WATERSHED MODELING USING REMOTE SENSING AND GIS

A DISSERTATION
Submitted in partial fulfillment of the
requirements for the award of the degree
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in
IRRIGATION WATER MANAGEMENT

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CANDIDATE'S DECLARATION

I hereby certify that the work being presented in this Dissertation entitled "**WATERSHED MODELING USING REMOTE SENSING AND GIS** " in partial fulfillment of the requirement for the award of degree of MASTER OF TECHNOLOGY in Irrigation Water Management and submitted in the Department of Water Resources Development and management, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my work carried out during the period from August 2009 to June 2010 under the supervision and guidance of Dr. Ashish Pandey, Assistant Professor, Department of Water Resource Development and Management, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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ABSTRACT

The Wadsa-Chincholi watershed situated in the Bhandara , Chandrapur, Gondia , Nagpur district of Maharashtra, which is a part of Godavari river basin, was selected for the present study. The total area of the Wadsa-Chincholi watershed is 14690.43 km^2. It was divided into 50 m ×50 m, 100 × 100 m, 200 m × 200 m grid cells and the average annual sediment yields were estimated at the outlet of watershed. Remote Sensing (RS) technology provides 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. Average annual sediment yield data on grid basis was estimated using Morgan-Morgan and Finney (MMF) model and the Universal Soil Loss Equation (USLE). Based on eight years daily rainfall data, the estimated maximum and minimum values of kinetic energy were found to be 47452.82 and 25298.86 J m^{-2} for the year 2007and 2004 respectively. The DEM was used to generate slope map. Other inputs of the model closely related to the land use/land cover were successfully derived from remotely sensed data and the modeling part was carried out in GIS environment. Further, the sediment yields estimated by both the models were compared with observed data. The estimated average annual sediment yield from MMF model was found to be 11.17 t ha^{-1}yr^{-1}. The estimated average annual sediment yield from USLE model with 50 m ×50 m, 100 m× 100 m and 200 m×200 m grid cell size was found to be 63.80 t ha^{-1}yr^{-1}, 18.83 t ha^{-1}yr^{-1} and 3.67 t ha^{-1}yr^{-1} respectively. The estimated sediment yields in 200 m×200 m grid size from the observed value is satisfactory matching. Hence, the results of USLE model at 200 m×200 m grid size can be applied for spatial sediment yield estimation from the Wadsa-Chincholi watershed.

Key words: Sediment yield, GIS, MMF, RS, USLE, Watershed.

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CHAPTER –I

INTRODUCTION

1.1 General Scenario

Maharashtra is a State with the dubious distinction of having lowest area under irrigation and largest span of drought-prone area. The initial efforts towards dry land farming began in Maharashtra as early as in 1930s and the work on soil and water conservation through watershed technology has received good returns over years. In Maharashtra state the black soil (with depth of 60 cm) which constituted about 45 percent of the area in 1910 covers only 18 percent after 50 years; the remaining area were transformed to shallow soil. Reduced soil depth means reduced productivity or lower crop yields (Abrol, 1990). Watershed approach has shown prevention of such soil losses. Government of Maharashtra implemented the watershed development programme beginning with 1982 under Comprehensive Watershed Development Programme (COWDEP) which in 1986 developed into the National Watershed Development Program for Rainfed Agriculture (NWDPRA). Overall 380 watersheds were taken for development from each district. Deshpande and Narayanamoorty (1999) reported that hardly any plan for watershed management and action was made. The impact study of NWDPRA carried out by Deshpande and Rajshekaran (1995) highlighted that the interaction with the hill region environment seeks top priority in planning for watershed management. Increase in crop production, cropping intensity and optimum use of farm inputs are of relevance as these are in the case of plains. Soil degradation, protecting landslides, deforestation, gully/ravine formations, however, need immediate attention. They clearly reported that the planning exercises of NWDPRA were extremely mechanical and concentrated more on agriculture as the major activity. The absence of participation of beneficiaries particularly in hill areas has caused skewed impact of the programme.

1.2 Watershed approach

Watershed is defined as “natural hydrologic entity that cover a specific area expanse of land surface from which the runoff (due to rainfall) flow to defined drain, channel, stream or river at any particular point”. Watershed modelling implies the proper use of all land, water and natural resource of watershed for optimum production with minimum hazard to natural resource, an integrated approach to watershed modelling is insisted for sustained development of water resource. Watershed modelling is important tool used for watershed planning and management. It is basis for modelling of many other processes relevant to water resource analysis, planning and management. Watershed model are the reflection of our understanding of watershed system and basin response .Their predictive ability depend thus on how we build and apply them, and quality of prediction is generally consistent with the quality of your understanding of the system and of model representing it. Watershed has emerged as the focus of planning for agriculture and rural development especially for the fragile dry land, hilly and other stress areas since early 1980s. India is one of the very few developing countries in the world, which recognized the importance of conservation of soil as early as 1952 when the action for establishment of research and training facilities was initiated.

1.3 Watershed Management

Scientific management of soil, water and vegetation resources on watershed basis is therefore, very important to arrest rapid siltation in rivers, lakes and estuaries. Watershed is a bio-geo-physical unit in which, interdependence of renewable and non-renewable resources from environment, are closeted. In other words, it is a resource region, where there are close systematic interdependences and only a harmonic balance of these can lead to optimum production potential. Major objective, of any watershed management program therefore, is to design a sustainable resource use in order to provide optimum production potential of the agro ecosystem. A watershed is used as a unit for planning and management of land, water and other resources, and all inter-related factors such as physical, biological, technological, economic, socio-cultural and managerial etc. are considered together in a system framework (Singh, 1991). It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of micro-units, which contribute to the maximum sediment yield would determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme.

1.4 Soil Erosion and Sediment Yield

The process of soil erosion involves the process of detachment, transportation and accumulation of soil from land surface due to either impact of raindrop, splash due to rain impact, shearing force of flowing water, wind, sea waves or moving ice. Erosion due to water is an area of interest to hydrologists and sedimentologist. Various form of soil erosion due to water is inter-rill, rill, gully and stream channel erosion. Rain drop plus sheet erosion jointly causes inter-rill erosion. Concentrated flow causes rill erosion. Gully erosion is an advanced stage of rill on account of head cutting at the gully head. Apart from rainfall and runoff, the rate of soil erosion from the area is also strongly dependent upon its soil, vegetation and topographic characteristics. During the process of erosion and transportation to downstream side, some part of the eroded material may get opportunity to deposit. The net amount of sediment flowing through the watershed is termed as sediment yield.

Soil erosion is a complex phenomenon as it is governed by various natural processes, and it in turn, results in decrease of soil fertility and reduction of crop yields. Each year, 75 billion tons of soil is removed due to erosion largely from agricultural land, and about 20 million-ha of land is already lost. The erosion is very high in Asia, Africa, and South America averaging 30-40 t ha^{-1} $year^{-1}$ (Barrow, 1991). In humid tropics of Asia, farmers grow subsistence crops on sloping lands using highly erosive practices, leading to an average soil loss rate of 138 t ha^{-1} $year^{-1}$ (Sfeir-Younis, 1986) for Asia, and about 5,334 Mt (16.4 t ha^{-1} $year^{-1}$) annually for India of which about 29% is carried away to the sea, and 10% deposited in reservoirs, considerably reduce their storage capacity (Dhruvanarayana and Rambabu, 1983).For assessing the soil erosion and, sediment yield, several empirical models based on geomorphologic parameters were developed in the past (Jose and Das 1982; Misra et al.1984).

Hydrologic processes are dynamic phenomena varying in both time and space. For locating vulnerable and priority areas, the catchment of a river has to be studied for intensities of erosion and mapping of different erosion units. Priority area delineations could be done to some extent by the study of toposheets and reconnaissance survey. This method, however, is slow and not very accurate. In this context, the advent of remote sensing (RS) technology has opened new vistas for the study of various components of hydrologic cycle. This offers an opportunity to study and obtain solutions for some of the complicated problems in hydrology through its spatial, spectral and temporal attributes, which are difficult to achieve by the conventional methods. Recently, the technology of Geographical Information Systems (GIS) is gaining importance as a powerful tool in the management of information in agriculture, natural resources assessment, environmental protection and conservation. There is considerable potential for the use of GIS technology as an aid to soil erosion inventory with reference to soil erosion modelling and erosion hazard assessment. A number of modelling approaches both empirical and physical processed – based are in vogue to quantitatively assess erosional soil loss. Input parameters in terms of spatial information on landuse / land cover could be obtained from multi-spectral RS data. GIS technique is very effective tool for integrating above inputs for modelling erosional soil loss.

1.5 Background of the Study

A Watershed is a land area which drains in to stream system, upstream from its mouth or other designed point of interest. Surface characteristic, soil depth, geological structures, topography and climate of the watershed play an interrelated role in the behaviour of water, which flow over and through it. Watersheds are subject to many types of modification by human and natural activates. Erosion is a natural geomorphic process occurring continually over the earth surface. The processes of erosion of soil from earth surface are largely depends on topography, vegetation, soil and climate variables. These areas found to have pronounced spatial variability in a catchment due to the spatial variation of climate factors and catchment heterogeneity. This is one of the reasons given for promoting the use of distributed information of catchment resources using a GIS. By using a GIS the catchment is discretized in to sub-areas having approximately homogenous characteristics and rainfall distribution. The technique of GIS is well suited for quantification of hetergenneity in the topographic and drainage feature of a catchment (Shamsi, 1996; Rodda et al., 1999). The remote sensing and GIS technique have been used for sediment and erosion modelling across the globe. The model stimulates the dynamics of event runoff, soil detachment and transport process. Jain and Kothyari (2000) demonstrated the utility of GIS and satellite data in identification of source area and prediction of storm sediment yield from catchment. The concept of sediment delivery ratio with USLE was used in the study for Karso and Nagwan watershed in Jharkhand. With the same watershed and concept of sediment delivery ratio, Kothyari et al., (2002) estimated the temporal variation in sediment yield. Jain and Geol (2002) used these techniques for the assessment of vulnerability of 16 watersheds in the Western India to assess soil erosion. No such study has been reported for the Godavari catchment of Wainganga river in Maharashtra. Keeping above in view, this study has been proposed to envisage estimation of sediment yield utilizing remotely sensed data and GIS using USLE and MMF models. The present study attempts to assess soil erosion and sediment yield risk of the Waingangā river of Godavari Basin in the Vidarbha region of Maharashtra state using the RS and GIS technology.

1.6 Objective of study

1. Application of the USLE and MMF model for estimation of sediment yield using remote sensing and GIS.
2. Estimation of sediment yields of the Wadsa-Chincholi watershed on different grid sizes i.e. 50m, 100m, 200m.
3. Recommendation of optimal grid size for sediment yield estimation.

CHAPTER-II

REVIEW OF LITERATURE

On site measurement and monitoring of soil erosion is difficult, expensive and time consuming. Erosion events are intermittent and long term record would be required in order to measure the erosion from specific site. In such cases models are very helpful for land use, planning and decision making. Therefore, it is necessary to asses erosion rate at the time of planning and designing of any water resource project.

Review of literature reveals that many models are available for estimation of soil erosion and sediment yield from watersheds. Most of these models can be grouped in to two broad categories. Models those based on empirical equations generally derived based on analysis of field data are commonly termed as empirical models. Simple method such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) or Revised Universal Soil Loss Equation (RUSLE) (Renard et al.1991b) or Morgan Morgan Finney Model (MMF) (Morgan et al,1984) are quite frequently used empirical models for estimation of soil erosion from watersheds (Ferro and Minacapilli 1995 ; Ferro 1997 ; Kothyari and Jain , 1997 ; Ferro et al ., 1998 ; Stefano et al ., 1999, Jain and Kothyari ,2000 , Kothyari et al., 2002).

The other category of models which use theoretical description of processes involved in the form of mathematically equation are termed as physically based models. These models are intended to represent the essential mechanisms controlling erosion and they incorporate the laws of conservation of mass and energy. Most of them use particular differential equations and generally require more input parameters than the empirical models. Numbers of the physical based models are developed in recent past. Examples of physically based models available in literature for estimation of soil erosion are WEPP (Water Erosion Predicting Project, USA) (Nearing et al., 1989), EUROSEM (European Soil Erosion Model), SHESED (Wicks and Bathurst, 1996) and others .The power of physically based models is that they represent a synthesis of the individual components which affect erosion, including the complex interaction between various factors and temporal variability. The result is synergistic, the model as whole represents more than the sun of the individual pieces. The use of physically based models is limited for research use due to their complexity and non-availability of data required to use them. Therefore empirical models are commonly in use for field evaluation and modelling for data scarce regions. The main aim of this work is to use a empirical models in distributed sense, therefore the review of literature is limited to empirical models only

2.1 Empirical Sediment Yield Models

These are based on inductive logic and generally applicable only to those condition for which the parameter have been calibrated.

USLE Model: Soil erosion is most frequently assessed by using Universal Soil Loss Equation (USLE) since early 60's. The equation was designed for inter-rill and rill erosion (Wischmeier and Smith 1978, Renard et al., 1991). Although the equation is described as universal, its database though extensive, is restricted to slope normally 0-17°, and to soil with a low content of montmorrilonite, it is also deficient in information on erodibility of sandy soils. In addition to the limitation of its database there are theoretical problem with the equation .Soil erosion cannot be adequately described merely by multiplying together six factor values ($E=R*K*L*S*C*P$). There is considerable interdependence between variables (Morgan, 1995).

MUSLE Model: MUSLE is one of the modified versions of the USLE. In MUSLE (Williams. 1975), the rainfall erosivity factor was replaced with runoff. The runoff factor includes both total storm runoff volume and peak runoff rate. Compared to USLE, this model is applicable to individual storm, and climates the need for sediment delivery ratios, because the runoff factor represent energy used in detaching and transporting sediment. The main limitation is that it does not provide information on time distribution of sediment yield during a runoff event.

MMF Model (Morgan et al. 1984): MMF model is another empirical model for predicting annual soil loss from field - sized area on hill slopes. The model separates the soil erosion process in to two phases i.e. the water phase and sediment phase. In the water phase annual rainfall is used to determine the energy of the rainfall for splash detachment and the volume of runoff, assuming that runoff occur whenever the daily rainfall exceeds a critical value representing moisture storage capacity of the soil-crop complex and that the daily rainfall amounts approximate an exponential frequency distribution. In the sediment phase, splash detachment is modeled using a power relationship with rainfall energy modified to allow for the rainfall interception effect of the crop. The model has been revised with new changes incorporated owing to the rise in data availability and difficulties in estimating certain parameters as in the original version. In the revised version, changes have been made to the way soil particle detachment by raindrop impact is simulated, which now takes account of plant canopy height and leaf drainage , and a component has been added for soil particle detachment by flow SLEMSA (Elwell ,1978): The Soil Loss Estimation for Southern Africa (SLEMSA) was developed largely from data from Zimbabwe to evaluate the erosion resulting from different farming system so that appropriate conservation measures could be recommended . Generally, the model looks like USLE and it has the same limitation as USLE. Empirical Model possess severe limitation. They cannot be universally applied. They are not able to simulate the movement of water and sediment over the land and they cannot be used on scale ranging from individual field to small catchment.

2.2 Application of Remote Sensing, GIS in Soil loss and Sediment Yield Estimation

Prasad et *al.* (1997) has worked on Tripura sub watershed prioritization using remote sensing and GIS. These sub watersheds were prioritized by considering their degradation condition and land sensitivity .Land Sensitivity was defined as local relationship between forest loss and soil loss. Universal soil loss equation (USLE) in conjunction with remote sensing and GIS has been used for estimating soil loss and land cover change. Soil loss and land degradation were consider as indicator of prioritization.

Jain and Kothyari (2000) used the catchment for the study on Estimation of soil erosion and sediment yield using GIS. The catchment area for Nagwa and Karso are 70 and 28 sq.km respectively. The soils were classified in to three categories viz. Clay loam, very fine sandy loam and sandy loam. The objective of this paper study were to use GIS for the discretization of the catchment in to small gird 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 accumulation of soil in the different sub-area of a catchment . GIS method were used to partition the sub-area in to overland and channel types , to estimate the soil erosion in grid cells and to determine the catchment sediment yield by using the concept of sediment delivery ratio. The USLE has been employed to produce realistic estimate of surface erosion over area of small size (Wischmeier and Smith, 1978). The values for the factor K, C and P were estimated for different grids in overland and channel regions as per Wischmeier and Smith (1978) using the classified satellite data for land cover and soil. The gross amount of soil erosion for each cell during a storm event was generated by multiplying the term KLSCP with the R factor for the corresponding storm event. The eroded sediment was routed from each cell to the catchment outlet using the concept of sediment delivery ratio.

Morgan (2001) find a simple approach to soil loss prediction of Silsoe Catchment using Revised Morgan- Morgan Finney Model for prediction of annual soil loss. Change has been made to the way soil particle detachment by raindrop impact is simulated. Test was test taken against the same data set used to validate the original version at the erosion plot scale, prediction made with model gave slop of reduced major axis regression line closer to 1.0 when compared with measured values. The coefficient of efficiency for the site with measured runoff and soil loss, increased from 0.54 to 0.64. The result indicate that, the model provide useful information on the surface area of sediment, sediment delivery and annual sediment yield.

