LANDSAT-7	ETM+	30 m	2,3,4,5	185 km	144/44	26th Dec 2000

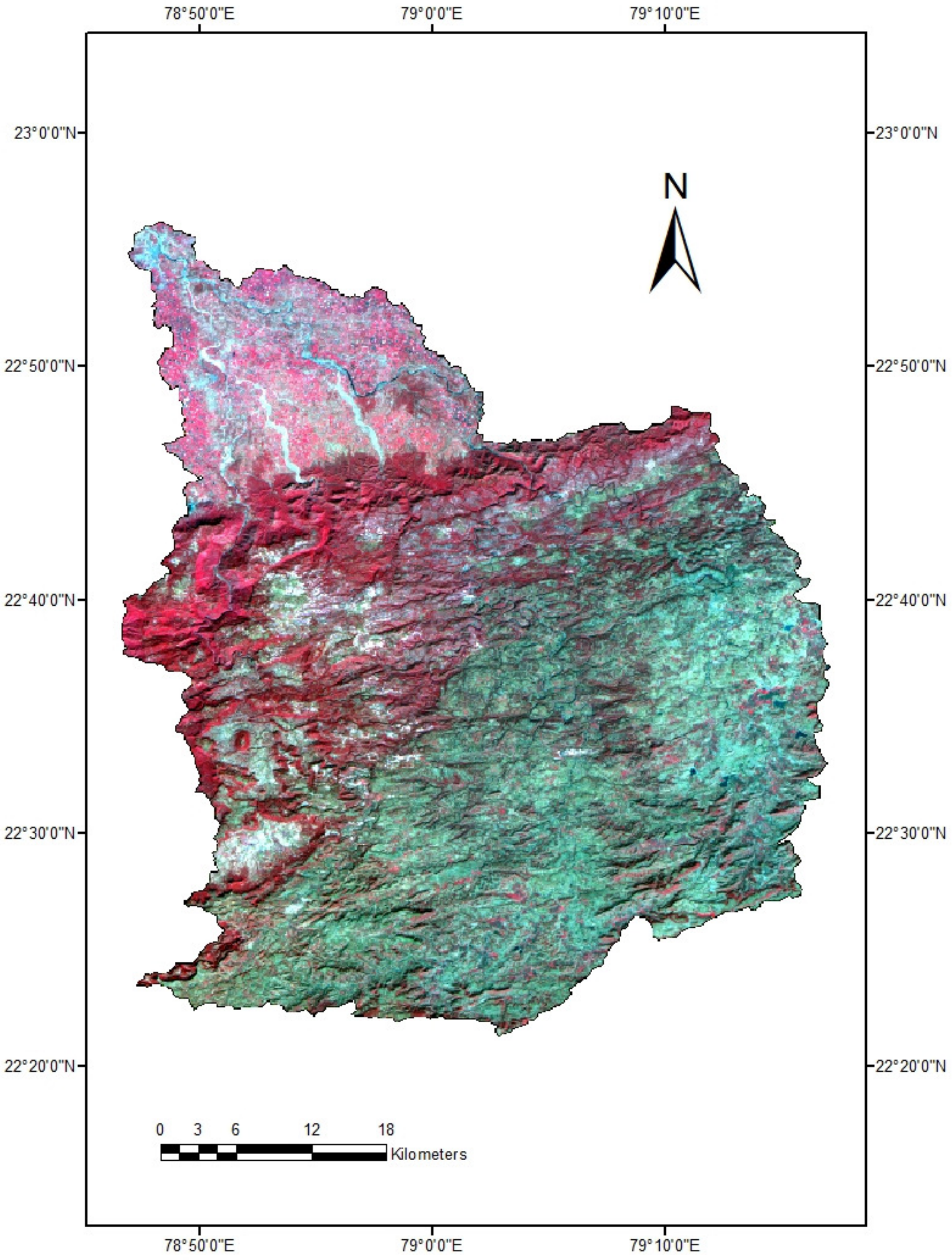

Fig 3.2 False Colour Composite (FCC) of the study area

3.3 Software used for preparation of thematic maps

Software available at a 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 the preparation of thematic maps and analysis of data. Details of software used are shown in Table 3.5.

Table 3.5 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 of ArcView and ArcEditor and adds advanced geoprocessing and data conversion capabilities. Professional GIS users use ArcInfo for all aspects of data building, modelling, analysis, and map display for screen and output. ArcCatalog is mostly used for creating, dleting and editing the spatial data file (ESRI)
ERDAS IMAGINE 2011	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 analyse them.

3.4 Introduction to Geographic Information System (GIS)

Development of Geographic Information System (GIS) closely follows advancement 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 software are capable of storing complex spatial information into separate, thematic layers (Fig 3.3).

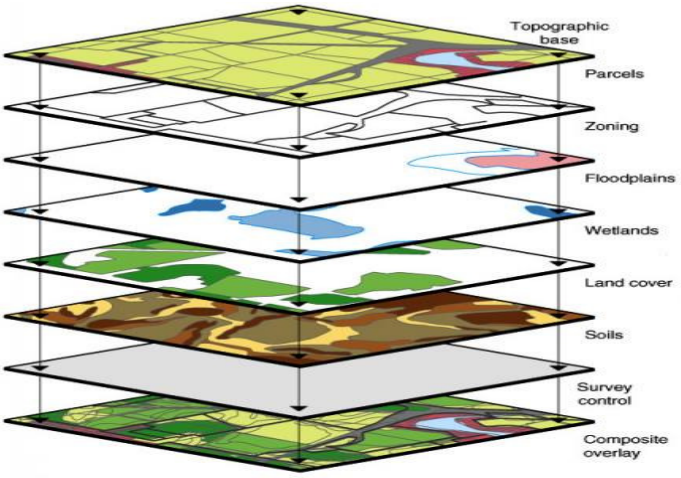

Fig 3.3 Example of GIS data layer organized into separate themes

The two spatial data types used in this research project are vector and raster files. Vector data contains features defined by a point, line, or polygon. Vector data models are useful for storing and representing discrete features such as building 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 dataset, such as a category, magnitude, distance, or spectral value. The category could refer to a land 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. The use of the same projection system allows one raster layer to overlay over other layer. This research has used the Datum India 1975 (D_Indian_1975) and Indian Polyconic Projection System for all data types.

3.5 Methods of analysis

For accurate estimation, use of the relevant data and methods of analysis are emphasized greatly. This section includes the theory and procedure used for estimation and analysis. The detailed procedure for estimation of various USLE factors has given below:

3.5.1 USLE based spatially distributed soil erosion estimation

The rate of soil erosion from an area is strongly depends upon rainfall, topographic characteristics, soil and vegetation. Therefore, a method which takes these factors into account while estimating soil erosion is expected to produce realistic estimate of rates of soil erosion (Das, 2008). The universal soil loss equation (USLE) 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 extensively used to realistically estimate surface soil erosion (Jain and Goel, 2002).

3.5.2 The USLE

The universal soil loss equation (USLE) (Wischmeier and Smith, 1965) for estimation of average annual rate of soil erosion can be expressed as:

$$A_i = R_i.K_i.L_i.S_i.C_i.P_i \tag{3.1}$$

Where,

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

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

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

L_i = slope length factor (Dimensionless),

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

C_i = crop or 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 and P) show spatial variability. Thus a watershed is needs to be discretized into smaller homogeneous areas to capture catchment heterogeneity (Jain and Kothyar, 2001). As the scale becomes coarser (e.g. larger grid/cell sizes), spatial heterogeneity often decreases due to averaging, which introduces uncertainty (Goodchild, 1998). Uncertainty also increases with spatial variability because modeling or forecasting relationships across an area is more difficult when phenomena are highly variable. Several studies have indicated changes in variability with changing geographic scales (Meentemeyer, 1989; Wu *et al.*, 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. Five different spatial scales; 20 m, 30 m, 50 m, 100 m, and 200 m were used to represent the cell as hydrologically homogeneous area in the present study, as well as all the USLE-GIS computations were carried out at all these five spatial scales.

3.6 Development of model database for USLE

3.6.1 Rainfall erosivity factor (R)

Rainfall erosivity factor (R) is the basic and important factor in the assessment of soil erosion in the mathematical model, Universal Soil Loss Equation (USLE) and its revised form RUSLE (Kamaludin *et al.*, 2013). Erosivity is the potential capacity of the raindrops to cause detachment of the soil particles from its location and it depends on rainfall intensity its recurrence. Therefore, it is important to accurately estimate the erosivity for 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.

Mathematically,

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

Where,

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

$$KE = 210.3 + 89 \log I \tag{3.3}$$

Where,

I = rainfall intensity in cm/h and

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

$$R = \sum Erosion\ index = \sum_{i=1}^{n}(KE \times I_{30}) \tag{3.4}$$

Where,

KE = Kinetic energy of the storm (MJ/ha)

To accommodate the natural climatic variations, Wischmeier and Smith (1978) recommended that at least 20 years of pluviographic data be used. Self recording rain gauges are usually expensive, so rainfall erosivity is typically known only at a limited number of locations. Hence, many researchers have been making attempt to establish a simplified relationship between erosivity and depth of rainfall, as depth of rainfall can be measured at all locations.

To compute storm KI_{30}, continuous rainfall data is needed. For Indian conditions, a linear relationship was developed by Babu *et al.*, (2004) between average annual and seasonal (June - September) rainfall and rainfall erosivity factor (R). They used 123 rain gauge stations situated in various parts of India. Derived relationships are as follow:
Annual relationship:

$$R = 81.5 + 0.38\, R_n \quad (340 \le R_n \le 3500 \text{ mm}) \qquad (3.5)$$

Seasonal relationship:

$$R = 71.9 + 0.361\, R_s \quad (293 \le Rs \le 3190 \text{ mm}) \qquad (3.6)$$

Where,

R is the average annual / seasonal erosion index,

R_n is the average annual rainfall (mm) and

R_s is the average seasonal rainfall (mm).

In this study, equation 3.5 was used to calculate annual values of R factor by replacing R_s with actual observed rainfall in a year.

The thematic map of rainfall erosivity factor (R) was developed in the GIS platform. The thiessen polygon of the study area was prepared using spatial analyst toolbox of the ArcGIS 9.3 considering three rain gauge stations namely, Gadarwara, Ammarwar and Harrai. Thiessen polygon gives fair distribution of rainfall in the surrounding area of the rain gauge station (Aggarwal *et al.*, 2000). After attributing the values of R factor to the thiessen polygon, raster maps of R factor of individual years were prepared at all the five spatial scales using the conversion toolbox of ArcGIS 9.3.

3.6.2 Soil erodibilty factor (K)

Soil erodibility factor (K) is closely related to various properties of soil by virtue of which a particular soil becomes susceptible to be eroded, by either water or wind. Physical characteristics of soil greatly influence the rate at which different soils are eroded. The soil erodibility factor (K) is expressed as tonnes of soil loss per hectare per unit rainfall erosivity index, from a field of 9% slope and 22.13 meters as field length. Soil erodibility factor (K) is a measure of the total effect of a particular combination of soil properties. Some of these properties influence the capacity of soil to infiltrate rain and therefore, help to determine the amount of rate of runoff (Young *et al.,* 1987). A simple nomograph was developed by Wischmeier *et al.*,(1971) to determine the K value using five soils viz, percent of silt (MS; 0.002 – 0.05 mm), percent of very fine sand (VFS; 0.05 – 0.1 mm), percent of sand greater than 0.1 mm, percentage of organic matter content (OM), structure (S) and permeability (P). An analytical relationship for nomograph by Wischmeier *et al.*, (1971) is given by the equation

$$100K = 2.1M^{1.14} (10^{-4}) (12 - a) + 3.25 (b - 2) + 2.5 (c - 3) \qquad (3.7)$$

Where,

K = soil erodibility factor,
M = percentage silt, very fine sand and
sand > 0.10 mm,
a = organic matter content,
b = structure of the soil,
c = permeability of the soil.

In this study the soil erodibilty factor (K) was taken from literature on the basis of soil properties (Singh *et al.*, 2009). For this purpose soil map of Madhya Pradesh was digitized into individual soil map unit in the ArcMap extension of ArcGIS 9.3. Then the values of K factor for respective soil map unit were attributed and raster maps of K factor at all the five spatial scales were prepared using Conversion toolbox of ArcGIS 9.3.

3.6.3 Topographic factor (LS)

It represents the erosive potential of a particular soil with a specific slope length (L) and slope steepness (S).

3.6.3.1 Slope Length Factor (L)

One can define slope length as the distance from the origin point of overland flow to the point, where, the slope gradient decreases either sufficiently because of which deposition starts or to where the flow connects to a river system (Wischmeier and Smith, 1978) as shown in Fig. 3.4.

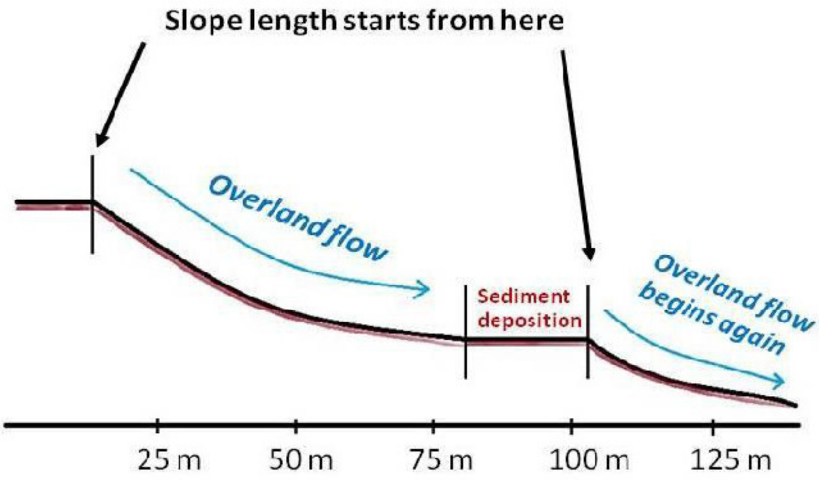

Fig 3.4 Field estimation of the slope length on a side profile of a hill.

The slope length factor is dimensionless because it is simply a ratio of the soil loss from a given length of slope to that from having 22.13 m length of slope: its values is generally expressed as (Wischmeier and Smith, 1978):

$$L = \left(\frac{\lambda}{22.1}\right)^{m} \tag{3.8}$$

Where,

λ = field slope length in meters and

m= an exponent having values ranging from 0.2 to 0.5

3.6.3.2 Slope steepness factor (S)

Slope steepness factor is defined as the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions (Renard *et al.*, 1997). Soil loss increases rapidly with slope steepness than it does with slope length. For typical slope conditions, a 10% error in slope length results in a 5% error in computed soil loss. In contrast, a 10% error in slope steepness will usually result in about 20% error in computed soil loss (Morgan, 2001). The slope steepness factor (S) is evaluated from (McCool *et al.,* 1987)

$$S = 10.8 \sin \theta + 0.03 \text{ for slopes} < 9\% \qquad (3.9.a)$$

$$S = 16.8 \sin \theta - 0.50 \text{ for slopes} \geq 9\% \qquad (3.9.b)$$

Where,

θ is slope in degree.

The effect of topography on soil erosion is accounted for by the LS factor in USLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S) and is shown in Fig. 3.5. It has been widely known that an increase in the slope length (L) will result in simultaneous increase in soil erosion per unit area, due to the accumulation of surface runoff on down slope direction. As the slope steepness (S) increases, the velocity and soil erosion of surface runoff also increases.

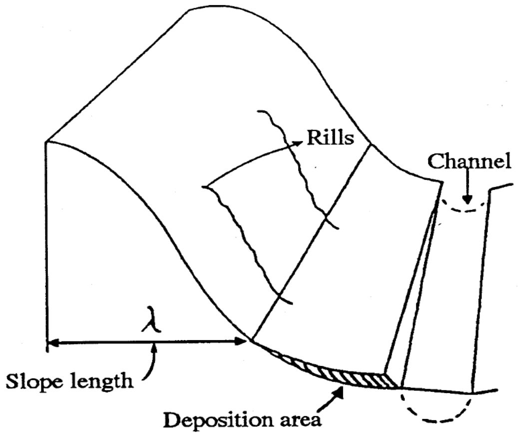

Figure 3.5 Schematic slope profile for USLE application (Renard et al., 1997)

. In the present study the LS factor was calculated by an executable C++ (Khosrowpanah *et al.,* 2007). The program was originally written in Arc Macro Language (AML) (Hickey 2000) and was upgraded in 2004 to C++ programming language in order to be more efficient in processing. 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 “Computer and Geoscience”.

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 txt format called ASCII. ArcMap has the function to do this located under the Conversion toolbox extension. Then, the C++ executable is run by double click on the application file. A series of command lines appears. The first line ask or the user to enter the path and filename for the DEM data, which must be in ASCII text format. Enter the full path to the text file in the form of “B:\Folder name\name of the file with .txt extension”. The second line then asks for the path of the output file to 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 the computation of the DEM text file.

