IDENTIFICATION OF CRITICAL EROSION PRONE AREAS FOR WATERSHED PRIORITIZATION USING GIS AND REMOTE SENSING

A DISSERTATION

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "IDENTIFICATION OF CRITICAL EROSION PRONE AREAS FOR WATERSHED PRIORITIZATION USING GIS AND REMOTE SENSING" in partial fulfillment of the requirement for the award of the degree of Master of Technology submitted in the Department of Hydrology of Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from July 2007 to June 2008 under the guidance of Dr. Manoj Kumar Jain.

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

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Soil erosion is a serious environmental problem as it increases level of sedimentation in the river and reservoir; reduce their storage capacity and life, causes flood due to reduction in carrying capacity of rivers and streams. To restore the productivity of the soil and prevent further reduction of storage capacity and life of reservoirs, the information on sources of sediment yield within a catchment should be given high priority for conservation of soil resources. Conservation of natural resources especially for soil and water carried out on a watershed basis are very useful for watershed management. In this context, prioritization of watershed based on different watershed components is required for any further relevant conservation measures.

The Haharo sub catchment having an area of 565 Km^2 in the Damodar-Barakar catchment of Upper Damodar Valley (UDV) area in Jharkhand State in eastern India is taken up for the present study. The catchment is selected due to availability of gauged data at multiple locations at, Sirma as (4/1), Barkagaon as (4/2), Bisrampur as (4/3) and Simratari as (4/4) within this watershed.

The major factors responsible for soil erosion include rainfall, soil type, vegetation, topographic and morphological characteristics of the basin. Surface erosion and sediment yield quantities are found to have large variability due to the spatial variation of rainfall and catchment heterogeneity. This study is, therefore, undertaken to use conventional Morphometric analysis to assess the vulnerability of watersheds with respect to time-independent factors likes soil type, topography and morphology, and to use most widely accepted empirical Universal Soil Loss Equation (USLE) with transport limiting

sediment delivery (TLSD) concept to compute soil erosion and sediment outflow in GIS environment utilizing remotely sensed data and other data for assessing the vulnerable soil erosion areas within a watershed. The ArcGIS package has been used for carrying out geographic analysis and Earth Resources Data Analysis System (ERDAS) Imagine image processor has been used for the digital analysis of the satellite data for deriving the land use land cover characteristics of the catchment.

Using morphometric analysis, four morphometric parameters i.e. bifurcation ratio, drainage density, stream frequency, texture ratio, and three basin shape parameters i.e., form factor, circularity ratio, and elongation ratio were computed. A rating procedure was adopted to assign relative weightage based on values of different morphological parameters to arrive at priority watersheds based on the arithmetic average value of all these parameter. According to morphometric analysis, among the four watersheds 4/4 is the highest priority area where conservation measure has to be taken first. Watershed 4/3 is the next highest priority watershed. Watershed 4/1 is the medium priority area and watershed 4/2 is the low priority area.

To compute soil erosion and sediment outflow in GIS using USLE with TLSD concept, the catchment was divided into smaller grid cells of 30m x30m to account for catchment heterogeneity by considering smaller grid cell as hydrologically homogeneous area. Grid thus formed was categorized as cells lying on overland areas and lying on channel areas based on channel initiation threshold in order to differentiate the processes of sediment erosion and delivery in them. GIS is used for generating representative raster layers based on rainfall erosivity, slope length/gradient, soil erodibility and conservation practices factor for estimation of spatial distribution soil erosion. Landsat TM imagery is utilised to produce a land use/cover map of the study area based on the Maximum Likelihood Classification method. This map was then, used to generate the conservation practice factor in the USLE. The empirical USLE model calculates the soil loss on each cell as a function of the rainfall – runoff erosivity and the soil erodibility factors. This is then modified with the factors of topography, cover management and the support practices. The rate of sediment transport from each of the discritized cell depends upon the transport capacity of the flowing water. The eroded sediment was routed from each cell following the defined drainage path to the catchment outlet. The concept of transport limiting sediment delivery (TLSD) was used for determination of spatial distribution of transport capacity of flow within the watershed and the total sediment yield at the watershed outlet. The Normalized Difference Vegetation Index (NDVI) is used for determination of spatial distribution of transport capacity factor used in TLSD equation. Thus the total amount of sediment coming out to the outlet is the sediment yield of the catchment.

The proposed USLE based approach was found to be mimicking sub-watershed-scaled soil losses quite realistically and logically and produces satisfactory estimates of sediment outflow from catchment with ± 40% deviation from observations thereby suggesting its immense application potential for priority area identification in the test watershed. As, in contrast to the proposed USLE based model, the morphometric analysis assigned totally reverse priorities to about 50% of the test sub watersheds and hence the morphometric analysis method of watershed prioritization techniques was adjudged inferior compared to proposed method.

Further analysis of results indicate that areas within a watersheds having high topographic factor with waste land and agricultural land and areas near first order stream produce more erosion. However, spatially computed soil removal from most of the catchment area is limited to 0-5 tons/hectare/year except to few pockets which produce more sediment yield indicating most of the areas in the catchment fall within tolerable limits of soil erosion.

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LIST OF SYMBOLS

Symbol	Description
Tc_i	Transport capacity in cell i,
K_{TC_i}	Transport capacity coefficient for cell i
Tin_i	Transport in
$Tout_i$	Transport out
$NDVI_i$	Normalized Difference Vegetation Index
β	A scaling factor transport capacity coefficient
A	Area
A_i	Upslope contributing area per unit contour length in cell i
C_i	Cover Management Factor of the i^{th} Cell.
D_d	Drainage density
$E I_{30}$	Rainfall erosion index
F_s	Stream frequency
ha	Hectare
K_i	Soil Erodibility Factor of the i^{th} Cell
L	Stream length
L_b	Basin length
L_i	Slope Length Factor of the i^{th} Cell
Mha	Million hectares
MJ mm $ha^{-1}h^{-1}$	Mega joule millimeters/ hectare/hour
MT	million tones
N	Total no of stream
$N_{(u+1)}$	Stream of order (u+1)
Nu	Stream of order u
P	Perimeter
P_i	Practice Management Factor of The i^h Cell
R	Average annual/seasonal erosion index,
R_b	Bifurcation ratio
R_c	Circularity ratio
R_e	Elongation ratio
R_f	Form factor
R_i	Rainfall Erosivity Factor of the i^{th} Cell
R_N	Average annual rainfall
SE_i	Gross Soil Erosion in i^{th} Cell
S_i	Slope Steepness Factor of the i^{th} Cell
S_i	Slope gradient in cell i
T	Drainage texture
t ha h $ha^{-1}MJ^{-1}mm^{-1}$	Tonnes hectare hour/ hectare/ mega joule millimeters
t/ha/yr	Tonnes/ hectare/year

CHAPTER 1

INTRODUCTION

Soil erosion is a serious problem though out the world. Globally, 1,964.4 Mha of land is affected by human-induced degradation (UNEP, 1997). Of this, 1,903 Mha are subject to soil erosion by water and 548.3 M ha by wind erosion. In India out of the total geographical area of 329 Mha, about 167 Mha is affected seriously by water and wind erosion. This includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, water logging, salinity and alkalinity, shifting of river courses and desertification. Land affected due to water erosion is estimated to be about 113.3 Mha (Ministry of Agriculture, 1985). In quantitative terms an estimated amount of about 5334 MT (million tones) of soil is being detached annually (Narayan and Babu, 1983). In terms of erosion rates this corresponds to about 16.75 t $ha^{-1}yr^{-1}$ (or about 1mm depth of top soil each year) against permissible range of 7.5 to 12.5 t $ha^{-1}yr^{-1}$ (DAC, 1988b). About 29% of the soil detached is carried away by the rivers into the sea and about 10% is deposited in reservoirs resulting in the considerable loss (by 1-2% annually) of the storage capacity (Narayan and Babu, 1983). Estimates also indicate that the loss of nutrients due to soil erosion ranges from 5.37 to 8.4 million tons thus involving a production loss of 30 to 40 million tons of food grain per year (DAC, 1988a).

Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, shearing or drag forces of water and wind. Detached particles are transported by flowing water and wind, and may get deposited when the transport capacity of water or wind decreases (Haan et al., 1994). However, water is probably the most important single agent causing soil erosion. Accelerated erosion due to human activities is a serious environmental problem as it increases level of sedimentation in the rivers and reservoirs, reduce their storage capacity and life, causes flood due to reduction in carrying capacity of rivers and streams.

Proper assessment of soil erosion in space and time involve:

(a) Identification of source areas of sediments: Although erosion source areas and sediment contributing areas are receiving preliminary investigation, there is a need to identify the nature of the areas, their variability, and other basin variables indicative of source areas.
(b) Determination of transportation and depositional processes: Factors controlling the initiation of soil erosion by the forces of water have been fairly well documented in literature. However, the processes associated with the transport and deposition of sediments must be viewed on a spatial basis.

Soil and water conservation are key issues in watershed management in India behind demarcating the priority watersheds. Therefore, any sediment control management or policy should be directed to those areas that are the major contributors of sediment. It is simply not efficient to apply measures on those areas that hardly contribute sediment to river channels. However, this requires a basic understanding of the spatial patterns, rates and processes of sediment transport at the watershed scale. Therefore, it becomes essential to locate those critical sediment yielding source areas within a (representative) watershed, that need priority attention to improve soil productivity and to prevent further damage from soil erosion.

Many soil erosion and sediment yield estimating methods have been designed so far for watershed prioritization ranging from simple empirical models to process oriented physically based models. Despite the development of a range of physically based soil erosion and sediment transport equations, sediment yield predictions at a watershed or regional scale are at present achieved mainly through simple empirical models. Simple methods include models based on the geomorphological parameters (e.g. Pandey et al, 2007; Mesa, 2006; Sreedevi et al., 2005; Senadeera, 2004; Biswas et al., 2002; Jain and Goel, 2002, Misra et al., 1984; Samuel and Das, 1982); methods based on Sediment Yield Index (SYI) (e.g. Kaur et al., 2004; Khan, et al., 2001; Bali and Karale, 1977); and simple empirical models like Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE) or the Revised Universal Soil Loss Equation (RUSLE) were also widely used for the estimation of surface erosion and sediment yield from the catchment area (Jain and Kothyari, 2000; Pandey et al., 2007; Yusof and Baban, 2002; Rinos et al., 2000; Jain et al., 2001, 2002; Onyando et al., 2007).