Fistikoglu and Harmancioglu (2002) used GIS with USLE for Assessment of Soil Erosion for a small region (23 km^2) in the Gediz River Basin along the Aegean western coast of Turkey. The main focus of the study was to integrate a GIS with the USLE model for identification of rainfall based erosion and the transport of non point source pollution loads to the Gediz River, which discharge in to Aegean Sea along the western coast of Turkey. The study identified the gross erosion, sediment load and organic N loads within a small region of the Gediz River Basin. The result of the study have shown that GIS permit more effective and accurate application of the USLE model for small watershed provide that sufficient spatial data are available.

Haregeweyn and Yohannes (2002) evaluate the agricultural non-point source pollution model (AGNPS) on Augucho catchment. The model was evaluated at 100 and 200 m grid cells. GIS was employed to derive some of the parameters in addition to the primary and secondary data collection techniques. Correlation coefficients, coefficient of efficiency and homogeneity test of the correlation coefficients were used to evaluate the two grid cells and the overall model performance. The validation result indicated that the correlation coefficients were 0.59 and 0.58 for runoff, 0.96 and 0.95 for peak runoff rate, and 0.97 and 0.97 for the 100 and 200 m grid cells, respectively. The coefficients for sediment yield and peak runoff rate were highly significant ($p \geq 0.01$) and the pair of correlation coefficients for the same event for the two grid cells was homogeneous. . The coefficients of efficiency were -1.0286 and -1.006 for runoff, 0.75 and 0.74 for peak runoff rate, and 0.656 and 0.654 for sediment yield for the 100 and 200 m grid cells, respectively. There was, however, no significant difference in the output between the 100 and 200 m grid runs. For the average year of 1991 and for the 100 m grid cell run, the model estimated an average soil loss of 22 t ha^{-1} per year, which is much greater than the rate of soil formation (1 t ha^{-1} per year).

Jain and Geol (2002) used the catchment for the study on assessing the vulnerability to soil erosion of the Ukai catchment using remote sensing and GIS. The investigation of basins for planning soil conservation requires a selective approach to identify smaller hydrological units, which would be suitable for more efficient and targeted conservation management programme. It is pointed out that in India sediment yield data are generally not collected for small catchments and it become difficult to identify the most vulnerable areas for erosion that can be treated on a priority basis. An index based approach based on the surface factor mainly responsible for soil erosion, is suggested in this study. These factors are soil type, vegetation, slope and various catchment properties such as drainage density, Form factor, etc. Satellite data are used to evaluate the topography and morphology related indices. The integrated effect of all the parameters is evaluated to find different areas vulnerable to soil erosion.

Martinez *et al.* (2002) used the USLE to predict soil erosion hazard in the upper Ewaso Ng'iro North basin of Kenya using data from erosion plots and reconnaissance surveys. Individual GIS files were built for each factor in the USLE and combined by cell-grid modelling procedures in ARC/Info GIS (ESRI, 1997), soil loss was predicted in the spatial domain. Under their study, LS-factor (slope, length and steepness) was determined from vegetation cover data, obtained from SPOT imagery and field surveys. The p-factor (conservation practice) was estimated from the map of soil conservation. The R-factor was determined by extrapolation from the rainfall data obtained from autographic records. The K-factor (soil erodibility) was determined using data obtained by laboratory analysis of soil samples collected from 83 sites in the basin.

Paringitand and Nadaoka (2003) studied Sediment yield modelling for small agricultural catchment. The paper discuss the application of remote sensing technique in the retrieval of vegetation and soil parameter necessary for the distributed soil loss modelling in small agricultural catchment and analyse the variation in erosion pattern and sediment distribution during rainfall event using numerical solution of overland flow simulations and sediment equation , a method is proposed to account for the variability of associated vegetation cover based on their spectral characteristics as captured by remotely sensed data . This study lends a theoretical support and empirical evidence to the role of vegetation as a potential agent for soil erosion control.

Flugel *et al.* (2003) used the catchment for study on Integrated geographical information system , remote sensing , ground truth and modelling approaches for regional erosion classification of semi-arid catchment in South Africa (Kwazulu ; South Africa). With respect to water quality problem, the understanding of the dynamics of integrated soil erosion process in river basins is of crucial importance. This Study is on the delineation of response unit in the catchment. It was carried out within the framework of an interdisciplinary project aimed at developing and integrated water resource management system for water resources analysis in the catchment. Particular attention was focused on the identification of sediment source areas. For this purpose response unit concept was applied to delineate erosion. Spatially distributed input data from the catchment were derived by remote sensing technique and geographical information system analysis. Taking into account the high amount of sediment produced by gully erosion, not considered in USLE type models, Special attention was focused to gully erosion, a dynamic gully erosion model.

Kumar and Sharma (2005) used the Tons watershed for the study on Soil erosion risk assessment based on MMF model using remote sensing and GIS. Soil erosion is a serious problem in lesser Himalayas and foothill ecosystem. High rainfall coupled with fragile rocks and high relief prevalent in Himalayas is conductive to soil erosion. MMF model has been used to assess average annual soil loss in the study for soil erosion risk assessment. The loss was found highest from the area under open scrub and lowest from that under dense forest cover. The study indicate nearly 40% of watershed is subjected to serve erosion risk . The assessment of soil erosion is of great significance for land use planning and watershed management in hilly region. Remote sensing and GIS application helped to identify the spatial patterns of soil loss present in the watershed. The study revealed that highest soil loss is from open scrub and lowest from dense forest cover.

Pallavi *et al.* (2005) studied the soil erosion modelling using MMF model-remote sensing and GIS perspective. Remote sensing and GIS technique hold great promises for assessment and conservation of natural resources including surface soil. MMF model was used to quantify soil erosion by incorporating layer derived from both remote sensing and ancillary data. Result show high value 4577.333kg/sq.cm for G map which depicted transport capacity of overland flow. Comparatively lower values 13.15, 7.98 kg/sq.cm were observed for F map, which depicted for soil detachment by raindrop impact. The subtracted image of foresaid layer produced the real picture. This in the highest value 3.770 kg/sq.cm was found in middle region of sub-watershed area.

Simon 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 30 m resolution for a case watershed is resampled to six realizations of grid sizes (50m, 100m, 150m, 200m, 250m, and 300m) for a comparative examination. The results suggest that the selection of the gird size has considerable influence on the soil loss estimation with the empirical models. The estimate of total soil loss from the watershed decreases significantly with the increasing grid cell size as the spatial variability is reduced by the cell aggregation. The empirical modelling approach is a useful tool for qualitative assessment of soil erosion. Discretion is suggested for its applications to quantitative estimation of soil loss concerning the sensitivity to the grid size selection.

Ismail and Ravichandran(2007) derived the RUSLE2 Model application for Soil Erosion Assessment Using Remote Sensing and GIS. The soil erosion is estimated for each of the hill slope units in that study area. The factors considered are 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 hill slope 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 sub factor values for the hill slope units. Incorporation of remote sensing technique and Geographic Information System (GIS) made the spatial analysis of the study more reliable and accurate. The annual average soil erosion rate is estimated at 25 t/ha/year, which is on a higher range. That result indicates the immediate need for the adoption of proper conservation strategies in that area to control the eutrophication in the Krishnagiri reservoir and to prevent further watershed degradation.

Pandey *et al.* (2007) identified critical erosion prone areas in small agricultural watershed of Karso, hazaribagh, Jharkhand, India using USLE, GIS and remote sensing. The study area was divided into 200 × 200 grid cells and average annual sediment yields were estimated for each grid cell of the watershed to identify the critical erosion prone areas of watershed for prioritization purpose. Average annual sediment yield data on grid basis was estimated using Universal Soil Loss Equation (USLE). Remote sensing (RS) technology provides the vital spatial and temporal information on some of these parameters. In their study the deviation of estimated sediment yield from the observed values in the range of 1.37 to 13.85 percent indicates accurate estimation of sediment yield from the watershed.

Rosaliya *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 model response to raster-based grid cell sizes. The model was parameterized at a 30 m grid, then calibrated and validated to three representative thunderstorms. The simulated hydrographs replicated the measurements of peak discharge, runoff volume, and time to peak. The model also calculated sediment yields within ±50% of the field measurements. Resampling the watershed digital elevation model at scales from 30 m to 330 m reduced the land surface slopes and changed the channel topology. Model gives good result at grid sizes of 30 m and 90 m, which is comparable to the plot sizes of the universal soil loss equation. At grid sizes coarser than 150 m, the sediment source areas became less appropriately depicted and the calculated sediment delivery ratios became unrealistically high. Grid sizes smaller than 150 m are recommended for proper watershed simulation of upland erosion and sediment yield.

Pandey *et al.* (2009a) carried out sediment yield modelling of an agricultural watershed using MUSLE, remote sensing and GIS. The runoff factor of MUSLE was computed using the measured values of runoff and peak rate of runoff at outlet of the watershed. The topographic factor (LS) was determined using GIS .while crop management factor (C) was determined from land use/land cover data, obtained from RS and field survey. The conservation practice factor (P) was obtained from the literature. Sediment yield at the outlet of the study watershed was simulated for 345 rainfall events spread over a period of 1996–2001 and validated with the measured values. Nash–Sutcliffe simulation model efficiency of 0.8 and high value of coefficient of determination (0.83) indicated that MUSLE model estimated sediment yield satisfactorily.

Pandey *et al.* (2009b) carried out an assessment of the sediment yield from Dikrong river basin of Arunachal Pradesh , India employing RS and GIS and using the Morgan –Morgan – Finney (MMF) model and Universal Soil Loss Equation (USLE).A spatial grid scale was of

100m x100m was selected. They conclude that for soil loss estimation using USLE model accounts for topographical characteristics and the result may be more realistic

Jain *et al.* (2009) identified sediment source and sink areas in Himalaya watershed using RS and GIS. They used remote sensing and GIS technique used for derivation of spatial information, catchment discritization, and data processing for Himalaya watershed. Various thematic layers for different factor of USLE were generated and overlaid to compute spatially distributed for gross soil erosion map for the watershed using 18 years rainfall data.

CHAPTER –III

MATERIAL AND METHODS

This chapter deals with the description of the study area, data acquisition and methods used for data processing, preparation of thematic maps and estimation of sediment yield at the watershed outlet using MMF (Morgan–Morgan-Finney) Model, Universal Soil Loss Equation (USLE), Remote Sensing and GIS.

3.1 Description of the Study area

The Godavari river basin is one of the 14 major river basins of India having a catchment area of 3,12,812 km^2 which is nearly 10 percent of the total geographical area of the country. It spreads over Maharashtra (48.7%), Madhya Pradesh (20.8%), Andhra Pradesh (23.4%) and Karnataka (1.4%). The river traverses a distance of 694 km through Maharashtra and 771 km through Andhra Pradesh, total 1,465 km, before discharging into the Bay of Bengal. The major tributaries of the river Godavari are Pravara, Manjira, Penganga, Wainganga, Wardha. The Wadsa-Chincholi watershed is located in Bhandara, Chandrapur , Gondia and Nagpur district of Maharashtra State. It lies between 78°30′ E to 80°45′ E longitude and 20°30′ to 21°45′ N latitude. The main stream of the watershed joins the Godavari River. The study area of the watershed is 14690.43 km^2. The department of the Hydrology circle, Nasik is monitoring the hydrological data. The area is dominated by Clayey, Clay loam, Gravelly Clay loam, Gravelly Sandy Clay loam, Gravelly Sandy loam, Sandy Clay, Sandy Clay loam, Sandy loam, and Silt Clay loam soils. The region falls within sub-tropical climate with alternate dry and wet periods with three well-defined seasons, *i.e.* summer, monsoon and winter. Average annual rainfall of the study area is 1402.7 mm, more than 85% of the rainfall occurrs during the monsoon months (June–September). Daily mean temperature ranges from a maximum of 45.5 °C (May) to a minimum of 6 °C (January). The daily mean relative humidity varies from a minimum of 40% (April) to a maximum of 95% (July).

3.2 Problem of the Study Area

Depletion of forest covers due to changing of land use from forest in to pasture agriculture land and over use of water resource result in deterioration of the watershed. The high velocity runoff causes erosion of the soil. Deposition of sediment transported by a river in to reservoir reduces the reservoir capacity, thereby adversely affecting the water availability for power generation, irrigation, domestic and industrial use deposition of sediment in the stream and problem of flood downstream, therefore, loss of fertile soil cause reduction in crop production. There is lack of soil and water conservation management practices are the main cause for poor amount of water availability during Kharif season.

3.3 Data Acquisition

The details of collection of metrological data, observed sediment data, satellite data and the other data/information used in this study are briefly discussed below.

3.3.1 Metrological data

Daily rainfall data for eight years (2000-2007) were collected from the non recording rain-gauges located in the watershed. The data were collected from the department of the Hydrology circle, Nasik, Maharashtra State.

3.3.2 Observed sediment data

Daily sediment sampling was done manually at the outlet of the Wadsa-Chincholi watershed. The concentration of sediment for each collected sample was determined by filtering, drying and weighing the collected sample. Discharge flowing through the stream at the outlet was measured by notching the staff gauge reading and using the rating curve. Discharges multiplied by the time of flow gave the total volume of runoff for a rainfall event. The volume of runoff (m^3) times the sediment concentration (mg l^{-1}) adjusted for units gave the sediment production from a rainfall event. The sediment production values of all rainfall events of a year were summed up to get the annual value in tonnes. The annual sediment production in tonnes divided by the watershed area gave the annual sediment yield in tonnes per hectare.

3.3.3 Hardware and software used

The cloud free digital data of Land sat 5 Imagery of 30 m spatial resolution pertaining to 31 October, 2004 in seven spectral bands was downloaded from http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp. Personal computer equipped with ERDAS IMAGINE and ARC-GIS software was used in the study.

3.3.4 Delineation of watershed boundary

The watershed boundary was delineated and then watershed was considering topographical parameters derived from Digital Elevation Model and Drainage network.

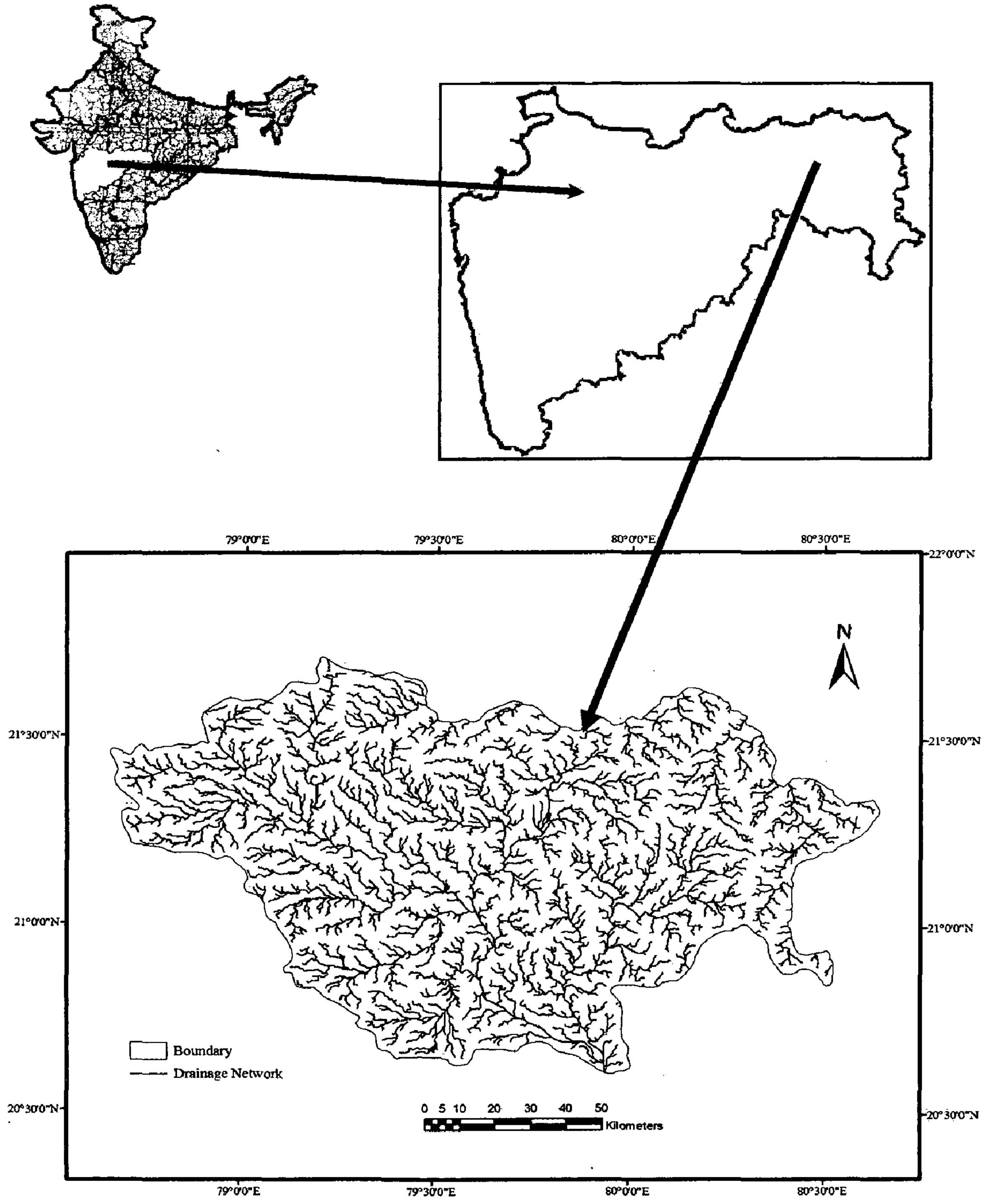

Figure 3.1. Location map of Wadsa-Chincholi Watershed

when wet.These soils are moderately drained and have slow to moderate rate of water infiltration. Clay proportion is high above 40% while erodible (silt + very fine sand) and non-erodible (sand + coarse material) proportion of materials in these soils are 7 to 18% and 35 to 40% respectively.