The output of the program consist 16 total files with the .dat file extension. To convert the output file back to a raster format, the extension 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.

3.6.3.3 Description of C++ program’s operation

The program begins with a fill function on any depressions or sinks found in DEM input. The highest elevations on the DEM are identified by program and then the flow direction is determined. Theoretically, if rainfall lands on a high point, the direction of flow can be in either one of the cardinal direction (ie. N, S, E, W) or the diagonal directions (ie. NE, SE, SW, NW). In situation of converging flow, the flow direction of steepest decent takes precedence. Then, distance between the centre of one grid cell to the next grid cell is calculated by the C++ program as the non-cumulative slope length (NCSL). The logic of the program to calculate L factor is based on the following concepts (Hickey, 2000):

If the cell being calculated is at 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)

if flow is in diagonal direction (NE, NW, SE, SW)

then 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 that it recognizes the areas where deposition is the dominant process instead of erosion. The assumption is that the deposition will begin in areas where the slope angle decrease enough that surface flow can no longer transport sediment. The program use a function called the cut-off slope angle defined as the ratio of change in slope angle from one grade to the next along the flow direction. The default values for the slope cut-off angle are 0.5 for slope gradients greater than 5% and 0.7 for slope gradients less than 5%. These values are based on observations that depositions are easier to start on slopes with low gradients (Van Remortel *et al.*, 2004). When the slope angle decrease enough, the cumulative slope length calculation process stops and when the land surface extend further downhill, the calculation restarts. The methodology for calculating the L and S factors using C++ programming has summarized in Figure 3.6.

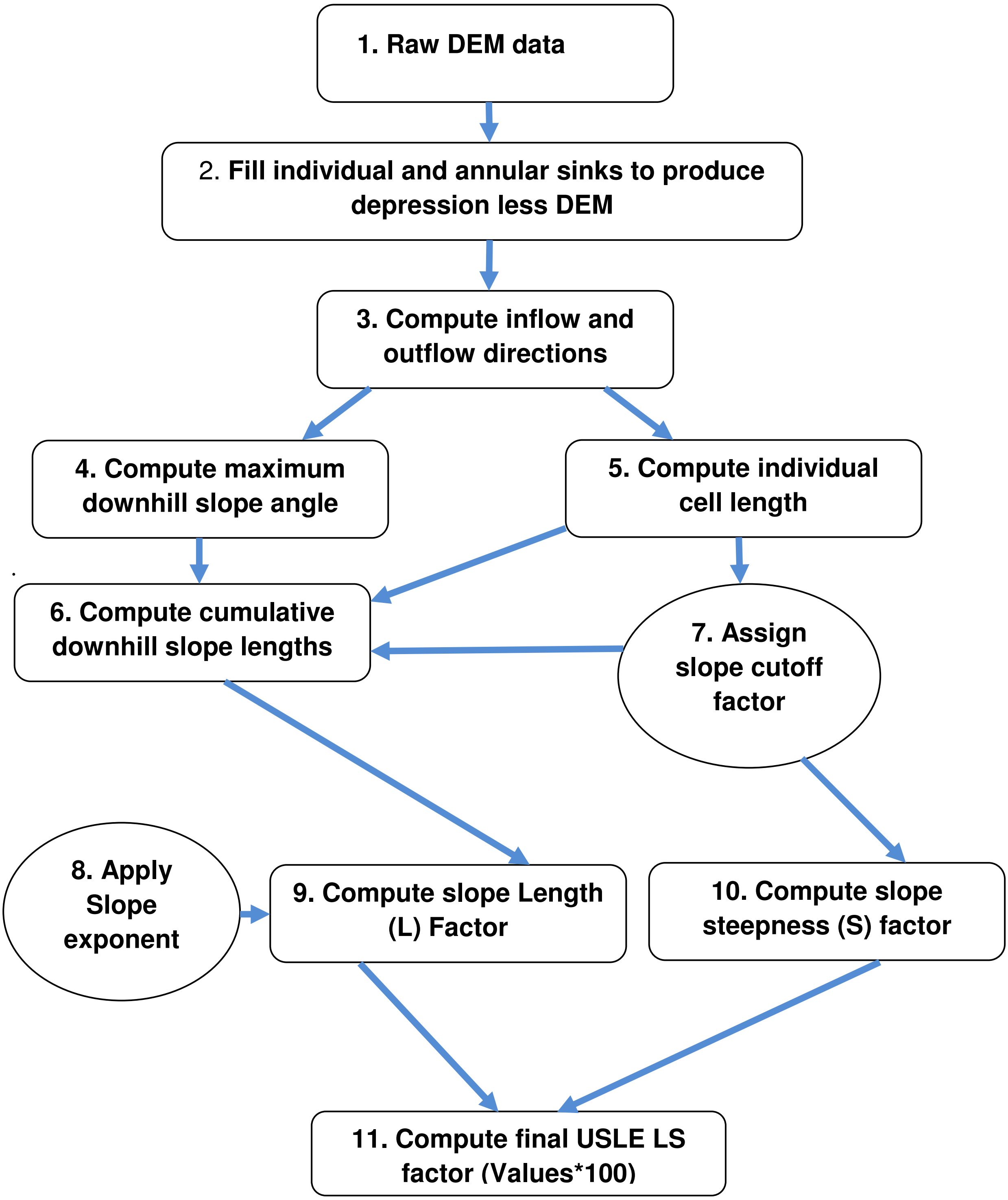

Figure 3.6- Flowchart illustrating process of calculating cumulative downhill slope length, slope steepness and final LS factor values using C++ executable program, for application of RUSLE erosion model (Van Remortel *et al.*, 2004).

3.6.4 Crop Management Factor (C)

The C-factor represents the effect of cropping and management practices on soil erosion rates in agricultural lands as well as the effects of vegetation canopy and ground cover on soil reduction in forested regions (Renard *et al.,* 1997). It is defined as the ratio of soil loss occurring on field plots with the variables in place over field plots with no vegetation cover or techniques in place. It is dimensionless parameter in USLE. The value of *C* depends on vegetation type, stage of growth and cover percentage. Therefore, it is very important to have good knowledge concerning land-use pattern in the basin to generate reliable *C* factor values (Praveen and Kumar, 2012).

The amount of protective cover of crops or vegetation for the land surface influences the soil erosion rates. The cover management factor (C) value is 1 when the land has continuous bare fallow with no vegetation coverage (standard plot condition) and it is lower when there is more vegetation or crop cover resulting in lower amount of soil erosion (Schonbrodt *et al.,* 2010). Therefore knowledge of land use, crop types and information of cropping history are needed to determine C-factor value (Gitas *et al.,* 2009).

A regression analysis is used by many researchers for estimation of C-factor in erosion assessment (Lin *et al*., 2002; Symeonakis and Drake, 2004; Van der Knijff *et al*., 2002). The crop management factor (C) is estimated by normalized differential index (NDVI) and the relationship between c-factor and NDVI is given below. (Lin *et al*., 2002).

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED}) / (\mathrm{NIR} + \mathrm{RED}) \qquad (3.10)$$

In this study, C factor map was prepared by using satellite data of IRS-P6 LISS III and Landsat-7 ETM+ images covering area of watershed. These images were processed and three land use/ land cover map were prepared with the help of ERDAS IMAGINE 2011. In this study, Google Earth was used as a assistance for verification of the Satellite images with the ground features throughout the study. The values of C factor as suggested by Pandey *et al.,* (2007) were attributed to the land use/ land cover maps and raster maps of C factor at five different spatial scales were prepared by using the Conversion Tool Box of ArcGIS 9.3.

3.6.5 Soil conservation practice factor (P)

It is the ratio between soil loss with a specific support practice and the corresponding loss with upslope and down slope tillage. These conservation practices dominantly affect erosion by improving the flow pattern, grade, or direction of surface runoff and reducing the rate of runoff. The conservation/support practices consider strip-cropping, terracing, contouring and sub-surface drainage (Renard *et al.,* 1997).

In present study for the preparation of P factor map, the land use/ land cover map was used. 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 maps and raster maps of the P factor at five different spatial scales were prepared using the Conversion tool box of ArcGIS 9.3.

3.7 Assessment of annual gross soil erosion at variable spatial scale

To calculate the annual gross soil loss (A) the USLE model (Wischmeier and Smith, 1965) was combined with the ArcGIS 9.3. The estimations were done at five different spatial scales; 20 m, 30 m, 50 m, 100 m, and 200 m. Raster layers corresponding to each of the USLE factors at different spatial scales were created, stored and analyzed within the ArcGIS. This combination computes the simulated gross erosion of the entire watershed. The cells/grids in each layer overlap on that of the other layers and the USLE computation can be done by multiplying all the USLE factors together. The estimations were carried out for 20 years (1992-2011), using distributed information for rainfall, soil, topography and land use of the entire study area. 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.

3.8 Analysis of effect of variable spatial scales on simulated gross soil loss.

The simulated gross erosion/soil loss at five different spatial scales was compared with observed soil loss 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 System Organization, Water Planning and Projects Wing, Central Water Commission. The validation of the USLE simulated gross erosion was done with the observed values for 20 years (1992-2011). Firstly, the percent deviation between observed and estimated values at five different spatial scales was calculated. The limits of over/under estimation, if falls within 20 percent from the observed, then the model is considered as the acceptable level of accuracy for the simulation (Pandey *et al.,* 2007).

Secondly, the estimated values at all the spatial scales was plotted against observed values and a straight line was plotted with every dataset to study the fit between observed and estimated values and to obtain the co-efficient of determination between observed and estimated values at respective spatial scales.

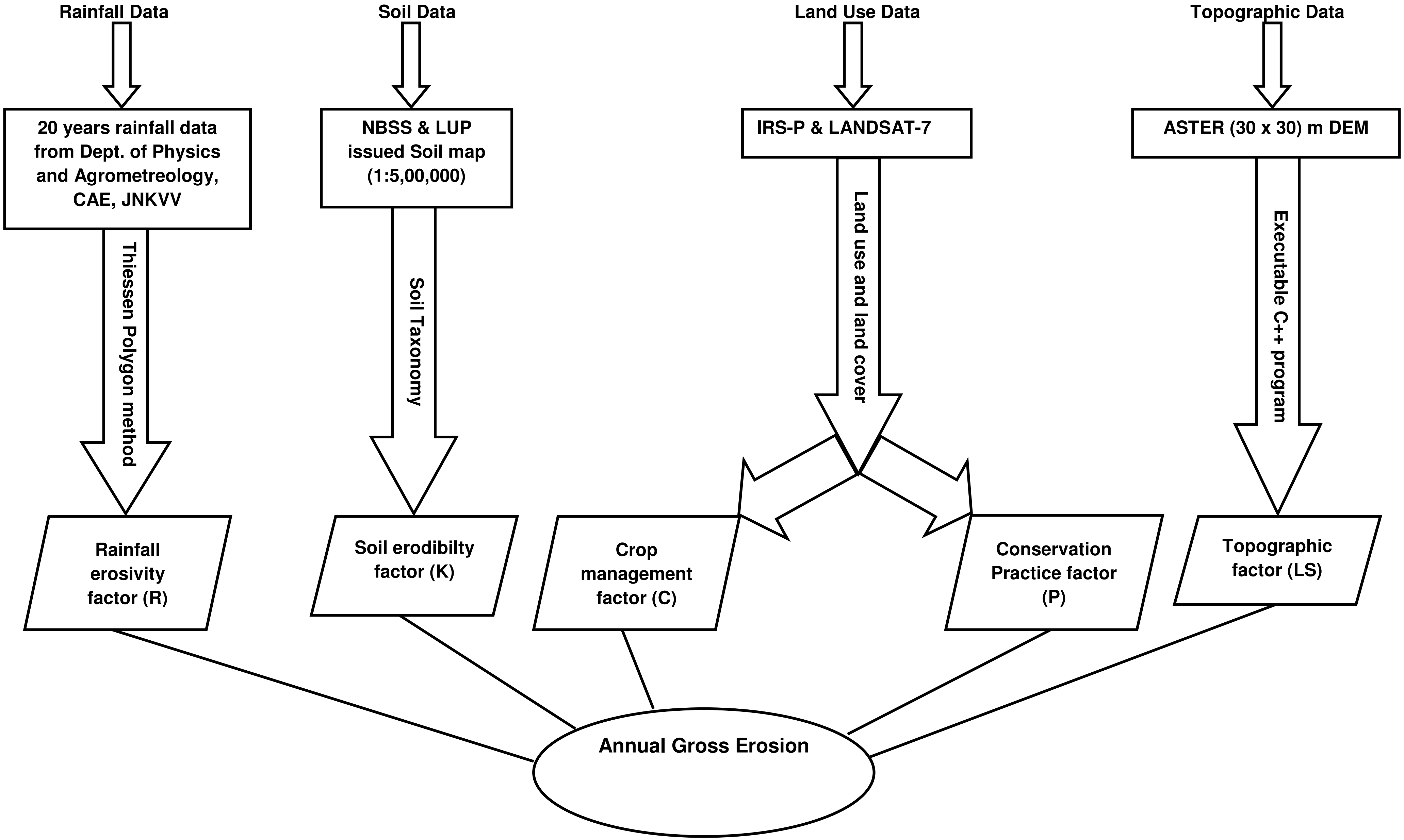

Fig 3.7 Flowchart for Gross Erosion estimation using USLE with GIS

RESULT AND DISCUSSION

The USLE based spatial erosion modelling was performed in Shakkar River watershed to predict the gross erosion on annual basis using spatial techniques. Estimated soil loss was compared with the observed soil loss at the watershed outlet to assess status of sediment delivery of the area. This chapter briefs the core findings of the present study.

4.1 Preparation of the base map of the study area

A geo-coded Digital Elevation Model (DEM) generated from Advance Space-borne Thermal and Reflection radiometer (ASTER) data was used for delineation of the Shakkar River watershed boundary and preparation of drainage map. The digital elevation model (DEM) was downloaded from GLCF website (Global Land Cover Facility, Maryland, 2000) with 30-meter ground resolution. Drainage map of the study area has shown in Fig. 4.1.

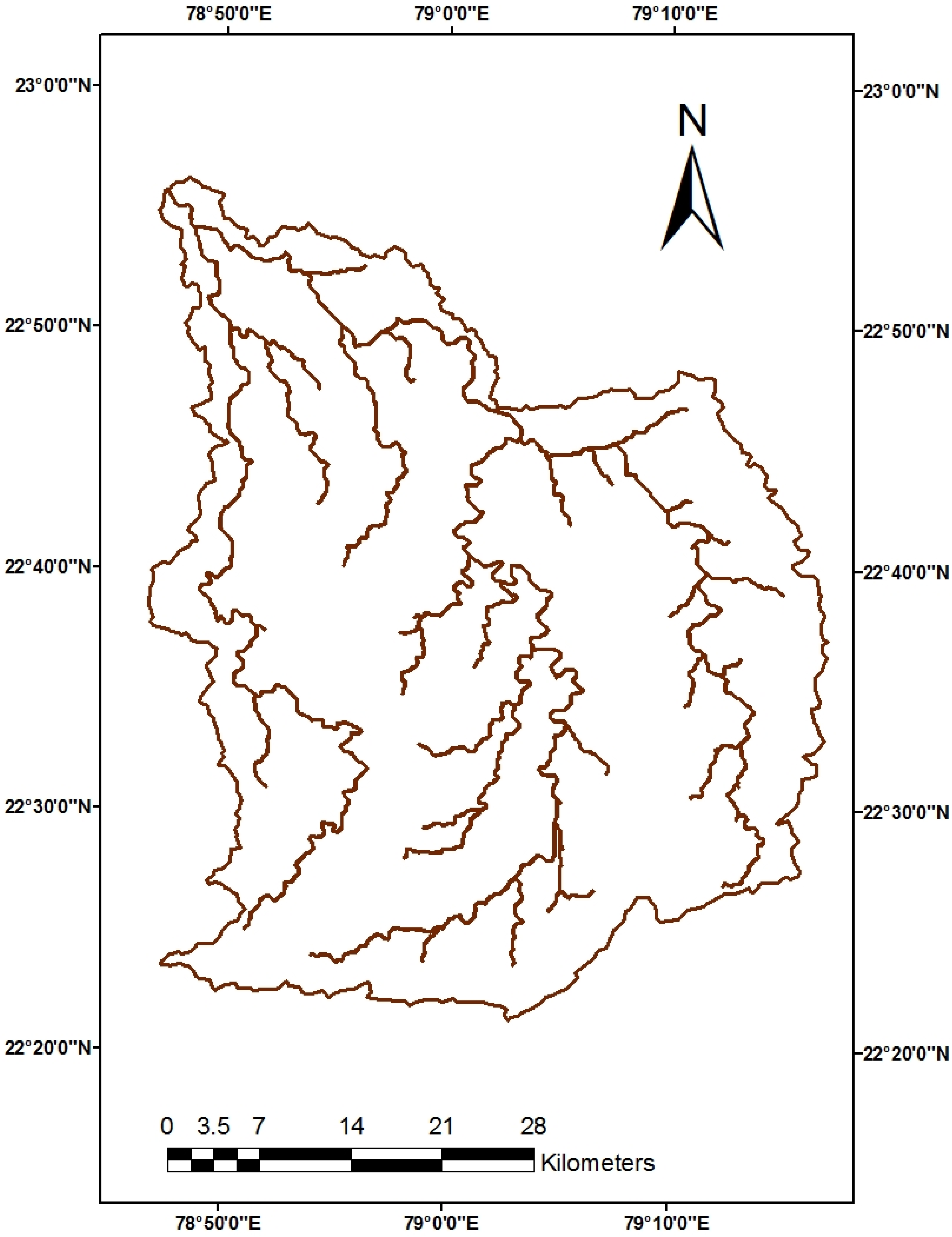

Fig 4.1 Drainage map of study area

4.2 USLE based spatially distributed soil erosion estimation

The estimation of gross soil erosion with precision defies a large variation due to the complex nature of soil erosion variables. Various erosion models needs information related to soil type, land use, landform, climate, and topography to predict soil loss which vary greatly within a watershed. Therefore, a realistic model is expected for the accurate soil erosion estimation, which takes into account all the complex variables of the watershed (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 gross erosion.