Major factors responsible for soil erosion include rainfall, soil type, and vegetation, topographic and morphological characteristics of the basin. These are found to have spatial variability. Therefore, surface erosion and sediment yield quantities are found to have large variability due to the spatial variation to rainfall and catchment heterogeneity. To account for spatial variability, watersheds can be divided either into grids or sub-areas having approximately homogeneous characteristics and rainfall distribution (Jain and Kothyari, 2000). A recent and emerging technology known as Geographic Information System (GIS) can be used to efficiently manage spatially discretized data such as topography, soil, land use/ land cover etc, for sediment yield modeling and for quantification of heterogeneity in the topographic and drainage feature of a catchment (Shamsi, 1996). Where there is a lack of data on rainfall and sediment yield, the relative vulnerability of watersheds can be assessed with respect to time-independent factors like soil type, topography and morphology (Jain and Goel, 2002).

This study is, therefore, undertaken to use conventional Morphometric analysis of the watershed for its ability to assess vulnerability of watersheds with respect to time-independent factors likes soil type, topography and morphology, and to use most widely accepted empirical Universal Soil Loss Equation (USLE) to compute soil erosion and sediment outflow in GIS environment utilizing remotely sensed data and other data to assess the vulnerable areas to soil erosion in the watershed.

1.1 Objectives

Broad objective of this study is to identify the critical erosion producing source areas within the study watershed for effective implementation of watershed development programme. Specific objectives include:

1. Preparation of geo-database in GIS environment.
2. Calculation of various morphometric parameters of the watersheds within the sub catchments.
3. Identification of critical erosion prone watershed areas on the basis of morphometric analysis.
4. Quantification of soil erosion and sediment yield in spatial domain using USLE and transport limiting sediment delivery concept (TLSD).
5. Identification of critical erosion prone watershed areas based on soil erosion result by USLE model and TLSD concept.
6. Prioritization for source areas/ watersheds based on soil erosion severity.

CHAPTER 2

REVIEW OF LITERATURE

Enormous amount of literature is available on the topic of sediment yield from the catchments. Although different aspects of catchment erosion and sediment yield have been studied from time to time, large difference still exist between the observed and predicted sediment yield by different models currently in use for this purpose. This emphasizes the need for better approach for more realistic prediction of sediment yield.

Models available in literature to compute soil erosion and sediment outflow ranges from, simple empirical models to process oriented physically based models. Physical process based prediction models for soil erosion combine the laws of conservation of mass of sediment and water. Hydrological processes (such as infiltration, overland flow routing, rill, and interrill erosion) are defined in mathematical forms. The physically based process oriented models are expected to provide realistic estimates of soil erosion and sediment outflow, their practical utility is still limited to small experimental watersheds where extensive data is available to calibrate such models. Therefore for practical use on large watersheds or regional scale where only limited data is available, simple models based on morphometric parameters and empirical models are still being used to predict soil erosion and sediment outflow and the same are being reviewed in the following text.

2.1 Review of studies based on morphological analysis

Critically eroding sub watersheds in the river valley projects (RVP) catchments of India were identified by All India soil and land use survey (AISLUS) based on Silt Yield Index (SYI) method. Based on physiographic factors such as area, slope, soil characteristics like soil class, depth, texture and colour; surface cover condition and land use of a sub watershed, a numerical value was assigned to the each sub watershed with in a watershed. The Silt Yield Index (SYI) is finally computed by using the following empirical equation.

$$SYI = \frac{\sum Ai * Wei * Dr}{Aw} \tag{2.1}$$

Where A_i is the area of the sub watershed W_{ei} is the weightage value the sub watershed, Dr is the delivery ratio and Aw is the total area of the watershed.

The delivery ratio is decided on the basis of information on nature of soil, distance of the watershed from the reservoir, proximity to active stream, relief length ratio and drainage density, slope gradient, surface cover conditions and existing lakes, ponds and silt traps in the watershed. Due to non-utilization of hydrologic parameters like rainfall, runoff etc., this methodology has its own limitations of quantifying absolute sediment production rate from the catchment.

Pandey et al., (2007) used ArcGIS for prioritization and development of integrated watershed management plan for Dirkong river basin of Arunachal Pradesh, India using morphometric parameters. The DSS for integrated watershed management plan was developed by using land use, soil type etc. and concluded that morphometric parameters are useful for prioritization studies especially in ungauged watershed.

Rao et al., (2006) selected a minor watershed located in the hilly terrain of Eastern Ghats Mobile Belt (EGMB) region of Visakhapatnam District of Andhra Pradesh, with a reservoir called Ghambhiram for study. It is characterized by khondalite suite of rocks. Thematic information has been generated on the drainage pattern of the river, geological setting, and geomorphological evolution of landforms, lineament/structural trend and landuse/landcover. In this study, the Silt Yield Index (SYI) technique was used to assess the effects of silt on the storage capacity of the reservoir. The study area was divided into micro watersheds on the basis of drainage conditions. The micro watersheds adjacent to the reservoir have rolling topography with moderate slopes contributing more silt to the reservoir. Sheet, gully and stream erosions are responsible for the reduction of the storage capacity of the reservoir to around 40% of its designed capacity. Mitigation measures like check-dam, afforestation and concrete slab have been suggested to arrest silt deposition.

Sreedevi et al., (2005) used morphometric analysis to understand the topography, erosion status, drainage pattern and the drainage characteristics of Pageru River basin a chronically drought prone area of the Rayalaseema region, Cuddapah district, Andhra Pradesh, India. The importance of such analyses is emphasized in the utilisation of its results, for locating sites for artificial recharge. The quantitative analysis of various aspects of river basin drainage network characteristics reveals complex morphometric attributes. The streams of lower orders mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall. For this area the following remarks are attributed: Mostly all streams originate from basic intrusives and quartzite hilly terrains. It is noticed that the 4th, 5th

and 6th order stream segments occur in comparatively flat lands, these are important locations for constructing check dams.

Singh et al.,(2005) studied the soil loss using MMF model, remote sensing and GIS; morphometric analysis using GIS; prioritization of sub watersheds based on estimated soil loss and morphometric indices; and suggesting suitable soil conservation measures of the watershed for the Maskara Rao river watershed situated in parts of Saharanpur district, Uttar Pradesh and Haridwar district, Uttrakhand, India. Morphometric indices were determined and rating has been done based on every single morphometric parameter value, the rating values for every sub-watershed are averaged to arrive at a compound value. Based on average value of these parameters, the sub-watershed priority of the sub-watershed was done. The final priority of sub-watersheds based on soil loss estimation and morphometric indices is compared.

Senadeera et al., (2004) carried out the study of Morphmetric Characteristics of Kotmale Reservoir catchment of Sri Lanka using a GIS. Methods of Horton and Strahler ordering were used to rank the stream segments using GIS. The relevant numbers of the streams and all other morphometric analyses has been done based on the mathematical formulas. It shows the effectiveness to analyze the morphometric features of the catchment using GIS. Size, shape, slope of the catchment & distribution of stream network within the catchment indicated the catchment characteristics. This is useful to conserve reservoirs and apply proper catchment management practices.

Kaur et al., (2004) compare the watershed prioritization capabilities of a physical model based spatial decision support system (SDSS) with the SYI and RPI model based subjective-SDSS, conventionally devised for prioritization of watersheds, by

All India Soil Survey and Land Use Planning Division of Ministry of Agriculture, Government of India on a watershed situated in Damodar-Barakar catchment in India, the second most seriously eroded area in the world. They found physical model based SDSS capable of realistically and logically mimicking the sub-watershed-scaled water and soil losses thereby suggesting its immense application potential for priority area identification within the test watershed. The study further reveals that the SYI and RPI approach is incapable of realistically assessing the impact of topography, varied land use and soil types in the test watershed on their sub watershed scaled run-off and soil loss generating potential resulting assignment of reverse priority to about 70% of the watershed area.

Biswas et al., (2002) divided the Murli sub watershed in the Subarnarekha Basin of the Nayagram block in the Midnapore district of West Bengal State in eastern India into 44 micro watersheds with areas less than 10 km^2, which were prioritized based on morphometric parameters. Morphometric indices are determined after the rating has been done based on every single morphometric parameter, the rating values for every sub-watershed are averaged to arrive at a compound value. Based on average value of these parameters, the prioritization of different sub-watersheds was done. Accordingly, suitable soil conservation measures were suggested. They conclude that the present approach of morphometric analysis can be of immense use in prioritizing micro watersheds, and it is time saving.

Jain and Goel, (2002) studied an index-based approach, based on the surface factors mainly responsible for soil erosion at the upstream of the Ukai Reservoir located on the River Tapi in Gujarat State, India. These factors include soil type, vegetation, slope and various catchment properties such as drainage density, form factor, etc.

They found that higher the drainage density favourable for higher erosion from the catchment. A higher circulatory ratio and a higher elongation ratio induce lesser erosion.

In watershed prioritization study by Khan, et al., (2001), Guhiya catchment of Rajasthan in India having area of 1614 sq. km was taken as study area. The priority watershed concept study was made involving (1) consideration of natural resources such as landform, storage, drainage morphometry, present land-use/land-cover using topographical sheets at 1:50,000 scale, satellite data at 1:250,000 and field survey and their thematic mapping; (2) delineation of watersheds using same data source; (3) mapping and assessment of erosion intensity units (EIU) using Geographical Information System (GIS) procedures, and (4) estimation of sediment yield index (SYI). The landform units were identified and mapped as erosion intensity units as landforms are the immediate surfaces which are exposed to various agents of erosion etc. These erosion intensity units were evaluated with respect to surface characteristics, soil depth and texture, land slope, present land use, vegetation and drainage density to assess their susceptibility towards erosion as per recommendations made by All India Soil and Land Use Survey. An area weighting value for each EIU and sediment yield index of the watersheds were calculated using standard formulae. Based on the sediment yield index (SYI) values, watersheds were grouped into very high, high, moderate and low priority categories. The very high priority watersheds have higher erosive values due to their location in the hilly terrain with undulating topography and nearer to the reservoir, therefore have better delivery ratio value considering the fluvial nature of hazards and need immediate attention.