3.3.5.2 Clay loam soil

Clay loam consists of soil material having the most even distribution of sand, silt, and clay of any of the soil textural grades. But it feels as though it possesses more clay than sand or silt. Sticky and plastic when wet, it forms casts that are firm when moist and hard when dry. Clay loam soil cover an area of 2818.91 km^2.They are characterized by moderate to rapid permeability having OM content of 0.1 to 0.4, clay proportion from 31 to 33%, erodible matter 8 to 29% and non-erodible portion varying from 45 to 60%.

3.3.5.3 Sandy loam soil

Sandy loams consist of soil materials containing somewhat less sand, and more silt plus clay, than loamy sands. As such, they possess characteristics which fall between the finer-textured sandy clay loam and the coarser-textured loamy sands. Sandy loam soil covers an area of 1120.17 km^2. These are well-drained soils with high permeability. The erodible and nonerodible material constitute 10 to 33% and 60 to 85% respectively. It contains 30% or more very coarse, coarse, and medium sand (but less than 25% very coarse and coarse sand), and less than 30% either fine sand or very fine sand.

3.3.5.4 Silt clay loam

Silt clay loam is intermediate in characteristics between the silty clay and the silt loam. This soil material resembles clay loam in cohesive properties, but possesses more silt and less sand and thus has a rather smooth feel. Silt clay loam soil covers an area of 491.38 km^2. These are moderately high drained soils with moderately rapid permeability. They contain a very low OM of below 0.2%, clay percentage above 30%. Erodible and no erodible parts constitute 20 to 30% and some 40% respectively.

3.3.5.5 Silt clay soil

They are excessively drained moderate to high permeable soils with OM of 0.8%, low clay content of 10 to 18%, moderate proportion of 15 to 20% of silt very fine sand and some 65% of sand and coarse material. Silt clay soil covers an area of 234.24 km^2.

3.3.5 Soil of the Wadsa-chincholi Watershed

The soil map of the study area was obtained from the National Bureau of Soil Survey and Land use Planning (NBSSLUP), Nagpur. The soils of the watershed are strongly to moderately acidic with low to medium organic matter content and moderate water holding capacity. Soil profiles in Godavari basin of Wadsa – Chincholi watershed basin were studied. The basin exhibits eleven types of textural classes of soils viz., Clay, Clay loam, Sand , Sandy clay , Sandy clay loam, Sandy loam , Silt clay loam, Silt clay , Gravelly sandy loam and Silt soil respectively.

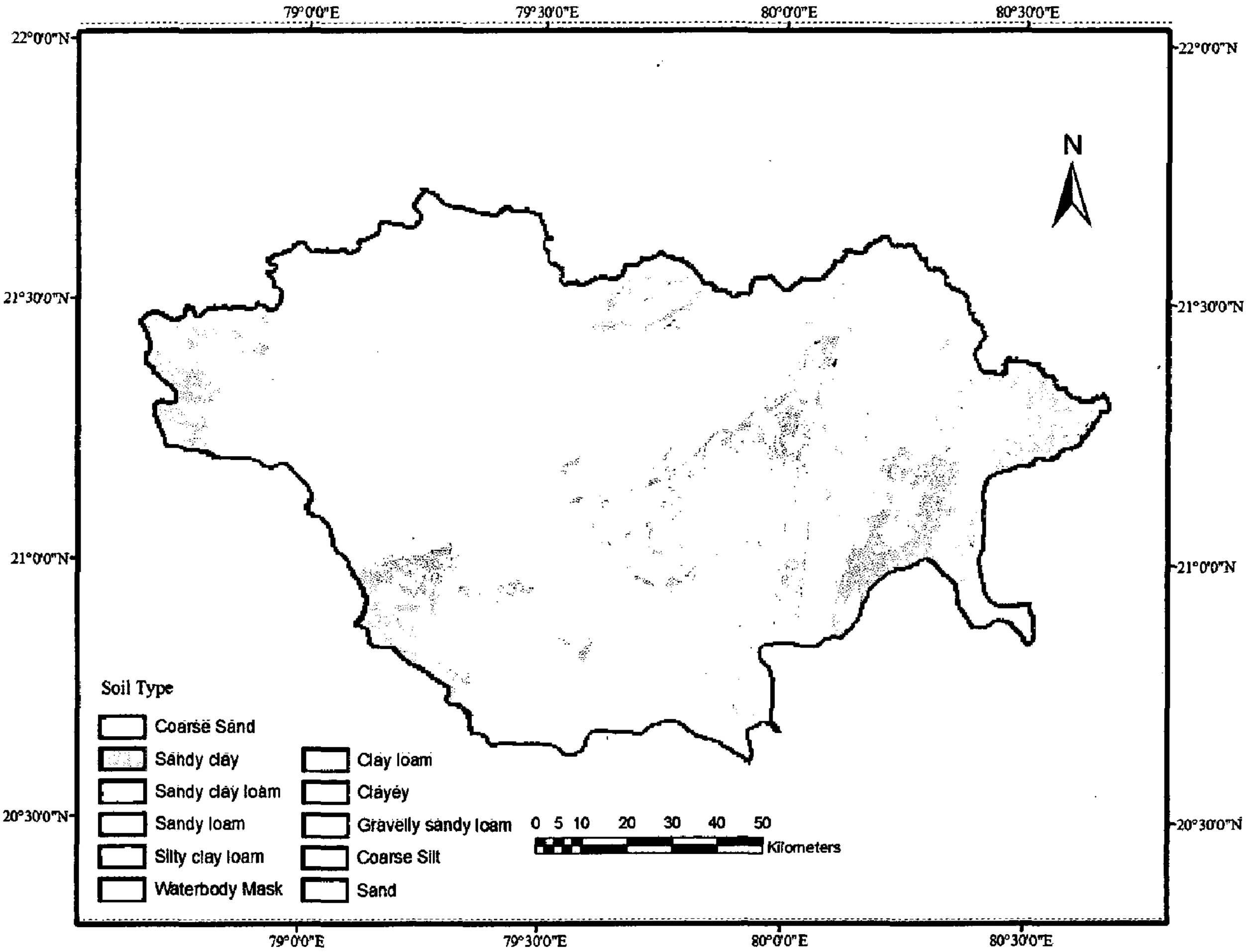

Figure 3.2. Soil map of Wadsa-Chincholi watershed

3.3.5.1 Clayey soil

Clay is the finest textured of all the soil classes. Clay soil cover an area of 5242.89 km^2. Clay usually forms extremely hard clods or lumps when dry and is extremely sticky and plastic when wet.These soils are moderately drained and have slow to moderate rate of water infiltration. Clay proportion is high above 40% while erodible (silt + very fine sand) and non-erodible (sand + coarse material) proportion of materials in these soils are 7 to 18% and 35 to 40% respectively.

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Clay loam consists of soil material having the most even distribution of sand, silt, and clay of any of the soil textural grades. But it feels as though it possesses more clay than sand or silt. Sticky and plastic when wet, it forms casts that are firm when moist and hard when dry. Clay loam soil cover an area of 2818.91 km^2.They are characterized by moderate to rapid permeability having OM content of 0.1 to 0.4, clay proportion from 31 to 33%, erodible matter 8 to 29% and non-erodible portion varying from 45 to 60%.

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Sandy loams consist of soil materials containing somewhat less sand, and more silt plus clay, than loamy sands. As such, they possess characteristics which fall between the finer-textured sandy clay loam and the coarser-textured loamy sands. Sandy loam soil covers an area of 1120.17 km^2. These are well-drained soils with high permeability. The erodible and nonerodible material constitute 10 to 33% and 60 to 85% respectively. It contains 30% or more very coarse, coarse, and medium sand (but less than 25% very coarse and coarse sand), and less than 30% either fine sand or very fine sand.

3.3.5.4 Silt clay loam

Silt clay loam is intermediate in characteristics between the silty clay and the silt loam. This soil material resembles clay loam in cohesive properties, but possesses more silt and less sand and thus has a rather smooth feel. Silt clay loam soil covers an area of 491.38 km^2. These are moderately high drained soils with moderately rapid permeability. They contain a very low OM of below 0.2%, clay percentage above 30%. Erodible and no erodible parts constitute 20 to 30% and some 40% respectively.

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They are excessively drained moderate to high permeable soils with OM of 0.8%, low clay content of 10 to 18%, moderate proportion of 15 to 20% of silt very fine sand and some 65% of sand and coarse material. Silt clay soil covers an area of 234.24 km^2.

3.3.5.6 Sandy clay loam soil

Soil having this texture consists of materials whose behavior is dominated by sand and clay. It most nearly resembles the sandy loams in that it has considerable amounts of sand, which can be most easily detected by moistening the soil. Sandy clay loam has more clay than the sandy loams and thus possesses greater cohesive. Sandy clay loam soil cover an area of 1856.13 km^2. They are moderately well drained soil with 20-35 % clay, less than 28% silt and 45 % or more sand.

3.3.5.7 Gravelly sandy loam

Gravelly sandy loam soil is on mountains, mainly at or near fault zones. Erosion and slippage hazard slightly too severe depending upon slope. Available water holding capacity of gravelly sandy loam soil is very low. Permeability of this soil is very rapid. It covers an area of 283.32 km^2.

3.3.5.8 Sandy clay

Sandy clay is somewhat similar to silt clay, but it contains much more sand and less silt. They are moderately well drained soil with high permeability. Soil materials contain 35% or more clay and 45 % or more sand. Sandy clay covers an area of 1067.1 km^2.

3.3.5.9 Sandy soil

Sandy soil means most of the soil particles (1mm- 2mm) in diameter. It gives good water drainage and has a low capability to hold nutrients. Rocks and other sediments get weathered to the point where they are so small becoming sand. . It contains 25% or more very coarse, coarse, and medium sand (but less than 25% very coarse plus coarse sand), and less than 50% either fine sand or very fine sand. Sandy soil covers an area of 439.03 km^2.

3.3.5.10 Coarse silt soil

Coarse silt soil particles size (0.02 – 0.06 mm) in diameter. Silt is easily transported by moving currents but settles in still water. It has more nutrients than sandy soil yet still offers good drainage. When dry it has rather a smooth texture and looks like dark sand. Its weak soil structure means that it is easy to work with when moist and it holds moisture well. Soil materials that contain 80% or more silt and less than 12% clay. It covers an area of 374.45 km^2.

3.3.5.11 Coarse sandy soil

Coarse sandy soil particles size (greater than 2 mm) diameter. This is the sand that looks and feels most coarse and gritty. It must contain 25% or more very coarse sand and coarse sand, and less than 50% any other single grade of sand. It covers an area of 764.63 km^2.

3.3.6 Establishment of Digital Elevation Model

Digital elevation model (DEM) was developed from the Shuttle Radar Topography Mission (SRTM) data. The Digital Elevation Model (DEM) is digital representation of a topographic surface. However, most often it is used to refer specially to a raster or regular grid of a spot elevation. The DEM are used in determining attribute of terrain, such as elevation at any point, slope and drainage basin.

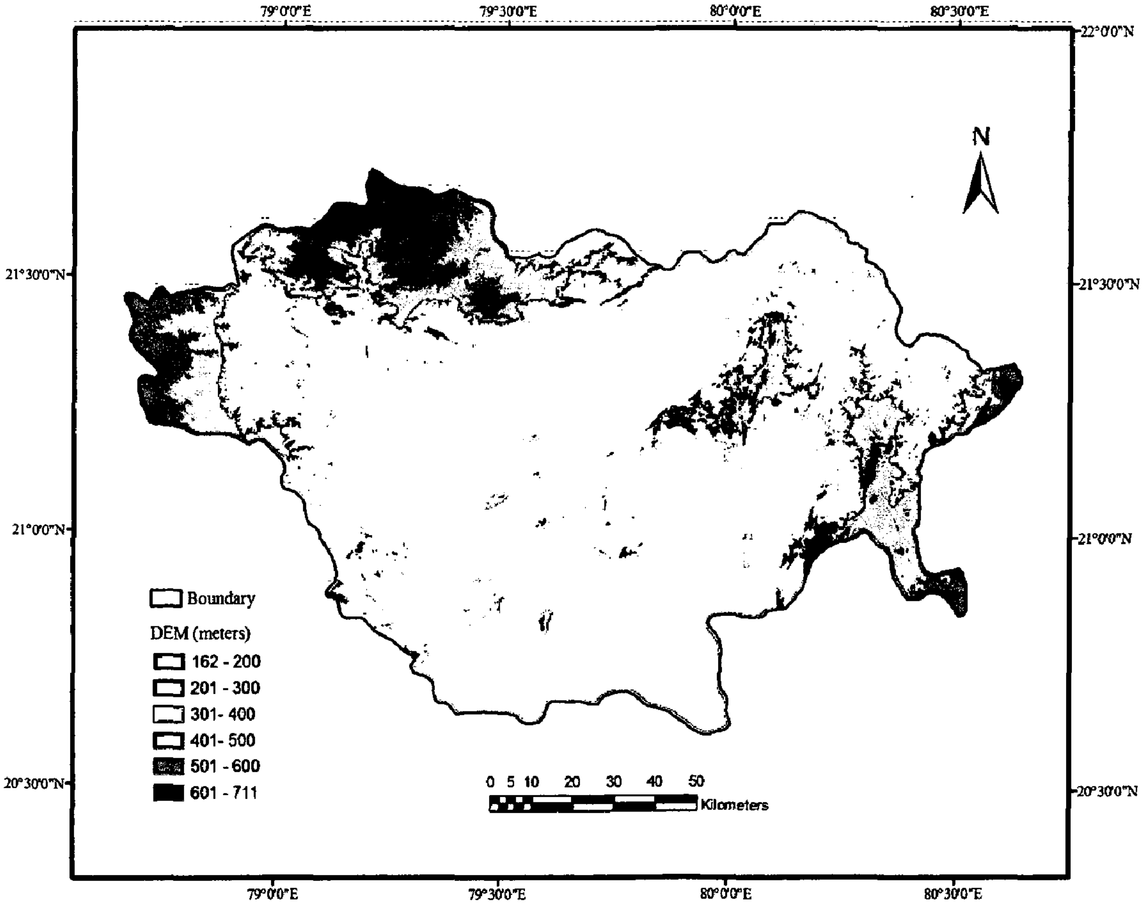

Figure 3.3. Digital Elevation Model (DEM) map of Wadsa-Chincholi watershed

3.3.7 Generation of drainage coverage

The drainage coverage was established from SRTM data. The drainage map of the Wadsa-Chincholi watershed is presented in Figure 3.4.

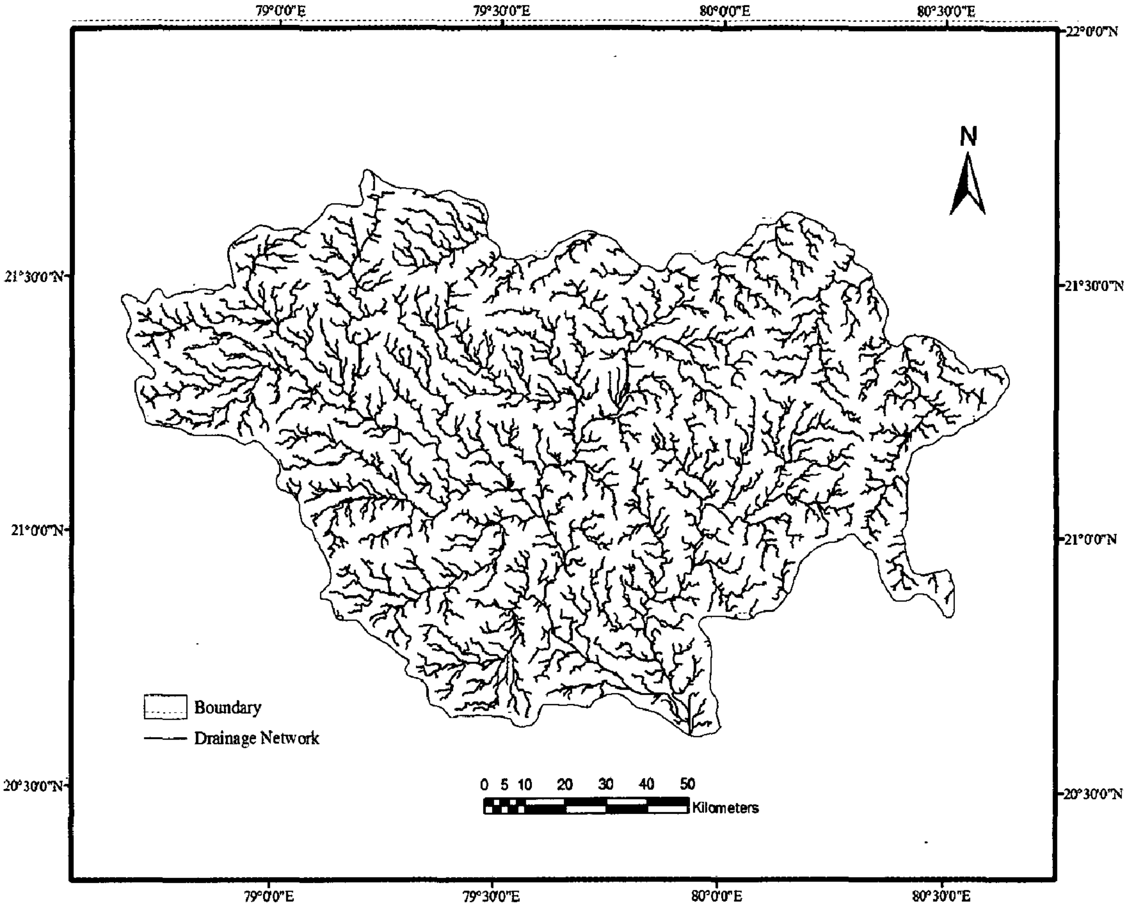

Figure 3.4.Drainage map of the Wadsa-Chincholi watershed

3.3.8 Generation of slope coverage (50 m × 50 m, 100 m × 100 m and 200 m × 200 m) grid size

The ARC- GIS was used for generating the slope coverage. Grid size of 50 m × 50 m, 100 m × 100 m and 200 m × 200 m were selected. For generating slope map of the study area, Digital elevation model (DEM) was used. Slope map of the grid sizes of 50 m × 50 m, 100 m × 100 m and 200 m × 200 m of the Wadsa-Chincholi watershed is presented in Figures 3.5 to 3.7.