4.3 Development of database for USLE

4.3.1 Rainfall erosivity factor (R)

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

The R factor values were calculated for the three raingauge stations falling in the study area and are presented below in Table 4.1.

Table 4.1 Annual rainfall and annual rainfall erosivity Factor (R)

Year	Annual rainfall stations name			Annual rainfall erosivity factor (R)		
	Gadarwara	Harrai	Amarwara	Gadarwara	Harrai	Amarwara
1992	909	1015	844	426.92	467.20	402.22
1993	1279	1276	1258	567.52	566.38	559.54
1994	860	1794	1532	408.30	763.22	663.66
1995	733	951	1085	360.04	442.88	493.80
1996	558	834	899	293.54	398.42	423.12
1997	951	1436	1907	442.88	627.18	806.16
1998	395	1011	1212	231.60	465.68	542.06
1999	2210	2023	1713	921.30	850.24	732.44
2000	928	1018	797	434.14	468.34	384.36
2001	993	1149	625	458.84	518.12	319.00
2002	1031	965	961	473.28	448.20	446.68
2003	1033	1357	938	474.04	597.16	437.94
2004	889	973	601	419.32	451.24	309.88
2005	1279	1202	1392	567.52	538.26	610.46
2006	684	1101	1351	341.42	499.88	594.88
2007	597	1078	1017.4	308.36	491.29	468.11
2008	619	916	847.6	316.99	429.73	403.59
2009	1348	1384	1971.4	593.74	607.57	830.63
2010	907	1194	769	426.16	535.37	373.72
2011	711	1282	857.8	351.68	568.81	407.46
Average	945.74	1198.05	1128.91	440.88	536.78	510.49

The R factor map of the area was prepared using the Thiessen polygon method as stated earlier, considering three raingauge stations namely Gadarwaara, Harrai and Amarwara. The Thiessen polygon of the area is presented in Fig 4.2

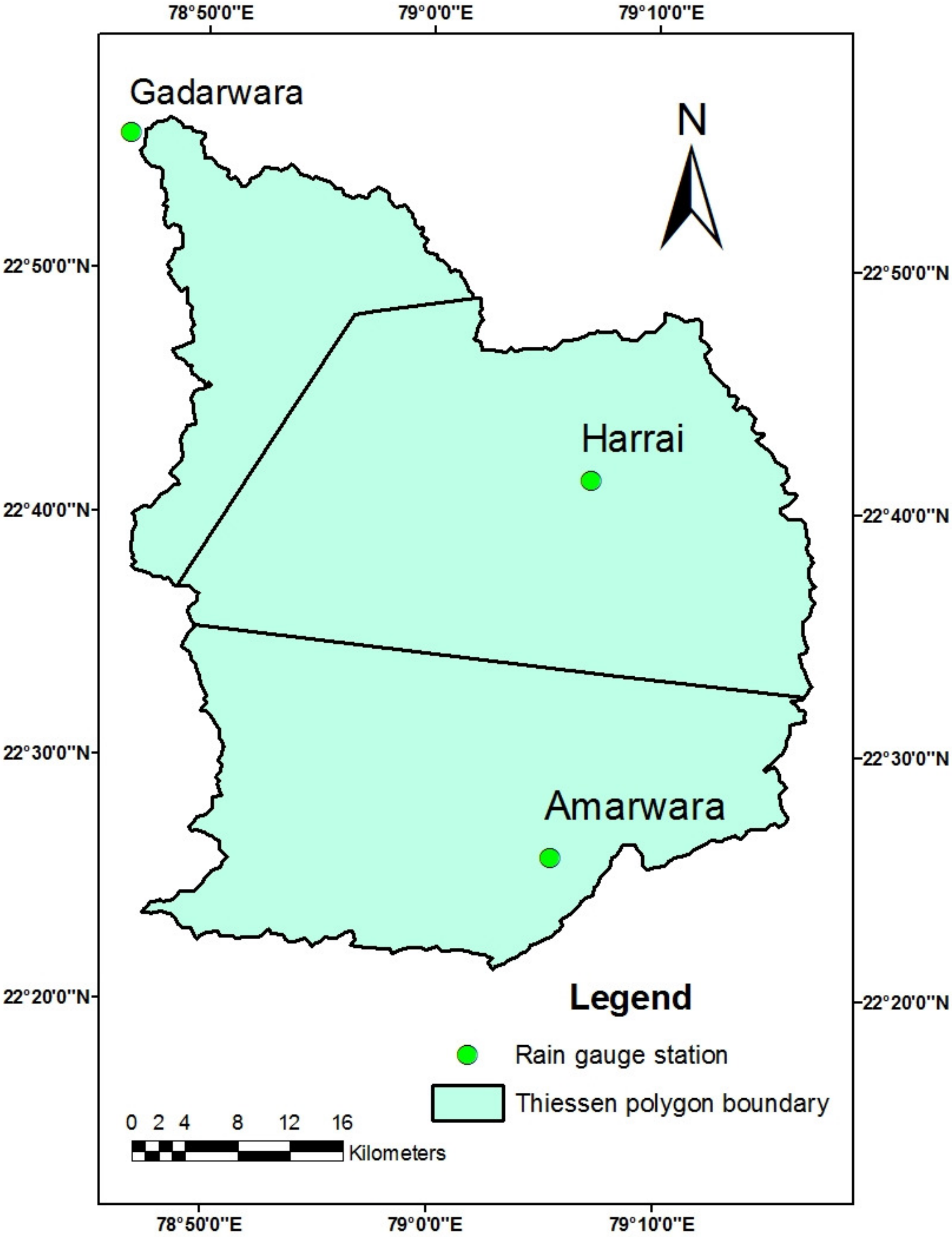

Fig 4.2 Thiessen polygon of the study area

Then, the raster maps of R factor were prepared for five different grid/cell sizes (20m, 30m, 50m, 100m and 200m).The thiessen polygon of the area has been presented in Fig 4.2. And the R factor map of the year 2010 has only shown for representation purpose in Fig 4.3.

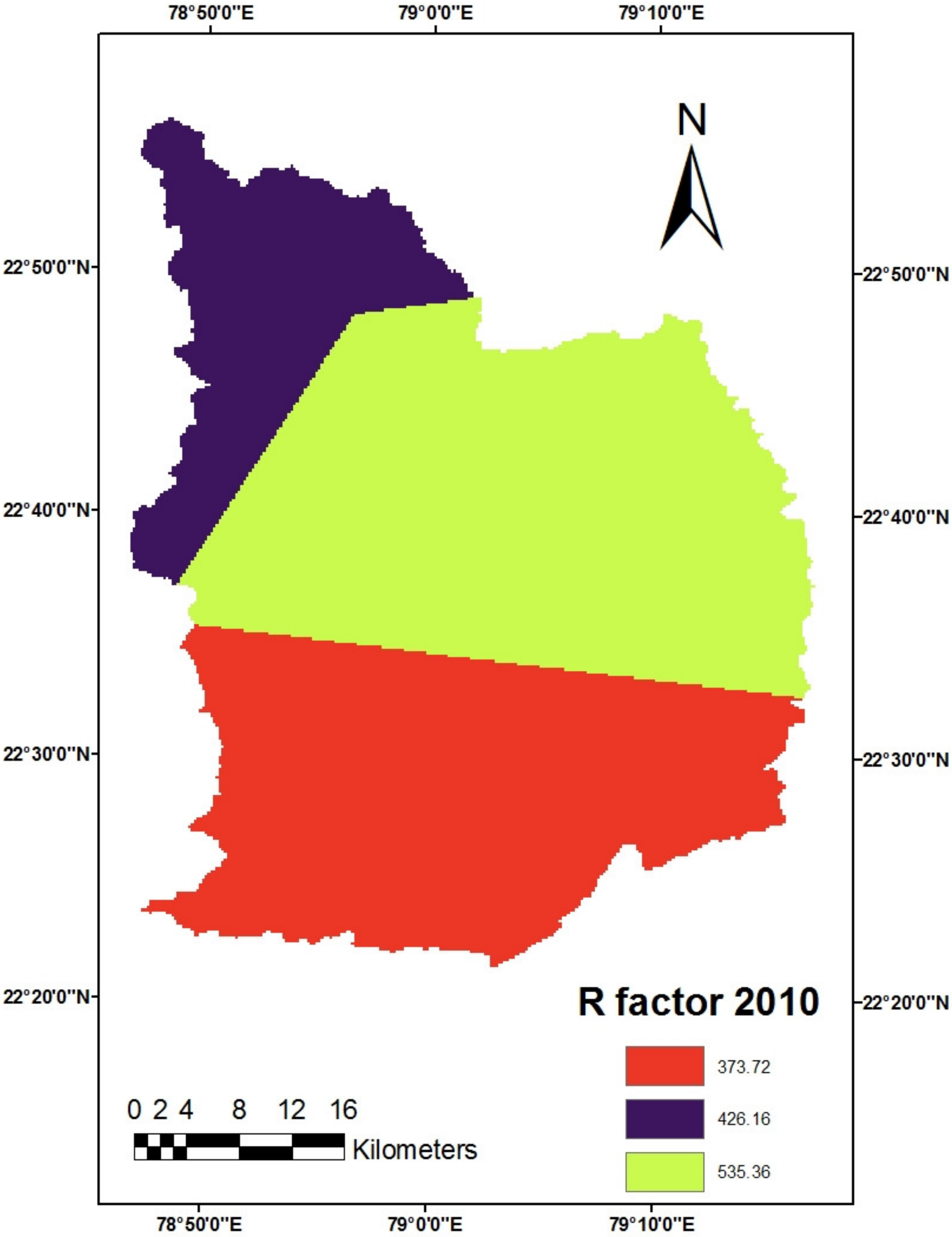

Fig 4.3 Rainfall erosivity factor (R) map of year 2010

4.3.2 Soil erodibilty factor (K)

Soil erodibilty is a function of complex interactions of soil physical and chemical properties affecting detachability, transportability and infiltration capacity. Since erodibilty represents the vulnerability or susceptibility of the soil erosion, erodibilty is the most important fundamental property dependent upon soil type. The soil erodibilty is a lumped parameter that represents an integrated average annual value of the total soil and soil profile to a large number of erosion and hydrologic processes (Young *et al.,* 1987).

Using the methodology described earlier, K map was also 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 Shakkker River watershed.

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

Soil type	**Soil class area (km^2)**	**% 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

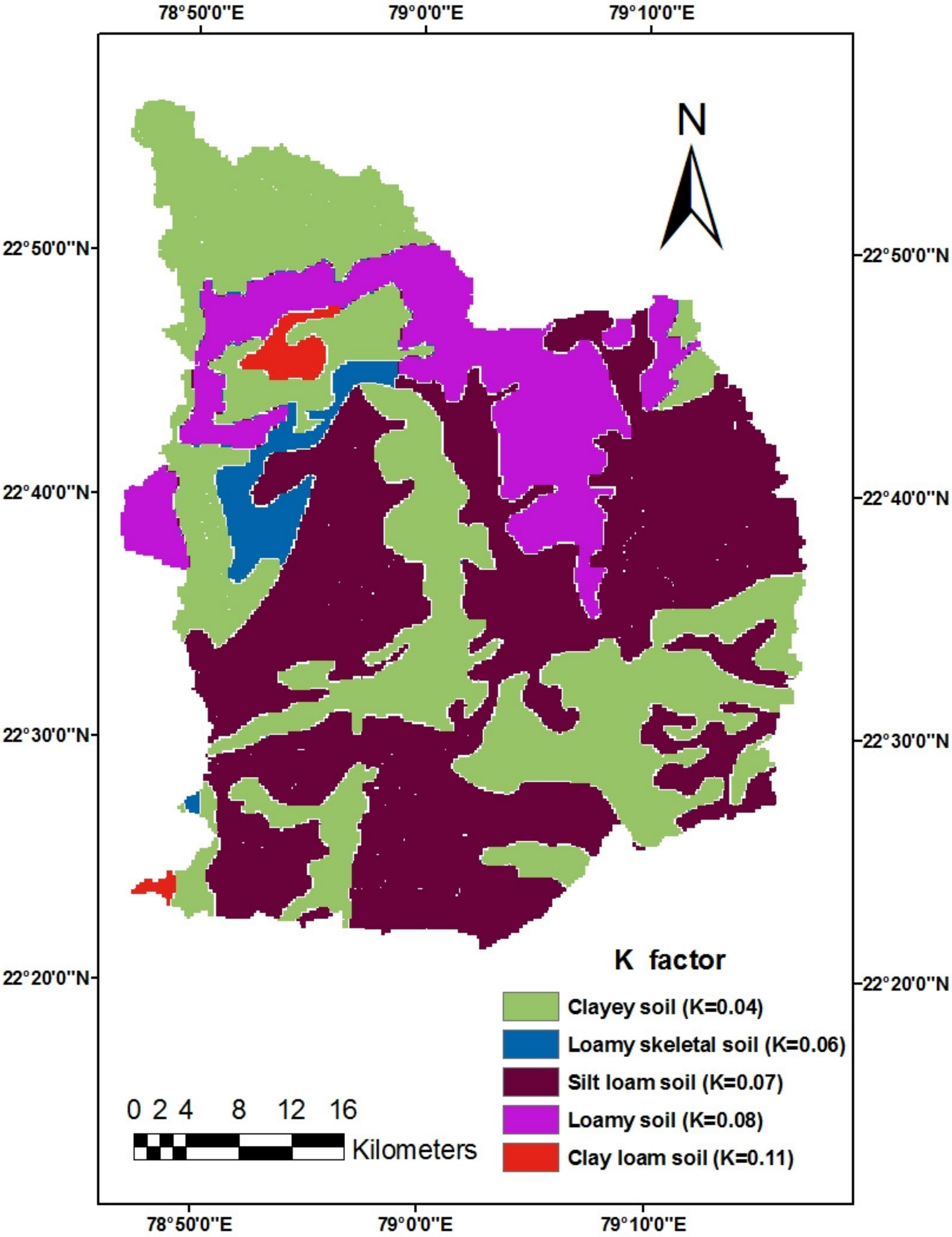

Fig 4.4 Soil erodibilty factor (K) map of Shakker Watershed

4.3.3 Topographic factor (LS)

The digital elevation model (DEM) of the study area was used for computation of LS factor. The digital elevation model (DEM) of the study area was clipped from the downloaded ASTER data and after filling the sinks in the area has been presented in Fig 4.5.