Shrestha et al., (1997), has done prioritization of watershed on the basis of soil degradation status of various watershed using simple methods. They used remotely sensed land use land cover classification data, aspect, slope gradient, drainage density, soil type data together with socio economic data and then fixed weightage to each parameters on attribute table in GIS for a watershed in western Nepal. Then final soil erosion map was developed by overlaying such thematic map layers for each parameter using the eq.

$$SES = \frac{LEA*10 + MEA*20 + HEA*30}{TotalArea} \tag{2.2}$$

Where, SES= soil erosion status of the sub watershed, LEA= low erosion area, MEA medium erosion area, and, HEA= high erosion area. This was then used to prepare soil erosion status map and prioritization of watershed.

Jose (1988) develops a model for predicting sediment production rate of watershed by combining rainfall, length width ratio, bifurcation ratio, weighted slope and percents of area covered. It was evident from the analysis that the sediment production rate is inversely proportional to variables like length of main stream, length width ratio, compactness coefficient and rotundity factor. Bifurcation ratio, drainage area and weighted average slope of watershed have positive direct influence on sediment production rate.

Mishra et al., (1984) studied the effect of different topographical characteristics such as area, drainage density, form factor, etc. on the sediment production rate of the sub watersheds in the upper Damodar Valley in eastern India, and concluded that the increase of the form factor reduces the sediment production rate.

Morisawa, (1958) observed that the shape parameters show a negative correlation with the runoff-rainfall ratio while analyzing the effect of different shape parameters on runoff-rainfall ratios in the United States.

Studies reported by Nautiyal (1994); Chaudhary and Sharma (1998) have found a relationship between cumulative stream length and stream order, and bifurcation ratio, drainage density, texture ratio, and relief ratio for assessing the level of soil erosion.

An urban land-use suitability analysis with the help of GIS in ''Prioritization of land for urban development.' was carried out by the Space Applications Center of the Indian Space Research Organization (ISRO), Ahmedabad, located in the western Indian state of Gujarat (Space 1993). Lole (1992) used GIS for district planning based on soil and water conservation plan based on the sediment yield index and socioeconomic criteria for the Panchmahal district within the same state of Gujarat.

Ojavsi et al., (1994) also evaluated several morphological parameters for priority fixation of Kohali river basin in Tripura. Ghosh et al.,(2004) developed a GIS customize package for characterization of drainage and shape parameters of watershed using ARC/INFO GIS, involves computation of morphometric parameters, which were further used for prioritization of watersheds. For assessing soil erosion from the watersheds, several empirical models based on the geo-morphological parameters were developed in the past to quantify the sediment yield (Jose and Das, 1982). Several other methods such as Sediment Yield Index (SYI) method was proposed by Bali and Karale (1977).

2.2 Review of studies on USLE based models

The Universal Soil Loss Equation is an erosion model which computes longtime average soil losses from sheet and rill erosion from specific field areas in specified cropping and management system, but it does not predict deposition, and does not compute sediment yields from gully, stream bank, and steam bed erosion. It is an empirical equation derived from more than 10,000 plot-years of data collected on natural runoff plots and an estimated equivalent of 2,000 plot-years of data from rainfall simulators. USLE can be expressed as (Wischmeier and Smith, 1978)

$$A = R\,K\,L\,S\,C\,P \tag{2.3}$$

A is the computed soil loss (tons/ha/year), R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover-management factor, P is the supporting practices factor. There are some limitations in USLE. The equation is empirical one and does not mathematically represent the actual erosion process. The equation was developed to predict loss soil loss on an average annual basis. Hence unusual rainfall seasons especially higher than normal may produce more sediments than estimated. Williams, (1975) Modified universal soil loss equation to predict storm event sediment yield rather than annual sediment yield. The rainfall energy factor of the USLE was replaced by runoff energy factor derived as a product of storm runoff volume and peak runoff rate for an individual storm thus eliminates the need for sediment delivery ratio. The USLE was further revised (RUSLE) in a new Agriculture Handbook (No. 703) which describes RUSLE in great detail was published in 1997 by the U.S. Department of Agriculture (USDA, 1979). It retains the same six factors of USLE

(A= R * K * LS * C * P) but the technology has been changed for evaluating this factor. Thus soil loss evaluation can be made for conditions not included in the USLE. Several studies are available where USLE is used for calculating gross erosion from watersheds. Some of them are reviewed in the following paragraph.

Pandey et al., (2007) used USLE to predict the spatial distribution of the sediment yield on grid basis. A Geographic Information System (GIS) was used to generate, manipulate and spatially organize input data. The deviations of estimated sediment yield from the observed values were found in the range of 1.37 to 13.85 percent indicating reliable estimation of sediment yield from the watershed.

Singh and Phadke, (2006) used USLE to predict soil erosion from a catchment area of Jamni River, a tributary of the Betwa, spread over parts of Uttar Pradesh (UP), and Madhya Pradesh (MP) in Bundelkhand region. GIS Software was used as a platform for spatial data analysis required in the USLE. The potential soil loss has been estimated and mapped. Maps covering each parameter were integrated to generate a composite map of erosion intensity based on advanced GIS functionality. They found that high erosion intensity area was under steep slopes.

Yusof and Baban (2002) developed a soil erosion risk map for Langkawi Island, Malaysia using the Universal Soil Loss Equation (USLE), remote sensing and GIS. GIS method was used for generating representative raster layers based on rainfall erosivity, slope length/gradient, soil erodibility and conservation practices factor for estimation of spatial distribution soil erosion. Landsat TM imagery was utilised to produce a land use/land cover map of the Island based on the Maximum Likelihood Classification method. This map was then, used to generate the conservation practice factor in the USLE. The analysis was performed using IDRISI, a raster based GIS software. The produced erosion map showed significant similarities with an erosion risk map of the Island produced by conventional means. The majority of high erosion risk areas seem to be confined to the highlands. This study demonstrates the effectiveness of remote sensing and GIS in generating soil risk maps.

Jain et al., (2001) used two different soil erosion models, i.e. the Morgan-Morgan-Finney (MMF) model and Universal Soil Loss Equation (USLE) model to estimate soil erosion from a Himalayan watershed. Parameters required for both models were generated using remote sensing and ancillary data in GIS platform. It was found that the soil erosion estimated by USLE gives a higher prediction where as the Morgan model gives fairly good results for area located in hilly terrain.

Rinos et al., (2000) studied erosion status in the Bata river basin, a tributary of Yamuna river using MUSLE. They used IRS-1D LISS III and 1D Pan data to prepared the land use/land cover map of the Bata river basin to generate C factor map. Digital Elevation Model (DEM) of Bata river basin was created by digitizing contour lines and spot heights from the SOI topographic maps at 1:50,000 scale. The modified LS factor map was generated from the slope and aspect map derived from the DEM. The K factor map was prepared from the soil map, the P and C factor values were chosen based on the research findings of Central Soil and Water Conservation Research and Training Institute, Dehradun. Maps covering each parameter (R, K, LS, C and P) were integrated to generate a composite map of erosion intensity based on the advanced GIS functionality. This erosion intensity map was classified into different priority classes. Study area was subdivided into sub watersheds to identify the priority areas in terms of soil erosion intensity. Each sub watershed was analyzed individually in terms of soil type, average slope, drainage length, drainage density, drainage order, height difference, landuse/land cover and soil erosion to find out the dominant factor leads to higher erosion. They found that barren lands were the most contributor of soil erosion.

Most of the studies reviewed above compute soil erosion only, however, not all the soil eroded find its way to catchment outlet in the form of sediment outflow. Several studies have been conducted wherein such phenomenon have been incorporated by using the concept of sediment transport capacity.

2.3 Sediment transport capacity of flow

Sediment transport capacity of overland flow is the maximum flux of sediment that flow is capable to transport. Sediment transport is an important process in catchment soil erosion as it determines the amount of soil removed. Water can transport sediment in the form of bed load and suspended load. Water flow is also often subdivided in overland flow and channel flow (or stream flow), which is a distinction that is relevant to sediment transport as well. There are several differences between stream flow and overland flow. Overland flow is much shallower. Shallow flow exhibits undulation, so that flow conditions are changing continuously (Alonso et al., 1981; Singh, 1997). Overland flow is much more influenced by surface roughness and raindrop impact (Alonso et al., 1981; Singh, 1997; Abrahams et al., 2001). Saltation and even suspension might be limited in overland flow because of the small flow depth, so that bed load transport is likely to be the dominant mode of transport (Julien and Simons, 1985; Singh, 1997). In upland areas soil surfaces are usually more cohesive than in alluvial channels (Singh, 1997). Overland flow is often laminar, while streamflow is usually turbulent (Julien and Simons, 1985). Slopes are usually much steeper in the case of overland flow than in the case of stream flow (e.g.

Govers, 1992). Most of the physically based soil erosion models contain a sediment transport equation. Many of the existing models use either a bed load or a total load formula originally developed for rivers. Other soil erosion models use simple empirical formulas.

Rudi Hessel et al., (2007) evaluated the suitability of a number of transport equations for use in erosion modeling under very steep terrain such as the gully catchments of the Chinese Loess Plateau. Vlassios, (2005) presented three mathematical models for the estimate of sediment yield, due to soil and stream erosion, at the outlet of a basin. The sediment transport sub model for streams aims to estimate the sediment yield at the outlet of a sub-basin. This was then compared with the available sediment amount in the main stream of a sub-basin with the sediment transport capacity by stream flow.