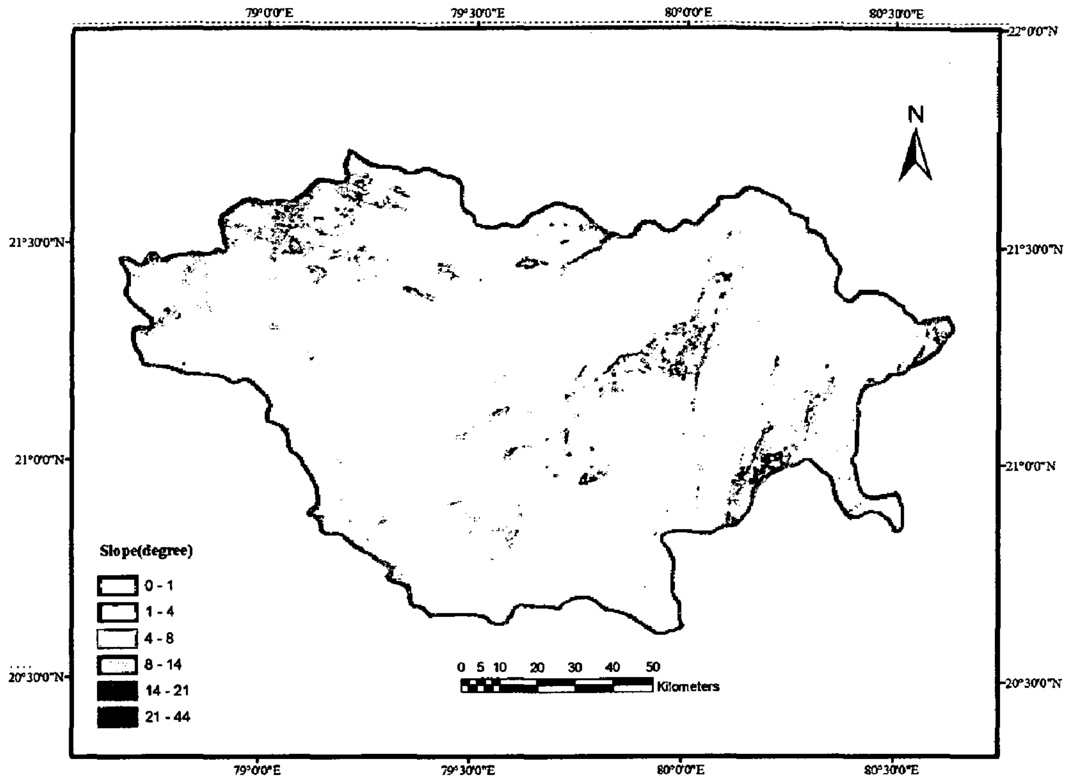

Figure 3.5.Slope map (50 m× 50 m) grid size of Wadsa-Chincholi watershed

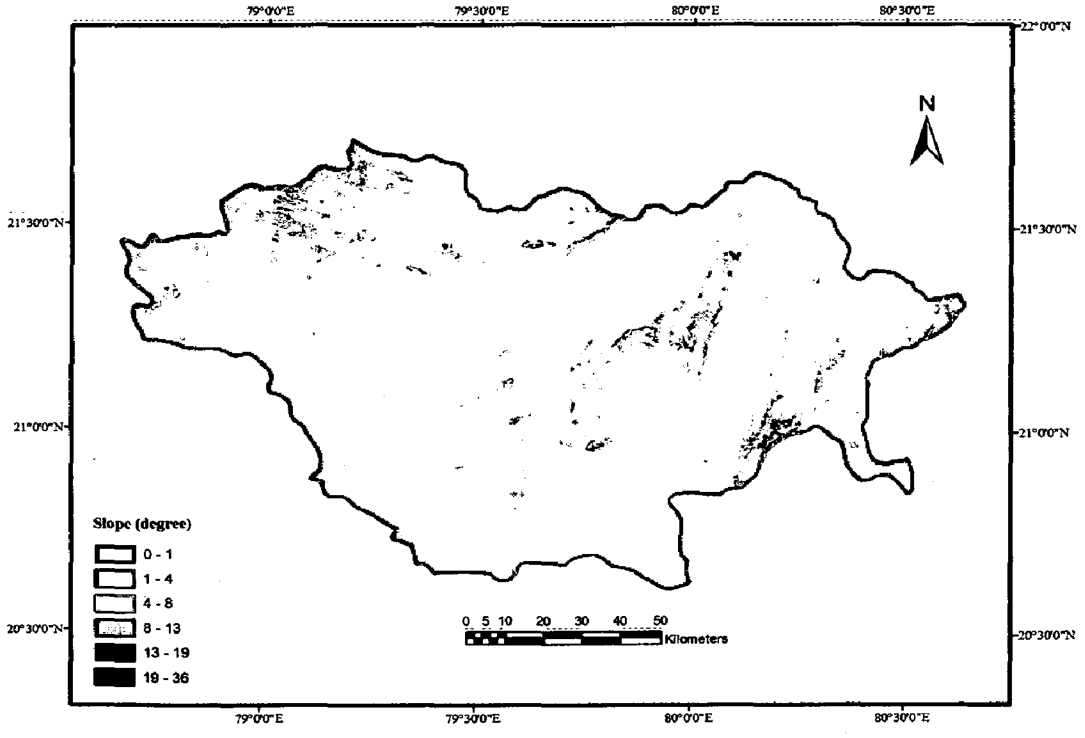

Figure 3.6.Slope map (100 m× 100 m) grid size of Wadsa-Chincholi watershed

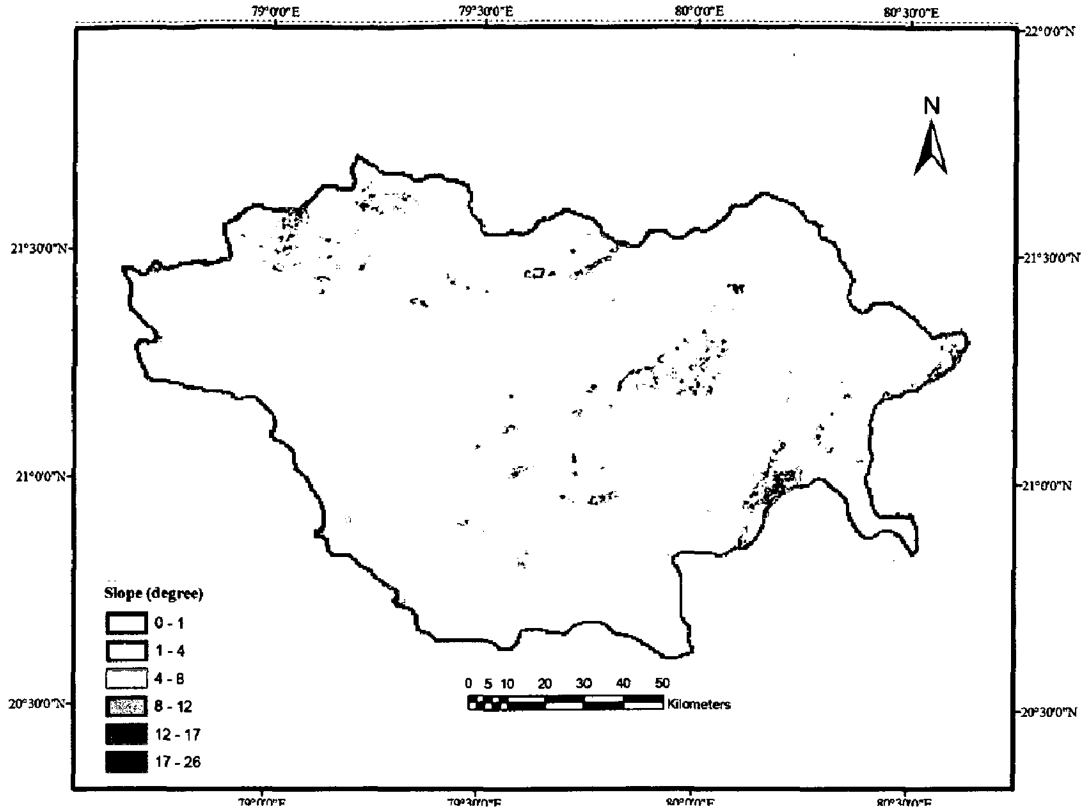

Figure 3.7.Slope map (200 m × 200 m) grid size of Wadsa-Chincholi watershed

3.3.9 Land Use Land Cover Classes Mapped in Study area

Land use Land cover map of the study area was obtained from the National Bureau of Soil Survey and Land use Planning (NBSSLUP), Nagpur. Land use refers to "man's activity and the various uses which are carried on land". Land cover refers to "natural vegetation, water bodies, rocks/soil, artificial cover and others resulting due to transformations". Prominent sixt land use/cover classes were identified in the study watershed. Finally, MLC report and classified image depicting various land use/ cover classes of the study area are presented in Table 3.1.

Table 3.1. Area under different Land use/Land cover of Wadsa-Chincholi watershed

Sl. No.	Land use/Land cover	Area (km^2)	% (area)
1	Water body	656.66	4.47
2	Dense forest	2564.61	17.45
3	Agriculture	8570.48	58.34
4	Waste land	2461.53	16.75
5	Built -Up	377.27	2.56
6	Open forest	59	0.40
Total area		14690	100

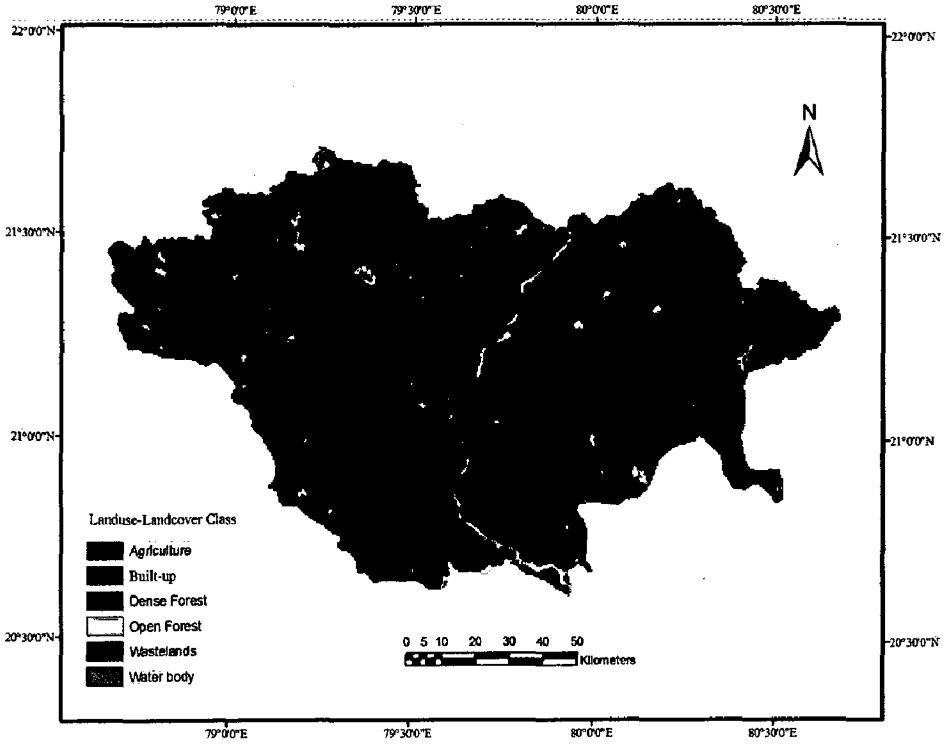

Figure 3.8.Land use / land cover map of Wadsa-Chincholi watershed

3.3.9.1 Built up land

This can be defined as area of human habitation developed due to non agricultural use and that which has a cover of buildings, transport and communication, utilities in associated with water, vegetation and vacant lands. The built up land includes Residential (Urban), Industrial,

3.3.9.1 Built up land

This can be defined as area of human habitation developed due to non agricultural use and that which has a cover of buildings, transport and communication, utilities in associated with water, vegetation and vacant lands. The built up land includes Residential (Urban), Industrial, Transformational, Restricted areas, open space, vacant land and villages (Rural) .Built Up land occupies a total of 377.27 km^2 area.

3.3.9.2 Agricultural land

Agricultural land can be defined as land primarily used for farming and production of food , fiber, and other commercial and horticultural crops . It include land under crops (irrigated and no irrigated), fallow, plantations etc. Kharif is the one of major crop season in the block, which is sown during the month of June and July and harvested in month of September and October and sowing operations for Rabi crop start during November and December and harvested in March and April. The total areas occupied by Agriculture land are 8570.48 km^2.

3.3.9.2.1 Crop land

These are characterized by their dark red and fine texture. Kharif and Rabi crops have been marked in the area using imaginary two seasons. The major kharif crop sown in the area are paddy (oryza sativa), maize (zea maize), finger millet etc and main rabi crop include wheat (triticum sativum) barely (Hordeum vulgare), mustard (brassica juancea) and some vegetables.

3.3.9.2.2 Fallow land

These include agricultural lands which are taken for the cultivation but are temporarily left uncropped. They are recognized by shape and their regular pattern. The fallow land uncropped for one or more season.

3.3.9.2.3 Plantation

Agricultural plantations are the area under agricultural tree crops, planted adopting certain agricultural management techniques.

3.3.9.3 Forest

It is an area (within the notified forest boundary) bearing an association predominately of trees and other vegetation types of capable of producing timber and other vegetation type. Total forest covers which include dense forest and open forest. Present forest type include deciduous with scrub and deciduous without scrub types. Forest of various types which include dense forest and open forest comprises 2613.61 km^2 areas.

3.3.9.4 Wasteland

Waste land which can be described as degraded land which can be brought under vegetation cover with responsible efforts, and which currently are underutilized due to lack of appropriate water and soil management or account of natural causes. Wasteland demarcated in the area land with or without scrub, gullied /ravenous land, barren rocky /stony waste and mining and industrial wastelands. Wasteland of various types comprises 2461.53 km^2 areas.

3.3.9.4.1 Gullied /Ravenous land

In the study area gullied are formed as result of localized surface runoff affecting the unconsolidated sediment in the formation of perceptible channel resulting in undulated landscape.

3.3.9.4.2 Land with or without scrub

These are prevalent in relative higher topography, excluding hilly and mountains terrain. These lands are generally prone to erosion. Area mapped as land with or without scrub.

3.3.9.4.3 Barren rocky /stony land

These are rocky exposures often barren and devoid of soil cover and vegetation, not suitable for cultivation .It is mainly marked on granite exposures, which are outside the notified boundary.

3.3.9.5 Rivers / Water body

Water bodies include reservoir, tank, abandoned quarry with water etc which comprise 656.66 km^2 areas.

3.4 Estimation of Sediment Yield

The MMF model was used to estimate the sediment yield using the parameters derived from RS data, GIS, and standard tables. The annual average sediment yield values were estimated for each grid cell of the watershed for identification and, in turn, prioritization of critical erosion prone areas was done by grouping them into different categories (Singh et al., 1992).

3.4.1 Morgan- Morgan and Finney (MMF) model

Modeling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces. Morgan *et al.* (1984) developed a model to predict annual soil loss, which endeavors to retain the simplicity of USLE and encompasses some of the recent advances in understanding of erosion process into a water phase and sediment phase. The later phase considers soil erosion to result from the detachment of soil particles by overland flow. Thus, it comprises two predictive equations, one for the rate of splash detachment and the other for transport capacity of overland flow. The model uses six equations consisting of 15 input parameters. The model compares predictions of detachment by rain splash and transport capacity of runoff and retains the lower of the two values as an estimate of the annual rate of soil loss, representing detachment or transport limiting factor. The methodology used for estimation of soil loss using MMF model is presented in Figure 3.9.

3.4.2 Flow chart of the MMF model

For the estimation of Soil loss by Morgan approach, the various factor maps like kinetic energy of rainfall, top soil rooting depth, percentage rainfall contributing to permanent interception and stream flow, crop cover management factor, ratio of actual to potential evapotranspiration and soil moisture storage capacity were generated to get final output maps like volume of overland flow; rate of soil detachment by raindrop impact and transport capacity of overland flow. Annual soil loss estimation was calculated by comparing two maps of soil detachment rate and transport capacity and taking the minimum value from them. Results were obtained by running a soil erosion model. In this study soil loss due to splash detachment (F) was taken into consideration.