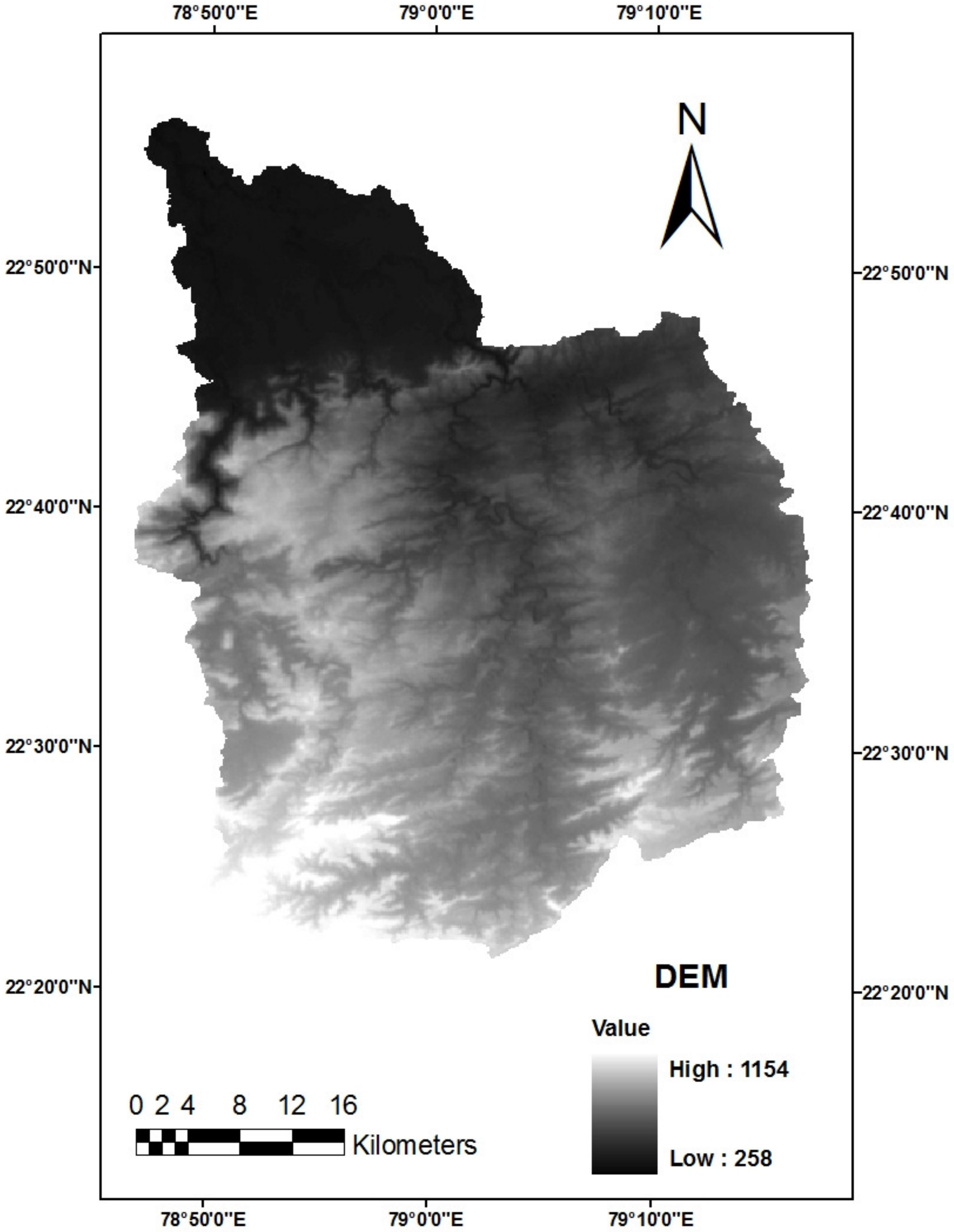

Fig 4.5 Digital elevation model (DEM) of study area.

The topographic factor (LS) was computed using an executable C++ programming language which takes filled digital data as input and yields slope factor map and length of slope map as outputs (Khosrowpanah *et al.,* 2007). 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 97.65. The slope map of the watershed is presented in Fig 4.6 and LS factor map is presented in Fig 4.7.

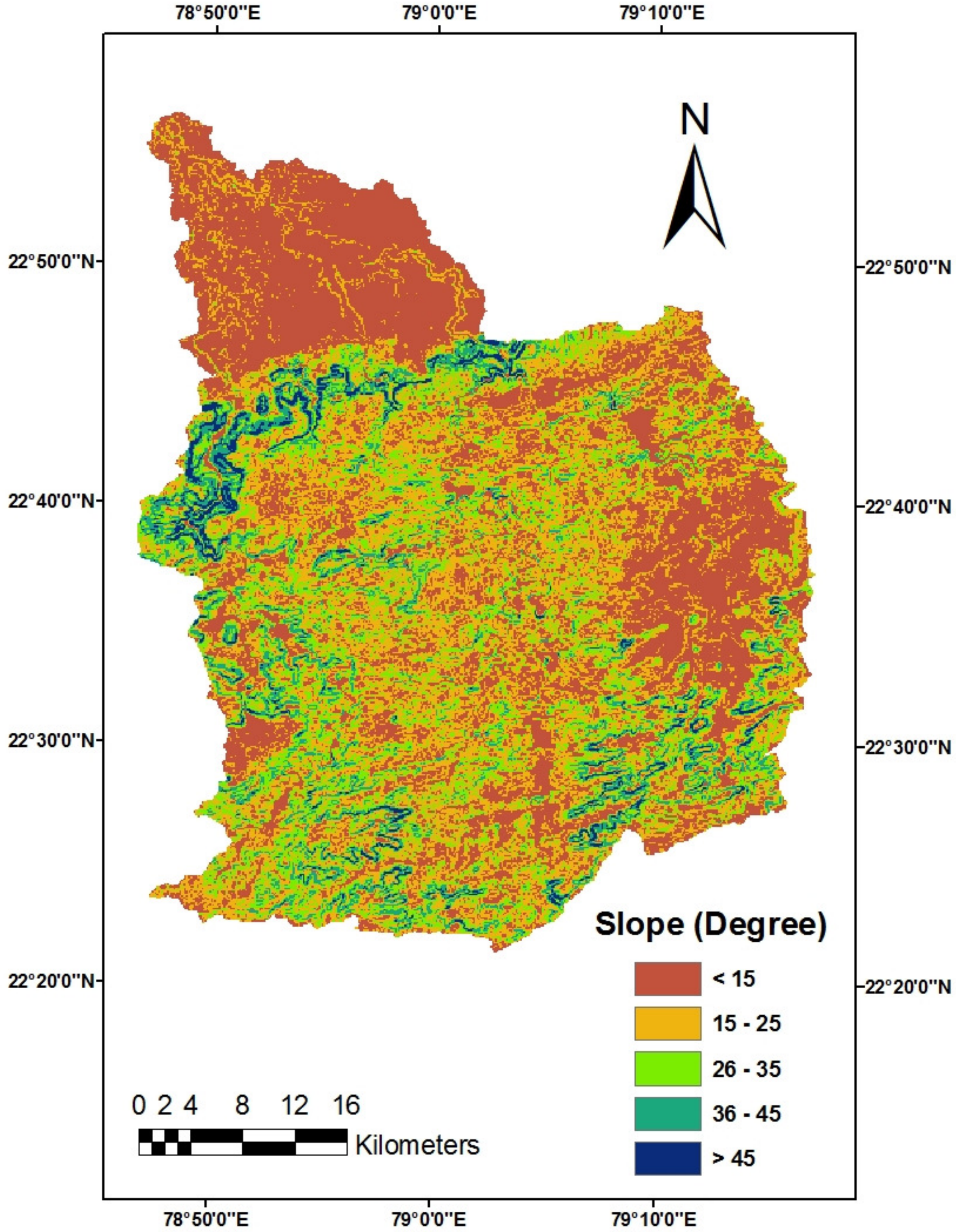

Fig 4.6 Slope map of Shakker watershed.

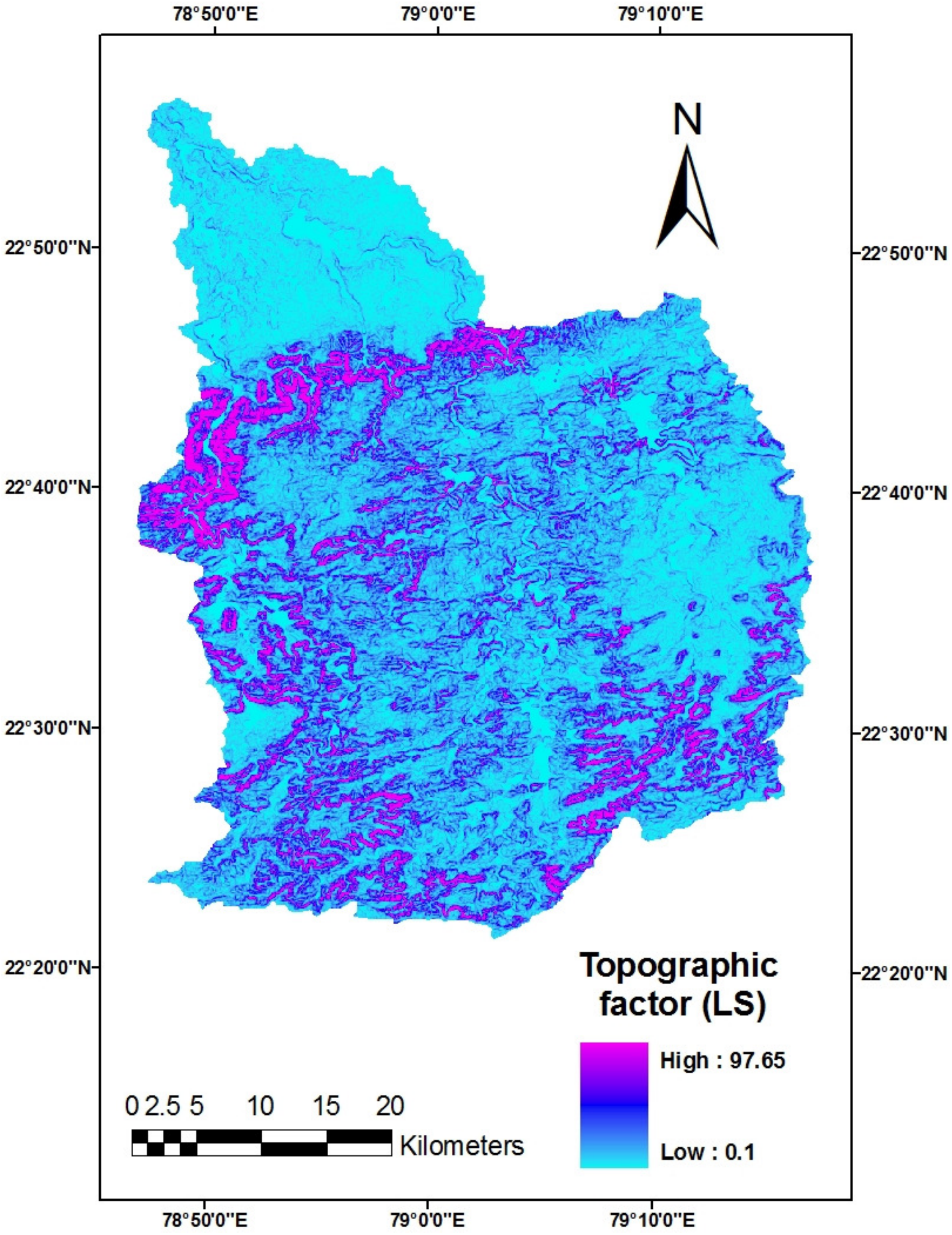

Fig 4.7 Topographic factor (LS) map of study area.

4.3.4 Crop/cover management factor (C)

The C, crop/cover management factor is used to express the effect of plants and soil cover. The C factor measures the combined effect of all interrelated cover and management variables and it is the factor that most readily changed by human activities.

In present study, the land use/land cover map was derived from the satellite image as discussed earlier. It serves as a guiding tool in allocation of C and P factor for different land use classes (Dabral *et al.,* 2008). The C factor values were 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 better understanding and interpretation of the effect of vegetation or ground cover in the study area the land use/land cover map of the study area was prepared with the help of ERDAS 2011. In the process the study area has been classified into seven land use/land cover classes namely: (1) agricultural/other vegetation, (2) fallow/open land, (3) waste land, (4) forest, (5) habitation, (6) river and (7) water body. The land use/land cover maps of the area for three year (2000, 2006 and 2011) are presented respectively in Fig 4.3, 4.4 and 4.5. The soil erosion estimation is made making use of three different LULC map for three different periods. LULC map of 2000 is used for the period from 1992 to 2000, map of 2006 for the period from 2001 to 2006 and map of 2011 for the period from 2007to 2011. The land use/land cover statistics of the study area for the stated year are presented in Table 4.3.

Finally, crop management factor (C) values, as suggested by Pandey *et al.* (2007) were assigned to different land use/land cover patterns of the study area and have shown in Table 4.3. The magnitude and spatial distribution of crop management factor has shown in Fig. 4.11. Crop management factor was found to be in the range of 0.004 and 1.00.