Hafzullah and Kavvas (2005) reviewed the existing erosion and sediment transport models developed at hillslope and watershed scales. Alonso et al., (1981), after comparison of nine sediment transport formulas, suggested to use Yalin's (1963) equation for computing the sediment transport capacity for overland flow. Nearing et al. (1989) used a simplified function of the hydraulic shear stress acting on the soil for calculating the sediment transport capacity of flow.

A general relationship between variables that affect the sediment transport capacity was developed by Julien and Simons (1985) as

$$q_s = \alpha S^{\beta} q^{\gamma} r^{\delta} \left(1 - \frac{\tau_c}{\tau}\right)^{\varepsilon} \tag{2.4}$$

Where q_s is sediment discharge, S slope, q discharge, r rainfall intensity, τ_c critical shear stress, τ actual shear stress, α a coefficient and β, γ, δ, ε exponents to be determined from laboratory or field experiments. When τ_c remains very small compared to τ then the sediment transport capacity is

$$q_s = \alpha S^{\beta} q^{\gamma} r^{\delta} \tag{2.5}$$

In case of turbulent flow in deep channels it is not a function of rainfall and therefore $\delta = 0$, then Equation reduces to

$$q_s = \alpha S^{\beta} q^{\gamma} \tag{2.6}$$

The numerical value of the coefficient β varies from 1.2 to 1.9 and γ, varies from 1.4 to 2.4. When S > 0.05 an equivalent slope exponent value near 1.7 while discharge exponent 1.5 is an approximate value. Prosser and Rustomji (2000) addressed the same equation for the sediment transport capacity. The Kilinc and Richardson (1973) equation was developed for the estimation of sheet and rill erosion from bare soils.

The transport capacity equation given by Kirkby (1985) was used by Kandrika and Venkataratnam (1998) as it accounts for surface cover variations.

$$T = Q^{d} * C * \sin(S) * 10^{-6} * A \tag{2.7}$$

Where, T = Transport capacity of the flow (tons); Q = Runoff (mm); C = Cover factor (dimensionless); S = Slope of the land element (%); A = Area of the cell (m^2): d is an exponent.

Verstraeten, et al., (2007) used the following equation for calculating sediment transport capacity of flow for its simplicity.

$$T_C = K_{tc} * R * K * A^{1.4} * S^{1.4} \tag{2.8}$$

Whereby k_{tc} reflects the vegetation component within the transport capacity, however the same was assumed constant by the authors for entire watershed area, A is the contributing area per unit of contour length ($m^2\ m^{-1}$). S is the local slope gradient (m m^{-1}). R and K are the factor of the RUSLE. The above Eq. assumes that in areas with higher rainfall erosivity (mostly due to higher rainfall intensity), runoff coefficient and discharge will also be higher resulting in a higher transport capacity.

2.4 Watershed Prioritization

The rapidly increasing population and the consequent loss of forest and the intense agricultural land use in the slopes has resulted in degrading watershed by reducing the top soil nutrients through rain water erosion, reduces the life span of storage structure resulting floods as well as damage of properties and life in most of the countries of the world, specially developing country like India. Since it is not possible to launch watershed management projects all over the country at the same time as resource constraints, administrative constraints or even political constraints may limit the implementation of watershed managements programs initially to few locations only. It is very important to use some method to prioritize watershed on the basis of soil degradation status of various watershed. Watershed prioritization is thus ranking of watershed, the order in which they have to be selected for treatment according to critical erosion producing source areas.

2.5 Watershed prioritization using lumped model and sediment delivery/ sediment transport capacity concept

Bartholic et al., (1995). integrates GIS, LANDSAT imagery and AGNPS to estimate the loading potential of agricultural nonpoint sources and to evaluate the impact of agricultural runoff on water quality in the Cass River watershed, a large sub-watershed of Saginaw Bay. The Agricultural Nonpoint Source Pollution Model (AGNPS) was used to estimate soil erosion potential by water and the amounts, origin and distribution of sediment, nitrogen (N), and phosphorus (P) in the watershed. The project was designed to evaluate the conditions within the watershed and implement a methodology by quantifying the physical characteristics in terms of land use/land cover, hydrography, soil characteristics, and topographic characteristics (land surface and shape), utilizing the Universal Soil Loss Equation (USLE) as a screening tool for ranking counties and sub-watersheds erosion potential and sediment delivery and determining an overall unit area calculation which represents greatest erosion potential or sediment delivery areas. The results suggest that the total nitrogen and phosphorus runoff was higher in agricultural land.

Kandrika and Venkataratnam, (2000) conducted a study in three sub-watersheds to model the spatial distribution of runoff and sediment yield. The basic structure of the model includes generation of runoff using SCS curve number (CN) method and soil detachment by RUSLE, MUSS and MUST equations, which is in turn delimited by Kirkby's transport capacity equation. The input parameter i.e. cover, practice and soil erodibility grids were generated from satellite data with adequate field check. Routing of runoff and sediment was done in ARC/INFO's GRID module. Predicted results were validated with field-measured values. Results show that the runoff from CN method was better estimated after accounting for depression storage. Results from two hilly watersheds showed that the standard error of sediment yield prediction of RUSLE < MUSS < MUST equations. In a relatively flat watershed, sediment yields were underestimated, due to underestimation of transport capacity.

Jain& Kothiyari (2000) proposed and demonstrated a GIS based approach for the identification of sediment source areas and the prediction of storm sediment yield of the Nagwa and Kasro catchment in Bihar (India).The catchment was divided into overland cell and channel cell grid to simulate a catchment as it exists in nature by ILWIS GIS package. The cell size is selected as small as to represent a hydrologically homogeneous area. Grid cell drainage directions and catchment boundaries were generated by forming DEM using pour point model. The land cover and soil characteristics were determined by ERDAS imagine image processing software. The concept of sediment delivery ratio (SDR) was used for determination of the total sediment yield of each catchment during isolated storm events. The watershed prioritization (as low, medium, high and very high priority area) was done by overlaying the map layer of cell based soil erosion estimated by using USLE and sediment delivery map layers in ILWIS. Reasonable results were obtained for storm sediment yields on the study area by using proposed method. The prediction accuracy of the proposed methodology can be rated as satisfactory.

Kothyari et al., (2002) proposed a GIS-based method for computation of temporal variation of sediment yield during isolated storm events from three catchments of Indian. Estimation of the temporal variation of sediment yield is required in river morphological studies, the design of efficient erosion control structures and also for estimation of concentration and load of chemicals adsorbed to sediment particles. The USLE was adopted for estimation of gross erosion rates in the different cells of a catchment. The eroded sediment was routed from each cell to the catchment outlet using the concept of the sediment delivery ratio. The Integrated Land and Water Information System (ILWIS) GIS package was used for catchment discretization, evaluation of the spatial variation in catchment topographical characteristics and land use and presentation of the results. Unit sediment graphs for the catchments were derived by translation of the sediment yield from the grid cells and routing through a linear storage reservoir. The proposed method was found to provide satisfactory estimates of the temporal variation of sediment yield during isolated storm events. The total sediment yield of a storm event can be computed using the proposed method.

Simon et al., (2005) studied on the effect of topographic variability on grid-based empirical estimation of soil erosion and sediment transport with raster geographic information systems (GIS). An original digital elevation model (DEM) of 10 m resolution for a case watershed was resampled to six realizations of greater grid sizes for a comparative examination. The Universal Soil Loss Equation (USLE) and a distance-based sediment delivery equation were applied to the watershed to calculate soil loss from each cell and total sediment transport to streams, respectively. The results suggested that the selection of the DEM gird size has considerable influence on the soil loss estimation with the empirical models. The estimate of total soil loss from the watershed was decreased significantly with the increase of DEM cell size as the spatial variability is reduced by the cell aggregation. It was concluded that empirical modeling approach is a useful tool for qualitative assessment of soil erosion, provided that spatial variability can be adequately represented by applied DEM.

Rompaey et al., (2005) calibrated and validated the spatially distributed sediment delivery model WaTEM/SEDEM for sediment yield observations, derived from 40 long-term sedimentation records of semi-natural catchments in northern Italy as well as agricultural and semi natural basins in central and southern Italy. WaTEM/SEDEM along with the concept of detachment-limited or transport-limited local transport capacity was used to estimates mean annual sediment fluxes to permanent river channels. The global model calibration procedure taking into account all catchments in the dataset led to an overestimation of the sediment yield for the mountain catchments and an underestimation for the non-mountain catchments. Sediment yield estimates shows more reliability when calibration procedures are applied separately for mountain and non-mountain catchments. The performance of model for the non-mountain catchments was significantly better.

Verstraeten et al., (2006) used spatially distributed soil erosion and sediment delivery model (WATEM/SEDEM) that takes into account contribution from gully erosion was calibrated from long-term Sediment yield data in 26 small farm dams in SE Australia. Spatially distributed soil erosion was first calculated using an adapted version of the RUSLE and sediment yield was calculated along the runoff pattern towards the river, taking into account the gross sediment erosion and local transport capacity (T_C) of each pixel. The calibrated and best performing model was applied to the regional-scale river basin: the Murrumbidgee River drainage basin of Australia. The spatial patterns of suspended sediment delivery in the Murrumbidgee indicated over prediction due to part of this amount incorporated by gully erosion.

Onyando et al (2007) uses USLE in conjunction with ILWIS to estimate potential soil loss from River Perkerra catchment in Kenya. Various physical parameters of the equation were derived by analyzing spatial data and processing of Landsat TM satellite imagery of the catchment. The sediment delivery ratio derived using an empirical equation was 0.83 and it indicates that a higher proportion of sediment generated in the catchment is delivered at the outlet. The use of GIS enabled the results of erosion potential in identifying priority areas that require urgent management interventions in controlling soil erosion.