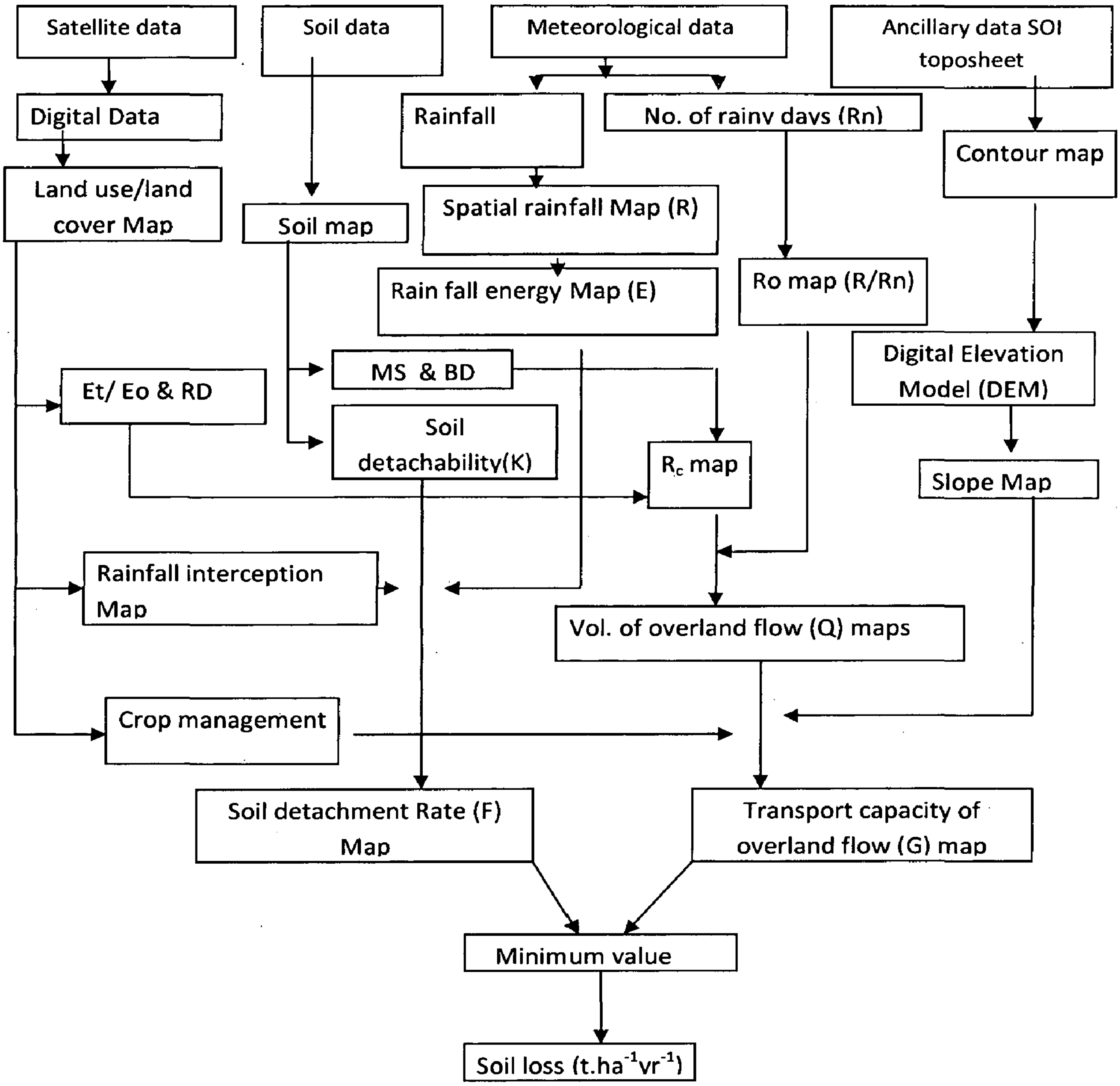

Fig 3.9 Flow chart of the MMF model.

3.4.3 Water phase

In the water phase, the annual precipitation is used to determine the rainfall energy available for splash detachment and the volume of runoff. The former was computed from the total annual rainfall and the hourly rainfall intensity for erosive rain, based on the relationship given by Wischmeier and Smith (1978). The annual volume of overland flow was predicted using the Kirkby (1976) model, which assumes the runoff to occur when the daily rainfall exceeds the critical value dependent on storage capacity of the surface soil layer.

(a) Estimation of rainfall energy

The kinetic energy of rainfall (E) depends on the amount of annual rain (R) and the rainfall intensity (I) and is given by the following relationship (Wischmeier and Smith, 1978):

$$E = R(11.9 + 8.7\log_{10} I) \tag{3.1}$$

where E is in J m^{-2} and I is in mm/hr, which is taken as 25 $mm.hr^{-1}$as the study area is located in sub-tropical climate.

(b) Estimation of soil detachment rate

Soil detachment rate is computed by using the formula given below:

$$F = K \times \left[E \times e^{-aP}\right]^{b} \times 10^{-3} \tag{3.2}$$

where F is the rate of detachment by raindrop impact (kg m^{-2}), K is the soil detachability index defined as the weight of soil detached from soil mass per unit of rainfall energy, and P is the percent rainfall contributing to permanent interception and stem flow (%), values of exponents are taken as: a = 0.05, b = 1.

3.4.4 Sediment phase

In the sediment phase, splash detachment is modeled as a function of rainfall energy, soil detachability and rainfall interception effect. The transport capacity of the overland flow is determined using the volume of flow, slope steepness, and the effect of vegetation or crop cover management (Kirkby, 1976).

(a) Estimation of overland flow

Overland flow is computed using the following equations:

$$Q = R \times \exp(-R_c / R_o) \tag{3.3}$$

$$R_c = 1000 \times MS \times BD \times RD \times (E_t / E_o)^{0.5} \tag{3.4}$$

$$R_o = R / R_n \tag{3.5}$$

Where Q is the volume of overland flow (mm), R is the annual rainfall (mm), R_c is the soil moisture storage (mm), R_o is the mean rain per rain day (mm), R_n is the number of rainy days in the year, E_t/E_o is the ratio of actual (E_t) to potential (E_o) evaporation, MS is the soil moisture content at the field capacity or 1/3 bar tension (% or w/w), BD is the bulk density of the top layer (Mg/m^3), and RD is the topsoil rooting depth (m).

(b) Estimation of transport capacity

Transport capacity of overland flow is calculated as follows:

$$G = C \times Q^2 \times \sin S \times 10^{-3} \qquad (3.6)$$

where G is the transport capacity of overland flow (kg/m^2), C is the crop cover management factor, and S is the steepness of the ground slope expressed as slope angle.

3.5 Estimation of Soil Loss using MMF Model

To determine the spatial distribution of average annual soil loss, the parameters of MMF models, viz., A, C, E_t/E_o, and RD for land use/cover map were calculated using typical values of plant parameters (Morgan *et al.,* 1984) presented in Tables 3.2 and 3.3. The parameters R and R_n were calculated from the daily rainfall data. Attribute maps were prepared for MS, BD, RD, E_t/E_o and land use/land cover map in GIS environment. All these were used as inputs for calculation of final value of Rc. Ro was computed using annual rainfall (R) and number of rainy days (R_n). The soil detachability (K) and percent permanent interception and stem (or stream) flow (A) maps were prepared in GIS environment. Finally, the values of detachment rate and transport capacity of runoff were computed for each pixel, and the minimum values from each of them were used for preparation of soil erosion map.

Table 3.2. Typical values of different soil parameters for use in Morgan Model

Sl. No	Soil Type	MS, (m/m)	BD, (Mg/m^3)	K
1	Silt clay	0.37	1.2	0.35
2	Sandy clay loam	0.38	1.2	0.30
3	Silt clay loam	0.25	1.3	0.30
4	Clay loam	0.4	1.3	0.4
5	Gavelly sandy loam	0.25	1.3	0.35

6	clay	0.45	1.1	0.02
7	Coarse silt	0.3	1.1	0.30
8	Sandy loam	0.28	1.2	0.30
9	Sandy clay	0.25	1.2	0.35
10	sand	0.08	1.5	0.7
11	Coarse sand	0.07	1.7	0.7

Table 3.3. Typical values of plant parameters for use in Morgan Model

Sl.No	Landuse/Land cover	Et/Eo	P	C	RD
1	Water body	1	25	0.001	0.05
2	Agriculture	0.67	39	0.2	0.1
3	Built-up land	0.1	25	0.1	0.05
4	Wasteland	0.05	5	1	0.05
5	Dense forest	0.98	30	0.002	0.1
6	Open forest	0.95	25	0.015	0.1

3.6 Universal Soil Loss Equation (USLE) Model

This empirical equations, based on a large mass of field data, computes sheet and rill erosion as annual average soil loss (t/ha/yr) using the values representing the four major factors affecting erosion. These factors are climatic, soil, topographic, land use and management.

To determine the spatial distribution of average annual soil loss in the Wadsa-Chincholi watershed, cell based USLE parameters were multiplied in the specified (50 m×50 m,100 m × 100 m , 200 m × 200 m) cells for each year separately i.e. 2000 to 2007. Average annual soil losses were estimated.

The USLE is defined as follows:

$$A = R \times K \times LS \times C \times P \qquad (3.7)$$

Where, A is the predicted annual soil loss per unit area (t/ha/year). It is an estimate of the average annual sheet plus rill erosion from rainstorms for field size upland area. It generally excludes gully or stream bank erosion, snowmelt erosion, or wind erosion, but it includes eroded soil that is deposited before it reaches down slope streams or reservoirs.

R is the rainfall-runoff erosive factor for a specific location. Usually, R is expressed as average annual erosion index units. Its units in SI system are MJ mm ha^{-1} $h^{-1}yr^{-1}$

K is the soil erodibility factor for a specific soil horizon. K is expressed as soil loss per unit of area per unit of R for a unit plot. Its units in System are t h $MJ^{-1}mm^{-1}$.

L is the dimensionless slope-length factor, not actual slope length. L is expressed as the ratio of soil loss from a given slope length to that from a 22.13 meter slope length under the same conditions.

S is a dimensionless slope-steepness factor, not actual slope steepness. S is expressed as the ratio of soil loss from a given slope steepness to that from a 9 percent slope under the same conditions.

C is a dimensionless cover and management or cropping factor. C is expressed as a ratio of the soil loss from the condition of intersects to that from tilled continuous fallow.

P is a dimensionless conservation practice factor. P is expressed as a ratio of the soil loss with practices, such as contouring, strip cropping, or terracing, that with from up-and-down slope.

3.7 Development of Model Database for USLE

3.7.1 Rainfall erosivity (R)

The erosivity factor of rainfall (R) is a function of the falling rainfall intensity, and is the product of kinetic energy of the raindrop and the 30 min maximum rainfall intensity. This product is known as the erosion index (EI) value.

Since rainfall intensity of the watershed could not be estimated in the absence of a recording type raingauge, monthly values were used in annual calculations using the following relationship (Wischmeier and Smith; 1978):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{(1.5 \log_{10}(p_i^2 / p) - 0.08188)} \qquad (3.8)$$

Where, R = rainfall erositivity factor in MJ mm ha^{-1} $h^{-1}yr^{-1}$, Pi = monthly rainfall in mm and P = annual rainfall in mm. Wadsa-Chincholi watershed basin has twelve rain gauge station

Therefore, average precipitation is calculated by thiesen polygon method .It is therefore , not possible to calculate the R factor separately for the individual rain gauge station.

3.7.2 Soil erodibility factor (K)

Wischmeier and Mannering (1969) developed a multiple regression equation based on variables as proportion of sand, silt and clay ratio, organic matter content, antecedent soil moisture, bulk density, amount of slope, pH of surface and subsoil, structure, thickness of soil layer, land use/land cover etc. The equation is statistically accurate and technically valid but has proven too complex as an operational tool for a technician.

Wischmeier et al. (1971) further simplified the procedure for determination of soil erodibility factor by developing an equation based on five soil parameters, which are used in the present study. Among these parameters, sand, silt and clay percentage and organic matter contents have been calculated from soil analysis data. Permeability code has been judged using Table 3.4 and soil structure code has been judged using Table 3.5.

The K-factor was calculated using the following relationship (Wischmeier et. al .1971):

$$100\,K = 2.1\,M^{1.14}\,(10^{-4})\,(12 - a) + 3.25\,(b - 2) + 2.5\,(c - 3) \qquad (3.9)$$

Where, K = soil erodibility factor, t ha h ha^{-1} $MJ^{-1}mm^{-1}$, M = particle size parameter ((% silt + 0.7 * % sand) * (100 - % clay)), a = organic matter content (percent), b = soil structure code and c = soil permeability class. Soil erodibility factor was found to be in the range of 0.022 to 0.058 t ha h ha^{-1} $MJ^{-1}mm^{-1}$

Table 3.4. Permeability code for different types of soil

code	Description	Rate, mm/h
1	Rapid	>130
2	Moderate to rapid	60-130
3	Moderate	20-60
4	Slow to moderate	5-20
5	Slow	1-5
6	Very slow	<1

Table 3.5. Structure code for different types of soil

code	Structure	Size, mm
1	Very fine granular	<1
2	fine granular	1-2
3	Medium or coarse granular	2-10
4	Blocky, platy or massive	>10

3.7.3 Topographic factor (LS)

The topography affects the runoff characteristics and transport processes of sediment on watershed scale.

Slope length factor (L)

The L-factor was calculated based on the relationship developed by McCool et al. (1987). The equation is as follows:

$$L = (\lambda / 22.13)^{m} \qquad (3.10)$$

Where L = slope length factor; λ = field slope length (m); m = dimensionless exponent that depends on slope steepness, being 0.5 for slopes exceeding 5%, 0.4 for 4% slopes and 0.3 for slopes less than 3%. The percent slope was determined from DEM (Fig. 3.5), while a grid size of 50 m, 100 m , 200 m were used as field slope length (λ). Similar assumption of field slope length was made by several researchers (Pandey et. al. 2007; Onyando et al. 2005; Fistikoglu and Harmancioglu 2002; Jain et al. 2001).

Slope steepness factor (S)

The S- factor was calculated based on the relationship given by McCool et. al., (1987) for slope longer than 4 meter as:

$S = 10.8 \sin\theta + 0.03$ for slopes < 9 per cent (11a)

$S = 16.8 \sin\theta - 0.5$ for slopes ≥ 9 per cent (11b)

Where, S = slope steepness factor and θ = slope angle in degree. The slope steepness factor is dimensionless.

3.7.4 Crop management factor (C)

Crop Management factor is the expected ratio of soil loss from a cropped land under specific condition to soil loss from clean tilled fallow on identical soil and slope under the same rainfall conditions. The C factor values were the representative values for allocating the USLE land cover and management factors corresponding to each crop/vegetation condition. The study area has been classified into eight land use classes namely; 1) Water body,2) Dense forest, 3) Agriculture land, 4) Wasteland, 5) Built-up land, 6) Open forest.

Finally, crop management factor was assigned for different land use patterns using Table 3.6. Crop management factor was found to be in the range of 0.003 to 0.6.

Table 3.6. Crop management factor for different land use/land cover class

Sl.No	Land use/Land cover	C
1	Water body	0.2
2	Dense forest	0.003
3	Agricultural land	0.33
4	Waste land	0.6
5	Built-up land	0.13
6	Open forest	0.006

3.7.5 Conservation practice factor (P)

Conservation practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation. In the study area, no major conservation practices are followed. The values for P-factor were assigned to be 0.9 for area under cultivation and 1.0 for other area. The values are based on the values suggested by Rao (1981). The conservation factor was found to be 0.9 and 1.00.

CHAPTER IV
RESULTS AND DISCUSSION

This chapter deals with the results obtained by analyzing the data collected during the course of investigation. The average annual sediment yield for the Wadsa-Chincholi watershed has been estimated using Morgan-Morgan-Finney (MMF) model and Universal Soil Loss Equation (USLE) in different grid sizes. The results of these two models were compared with the observed sediment yield. Finally, the optimal grid size for the sediment yield estimation has been proposed.

4.1 Estimation of Morgan-Morgan-Finney (MMF) Model Parameters

To determine the average annual sediment yield in the Wadsa-Chincholi watershed, the MMF parameters were calculated in the specified 100 m × 100 m cells. Sediment yield were estimated separately for each year i.e. 2000 to 2007. Average annual sediment yield was estimated.

4.1.1 Estimation of kinetic energy of rainfall.

The calculated kinetic energy of rainfall is presented in table 4.1. The Wadsa-Chincholi watershed is having twelve number of rain gauge stations. The average mean rainfall was estimated after drawing the Thiessen polygon. To estimate the soil erosion due to splash detachment, the annual rainfall and 25 mm h^{-1} intensity of rainfall were used as inputs. Based on eight years daily rainfall data, the estimated maximum and minimum values of kinetic energy were found to be 25298.86 and 47452.82 (J/m^2) for the year 2004 and 2007 respectively.