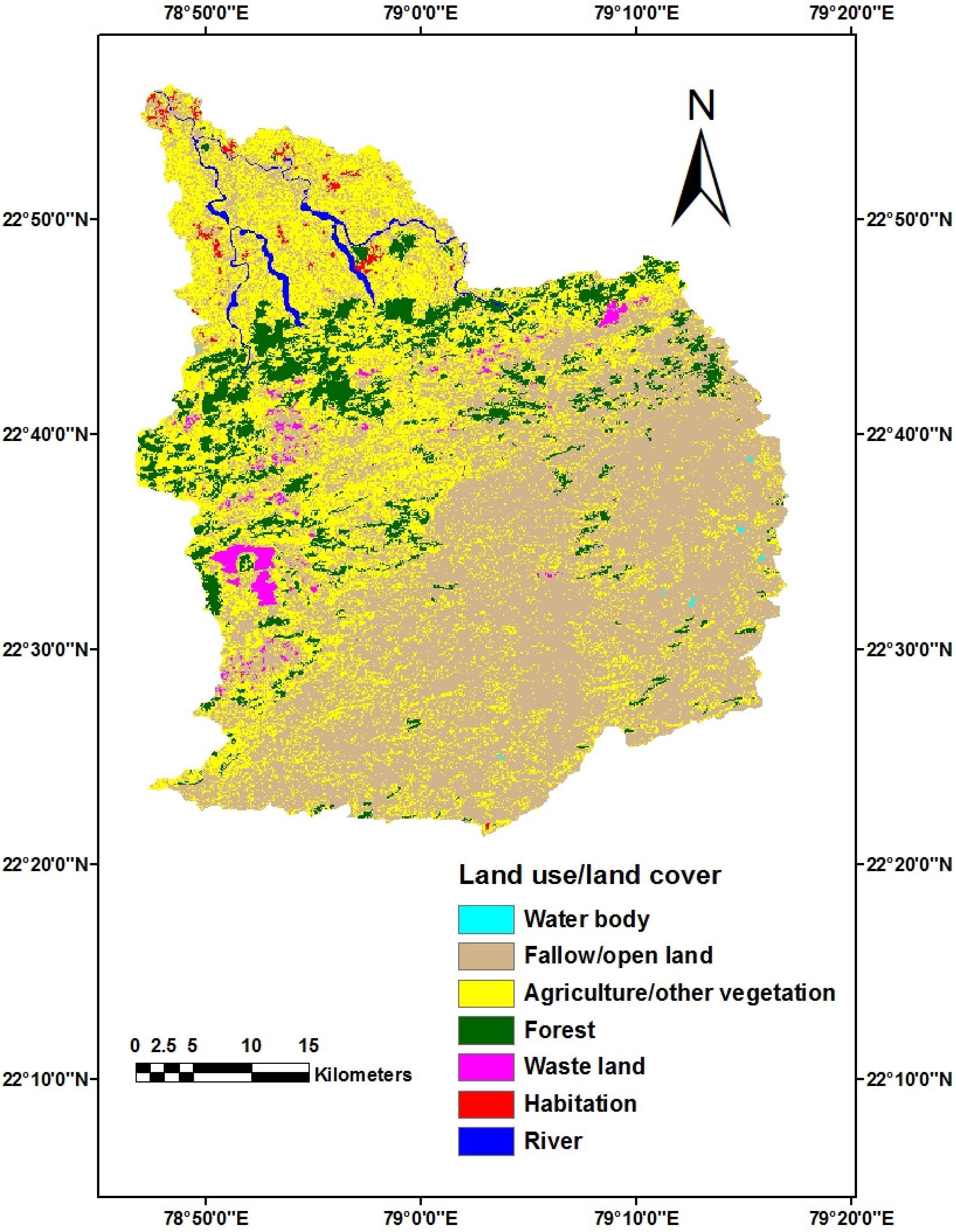

Fig 4.8 Land use/land cover for study area of the year 2000

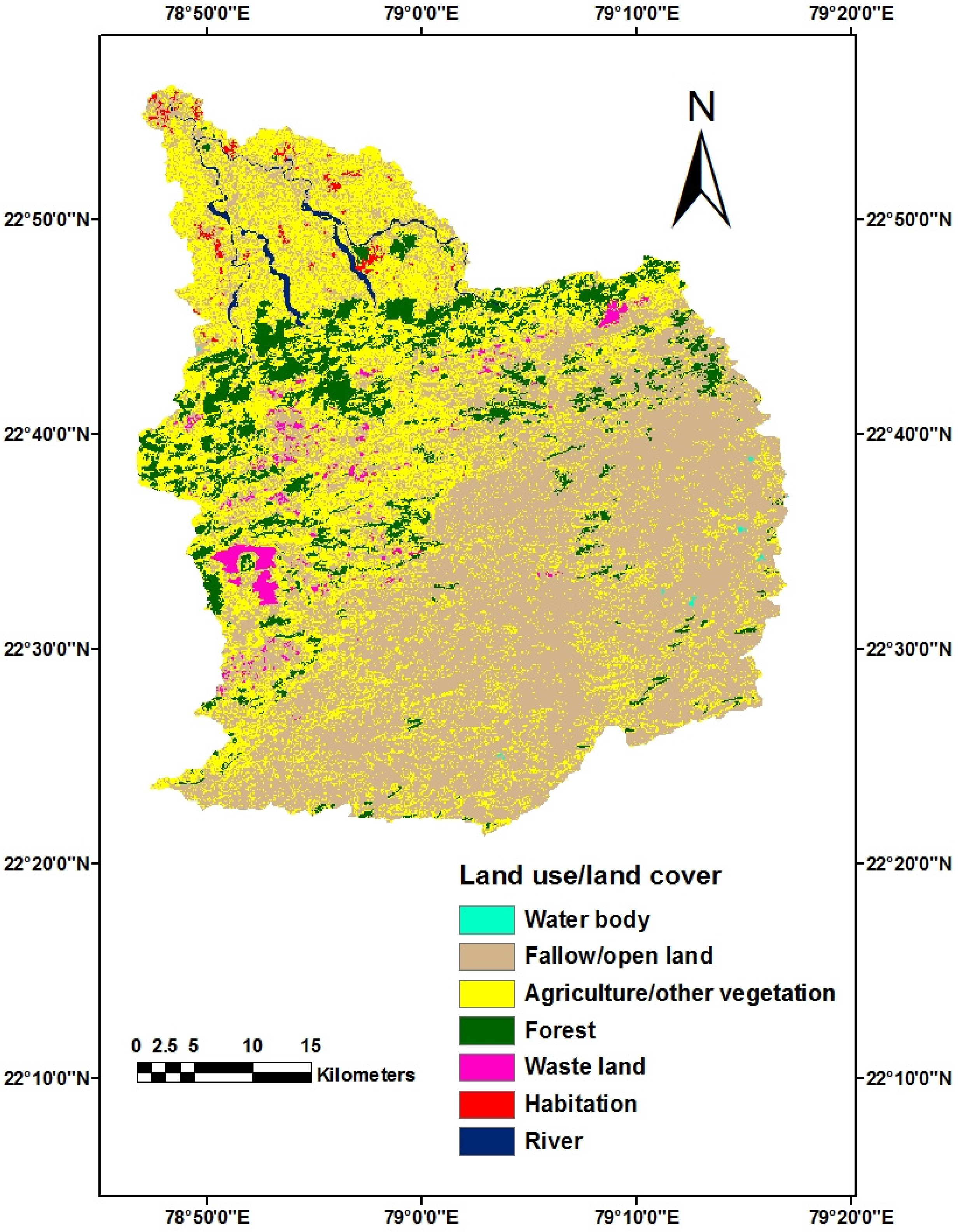

Fig 4.9 Land use/land cover for study area of the year 2006

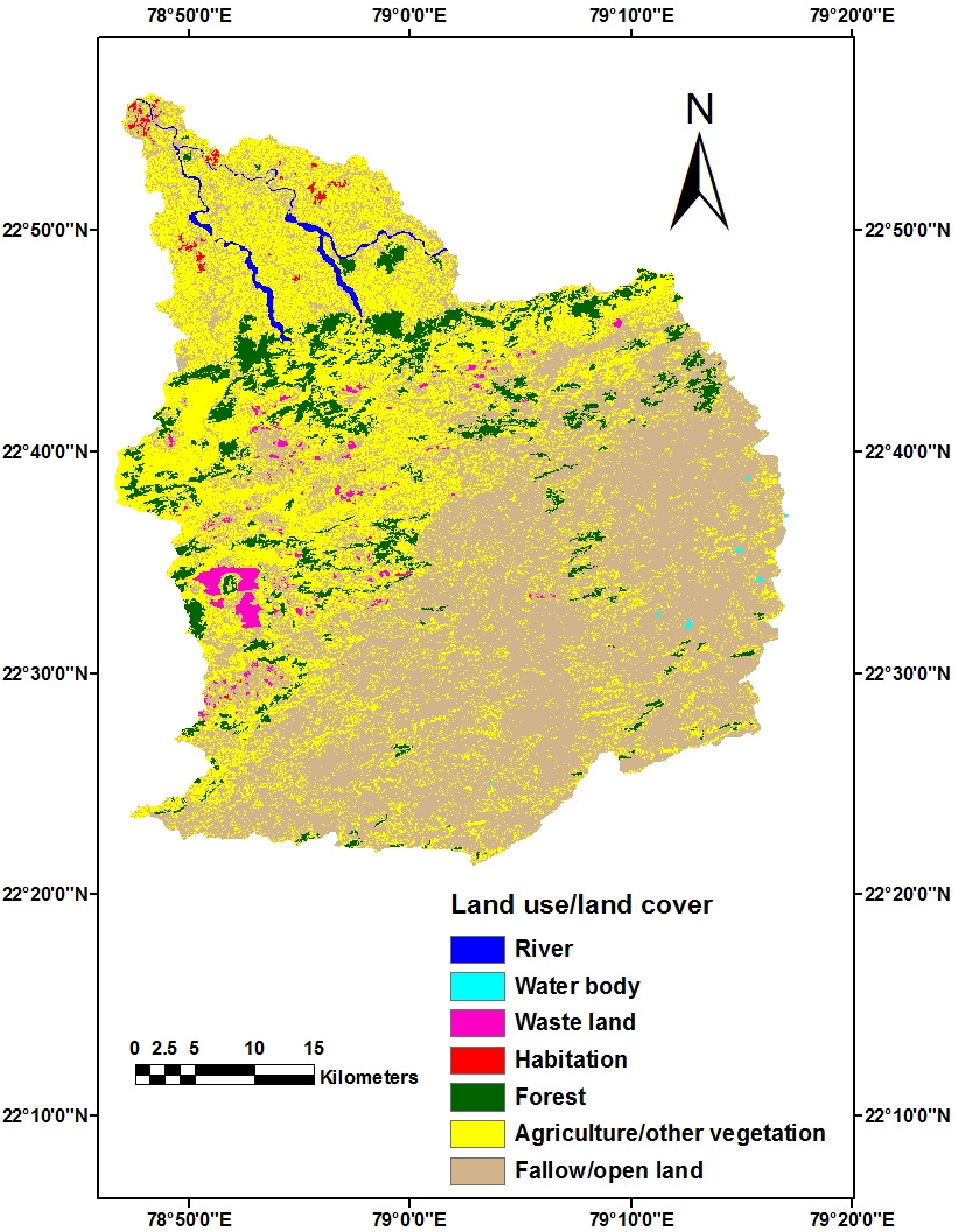

Fig 4.10 Land use/land cover for study area of the year 2011

Table 4.3 Land use/land cover statistics of the study area for the year 2000

Year		Land use/land cover classes						
		Agricultural/other vegetation	**Fallow/open land**	**Waste land**	**Forest**	**Habitation**	**River**	**Water body**
2000	**Area (km^2)**	710.69	1120.98	40.21	303.64	21.22	25.73	1.245
	Percent of total watershed area	31.97	50.43	1.81	13.66	0.95	1.16	0.06
2006	**Area (km^2)**	722.69	1139.83	43.11	272.66	25.69	18.65	1.11
	Percent of total watershed area	32.51	51.27	1.94	12.27	1.16	0.84	0.05
2011	**Area (km^2)**	762.69	1151.84	36.11	237.66	20.69	13.65	1.11
	Percent of total watershed area	34.31	51.81	1.62	10.69	0.93	0.61	0.05
C factor Values		0.28	0.18	1	0.004	1	0.28	0.28

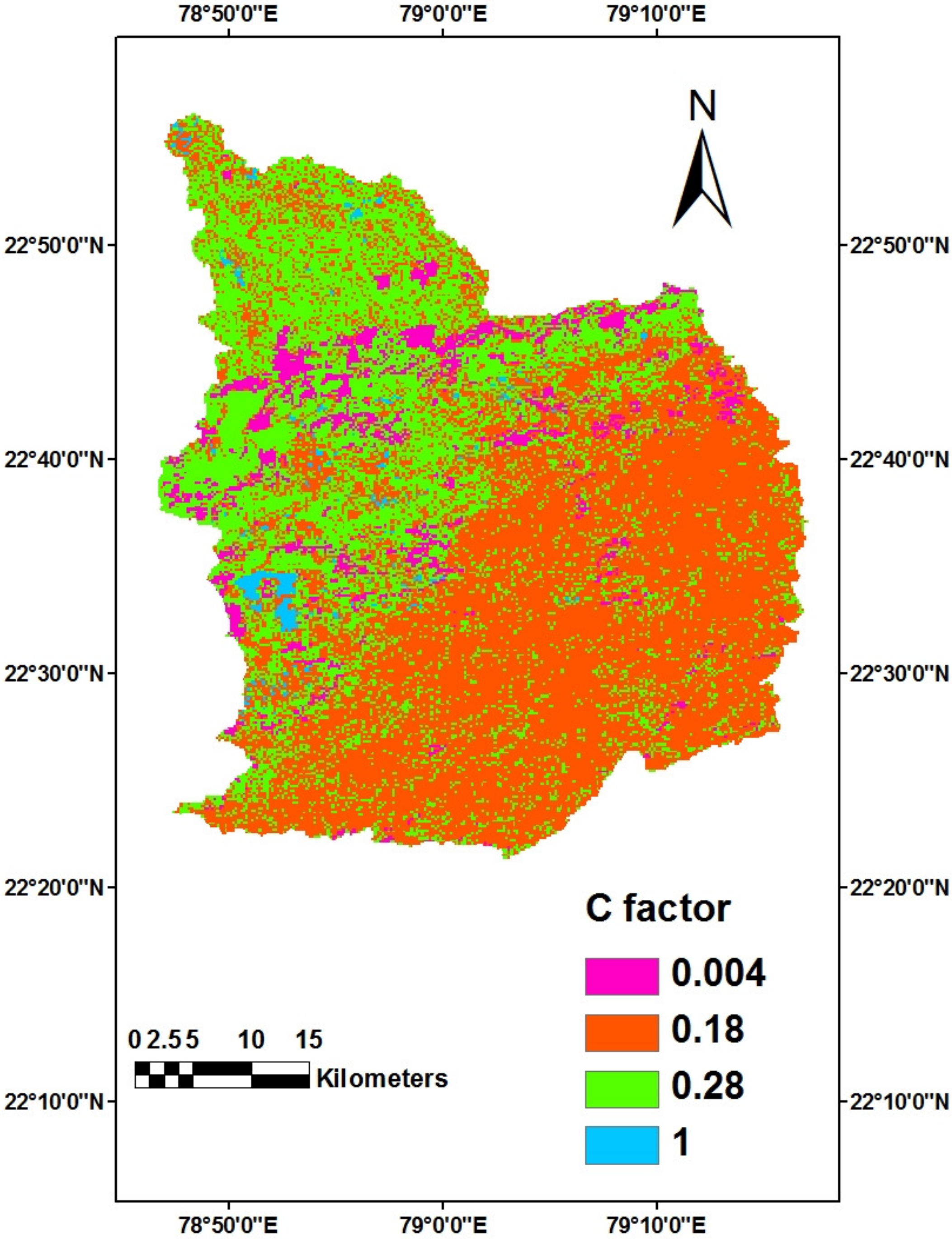

Fig 4.11 Crop management factor (C) map of study area.

4.3.5 Conservation/support practice factor (P)

Conservation or support practice factor (P) is basically the ratio between soil loss with a specific support practice and the corresponding loss with upslope and down slope tillage. These conservation practices dominantly affect erosion by improving the flow pattern, grade, or direction of surface runoff and reducing the amount of rate of runoff. In the study area no major conservation practices are followed. Referring to the studies of Aggarwal *et al.,* (2000) and Dabral *et al.,* (2008) for the present study the values for P factor assigned was 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. The magnitude and spatial distribution are shown in Fig 4.13.

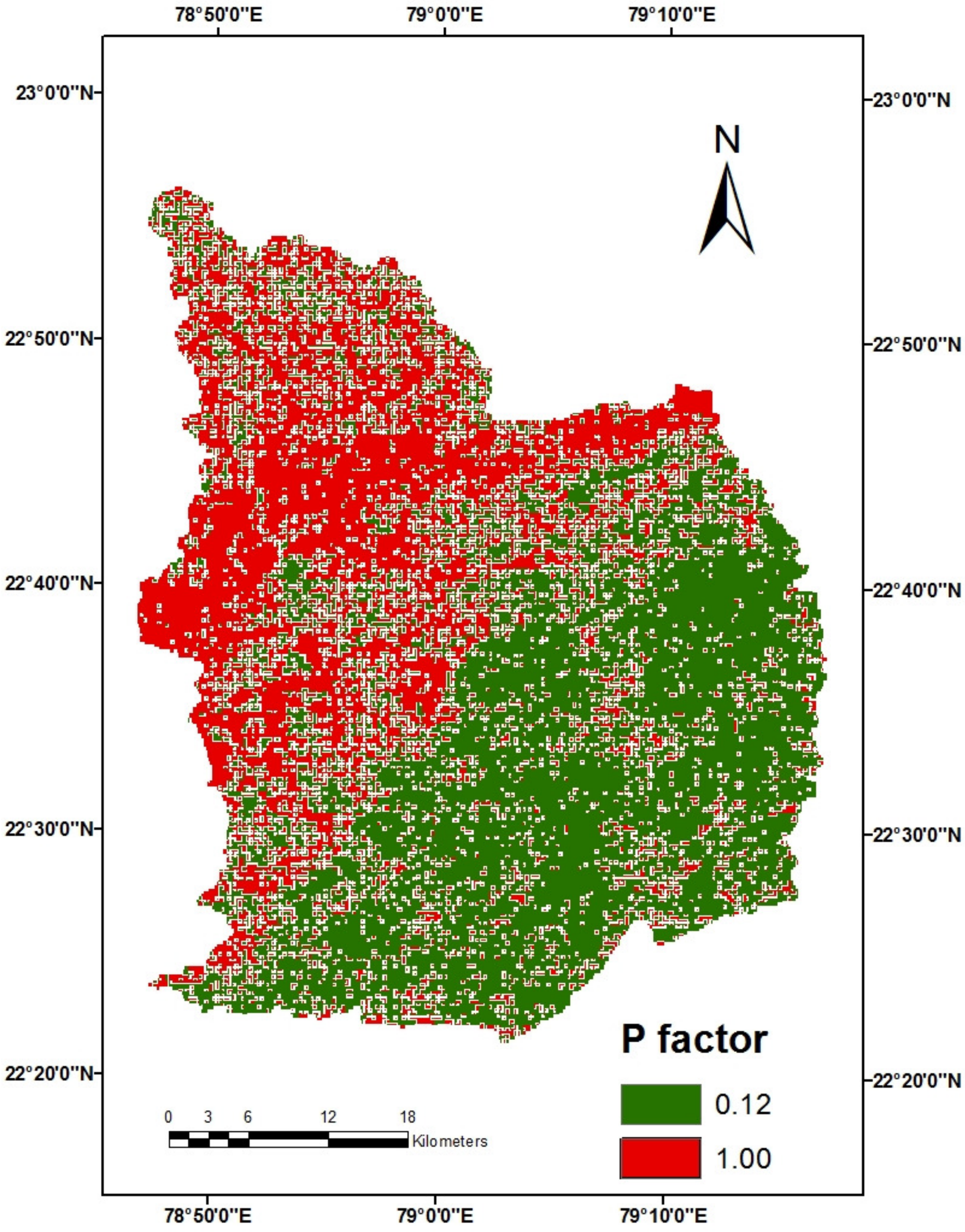

Fig 4.12 Conservation/support practice factor (P) map of study area.

4.4 Assessment of the annual gross erosion at variable spatial scales

To determine the annual gross erosion from the Shakkar River watershed, cell based USLE parameters were multiplied at specified cell resolutions of 20 m, 30 m, 50 m, 100 m, and 200 m and the results have presented in Table 4.7.

The estimated average annual soil loss was found to be 1.90 MT for the spatial scale of 20 m. At 20 m spatial scale, highest soil loss was 2.93 MT in 1999 and lowest was 1.43 MT in 2004. At 30 m spatial scale, highest and lowest value of annual gross loss was 1.50 MT and 2.98 MT in 2004 and 1999 respectively with average value of 1.96 MT. However, at 50 m spatial scale, highest and lowest value of annual rate of soil loss was 1.53 MT and 3.13 MT in 2008 and 1999 respectively with average value of 2.01 MT. On the other hand, at 100 m spatial scale, highest and lowest value of annual gross erosion was 1.56 MT and 3.23 MT in 2008 and 1999 respectively with average value of 2.08 MT. Though, at 200 m spatial scale, highest and lowest value of annual gross erosion was 1.58 MT and 3.37 MT in 2008 and 1999 respectively with average value of 2.15 MT.