2.6 Summary

The review of literature revealed that watershed prioritization for conservation planning is being done based on quantitative assessment of soil loss using the well-known USLE and qualitatively based on conventional Morphometric analysis. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the USLE parameters. Attempt was made to utilize remote sensing data for generating land use/land cover data which are essential prerequisites for generation of USLE factors. Thus, remote sensing and GIS played a significant role in generating parameters for remote areas of watersheds/river basins for sediment yield modeling and watershed management. The strength of GIS lies in its ability to handle spatial data and attribute information at a higher level of resolution. High-quality output, easy updating capabilities, and the possibility for testing management options make GIS particularly useful for providing information for decision-makers. GIS and RS were used in developing management scenarios and provide options to policy makers for handling soil erosion problem in the most efficient manner by prioritization of watershed areas for treatment. From the review transport capacity of overland flow, equation used by Verstraeten et al., (2007) was found simple and applicable in GIS environment. However use of constant value of landuse dependent transport capacity coefficient is probably a weak assumption and identified for further investigations.

CHAPTER 3

METHODOLOGY

In the present study, prioritization of different areas according to soil erosion severity in a watershed is attempted using methods based on morphometric analysis and USLE based spatially distributed approach. The details of methods used are presented in following text.

3.1 Watershed prioritization based on morphometric analysis of the catchment

To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage patterns of the region. Development of morphometric technique was a major advance in the quantitative description of the geometry of the drainage basins. These techniques helps in characterizing the drainage network and their inter comparison. Using a GIS, topographical and morphological characteristics of the watersheds can be estimated quite easily and all such information can be integrated for assessing the vulnerability of different watersheds to soil erosion.

To define the morphometric features of a watershed, the topographic information of the study area at1:50000 scaled can be taken for analysis with the help of GIS tools. The topographical information derived from this map can be utilized for fixing of priority of watershed for suggesting conservation measures. Steps needed for priority determination include (1) Generation of digital input maps. (2) Computation of morphometric parameters. (3) Ranking of each watershed of the catchment according to calculated values of morphometric parameters (4) Determination of average ranking and assignment of priority for watershed. Fig 3.1 shows a flow Chart depicting methodology adopted for watershed prioritization using morphometric analysis. Detailed steps needed to carry out morphometric analysis are described in following text.

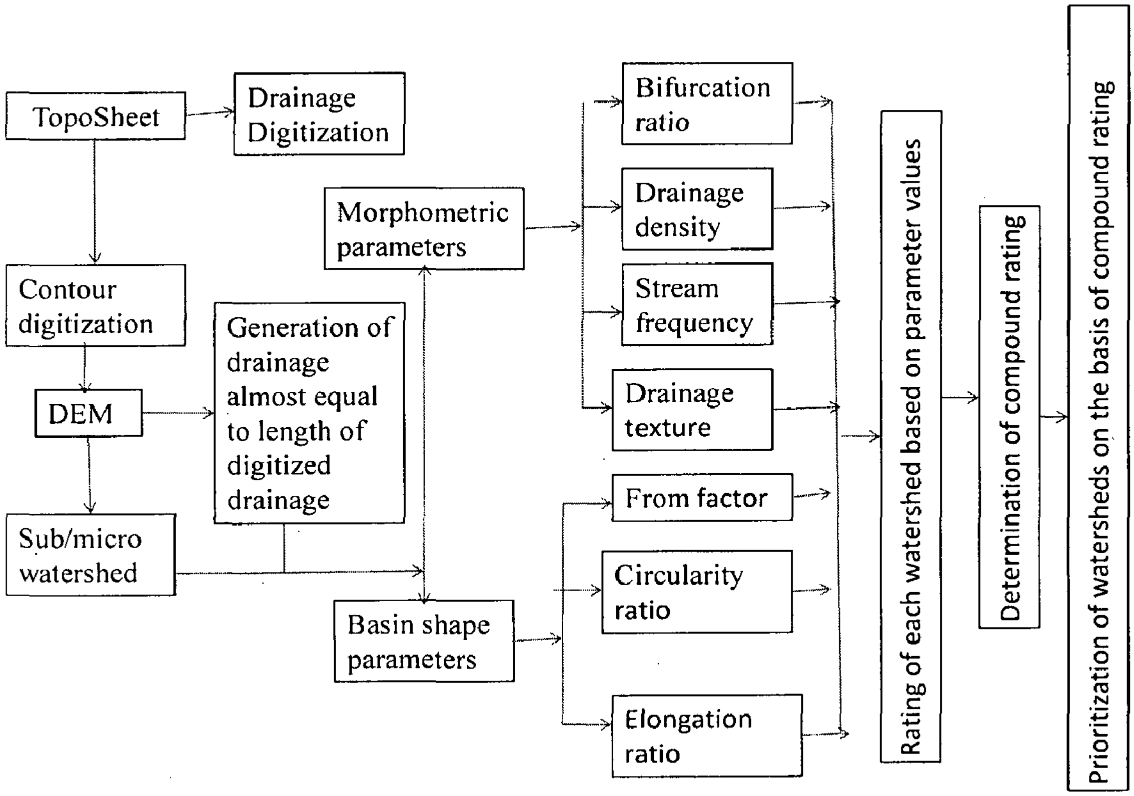

Fig 3.1: Flow Chart for watershed prioritization based on morphometric analysis.

3.1.1 Generation of digital input maps

1. The river network and contour lines of the study area are digitized in ArcGIS from topographic map at 1:50,000 scale.

2. Digital Elevation Model (DEM) of the area is created from digitized contour map by interpolating it at 30m grid cells in Arc GIS.

3. The DEM is further analyzed to remove pits and flat areas to maintain continuity of flow to the catchment outlet. The DEM was further conditioned by burning digitized drain lines on it to enforce observed drainage pattern on flatter areas.

5. The corrected DEM is then used to generate channel network using the concept of channel initiation threshold. The value of channel initiation threshold can be chosen such that the length of generated channel network is equivalent to the digitized channel network following Jain and Kothyari (2000).

6. The generated drainage and DEM can be used for further division of the sub catchment into sub watersheds.

3.1.2 Computation of morphometric parameters

The method of Strahler was used to rank the stream segments using GIS. The relevant numbers of the streams and other measured parameters were entered into the attribute table. The morphometric analysis of the watersheds was carried out with the help of drainage patterns and other measured parameters in ArcGIS. The parameters computed include the morphometric parameters (i.e. the bifurcation ratio, drainage density, stream frequency, and texture ratio), three basin shape parameters (i.e., form factor, circularity ratio, and elongation ratio), three geometric parameters (i.e. area, perimeter, basin length) and two stream parameter (i.e. stream length and no of stream of order u). Computation of morphometric parameters was done on the basis of formula given in Table 3.1.

Table 3.1 Formula used for computation of morphometric parameters

Serial no	Parameters	Formula	Reference	Type of parameters
1	Area	A		Geometric
2	Perimeter	P		Geometric
3	Basin length	L_b		Geometric
4	Stream length	L		Stream
5	No of streams of order U	Nu		Stream
6	Bifurcation ratio (R_b):	R_b=Nu/ $N_{(u+1)}$	Schumn (1964)	Morphometric
7	Drainage density (D_d)	D_d =L/A	Horton (1945)	Morphometric
8	Stream frequency(Fs)	Fs=∑ Nu /A	Horton (1945)	Morphometric
9	Drainage texture(T)	T = D_d X Fs	Smith (1950)	Morphometric
10	From factor (R_f)	R_f=A/ $(L_b)^2$	Horton (1945)	Morphometric(Basin shape)
11	Circularity Ratio (Rc)	Rc=4πA/P^2	Miller (1953)	Morphometric(Basin shape)
12	Elongation ratio (Re)	Re=(2/Lb)*√ (A/π)	Schumn (1956)	Morphometric(Basin shape)

3.1.3 Ranking of each watershed based on morphometric parameters

The highest value of each of the first four morphometric parameters (i.e., bifurcation ratio, drainage density, stream frequency and texture ratio) among 4 watersheds was given a rating of 1, the next highest value was given a rating of 2, and so on as the morphometric parameters generally shows positive co-relation with soil erosion. The lowest value was rated last in the series of numbers.

For the basin shape parameters (i.e. form factor , circularity ratio and elongation ratio) the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as the basin shape parameters generally shows negative co-relation with soil erosion.

3.1.4 Determination of average ranking and watershed priority

After assigning ranking based on every single parameter, rated values for each watershed were averaged to arrive at a composit value. Based on the average value of these parameters, the watershed having the least value of composit rating is assigned the highest priority denoted by 1, the watershed with next highest value of composit rating is assigned a priority denoted by number 2, and so on. The watershed that got the highest value of composit number is assigned the last priority number. The same procedure was adopted by Chaudhary and Sharma, (1998) , Biswas et al., (2002) Jain and Goel, (2002) ,Singh et al., (2005), and Pandey et al., (2007) for prioritization of watersheds with in a catchment.

3.2 USLE based spatially distributed Watershed prioritization method

The rate of soil erosion from an area is strongly dependent upon rainfall, runoff, its soil, vegetation and topographic characteristics. These characters are found to vary greatly within a catchment. Therefore a method which takes these factors into consideration while estimating soil erosion is expected to produce realistic estimates of soil erosion. The Universal Soil Loss Equation (USLE) (Wishmier and Smith, 1978) is one such equation that takes factors such as rainfall, topography, soil and land use while assessing soil erosion. The USLE is a simple empirical model used extensively to realistically estimate surface soil erosion over small areas (Wishmier and Smith, 1978; Ferro, 1997; Jain and Kothyari, 2000; Baban and Yusuf, 2002; Kothyari et al., 2002; Jain and Goel, 2002; Mishra et al., 2006; Pandey et al., 2007).

3.2.1 THE USLE

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) for gross erosion of area *i* can be expressed as

$$SE_i = R_i\, K_i\, L_i\, S_i\, C_i\, P_i \qquad (3.1)$$

Where SE_i is the average annual soil loss (t/ha/yr), R_i is the rainfall erosivity factor (MJ mm $ha^{-1}h^{-1}$), K_i is the soil erodibility factor (t ha h $ha^{-1}MJ^{-1}mm^{-1}$), L_i is the slope length factor (Dimensionless), S_i is the slope steepness factor (Dimensionless), C_i is the cover management factor (Dimensionless) and P_i is the practice management factor (Dimensionless) of the i^{th} cell.