4.2 Estimation of Sediment Yield using MMF Model

The analysis for the years 2000-2007 show that the highest sediment yield was 15.78 t $ha^{-1}yr^{-1}$ in 2007, the year of highest rainfall (1972.1 mm). The lowest value of sediment yield was 8.41 $ha^{-1}yr^{-1}$ in 2004, the year of lowest rainfall when rainfall was only 1051.4 mm. The average annual sediment yield for all the years at outlet of the watershed was determined. The wide variation in sediment yield for different years is mainly due to variation in rainfall pattern. Since the MMF Model considers the minimum values of soil losses between the splash detachment (F) and overland flow (Q), in this study soil loss due to splash detachment (F) was considered as it is the minimum of the two (Table 4.1).

Table4.1 Estimation of kinetic energy and annual sediment yield using MMF model

Sl. No	Year	Rainfall (mm), R	Rn	Ro = R/Rn	Kinetic Energy (J. m^{-2})	Sediment yield (F-Factor) (t ha^{-1}yr^{-1})	Sediment yield (G-Factor) (t ha^{-1}yr^{-1})
1	2000	1223.9	90	13.59	29449.57	9.79	34.3
2	2001	1619.3	107	15.13	38963.72	12.95	63
3	2002	1096.4	78	14.05	26381.66	8.43	27.3
4	2003	1303.5	93	14.01	31364.91	10.43	39.5
5	2004	1051.4	79	13.30	25298.86	8.41	25.01
6	2005	1631.5	94	17.35	39257.28	13.05	68
7	2006	1323.5	91	14.54	31846.16	10.59	41.06
8	2007	1972.1	89	22.15	47452.82	15.78	100
				Average		11.17	49.83

4.3 Estimation of USLE Parameters and Soil Loss

4.3.1 Rainfall erosivity (R) factor (MJ mm ha^{-1} h^{-1}yr^{-1})

The calculated values of R factor are presented in Table 4.2. It is seen from table 4.2 that the rainfall erosivity factor (R) during the period from 2000 to 2007 varied in the range of 2776.091 to 8024.261 MJ mm ha^{-1}h^{-1}yr^{-1}. The highest value (8024.261 MJ mm ha^{-1}h^{-1}yr^{-1}) of R factor was observed in the year 2007 when the total rainfall and rainy days were 1972.1 mm and 89 days respectively. The lowest value (2776.091 M J mm ha^{-1}h-yr^{-1}) of R factor was found to occur in the year 2004, when the total rainfall and rainy days were 1051.4 mm and 79 days respectively. The average R factor value was calculated to be 5513.80 MJ mm ha^{-1} h^{-1}yr^{-1}.

Table 4.2 Annual rainfall erosivity factor for eight year rainfall data

Sl. No	Year	Rainfall erosivity (R) factor (MJ mm ha^{-1} h^{-1}yr^{-1})
1	2000	5044.067
2	2001	6818.908

3	2002	6600.876
4	2003	4667.005
5	2004	2776.091
6	2005	3197.161
7	2006	6982.084
8	2007	8024.261
Average R		5513.80

4.3.2 Soil erodibility (K) factor

Soil erodibility is regulated by a complex set of physical and chemical properties, and is usually determined empirically as the coefficient of proportionality in the erosion/ erosivity relationship. The factors like texture, structure, organic matter content and permeability are very significant in determining soil erodibility. Using soil analysis data, soil map and procedure given in section 3.5, K map was prepared and is presented in figure 4.1.

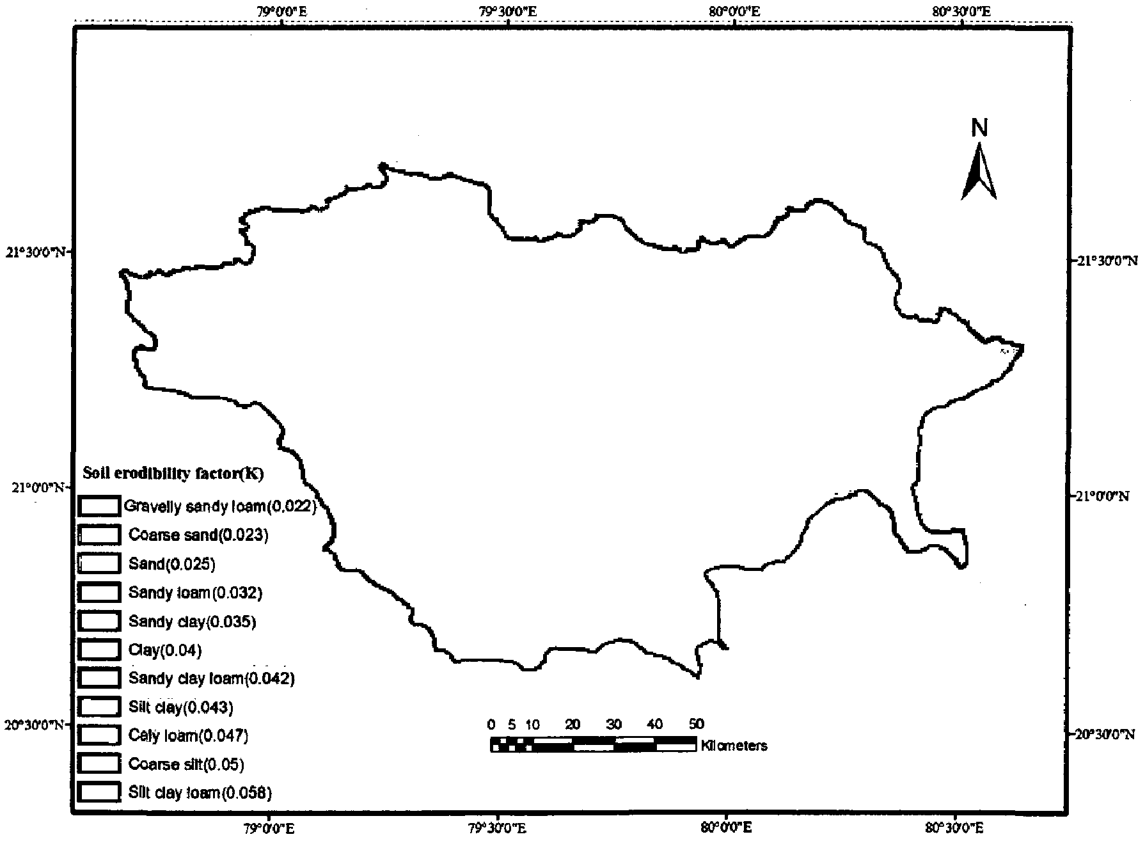

Figure 4.1- Soil erodibility (K) map of the Wadsa-Chincholi watershed

4.3.3 Topographic factor (LS) for grid cell size (50 m × 50 m), (100 m × 100 m) and (200 m × 200 m)

In this analysis, slope gradient (S) and slope length (L) factors were combined and topographic factor (LS) was estimated in the grid cell sizes of 50 m × 50 m, 100 m × 100 m and 200 m × 200 m for the Wadsa-Chincholi watershed and are presented in Figures 4.2 to 4.4. A DEM derived slope map was used to generate slope length (L) and slope gradient (S) maps. For grid cell sizes of 50 m × 50 m, 100 m × 100 m and 200 m × 200 m topographic factor was found to be in the range of 0.05 to 22.76, 0.04 to 21.32 and 0.03 to 19.31 respectively. It is seen from figures 4.2 to 4.4, as the grid size increases, highest and lowest values of LS factor decreases.

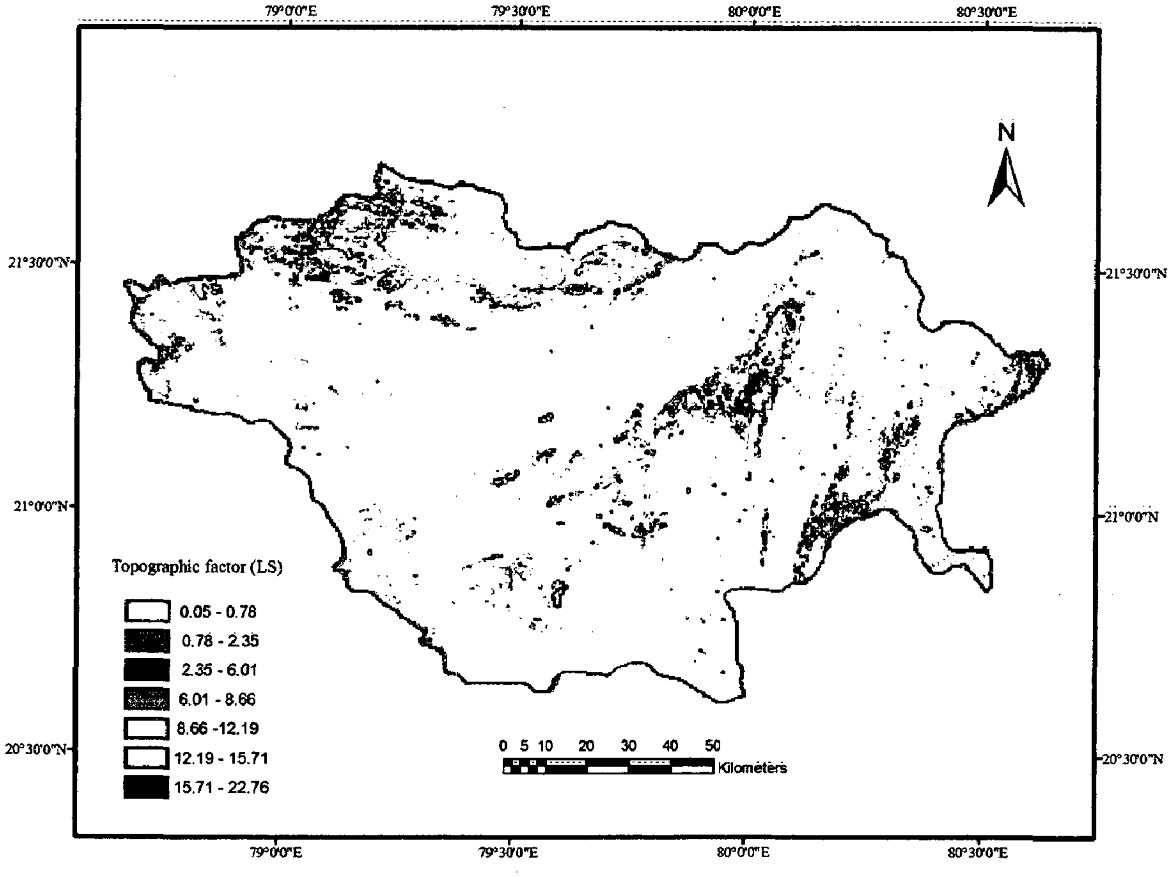

Figure 4.2 Spatial distribution of topographic factor (LS) for grid cell size (50 m × 50m) of theWadsa-Chincholi watershed.

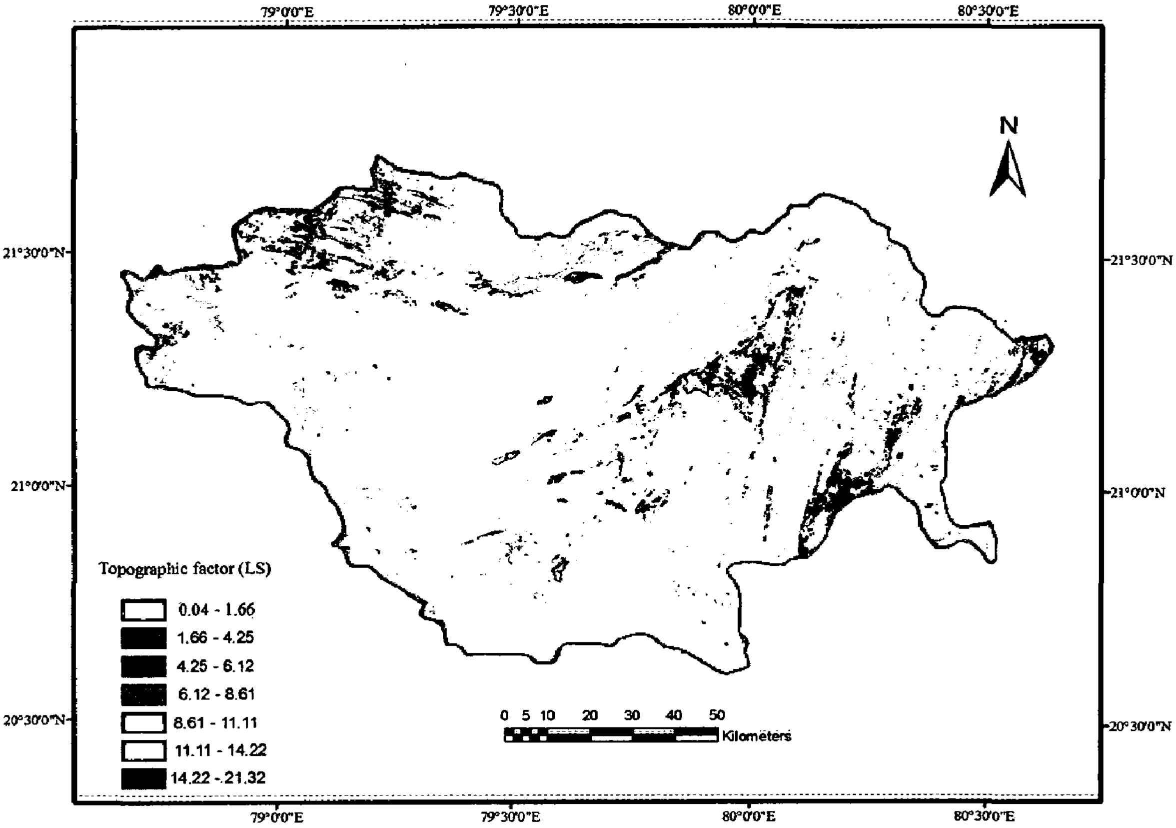

Figure 4.3 Spatial distribution of topographic factor (LS) for grid cell size (100 m × 100 m) of the Wadsa-Chincholi watershed

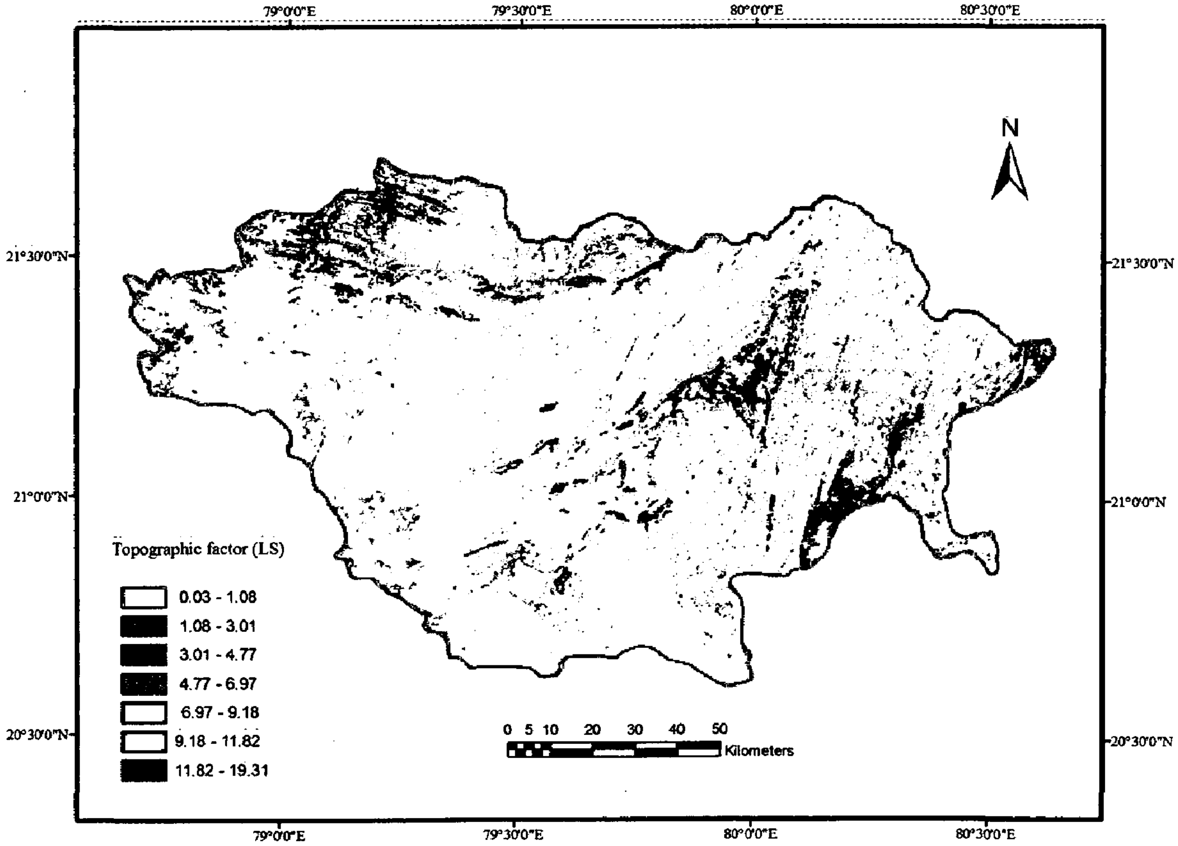

Figure 4.4 Spatial distribution of topographic factor (LS) for grid cell size (200 m × 200 m) of the Wadsa-Chincholi watershed

4.3.4 Crop management factor (C)

The crop management factor (C) maps was prepared from the land use map obtained from the National Bureau of Soil Survey and Land use Planning (NBSSLUP), Nagpur. The Crop Management Factor (C) values for different land use classes were obtained from previous studies (Jain (2002), Pandey (2009), Behera (2005)). C values ranged from 0.003 to 0.60. The magnitude and the spatial distributions of crop management factor are presented in figure 4.5.