Year	Observed sediment loss (MT)	Estimated sediment loss (MT) at different spatial scales and their percent deviation (%) from observed sediment loss values									
		At 20 m	Percent deviation	At 30 m	Percent deviation	At 50 m	Percent deviation	At 100 m	Percent deviation	At 200 m	Percent deviation
1992	1.42	1.68	18.40	1.68	18.52	1.75	23.23	1.75	23.55	1.83	29.36
1993	1.85	2.17	16.93	2.17	17.05	2.29	23.65	2.36	27.37	2.44	31.69
1994	2.39	2.49	4.00	2.64	10.51	2.67	11.81	2.78	16.19	2.89	20.74
1995	1.51	1.70	12.19	1.80	19.09	1.86	23.05	1.90	25.26	1.99	31.28
1996	1.30	1.47	12.78	1.51	15.50	1.61	23.34	1.66	26.92	1.72	32.03
1997	2.93	2.50	14.72	2.70	7.97	2.74	6.53	2.87	2.20	2.99	2.20
1998	2.15	1.77	17.58	1.83	14.68	1.89	12.20	1.99	7.65	2.05	4.86
1999	3.36	2.93	12.77	2.98	11.38	3.13	6.75	3.23	3.71	3.37	0.46
2000	1.58	1.61	2.26	1.62	2.54	1.65	4.65	1.75	11.14	1.77	12.55
2001	1.37	1.57	14.42	1.60	16.53	1.61	17.65	1.66	21.23	1.69	23.01
2002	1.46	1.68	14.92	1.70	16.07	1.71	17.35	1.84	26.18	1.92	31.66
2003	2.06	1.94	5.72	1.93	6.26	1.93	6.26	1.98	3.67	2.07	0.65
2004	1.32	1.43	8.60	1.50	13.83	1.56	18.21	1.61	21.75	1.65	25.13
2005	2.65	2.18	17.76	2.26	14.82	2.33	12.40	2.37	10.64	2.50	5.86
2006	1.75	1.92	10.06	2.05	17.32	2.10	20.38	2.22	27.13	2.30	31.59
2007	1.50	1.63	8.44	1.63	8.59	1.63	8.89	1.69	12.89	1.72	14.81
2008	1.48	1.50	1.80	1.53	3.61	1.54	4.06	1.56	5.56	1.58	6.77
2009	2.70	2.46	8.81	2.49	7.91	2.57	4.86	2.74	1.48	2.76	2.22
2010	1.73	1.74	0.77	1.78	3.35	1.82	5.54	1.85	7.22	1.89	9.79
2011	1.74	1.71	2.04	1.72	1.28	1.79	2.55	1.81	3.57	1.83	4.72
Average (MT)		1.90		1.96		2.01		2.08		2.15	