In large sized catchment, these factors (R, K, LS, C & P) show spatial variability. A catchment therefore needs to be discretized into smaller homogeneous areas to capture catchment heterogeneity (Jain and Kothyari, 2000). Several methods are available for discritization of catchment into smaller areas. The cell or grid approach is most commonly used due to its adoptability to raster based GIS systems and ease in collection of input data using remotely sensed satellite data. A cell size of 30m x30m is most widely used in distributed modeling and the same is adopted for representing the cell as hydrologically homogeneous area in the present study as well. Grid thus formed can be categorized as having lying on overland areas and those lying in channel areas. Such a differentiation is necessary because the process of sediment erosion and delivery in them are widely different. In the present study, such a differentiation is achieved using the concept of channel initiation threshold. In this procedure, a cell is considered to lie on overland region if the size of the area from which it receives flow contribution is smaller than or equal to a specified threshold area for the initiation of a channel. Cells receiving flow contribution from an area of more than the threshold value are considered to form the channel grid cells. Cells with no flow accumulation lie on the catchment boundary. Jain and Kothyari, (2000) considered equivalence of the total stream length generated using a given threshold and total stream length estimated from 1:50,000 scale topographic maps (digitized in vector from) for choosing value of channel initiation threshold. However in the present case it is noticed that in topographic maps, every minor incision has been mapped as a channel, resulting in a very high river density. Comparison of streams mapped on the topographic sheet and observation from satellite data and Google earth image clearly indicate over representation of morphological channels in topographic maps. Therefore for the present study channel network seen in satellite data and Google earth image is taken as base for comparison for choosing value of channel initiation threshold. Accordingly, a channel initiation threshold value of 0.45 km^2 i.e. 45 ha is adjudged appropriate value to define channel cells. Estimation of gross erosion from grid sized area of the catchment requires estimates of various factors appearing in eq. (1). Details procedure adopted to estimate these factors is given in the following text.

3.2.1.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) is a numerical value which expresses the capacity of locally expected rainfall to erode soil from an unprotected fallow land. According to Wischmeier (1962) the best estimator of soil loss was found to be a compound parameter, i.e. the one hundredth of the product of kinetic energy of the storm (KE) and the 30 minute intensity (I_{30}) and is termed as E I_{30}. This 30 minutes intensity is the greatest average experienced in any 30 minute period during the storm. Annual total of storm E I_{30} value is referred to as the rainfall erosion index and R is the location value of this index. The Kinetic Energy (KE) and Erosivity (R) of the erosive storms can be estimated by the following equations (Wischmeier and Smith, 1958):

$$KE = 210.3 + 89 \log_{10} I \tag{3.2}$$

$$R = (\sum_{i=1}^{n} KE * I_{30})/100 \tag{3.3}$$

On an annual basis, the R factor is the sum of values of EI_{30} of the storms in an individual year. Realistic estimation of monthly or annual rainfall erosivity EI_{30} value requires long term pluviographic data at 15 min interval or less (Wischmeier and Smith, 1978). In many parts of the world, especially in developing countries, spatial coverage of pluviographic data is often difficult to obtain (Yu et al., 2001; Cohen et al., 2005). Monthly, seasonal and annual rainfall data are usually available for long periods are generally used to calculate R (Mati et al., 2000; Rambabu et al., 2004; Natalia, 2005). In India, Ram Babu et al., (2004), computed EI_{30} values using the data for storms greater than 12.5 mm of 123 rain gauge station located in different zones of India using equation (3.2 & 3.3). Linear relationships were established between average annual and seasonal (June-September) rainfall with computed EI_{30} values for different zones of India. Derived relationships were as follows:

Annual relationship:

$R = 81.5 + 0.38R_N$ $(340 \leq R_N \leq 3500$ mm) (SE = 0.017, r = 0.9) (3.4)

Seasonal relationship:

$R = 71.9 + 0.361R_S$ $(293 \leq R_S \leq 3190$ mm) (SE = 0.017, r = 0.91) (3.5)

Where, R= average annual/seasonal erosion index, R_N = average annual rainfall (mm) and R_S= average seasonal rainfall (mm).

These relationships are valid within the rainfall range indicated in eq. (3.4) and (3.5). The above derived regression equations and average annual/ seasonal (June to September) rainfall data were used to approximate the erosion index values of 500 locations fairly distributed over whole of India and the iso-erodent maps were drawn for annual and seasonal EI. For the present study eq. (3.4) is used to compute annual values of R-factor by replacing R_N with actual observed rainfall in a year in a sub-watershed.

3.2.1.2 Soil Erodibility Factor (K)

It is the soil loss per unit of land of specific size per unit of rainfall erosion index. Physical properties like soil texture, size and stability of soil structure, type of clay, soil permeability, infiltration, organic matter content of the soil and depth of soil greatly influence the factor. A simple nomograph has been developed by Wischmeier et al., (1971) to determine the K value using five soil parameters. Five soil parameters need to be known viz. percentage silt (MS; 0.002 – 0.05 mm), percentage of very fine sand (VFS; 0.05-0.1 mm), percentage of sand greater than 0.1 mm, percentage of organic matter content (OM), structure (S) and permeability (P). An analytical relationship for the nomograph by Wischmeier et al., (1971) is given by the equation

$$K = 7.59 * \frac{2.1 * 10^{-4}(12 - OM) * M^{1.14} + 3.25(S_1 - 2) + 2.5(P_1 - 3)}{100} \quad (3.6)$$

OM is Percentage of organic matter content, M = (% of MS + % of VFS)* (100 – %CL), CL is the clay particle (< 0.002 mm), S_l= the soil structure code used in soil classification and P_l = the profile permeability class.

For the present study K values for different grid sized areas were assigned based on soil textural and related information taken from soil survey report of NBSSLUP (1996). To this end, soil map published by NBSSLUP (1996) was digitized in ArcGIS and based on detailed soil information of digitized soil class, value of K-factor was assigned as attribute information in attached attribute data base of the digitized soil layer in ArcGIS. Finally K- map was generated in ArcGIS using this attribute information.

3.2.1.3 Length and slope Steepness factor (LS)

Slope length factor (L): Slope length may be defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the run-off water enters a well defined channel (Smith and Wischmeier, 1958). Slope length factor (L) is the ratio of field soil loss to the corresponding loss from 22.13 m slope length; its value may be expressed as

$$L = \left[\frac{\lambda}{22.13}\right]^m \tag{3.7}$$

Where λ is the field slope length in meters and m is an exponent having a value ranging from 0.2 to 0.5.

Slope gradient factor (S): Steepness of slope factor is the ratio of soil loss from the field slope to that from the 9% slope under otherwise identical condition. The slope gradient equation as stated by Wishmeier and Smith (1978) is

$$S = 65.41 \, Sin^2\theta + 4.56 \, Sin\theta + 0.065 \qquad (3.8)$$

Where S is the slope gradient factor and θ is the angle of slope.

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

Besides relation of Wishmeier and Smith (1978) many other relations have been proposed to compute LS factor. Among these, the one that is best suited for integration with GIS is the theoretical relation proposed by Moore & Burch (1986) and Moore & Willson (1992) based on unit power theory, given as

$$LS = \left[\frac{A_s}{22.13}\right]^n * \left[\frac{Sin\beta}{0.0896}\right]^m \qquad (3.9)$$

Where A_s is the specific area (defined as the upslope contributing area per unit width normal to the flow direction) $=A/b$, A = the upslope contributing area for an overland cell, b = width normal to the flow direction, β is the slope gradient in radians, $n = 0.4$ and m = 1.3. For channel grid cells defined previously, the value of A is considered to be equal to the threshold area corresponding to channel initiation.

3.2.1.4 Cropping management factor (C)

The cropping management factor, C is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean tilled fallow on identical soil, slope and rainfall condition. This factor reflects the combined effect of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management and the expected time distribution of erosive rain storm with respect to seeding and harvesting date of the locality (Singh et al., 1981). It also depends upon particular stage of growth and development of vegetal cover at the time of rain. The C factor layer was prepared using satellite data using following methods.

1. The data used for the study of Land use land cover classification includes the LANDSAT TM data corresponding to November 1st, 1992 (path 140 to 141 & Row 43 to 44 and 185 km swath) downloaded from GLCF (NASA) site. The LANDSAT TM camera has seven spectral bands. The first four Bandwidths are in the range of 0.45–0.90 mm in the visible and near-infrared region with a spatial resolution of 30 m; the band 5, 6 & 7 are short-wave infrared band of bandwidth in the range of 1.55–12.5 mm with a spatial resolution of 30 m. In the present study, all the seven bands are used because they are useful in discriminating land.
2. The images of Seven bands were combined together using Earth Resources Data Analysis System (ERDAS) imagine image processor to make False Colour Composite (FCC) image.
3. The image was geometrically corrected and then reprojected to the projection system of other data by means of ERDAS Imagine image processing software. The projection type used is 'Polyconic' with the spheroid Everest_Definition_1962 and datum as 'Everest_India_Nepal'. A second order polynomial model was generated and care was taken to keep the RMS error less.
4. A rectangular area of interest was then subset from the entire path/row of the LANSAT TM image for the study area only.
5. Then Tassel Cap and Vegetation Index (VI) transformation was done for spectral enhancement to discriminate the vegetation from other surface cover type in ERDAS.

6. The area of interest (AOI) was then marked over the image and attributed to specific land cover class as a training sample for the classifier to classify pixels of unknown identity and then a stratified supervised classification using Maximum Likelihood Method and ground referenced data was carried out to generate the land use / land cover map for the sub catchment. Supervised classification can be defined normally as the process of sampling of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas. Training areas are defined as representative areas of each class in an image. Pixels located within these areas called as the training samples are used to guide the classification algorithm to assign specific spectral values to appropriate informational class.
7. This supervised classified image was again verified for locations and extensions of various land cover classed by the ground truth information collected from Google earth image and Survey of India topographic maps.
8. Generated land use/land cover map of the subcatchent was then filtered to remove the anomalies in the image by majority filter.
9. Finally a landuse map was generated with 5 classes Viz. degraded forest, agriculture, settlement, water body and wasteland. Based on the land cover categories, the attribute values for the C factor were assigned to individual cells from the tabulated values suggested by Jain et al., (2001), Singh et al., (1981), Singh and Phadke, (2006), Ahmed et al., (2000) and Deore, (2005).