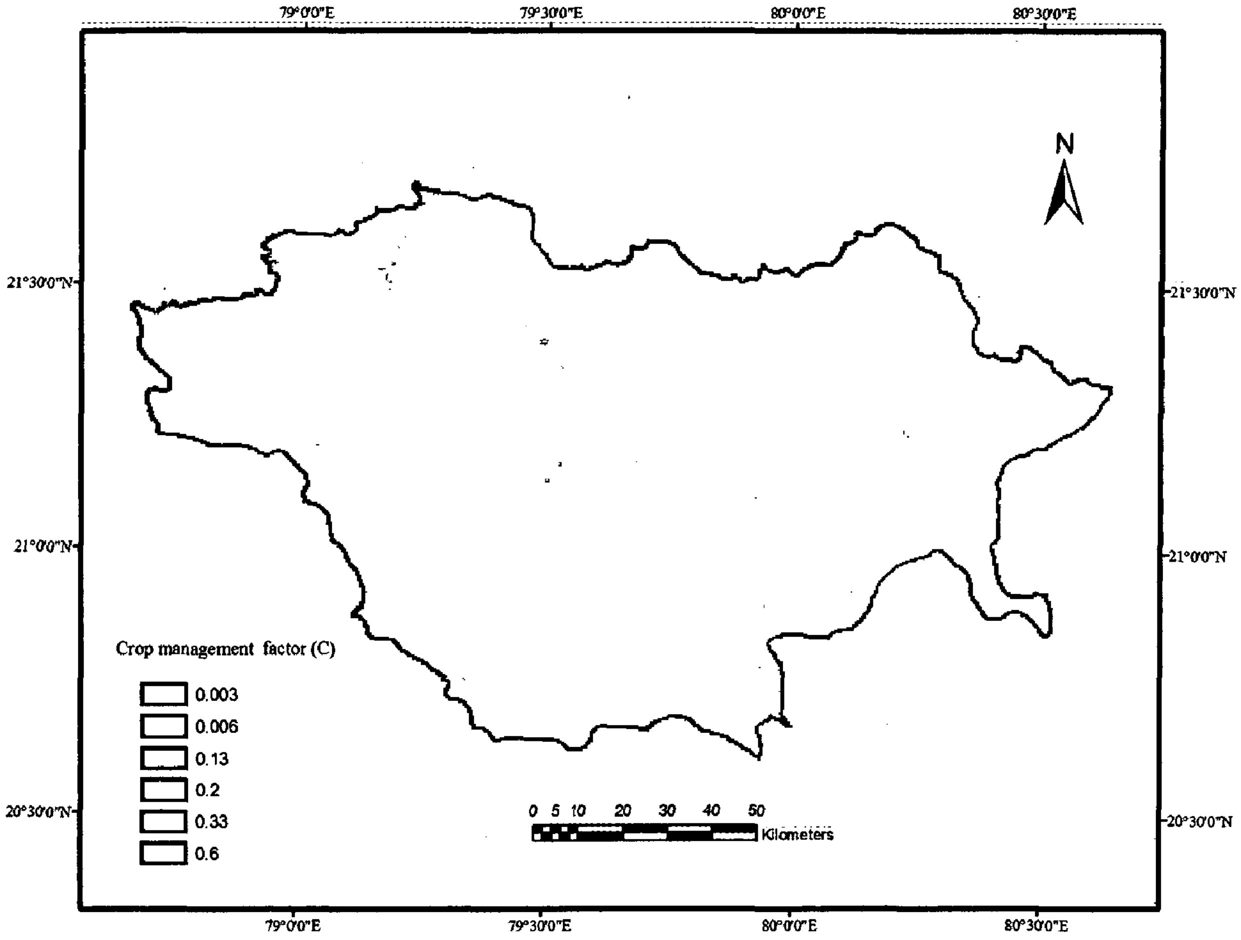

Figure 4.5- Spatial distribution of crop management factor (C) of the Wadsa-Chincholi watershed

4.3.5 Conservation practice factor (P)

The conservation practice factor (P) maps was prepared from the land use map obtained from the National Bureau of Soil Survey and Land use Planning (NBSSLUP), Nagpur. In the study area, no major conservation practices are followed except bunded agricultural lands. The Conservation practice factor (P) values for different land use conditions were obtained from previous studies (Prasad (97), Deshmukh (2007)). P values ranged from 0.9 to 1. The magnitude and the spatial distribution are given in figure 4.6.

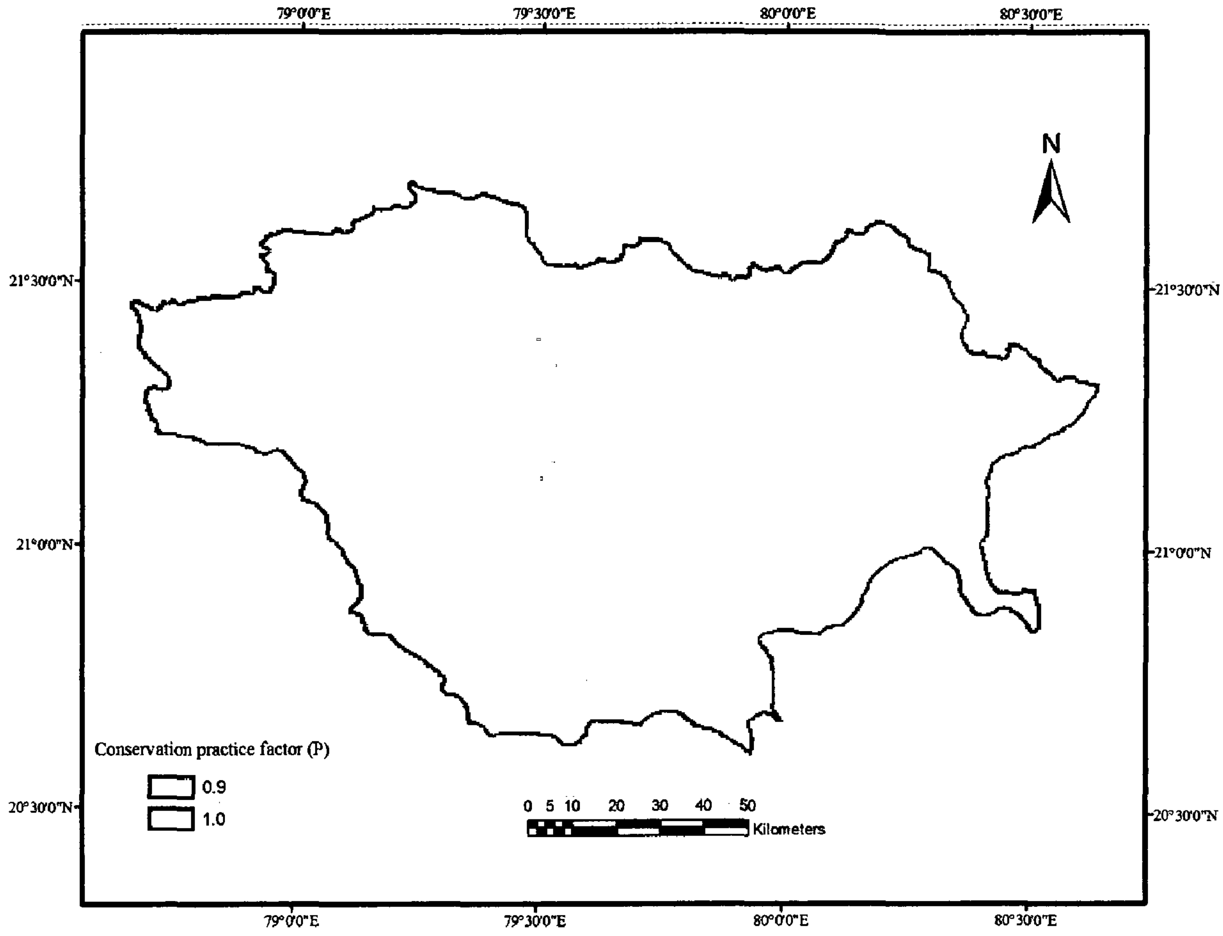

Figure 4.6- Spatial distribution of conservation practice factor (P) of the Wadsa-Chincholi watershed

4.4 Estimation of sediment yield using the USLE model for grid cell size (50 m × 50 m), (100 m × 100 m) and (200 m × 200 m)

To determine the sediment yield from the watershed, cell based USLE parameters were multiplied in the specified 50 m×50 m, 100 m×100 m and 200 m×200 m cells and the average annual sediment yield for all the years were determined and are presented in Table 4.3. Based on eight years daily rainfall data, the estimated maximum and minimum values of rainfall erosivity factors were found to be 8024.261 and 2776.091 MJ mm $ha^{-1}h^{-1}yr^{-1}$ for 2007 and 2004 respectively.

The estimated average annual sediment yield was found to be 63.80 t $ha^{-1}yr^{-1}$ for the grid size of 50 m×50 m. The analysis for the years 2000-2007 shows that the highest sediment yield was 92.97 t $ha^{-1}yr^{-1}$ in 2007, the year of highest value of R with a rainfall value of 1972.1 mm. The lowest value of sediment yield was 31.95 t $ha^{-1}yr^{-1}$ in 2004 (Table 4.3) with the lowest values of R with rainfall 1051.4 mm. It is seen from table that the annual sediment yield in different years ranges from 31.95 to 92.97 t $ha^{-1}yr^{-1}$ for 50 m × 50 m grid cells (Table 4.3).

Table 4.3 Annual sediment yield ($t.ha^{-1}.yr^{-1}$) using USLE model in different grid cell

Sl.No	Year	Annual Sediment yield (50 m × 50 m)	Annual Sediment yield (100 m × 100 m)	Annual Sediment yield (200 m × 200 m)
1	2000	58.47	17.23	3.36
2	2001	79.00	23.29	4.54
3	2002	76.66	22.55	4.39
4	2003	54.06	15.94	3.10
5	2004	31.95	9.48	1.84
6	2005	36.87	10.92	2.13
7	2006	80.69	23.85	4.65
8	2007	92.97	27.41	5.34
	Average	63.80	18.83	3.67

Similarly, cell-based USLE parameters were multiplied in specified 100 m × 100 m grid cells. The estimated average annual sediment yield was found to be 18.83 t $ha^{-1}yr^{-1}$. The analysis shows that the highest sediment yield was 27.41 t $ha^{-1}yr^{-1}$ in 2007, the year of highest value of R with a rainfall value of 1972.1 mm. The lowest value of sediment yield was 9.48 t $ha^{-1}yr^{-1}$ in 2004 (Table 4.3) with the lowest values of R with rainfall 1051.4 mm. It is seen from table 4.3 that the annual sediment yields in different years ranged from 9.48 to 27.41 t $ha^{-1}yr^{-1}$.

For the grid cell size of 200 m × 200 m the estimated average annual sediment yield was found to be 3.67 t $ha^{-1}yr^{-1}$. It is seen from the table that the annual sediment yield in different years ranges from 1.84 to 5.34 t $ha^{-1}yr^{-1}$ (Table 4.3). The analysis shows that the highest sediment yield was 5.34 t $ha^{-1}yr^{-1}$ in 2007, the year of highest value of R with a rainfall value of 1972.1 mm. The lowest value of sediment yield was 1.84 t $ha^{-1}yr^{-1}$ in 2004 (Table 4.3) with the lowest value of R with rainfall 1051.4 mm.

4.5 Comparison of estimated sediment yield from MMF and USLE models with observed sediment yield data

4.5.1 Comparison between estimated sediment yields using MMF and observed sediment yield in 100 m × 100 m grid size

It is seen from table 4.4 that the percent deviation of the estimated sediment yield from the observed values varies in the range of 81 to 299 percent. The over-prediction limits for the MMF model simulation are high from the measured values. Therefore, these results cannot be considered as the acceptable levels of accuracy for the simulations as reported by Bingner (1989). There is wide variation in the estimated sediment yield data from the observed data of the study watershed. Hence, the results of MMF model cannot be applied for sediment yield estimation from the Wadsa-Chincholi watershed.

Table 4.4 Comparison of estimated sediment yield and observed sediment yield (MMF Model)

Sl.No	Year	Observed sediment yield (t $ha^{-1}yr^{-1}$)	Estimated sediment yield (t $ha^{-1}yr^{-1}$)	Percent deviation
1	2000	3.69	9.79	165
2	2001	5.03	12.95	157
3	2002	4.65	8.43	81.29
4	2003	5.58	10.43	86.91
5	2004	2.99	8.41	181.2
6	2005	3.27	13.05	299
7	2006	5.51	10.59	92.19
8	2007	6.63	15.78	138

4.5.2 Comparison between estimated sediment yields using USLE and observed sediment yield in 50 m × 50 m grid size

It is seen from table 4.5 that the percent deviation of the estimated sediment yields from the observed values varies in the range of 868 to 1548 percent. The over-prediction limits for the USLE model simulation are very high. Therefore, these are not considered as the acceptable levels of accuracy for the simulations as reported by Bingner (1989). Hence, the results of USLE model at 50 m × 50 m grid cell size cannot be applied for sediment yield estimation from the Wadsa-Chincholi watershed.

Table 4.5 Comparison of estimated sediment yield and observed sediment yield (USLE model for 50 m × 50 m grid size)

Sl.No	Year	Observed sediment yield (t $ha^{-1}yr^{-1}$)	Estimated sediment yield (t $ha^{-1}yr^{-1}$)	Percent deviation
1	2000	3.69	58.47	1491
2	2001	5.03	79.00	1470
3	2002	4.65	76.66	1548
4	2003	5.58	54.06	868
5	2004	2.99	31.95	968
6	2005	3.27	36.87	1027
7	2006	5.51	80.69	1364
8	2007	6.63	92.97	1302

4.5.3 Comparison between estimated sediment yields using USLE and observed sediment yield in 100 m × 100 m grid size

It is seen from table 4.6 that the percent deviation of the estimated sediment yields from the observed values varies in the range of 185 to 384 percent. The over-prediction limits for the USLE model simulation are very high. Therefore, these are not considered as the acceptable levels of accuracy for the simulations as reported by Bingner (1989). Hence, the results of USLE model at 100 m × 100 m grid cell size cannot be applied for sediment yield estimation from the Wadsa-Chincholi watershed.

Table 4.6 Comparison of estimated sediment yield and observed sediment yield (USLE Model for 100 m × 100 m grid size)

Sl. No	Year	Observed sediment yield (t $ha^{-1}yr^{-1}$)	Estimated sediment yield (t $ha^{-1}yr^{-1}$)	Percent deviation
1	2000	3.69	17.23	366.9
2	2001	5.03	23.29	363
3	2002	4.65	22.55	384
4	2003	5.58	15.94	185
5	2004	2.99	9.48	217.05

6	2005	3.27	10.92	233.4
7	2006	5.51	23.85	332.8
8	2007	6.63	27.41	331.4

4.5.4 Comparison between estimated sediment yields using USLE and observed sediment yield in 200 m × 200 m grid size

It is seen from table 4.7 that the percent deviation of the estimated sediment yields from the observed values varies in the range of 5 to 44 percent. The under-prediction or over-prediction limits for the USLE model simulation are within 40 percent from the measured values, except for the year 2003. Therefore, these results are considered as the acceptable levels of accuracy for the simulations as reported by Bingner (1989). The results of the USLE model at 200 m × 200 m grid sizes were compared graphically and presented in figure 4.10. The coefficient of correlation (R^2) was found to be 0.71. This shows that the results of the USLE models for the 200 m × 200 m grid size are satisfactorily matching with the observed data. Hence, the results of USLE model at 200 m × 200 m grid size can be applied for sediment yield estimation from the Wadsa-Chincholi watershed.