Table 4.4 Comparison of observed and simulated soil loss

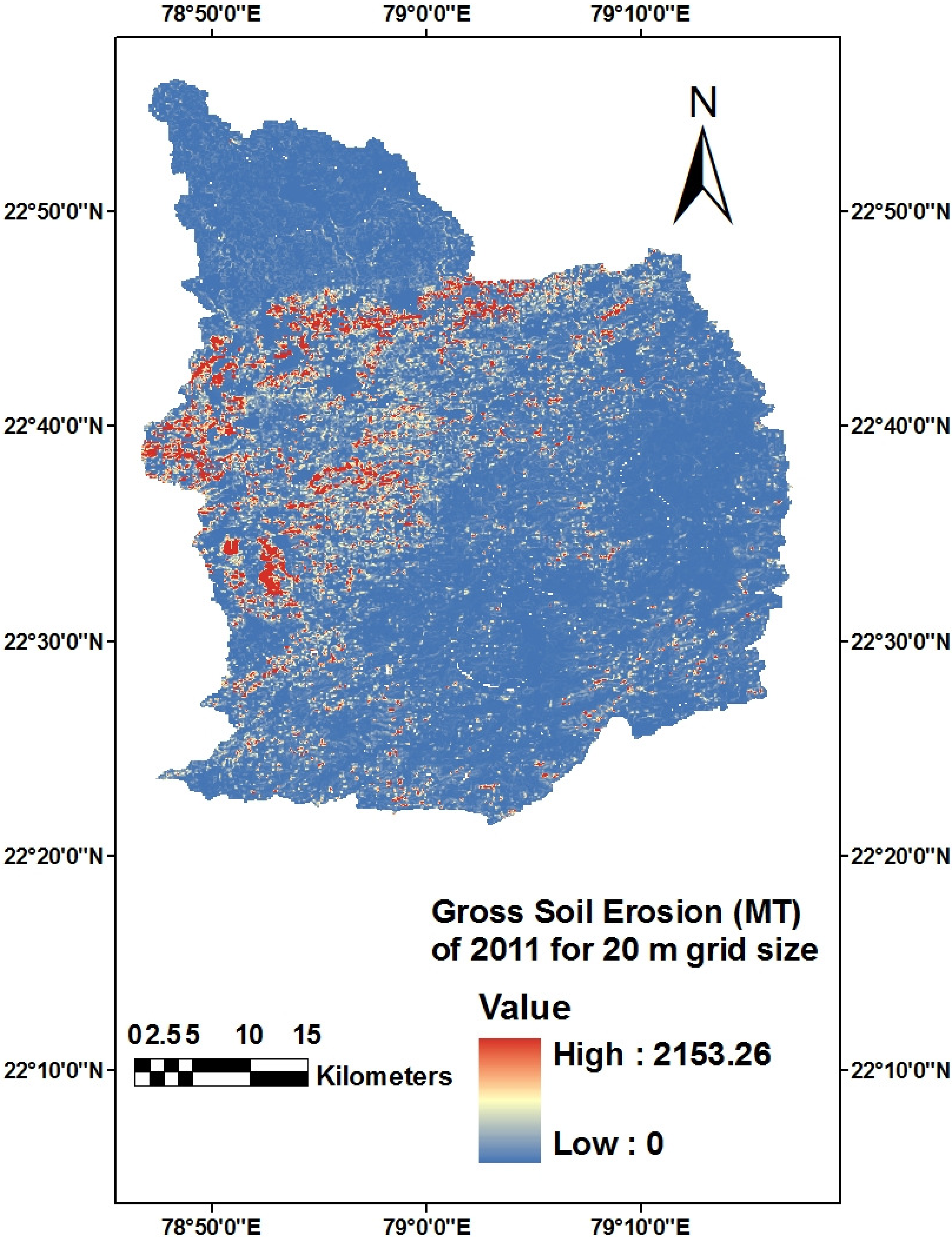

Fig 4.13 Soil erosion map of 2011 for 20 m grid size

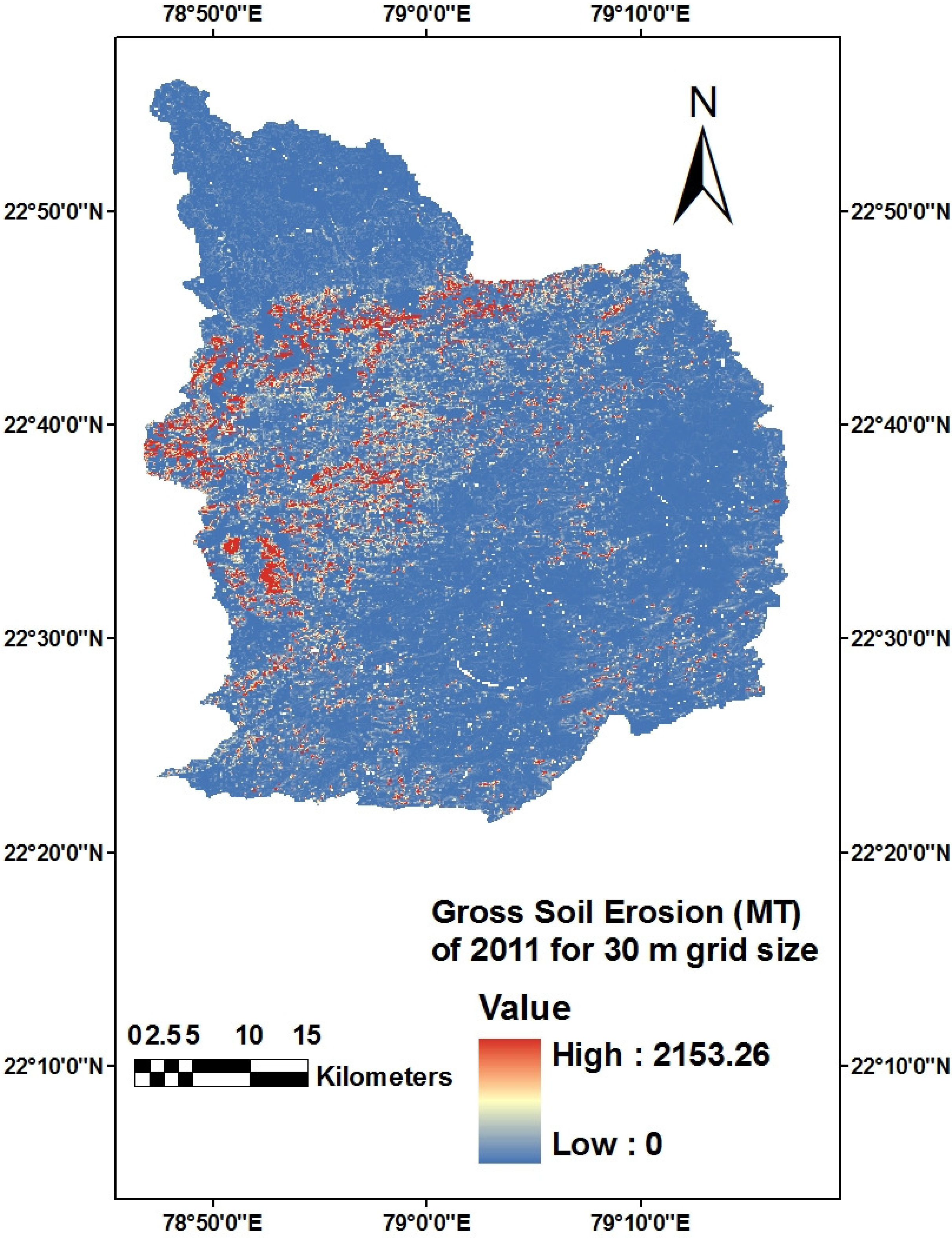

Fig 4.14 Soil erosion map of 2011 for 30 m grid size

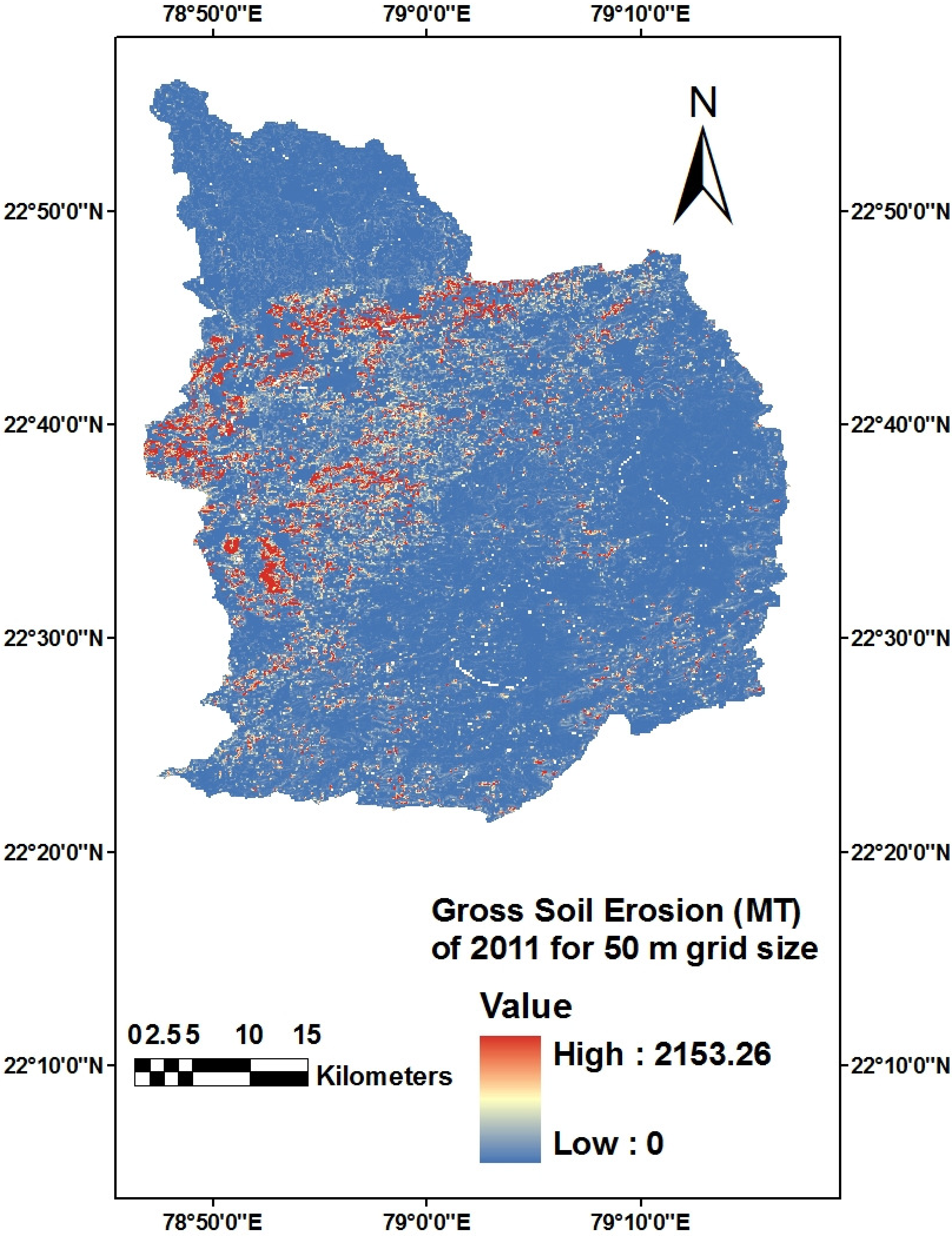

Fig 4.15 Soil erosion map of 2011 for 50 m grid size

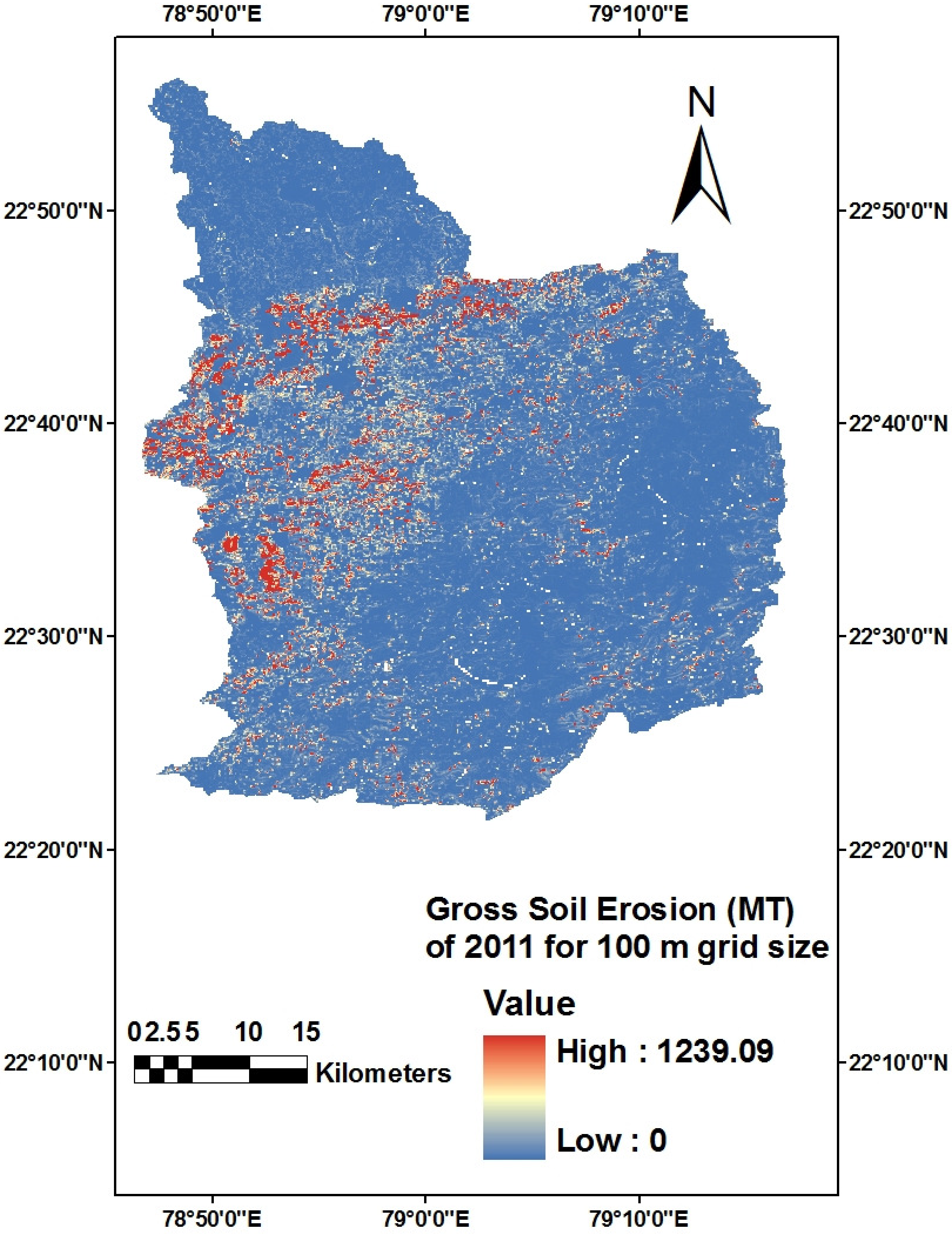

Fig 4.16 Soil erosion map of 2011 for 100 m grid size

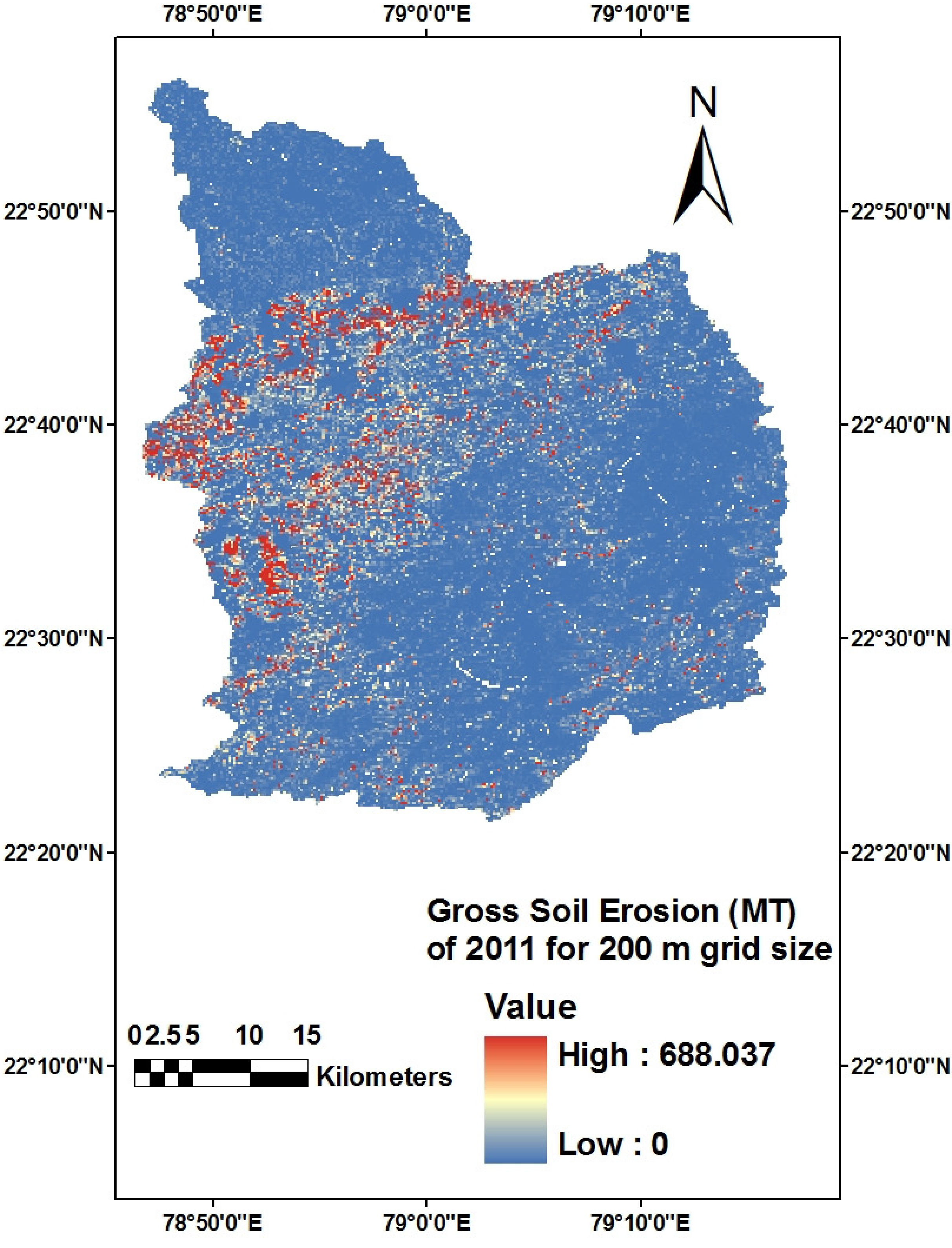

Fig 4.17 Soil erosion map of 2011 for 200 m grid size

4.5 Assessment of effect of variable spatial scale on simulated gross soil loss

It is seen from Table 4.7 that the high range of variation is observed in the percent deviation of the USLE-estimated sediment loss from the observed values when subjected to the change in spatial scales. The values obtained at 20 m spatial scale shows 0.77 to 18.40 percent deviation from observed values. Estimation at 30 m spatial scale shows 1.28 to 19.09 percent deviation, estimation at 50 m spatial scale shows 2.55 to 23.65 percent deviation whereas at 100 m spatial scale shows 1.48 to 27.37 percent deviation. However, values obtained at 200 m spatial scale show 0.46 to 32.03 percent deviation from observed values. As the USLE model simulated (under prediction and over prediction) values falls within 20 percent variation, are considered as acceptable levels of accuracy for the simulations (Pandey *et al.,* 2007). The wide variation in percent deviation among the above datasets shows that under-estimation and over-estimation of sediment loss increases with the increase in spatial scale. Because the heterogeneity of watershed is a crucial parameter that significantly affects spatial estimation of soil erosion. Increasing the spatial scales lump the influential variables in the erosion estimation and hence increase the level of under-prediction and over-prediction of soil losses occur over specified area. This ultimately put forward a considerable variation in the coefficient of determination (R^2) value and creates confusion over selection of particular spatial scale for soil erosion estimation on spatial basis. In this case the coefficient of determination (R^2) values obtained by plotting estimated values at particular spatial scale against observed values also show a considerable variation (Fig. 4.18). At 20 m spatial scale the R^2 is 0.885, at 30 m spatial scale R^2 was 0.879, at 50 m spatial scale R^2 was 0.872, and 0.868 for 100 m spatial scale. Finally at 200 m spatial scale the value of R^2 reduces to 0.864. Thus, while recommending use of specific spatial scale in a particular area only on the basis of either the coefficient of determination (R^2) or percent deviation is quite insignificant and hence the combination of both of them should be used. In this study the estimation at 20 m spatial scale shows the percent deviation between simulated and observed values lies within the acceptable limits of simulation as stated above along with very high coefficient of determination.

Finally, average annual soil loss was estimated on a cell basis and all the cells/grids of watershed were grouped in to following scales of priority given in Table 4.12: Slight (0 to 5 t/ha/yr), Moderate (5 to 10 t/ha/yr), High (10 to 20 t/ha/yr), Very High (20 to 40 t/ha/yr), Severe (40 to 80 t/ha/yr) and Very Severe (> 80 t/ha/yr) erosion classes as per the guidelines suggested by Pandey *et al.* (2007) for Indian conditions. Fig. 4.19 to Fig. 4.23 shows the magnitude and spatial distribution of potential soil erosion in the Shakkar River watershed on the cell basis at 20 m, 30 m, 50 m, 100 m and 200 m spatial scales respectively.

Table 4.12 Priority scale table 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

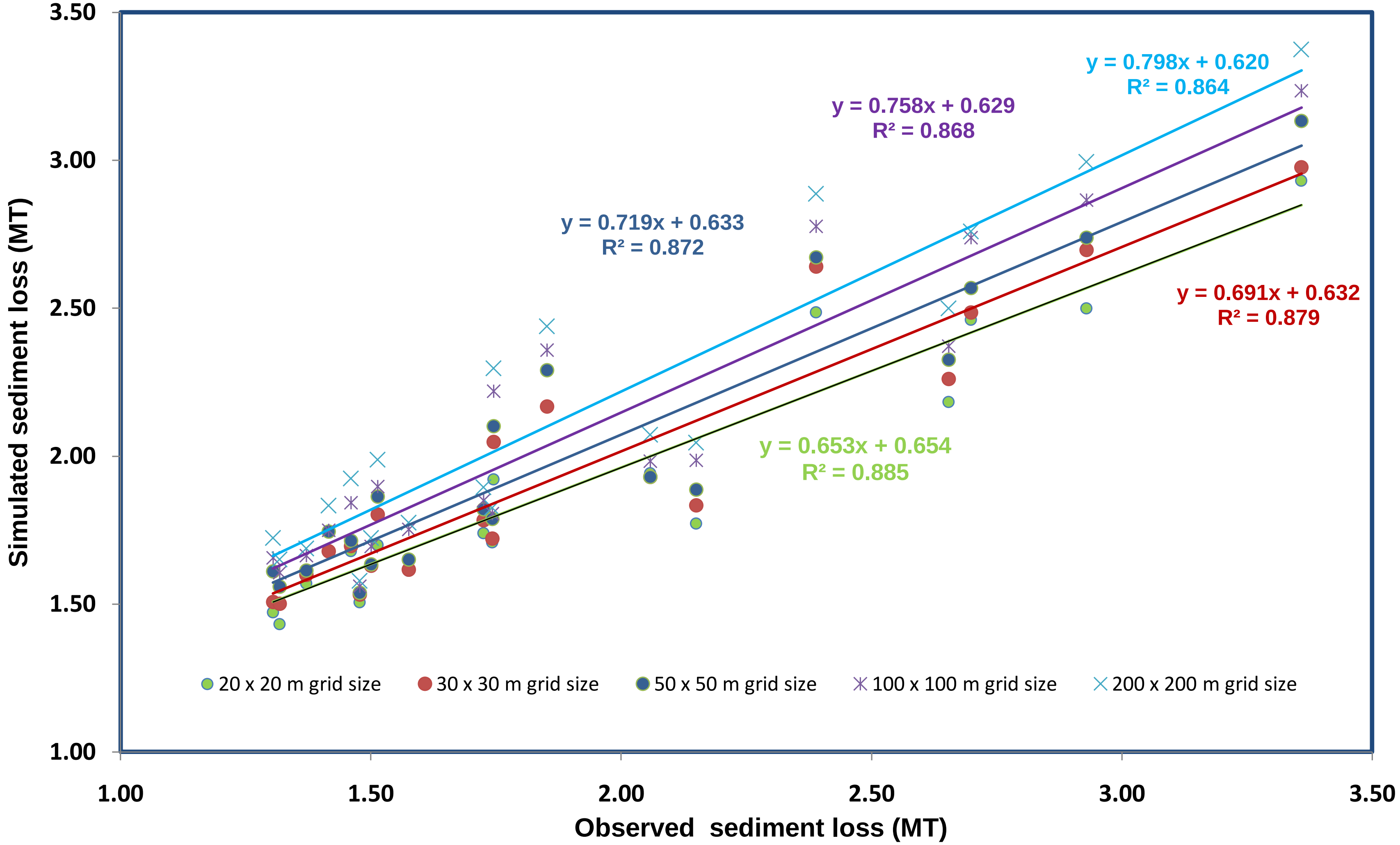

Fig. 4.18 Comparison between observed and simulated sediment loss.

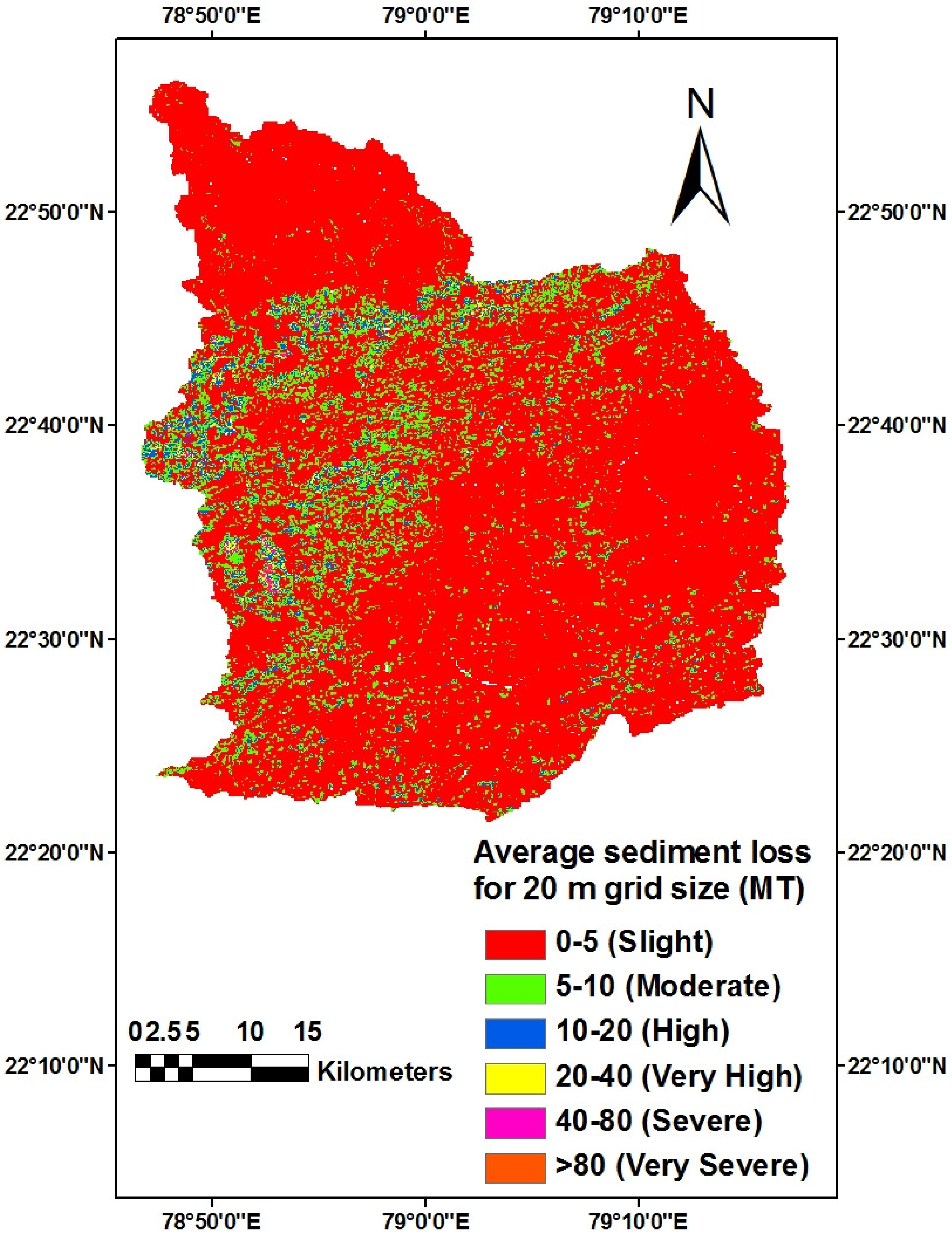

Fig 4.19 Spatial distribution of sediment loss in Shakkar River watershed at 20 m grid size