3.2.1.5 Support conservation practice factor (P)

It is the ratio of soil loss with a specific supporting practice to the corresponding loss with up-and-down cultivation. Since in the study area, no major conservation practices are followed except low height bunds in some of the agricultural areas only, the P factor was taken equal to 1 for all land use and land cover categories for simplicity.

3.2.2 Sediment transport and outflow

Erosion potential map was generated by multiplying K, LS, C and P map layer in ArcGIS. The composite term KLSCP represents the soil erosion potential of different grid cells. Gross amount of soil erosion for each grid cell can be calculated for each year by multiplying rainfall erosivity factor (R) map layer of each year with erosion potential map computed above. The gross amount of soil erosion computed using eq. (3.1) represent the amount of erosion taking place in a particular grid and only part or whole of it can outflow from its location to next downstream cell or outlet depending on the transporting capacity of the flowing water following a defined drainage path (Meyer and Wischmeier, 1969). The sediment outflow from an area is equal to soil erosion in the cell plus contribution from the upstream cells if transport capacity is greater than this sum. However if transport capacity is less then the amount of sediment excess of sediment transport capacity get deposited and sediment load equal to transport capacity is discharged to the next downstream cell. Many relations exist in literature to estimate mean annual sediment transport capacity. Based on the studies by Verstraeten et al., (2007) following equation for computation of mean annual sediment transport capacity was proposed and same is adopted in this study.

$$Tc_i = K_{TC_i} * R_i * K_i * A_i^{1.4} * S_i^{1.4} \tag{3.10}$$

Where Tc_i is transport capacity in cell i, K_{TC_i} is the transport capacity coefficient for cell i, R_i and K_i are the USLE factors of cell i, A_i is the upslope contributing area per unit contour length in cell i and S_i is the slope gradient in cell i. Eq. (3.10) assumes that in areas with higher rainfall erosivity (mostly due to higher rainfall intensity), runoff coefficient and discharge will also be higher resulting in a higher transport capacity. The coefficient K_{TC_i} reflects the vegetation component within transport capacity. Since K_{TC_i} is strongly depended on land use land cover types it is in order to co-relate it with some vegetative index value of the area to get the spatial distribution of transport capacity coefficient. To do this end, use of remotely sense images is proposed. It is known that the reflectance of any area depend on land cover present and vegetation reflects most in near infrared region (NIR). Using this property, many indices have been developed in past and can give a perspective on presence of vegetation in a cell. These indices have also been used to estimate factors which depend on land cover present. For example, Van der Knijff et al., (2002) assessed monthly cover management factor values for Italy using Advanced Very High Resolution Radiometer imagery (AVHRR) by relating Normalized Difference Vegetation Index (NDVI) with cover management factors (C). The NDVI is the image transformation based on the normalized difference between Near-Infra Red (NIR) and Visible Red (VR) bands (ERDAS IMAGINE 8.5), and expressed as

$$NDVI = \frac{NIR - VR}{NIR + VR} = \left[\frac{band4 - band3}{band4 + band3}\right] \tag{3.11}$$

The ranges of values for NDVI vary from -1 to +1. Where vegetated areas will typically have values greater than zero and negative values indicate non-vegetated surface features such as water, barren lands, ice, snow, or clouds. Typically higher +ve value for a pixel in NDVI image indicate more vigour or dense vegetation and vice versa. In the present study an empirical relation for computation of K_{TC} for a cell sized area is hypothesized as an exponential function of NDVI. Mathematically, K_{TC_i} is proposed to be expressed as

$$K_{TC_i} = \beta * \exp\left[\frac{-NDVI_i}{1-NDVI_i}\right] \quad (3.12)$$

Where $NDVI_i$ is the NDVI value for cell i and β is a scaling factor to be determined through calibration. Functional behavior of proposed eq. (3.12) is studied for possible range of NDVI values and plot of computed K_{TC} with NDVI is depicted in Fig 3.2 as illustration. Fig 3.2 also depicts effect of scaling coefficient β on computed values of K_{TC}. As can be seen from the figure, the computed values of K_{TC} increases as value of NDVI changes from +1 to -1 indicating increase in value of K_{TC} as vegetation density or vigour reduces. Also notice the scaling effect of parameter β to cater wide range of situations.

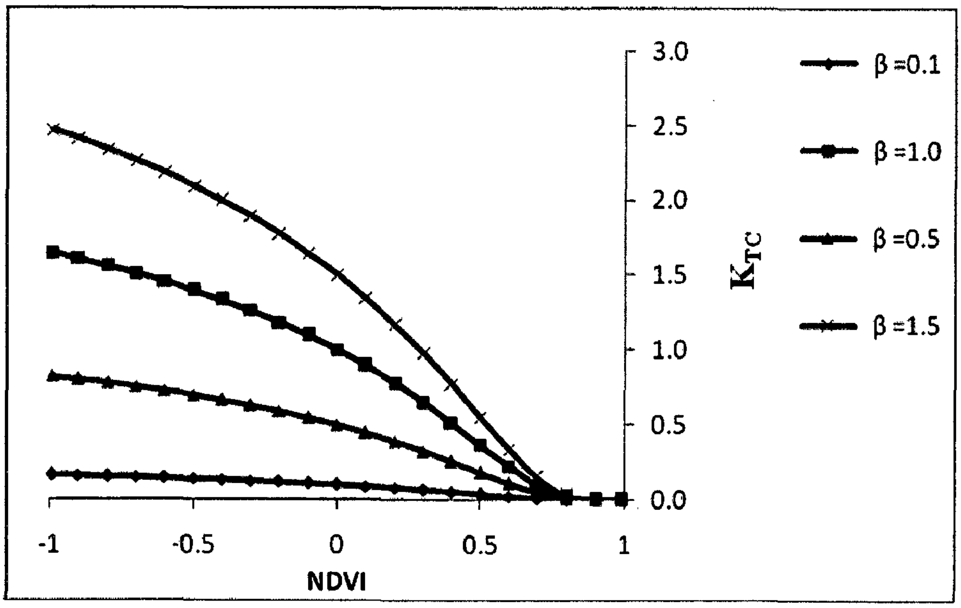

Fig 3.2: Proposed functional relation of K_{TC} with NDVI

3.2.3 Transport limiting sediment delivery concept and sediment yield computation

Transport limiting sediment delivery concept applies to the situation where there is a supply of substance (e.g. erosion) and capacity for transport of the substance (e.g. sediment transport capacity). This concept accumulates the substance flux subject to the rule that the transport out of any grid cell is the minimum of the total eroded sediment (i.e. transport in to that grid cell plus gross erosion of that grid cell) and the transport capacity. There is then deposition if the transport capacity is less than total eroded sediment as stated below otherwise there will be net erosion in that grid cell.

$$T_{out} = Min\left(SE_i + \sum Tin_i , Tc_i\right) \tag{3.13}$$

$$D_i = \left(SE_i + \sum Tin_i\right) - Tout_i \tag{3.14}$$

Here SE_i is the supply (erosion),Tc_i is the transport capacity, Tin_i and $Tout_i$ is the transport in and transport out of sediment from the i[th] cell respectively. $Tout_i$ at each grid cell becomes Tin_i for down slope grid cells and is reported as Transport limited accumulation. D_i is deposition. Sediment delivery map was prepared using this transport limiting sediment delivery concept by overlying the layers of gross erosion, sediment transport capacity and flow direction layers in ArcGIS.

3.2.3.1 Preparation of erosion-deposition or net erosion maps

The above model produces maps for gross erosion, sediment transport and sediment deposition rates, whereby a distinction is made between gross erosion, net erosion, total sediment deposition and net sediment deposition. First of all, the USLE erosion map is simply the spatial distribution of Eq. (3.1), and this is hereafter called the gross erosion rate. Secondly, a net erosion map is calculated by subtracting the deposition rates for each grid cell from the gross erosion rates for each grid cell. Negative values on the net erosion map are the areas where sediment deposition occurs (i.e. true sediment deposition), whereas positive values correspond to grid cells with net soil erosion. Consequently, different total values of erosion and soil loss can be defined. Finally, annual sediment yields were estimated on a cell basis and all the grid cells of the watershed are regrouped into the following scales of priority: Slight (0 to 5 t/ha/yr), Moderate (5 to10 t/ha/yr), High (10 to 20 t/ha/yr), Very High (20 to 40 t/ha/yr), Severe (40 to 80 t/ha/yr) and Very Severe (>80 t/ha/yr) erosion classes following the guidelines suggested by Singh *et al.*, (1992) for Indian conditions. Fig 3.3 shows a flow chart depicting methodology adopted for watershed prioritization using USLE model.