Table 4.7 Comparison of estimated sediment yield and observed sediment yield (USLE Model for 200 m × 200 m grid size)

Sl.No	Year	Observed sediment yield (t $ha^{-1}yr^{-1}$)	Estimated sediment yield (t $ha^{-1}yr^{-1}$)	Percent deviation
1	2000	3.69	3.36	8.9
2	2001	5.03	4.54	9.7
3	2002	4.65	4.39	5.59
4	2003	5.58	3.10	44.4
5	2004	2.99	1.84	38.46
6	2005	3.27	2.13	34.86
7	2006	5.51	4.65	15.60
8	2007	6.63	5.34	19.45

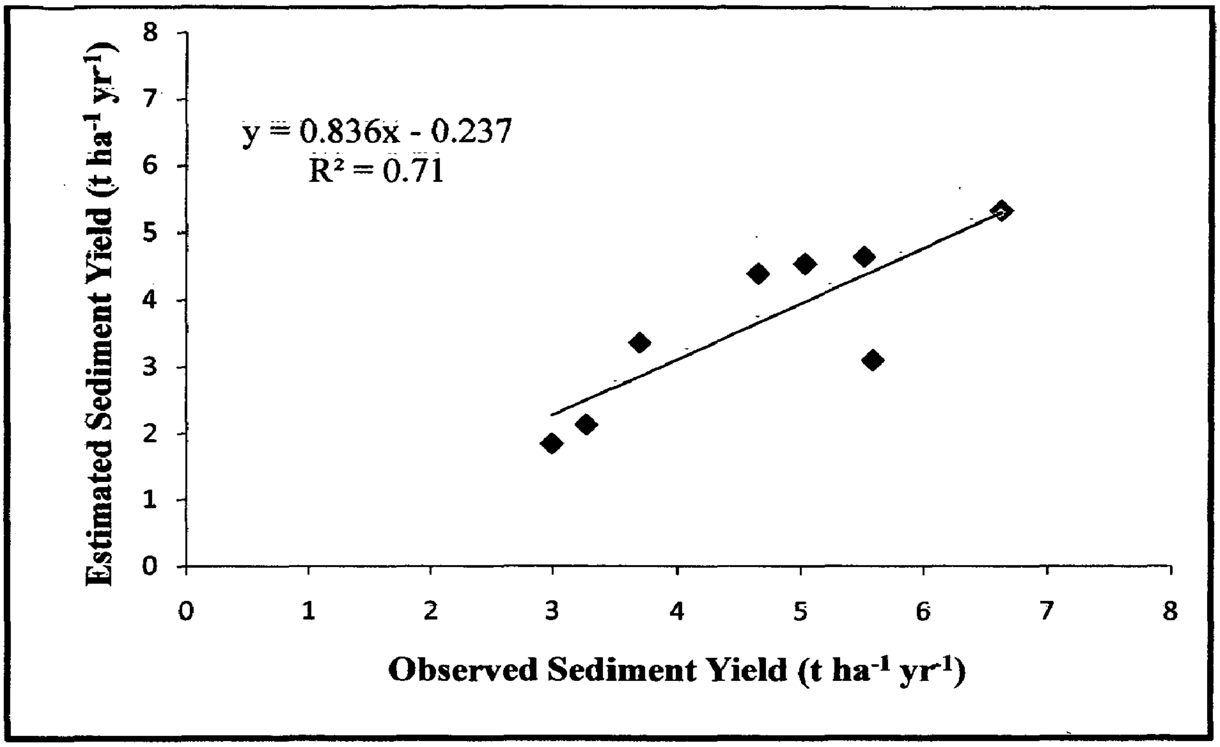

Figure 4.7- Comparison between observed and predicted sediment yields for USLE model (200 m × 200 m) grid size

4.6 Area under different class of soil erosion in the Wadsa-Chincholi watershed using USLE model for grid size of 200 m × 200 m

Areas under different classes of soil erosion in Wadsa-Chincholi watershed using USLE model for grid cell size of 200 m × 200 m is presented in table 4.8 and figure 4.8 .It is seen from table 4.8 that approximately 73.58 percent (10845.25 km^2) of the total watershed area falls under slight erosion class, 8.37 per cent (1230.25 km^2) under moderate erosion class, 2.2 percent (326 km^2) under high erosion class, 8.12 percent (1193.25 km^2) under very high erosion class, 4.23 percent (622.75 km^2) under severe erosion class and 3.46 percent (509.25 km^2) area falls under very severe erosion class (Singh, 1992). The soil loss data of the USLE model for grid cell size 200 m × 200 m shows that the area falling under Slight and moderate erosion class of the Wadsa-Chincholi watershed require immediate attention from soil conservation point of view.

Table 4.8. Areas under different classes of soil erosion in Wadsa-Chincholi watershed

Sediment yield ($t\,ha^{-1}yr^{-1}$)	Area (km^2)	Area (Percent)	Soil erosion class
0-5	10809.2	73.5	Slight
5-10	1230.25	8.3	Moderate
10-20	326.00	2.2	High
20-40	1193.25	8.1	Very high
40-80	622.75	4.2	Severe
>80	509.25	3.4	Very severe

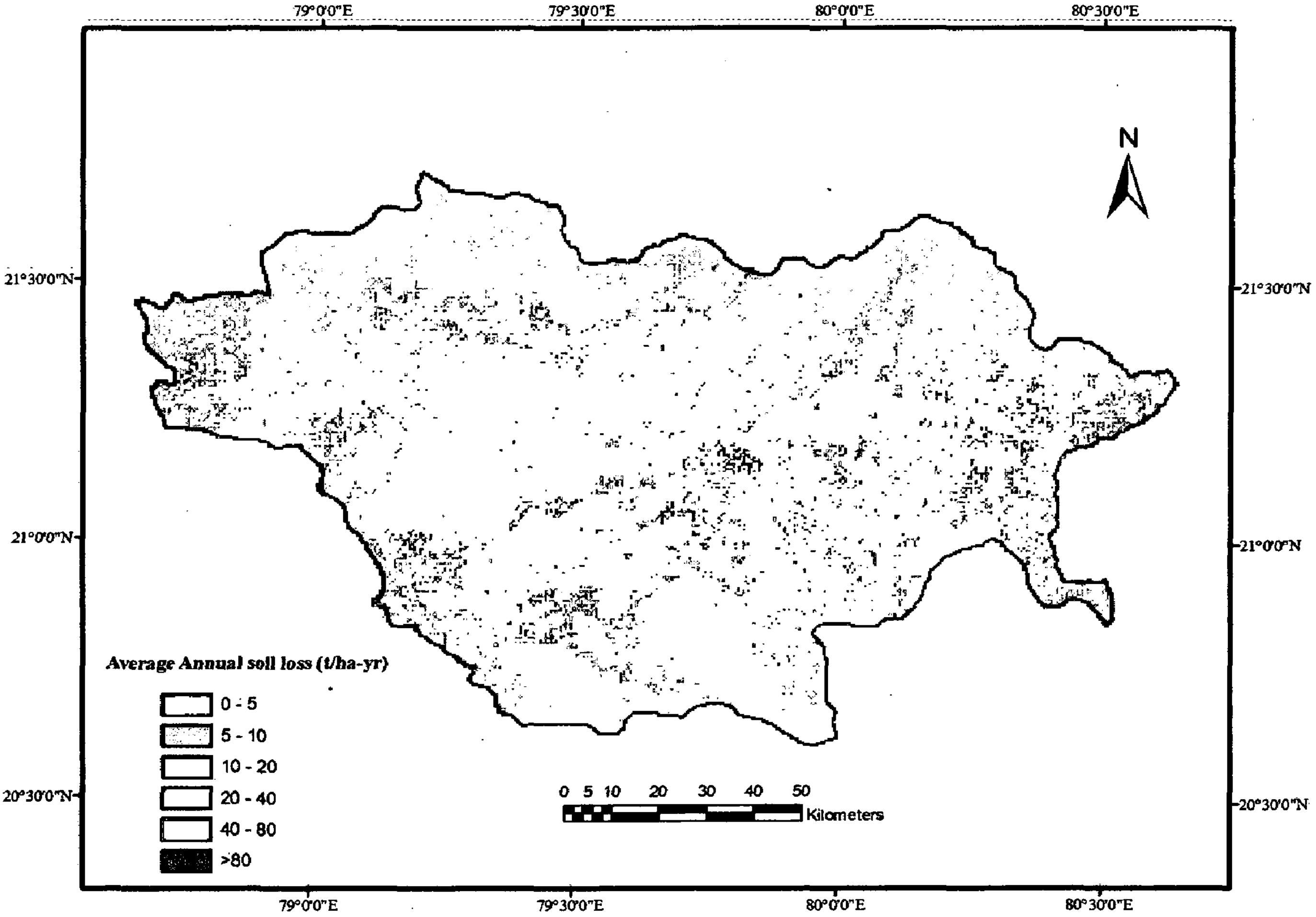

Figure 4.8. Spatial distribution of average annual soil loss of the Wadsa-Chincholi watershed

CHAPTER V
SUMMARY AND CONCLUSION

Summary and Conclusion

Soil erosion is complex phenomenon, which is governed by the nature. Soil erosion can never be stopped completely but it can be mitigated to some extent. Soil loss is the result or effect of soil erosion, which is governed by various natural processes. The Wadsa-Chincholi watershed is situated in the Bhandara , Chandrapur , Godia and Nagpur district of Maharashtra, India and is a part of the Godawari river basin. The total area of the Wadsa-Chincholi watershed is 14690.43 km^2. The annual average rainfall in the region is 1402.7 mm. The climate of the area is sub-tropical which makes the whole watershed prone to soil erosion.

The model proposed by Morgan et al. (1984) and the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) were used for estimation of sediment yield using satellite data and Geographic Information System. The DEM was used to generate slope map. Other inputs of the model closely related to the land use/land cover were successfully derived from remotely sensed data and the modeling part was carried out in GIS environment. Further, the sediment yields estimated by both the models were compared. Annual average sediment yield were estimated for the watershed.

Detailed study of the Wadsa-Chincholi watershed was planned with the following specific objectives:

1. Application of the USLE and MMF model for estimation of sediment yield using remote sensing and GIS.
2. Estimation of sediment yields of the Wadsa-Chincholi watershed on different grid sizes i.e. 50m, 100m, 200m.
3. Recommendation of optimal grid size for sediment yield estimation.

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

1. For the MMF model , the highest sediment yield was 15.78 t $ha^{-1}yr^{-1}$ in 2007, the year of highest rainfall (1972.1 mm).The lowest value of sediment yield was 8.41 $ha^{-1}yr^{-1}$ in 2004, the year of lowest rainfall when rainfall was only 1051.4 m and the estimated average annual sediment yield was 11.17 t $ha^{-1}yr^{-1}$.
2. For the USLE model with 50 m × 50 m grid size the estimated average annual sediment yield was 63.80 t $ha^{-1}yr^{-1}$.
3. For the USLE model with 100 m × 100 m grid size the estimated average annual sediment yield was 18.83 t $ha^{-1}yr^{-1}$.
4. For the USLE model with 200 m × 200 m grid size the estimated average annual sediment yield was 3.67 t $ha^{-1}yr^{-1}$.
5. The results of the USLE models for the 200 m × 200 m grid size are satisfactorily matching with the observed data (R^2=0.71). Hence, the results of USLE model at 200 m × 200 m grid size can be applied for sediment yield estimation from the Wadsa-Chincholi watershed.
6. In the Wadsa-Chincholi watershed for 200 m × 200 m grid size, 73.58 percent (10845.25 km^2) of the total watershed area falls under slight erosion class, 8.37 per cent under moderate erosion class, 2.2 percent under high erosion class, 8.12 percent under very high erosion class, 4.23 percent under severe erosion class and 3.46 percent area falls under very severe erosion class.
7. In the Wadsa-Chincholi watershed area falling under very high and sever erosion class requires immediate attention from soil conservation point of view.

REFERENCES

1. Abrol, I.P. (1990). Caring for our soil resources. Proceedings of an International Symposium on Water Erosion, Sedimentation and Resource Conservation, held at Dehradun during October, 1-9, pp 9-13.
2. Barrow, C.J. (1991). Land Degradation, Cambridge University Press.
3. Behera, P., Durga, K.H.V. and Das, K.K. (2005). Studied the soil erosion modelling using MMF model-remote sensing and GIS perspective, Journal of Indian society of remote sensing, 33(1): pp 165-176.
4. Deshpand, R.S. and Rajasekharan, N. (1995). Impact evaluation study of World Bank aided pilot project for watershed development in rainfed areas. Gokhale Institute of Politics and Economics, Pune.
5. Deshmukh, S.B., Pandey, V.K. and Jain, M.K. (2007). Integration of GIS with MUSLE in assessment of sediment yield. Indian Journal Soil Conservation 35(1): pp 1-5.
6. Dhruvanarayana, V.V. and Rambabu, P. (1983). Estimation of Soil loss in India. Journal of Irrigation and Drainage Engineering, 109(4): pp 419-433.
7. Fistikoglu, O. and Harmancioglu, N. (2002). Integration of GIS with USLE in Assessment of Soil Erosion, Kluwer Academic Publishers, Netherlands, pp 447-467.
8. Flugel, W. A., Marker, M., Moretti, S., Rodolfi, G. and Sidrochuk, A. (2003). Integrating geographical information systems, remote sensing, ground truthing and modeling approaches for regional erosion classification of semi-arid catchments in South Africa, Hydrologic Process, 17(5): pp 920-942.
9. Jain, M.K., Mishra, S.K. and Shah, R.B. (2010).Identification of sediment source and sink areas in Himalaya watershed using RS and GIS, Current Science Journal.98 (2):pp213-221.

10. Jain, S.K., Singh P. and Saraf, A.K. (2003).Estimation of sediment yield for rain, snow and glacier fed river in Western Himalaya region. Journal of Water Resource Management. 17: pp 377-397.

11. Jain, M.K. and Kothyari, U.C. (2000).Estimation of soil erosion and sediment yield using GIS. Hydrological Sciences Journal. 45 (5): pp 771-786.

12. Jain, S. K. and Goel, M. K. (2002). Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS, Hydrology Science's Journal. 47 (l): pp 31-40.

13. Jasmin, I. and Ravichandran, S. (2007). RUSLE2 Model application for Soil Erosion Assessment Using Remote Sensing and GIS. Journal of Water Resource Management, 21 (5): pp 569-585.

14. Jasrotia, A.S. and Singh, R.P. (2006). Modeling runoff and soil erosion in a catchment area, using the GIS in the Himalayan Region, India, Journal of Enviromental Geology, 32(7): pp 345-359.

15. Jose, C.S. and Das, D.C. (1982). Geomorphic prediction models for sediment production rate and intensive priorities of watershed in Mayurakshi catchment. Proceedings of the international symposium on Hydrological Aspects of Mountainous Watershed held at School of Hydrology, University of Roorkee, pp15-23.

16. Kirkby, M.J. (1976). Hydrological Slope Models the Influence of Climate in Derbyshire Geomorphology and Climate .Wiley, London, pp 247-267.

17. Kothyari, U.C. and Jain. S.K. (1997). Sediment yield estimation using GIS. Hydrology Science's Journal. 42(6): pp 833-843.

18. Kumar, S. and Sharma, S. (2005). Soil erosion risk assessment based on MMF model using remote sensing and GIS. Hydrology Journal, 28 (1-2): pp 47-58.

19. Lillesand,T.M. and Keifer , R.W. (1987). Remote sensing and image interpretation, Jon Willey and Sons, First edition.

20. Morgan, R.P.C., Morgan, D.D.V. and Finney, H.J. (1984). A Predictive model for assessment of erosion. Journal of Agricultural Engineering Research, (30): pp 245-253.

21. Pandey, A., Chowdary, V.M. and Mal, B.C. (2004). Morphological analysis and watershed management using GIS. Journal of Hydrology (India), 27(3–4): 71–84.

22. Pandey, A., Chowdary, V.M. and Mal, B.C. (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Resources Management, (21): 729- 746.

23. Pandey, V. K., Pandey, A. and Panda, S.N. (2007). Watershed management using remote sensing and GIS – a case study of Banikdih watershed (Eastern India). Asian Journal of Geoinformatics. 7 (1): 3-16.

24. Pandey, A., Choudary, V.M. and Mal, B.C. (2009b). Sediment Yield Modelling of an agricultural watershed using MUSLE, Remote Sensing and GIS, journal of Paddy Water Environmental 7:105-107.

25. Paringit, E.C. and Nadaoka, K. (2003). Sediment yield modelling for small agricultural catchments: land-cover parameterization based on Remote sensing data analysis, Hydrologic Process.17, pp 1845-1866.

26. Prasad, K.S.S., Gopi, S. and Rao, S.R. (1997). Demarcation of Priority Watersheds in Mahboob Nagar District, AP Using Remote Sensing Techniques. In Remote sensing application and GIS, recent trends, Tata Mcgraw-Hill Publishing Co Ltd., New Delhi, pp. 180– 186.

27. R.P.C.Morgan (2001). Estimate a simple approach to find soil loss estimation using revised Morgan –Morgan –Finney Model, Journal of Catena 44: pp 305-322.

28. Rosalia, R., Mark,V. and Pierre, Y. (2008). Studied grid scale effects on watershed soil erosion models. Journal of Hydrologic Engineering, 13(9):793-802.

29. Sharma, A., Tiwari, K.N. and Bhandoria, P.B.S. (2010). Effect of land use land cover change on Soil Erosion Potential in an Agricultural Watershed, Journal of Enviromental Monitoring Assement, 32(5): pp 223-231.

30. Singh, A. (1991). Management of agricultural lands for erosion control in N.E.H. region – case study (presented at National Symposium on Soil Conservation and water Management in 1980's at Dehradhun, March 12-13, 1991).

31. Singh, G., babu, R., Narain, P., Bhusan, L.S. and Abrol, I.P. (1992). Soil Erosion rates in India. Journal of Soil and water Conservation, 47 (1): pp 97-99.

32. Wischmeier, W.H. and Mannering, J.V. (1969). Relation of soil properties to its erodibility. Proceedings of American Soil Science Society, 33: pp 131-137.

33. Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses. USDA Agricultural Research Services Handbook 537. USDA, Washington, DC, pp.57.

34. Wischmeier, W.H., Johnson, C.B. and Cross, B.V. (1971). A soil erodibility nomograph from farmland and construction sites, Journal of Soil and Water Conservation, 26: pp 189-193.

35. Younis, A. (1986). Soil Conservation in Developing Countries, Western Africa Projects Department/ The World Bank, Washington, DC.

36. Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses. USDA Agricultural Research Services Handbook 537. USDA, Washington, DC, pp 57.

37. Wischmeier, W.H., Johnson, C.B. and Cross, B.V. (1971). A soil erodibility nomograph from farmland and construction sites, Journal of Soil and Water Conservation, 26: pp 189-193.