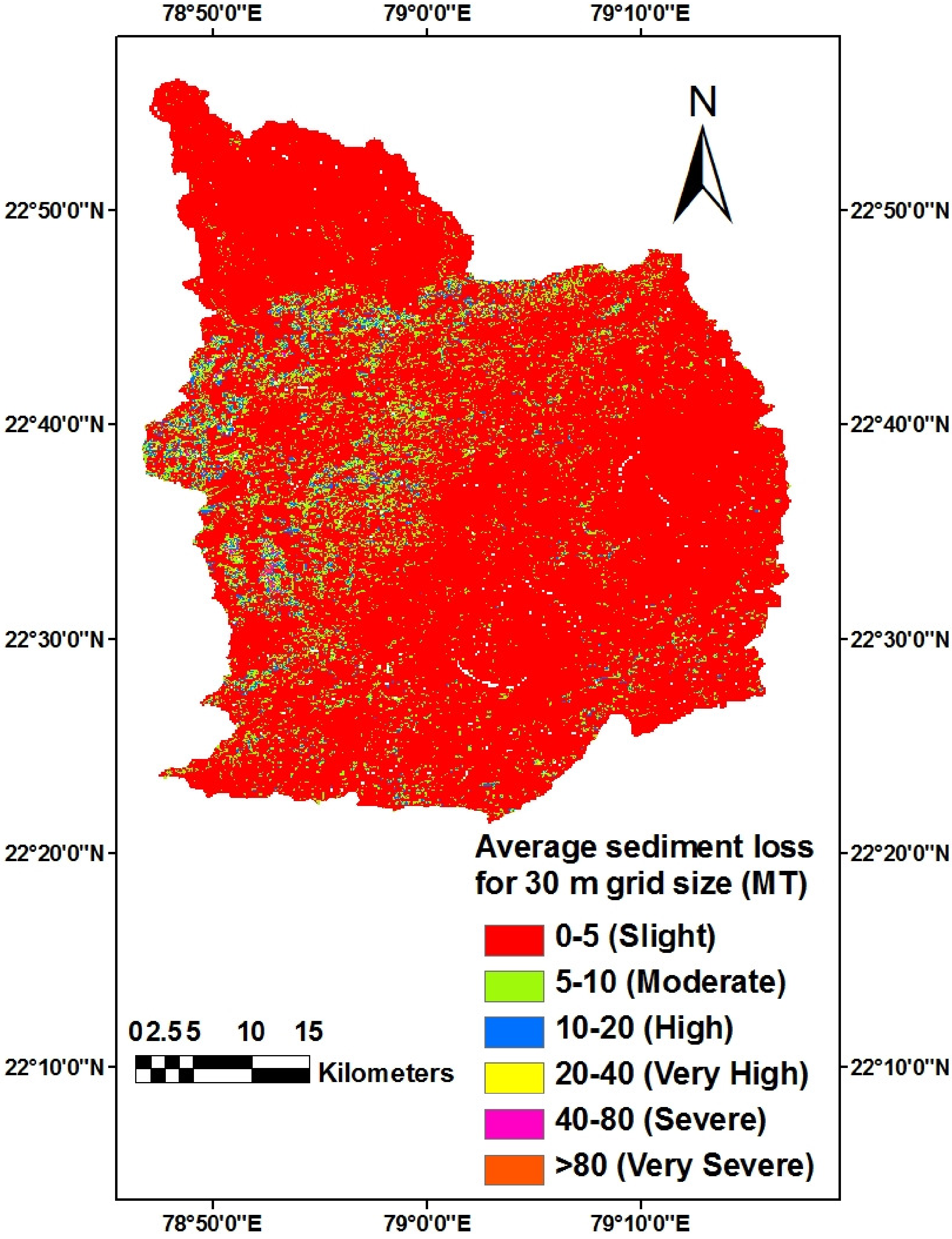

Fig 4.20 Spatial distribution of sediment loss in Shakkar River watershed at 30 m grid size

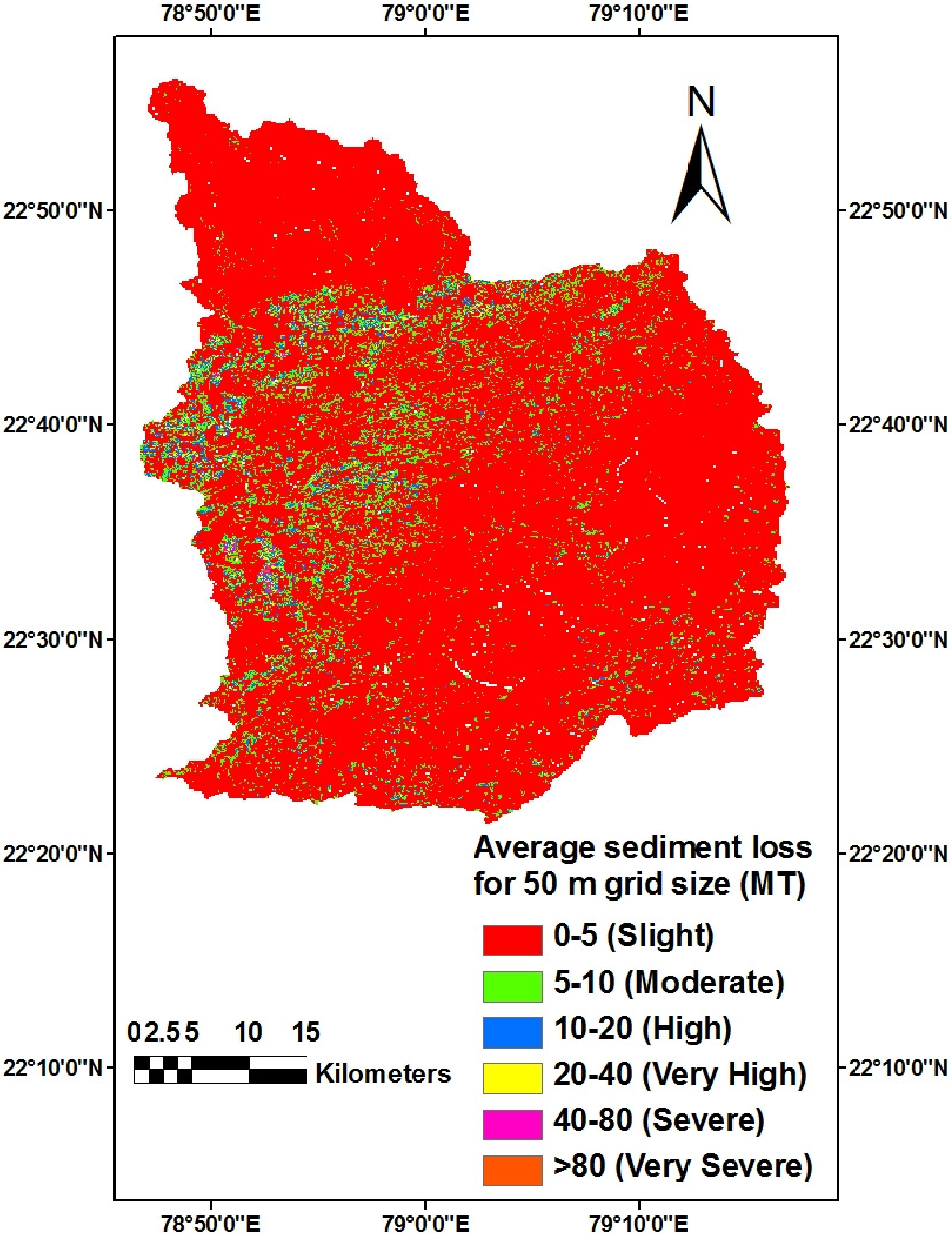

Fig 4.21 Spatial distribution of sediment loss in Shakkar River watershed at 50 m grid size

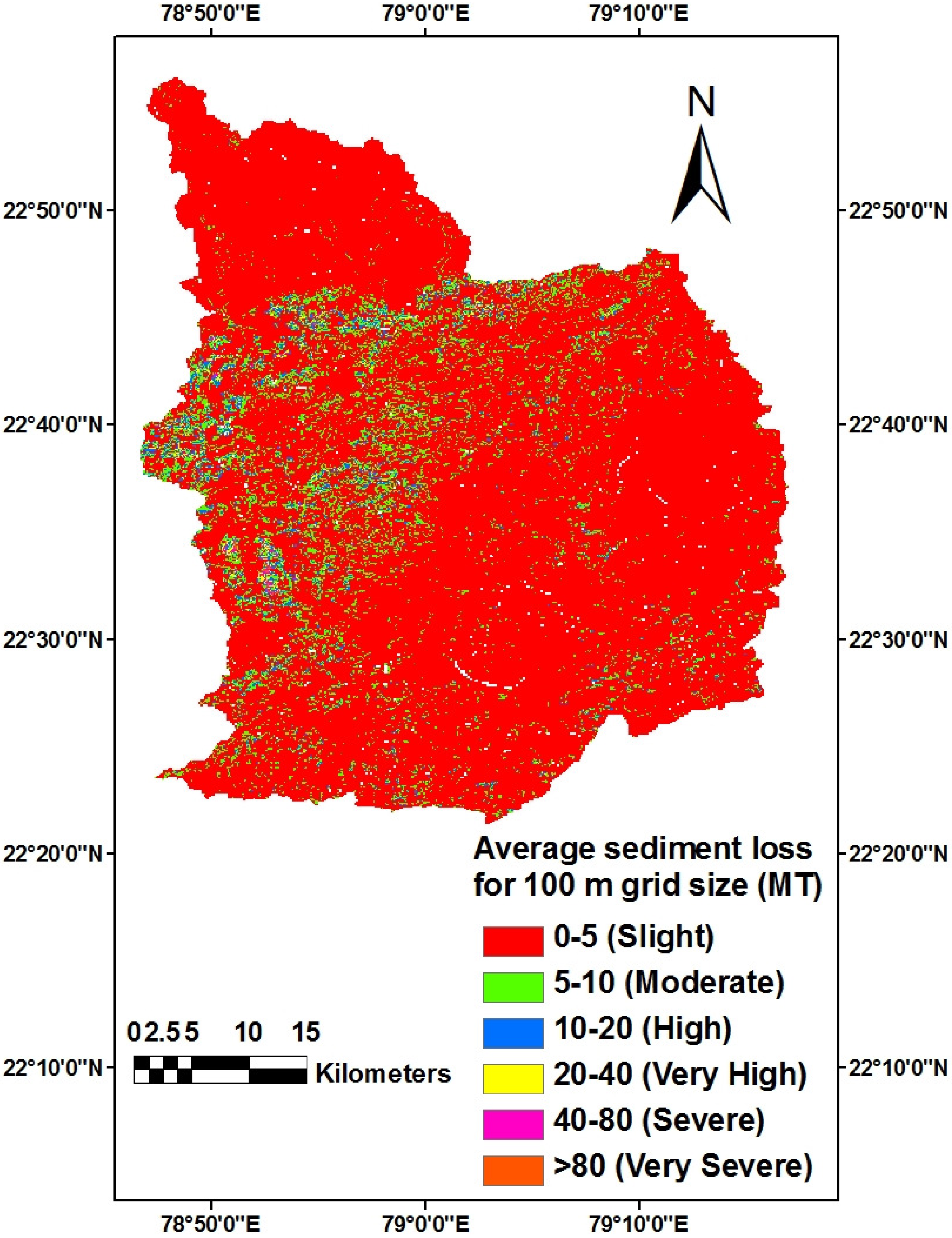

Fig 4.22 Spatial distribution of sediment loss in Shakkar River watershed at 100 m grid size

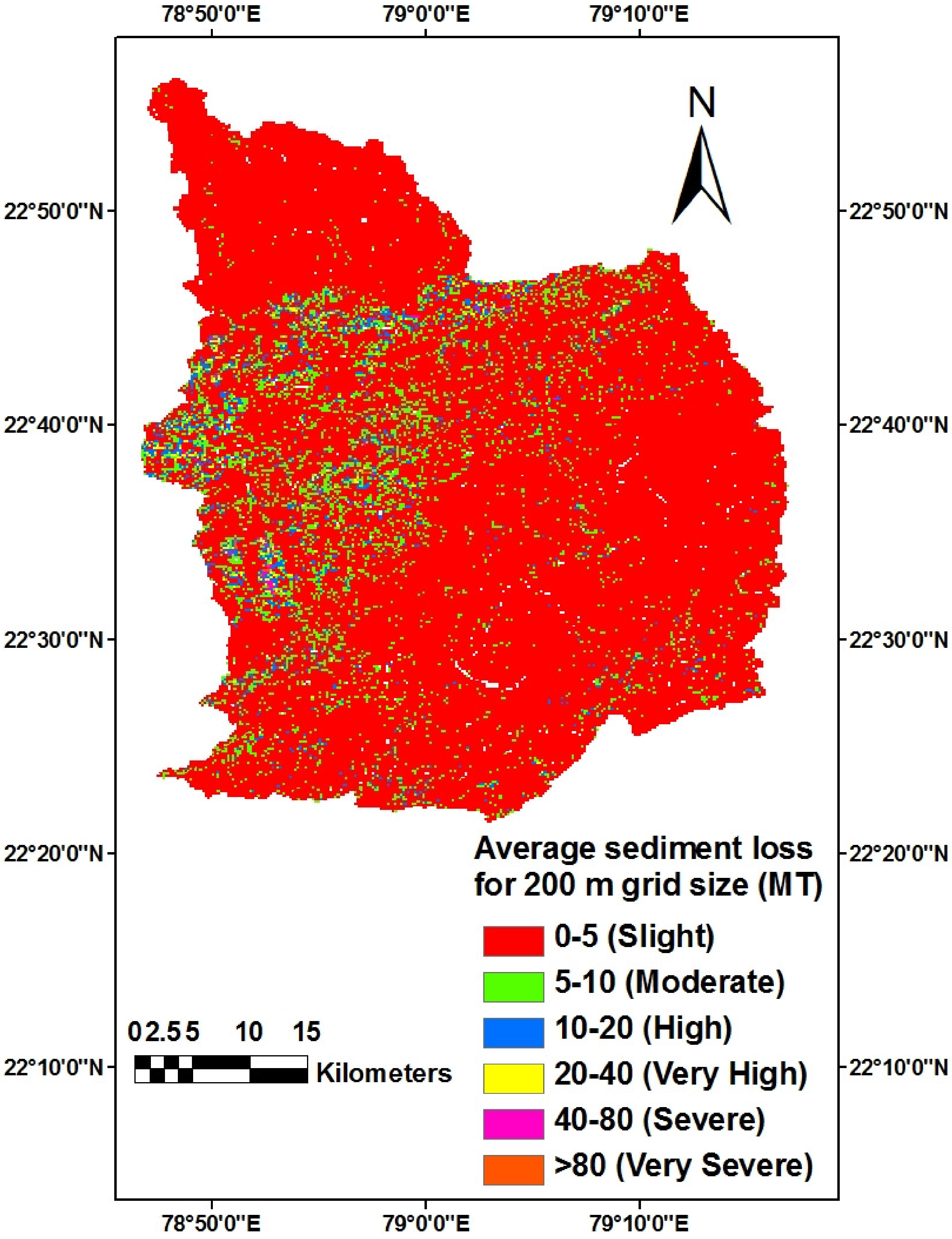

Fig 4.23 Spatial distribution of sediment loss in Shakkar River watershed at 200 m grid size

SUMMARY AND CONCLUSIONS

5.1 Summary

Soil is one of the most important natural resource for supporting life on Earth and soil erosion has become a serious environmental crisis in the world today that threats the environment and also the agriculture. Various human activities disturb the land surface of the earth and thereby induce the significant alteration of natural erosion rates. Continuous soil erosion results in reduction of fertility of soil, transport of millions of tonnes of sediment into the reservoir and lakes and rivers, leading to serious environmental effect and high economic costs affecting on agricultural production, infrastructure and water quality. For nation like India great concern on soil erosion is required as agriculture is adversely affected and its mitigation is must. Besides environmental hazards, soil erosion has threatened the global food security due to ever-growing population and its dependency for livelihood of the people who largely depends on the farming system and especially on subsistence agriculture.

The dynamics of soil erosion and sediment yield are affected by spatial and temporal characteristics of the catchment like climate, soil type, land use land cover, topography and anthropology activities. Since these factors bear temporal and as well as spatial variability, they can be captured by discretizing the catchment into smaller homogeneous units and adopting distributed soil erosion models. However, the major problem with these models is the generation of the input data which are too spatial and rare. Therefore, GIS and remote sensing techniques coupled with soil erosion model will be a promising and cost-effective tool for estimating the annual soil erosion especially in the un-gauged catchments of the developing countries.

The present study is concentrated to the Shakkar River Watershed which falls in the part of Narmada Basin. The total geographical area covers 2223 km^2 up to the gauging point. The geographical location of the area lies between 22^{o}20’N to 23^{o}00’N latitude and 78^{o}40’E to 79^{o}20’E longitude with elevation range from 314 to 1154 m above MSL (mean sea level). Various thematic layers representing the USLE factors are generated adopting above methodology and overlaid using ArcGIS software for obtaining the gross erosion maps. Finally, the simulated values were compared with the observed values.

Considering all the above discussed points, detailed study of the Shakkar River Watershed was planned with the following specific objectives:

1. To estimate gross erosion at variable spatial scales using distributed information for rainfall, soil, topography and land use using RS and GIS techniques.

2. To analyze effect of variable spatial scales on simulated gross soil loss.

5.2 Conclusions

Based on the result obtained from the present study, following conclusions can be drawn:

1. The minimum soil loss at 20 m spatial scale was 1.43 MT and maximum gross erosion at the same spatial scale was 2.93 MT whereas the minimum soil loss at 200 m spatial scale was 1.58 MT and maximum gross erosion at the same spatial scale was 3.37 MT.
2. The over estimation and under estimation varies according to spatial scale. The over estimation of the gross erosion increases as the spatial scale becomes coarser. The average values of simulated gross erosion; at 20 m spatial scale, 20 years average gross erosion was 1.90 MT, at 30 m spatial scale average value was 1.96 MT. Conclusively, the over estimation increased to 2.15 MT at 200 m spatial scale.

5.3 Suggestion for further work

Soil erosion estimation for the Shakkar River Watershed should be conducted using MMF model adopting the same spatial scale.

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