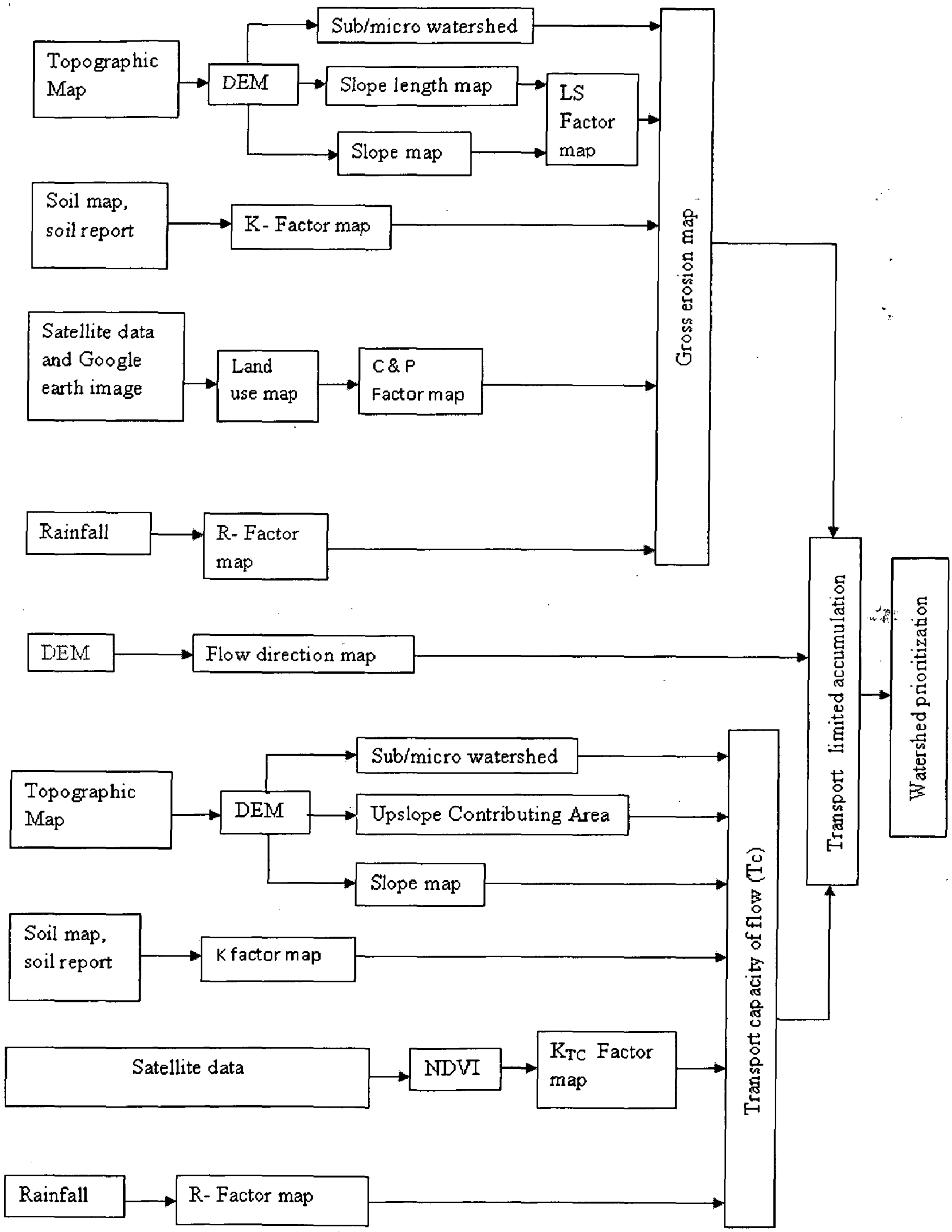

Fig 3.3 Flow Chart of methodology for watershed prioritization based on USLE model

CHAPTER 4

STUDY AREA AND DATA AVAILABILITY

In the present study Haharo sub catchment located in the Damodar catchment of Damodar- Barakar river system in the Upper Damodar Valley (UDV) area, Jharkhand, India is taken up for analysis. The study area is a head water catchment in Damodar-Barakar river system. Downstream of the study watershed the Damodar-Barakar river system has a network of five reservoirs, namely Maithan and Tilaiya on the Barakar River, Panchet, Tenughat and Konar on river Damodar. Among these, Panchet is the largest dam constructed across the Damodar River.

Geographically the Haharo sub catchment is located between 85°00' E to 85°24' E longitude and 23°45' N to 23°49' N latitude. As per the priority delineation report (AISLUS, 1980) it has been codified as Tg sub catchment, however, as per the national world atlas it has been codified as watershed no 2A2H3. The total area of the sub catchment up to the gauging point on the main stream is 565.km^2. The study sub catchment is covered in Survey of India topographic sheets of 73E/1, 73E/2, 73E/5 and 73E/6 at 1:50,000 scale. Fig 4.1 depicts location of Haharo sub catchment in Jharkhand state of India.

Physiographically the catchment falls into three main landscapes, viz. the hilly and undulating area in the north-west, gently undulating and rolling uplands, and valley lands. Most of the area of the catchment comprises of gently sloping uplands except for hilly and undulating areas. Elevation of the watershed ranges from 300–830 m above Mean Sea Level. Most of the uplands are subjected to severe sheet erosion. The climate of the study watershed is sub-humid tropical. The annual rainfall ranges between 1160 mm to 1400 mm. About 63% of annual rainfall is concentrated in the

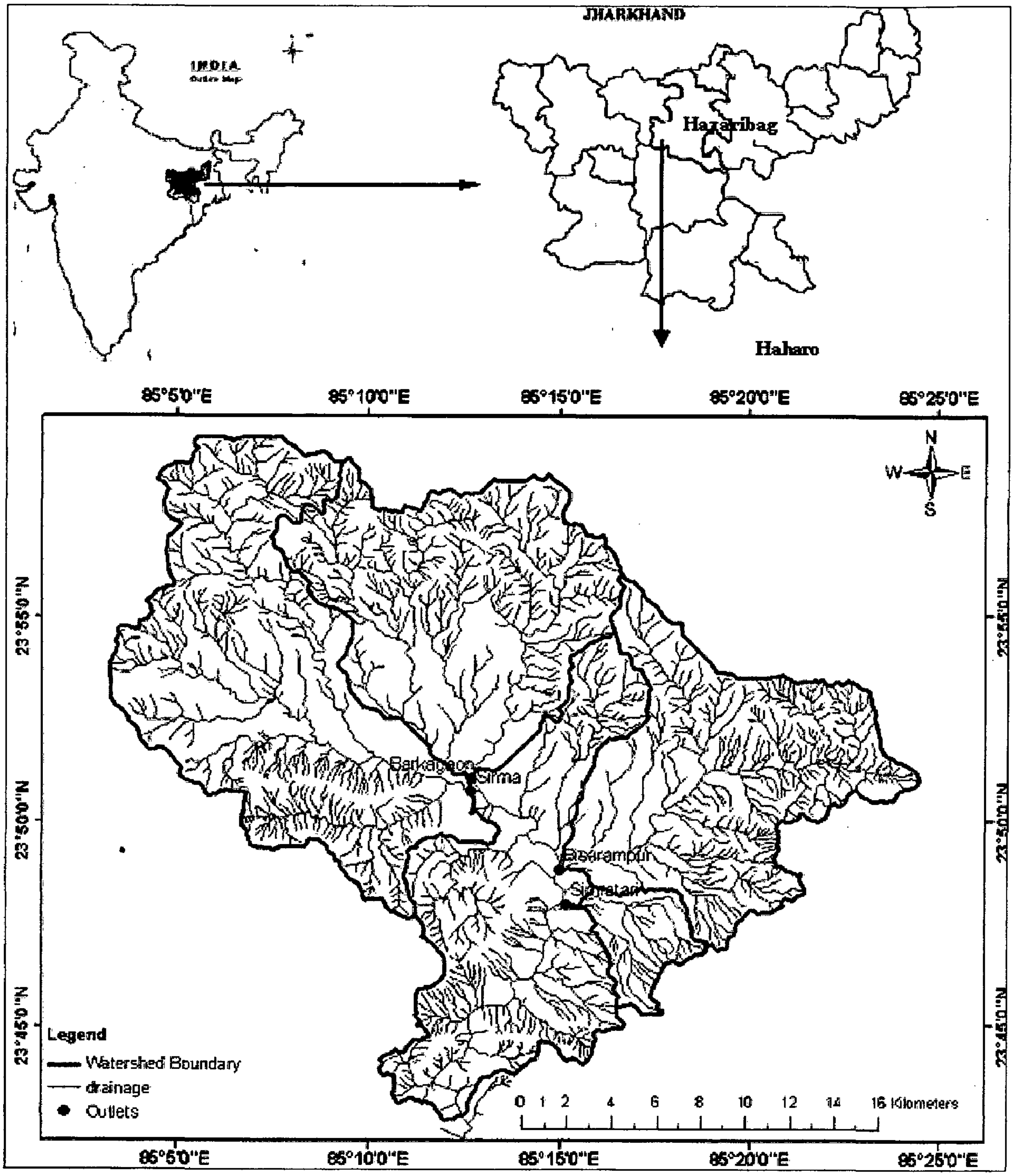

Fig 4.1 Location of Haharo sub catchment.

three monsoon months of July, August and September. Average numbers of rainy days per year are 56. Average seasonal percentage of annual rain fall for Jan. to Feb. is 3.9%, Mar. to May 6.5%, June to Sep.-82%, Oct. to Dec- 7.6 % (Rajan and Rao, 1978). The average storm intensity, by considering storms of more than 30 min duration, is about 10 cm/hr (Kaur et al., 2004).

The predominant land use in the sub catchment is agricultural and forest. The sub catchment like the main catchment is characterized by overgrazing, degraded forest cover and undulating topography coupled with erratic and intense rainfall.

The surface soil texture in the study watershed is mainly loamy type and particle size classes are fine loamy type. Depth of soil varies from shallow to very deep and having parent material as granite-Gneiss and sand stone (NBSSLUP, 1996, India).

4.1 HYDRO METEOROLOGICAL OBSERVATION:

In Haharo sub catchment rainfall, run-off and sediment data are being collected at (1) Sirma (2) Barkagaon (3) Bisrampur and (4) Simratari by DVC (Damodar Valley Corporation, India) since 1979. At all four locations, rainfall is being observed with ordinary rain gauge, runoff is being measured with a stage level recorder and sediment samples are being collected with the help of USDH-48 depth integrating sampler. Salient features of these sub watersheds are given in Table 4.1. The sediment samples are filtered at the gauging site itself after allowing it to settle for sometime. The total volume of runoff is multiplied by the sediment concentration to compute the total sediment volume. The density of sediment is taken as1.4gms/cc. In order to accommodate the bed load, 20% of suspended silt load was added to the measured suspended load as suggested by Varshney (1977). Rainfall sediment yield data are shown in Table 4.2. Location of gauging stations along with boundaries of different sub watersheds is shown in Fig. 4.2.

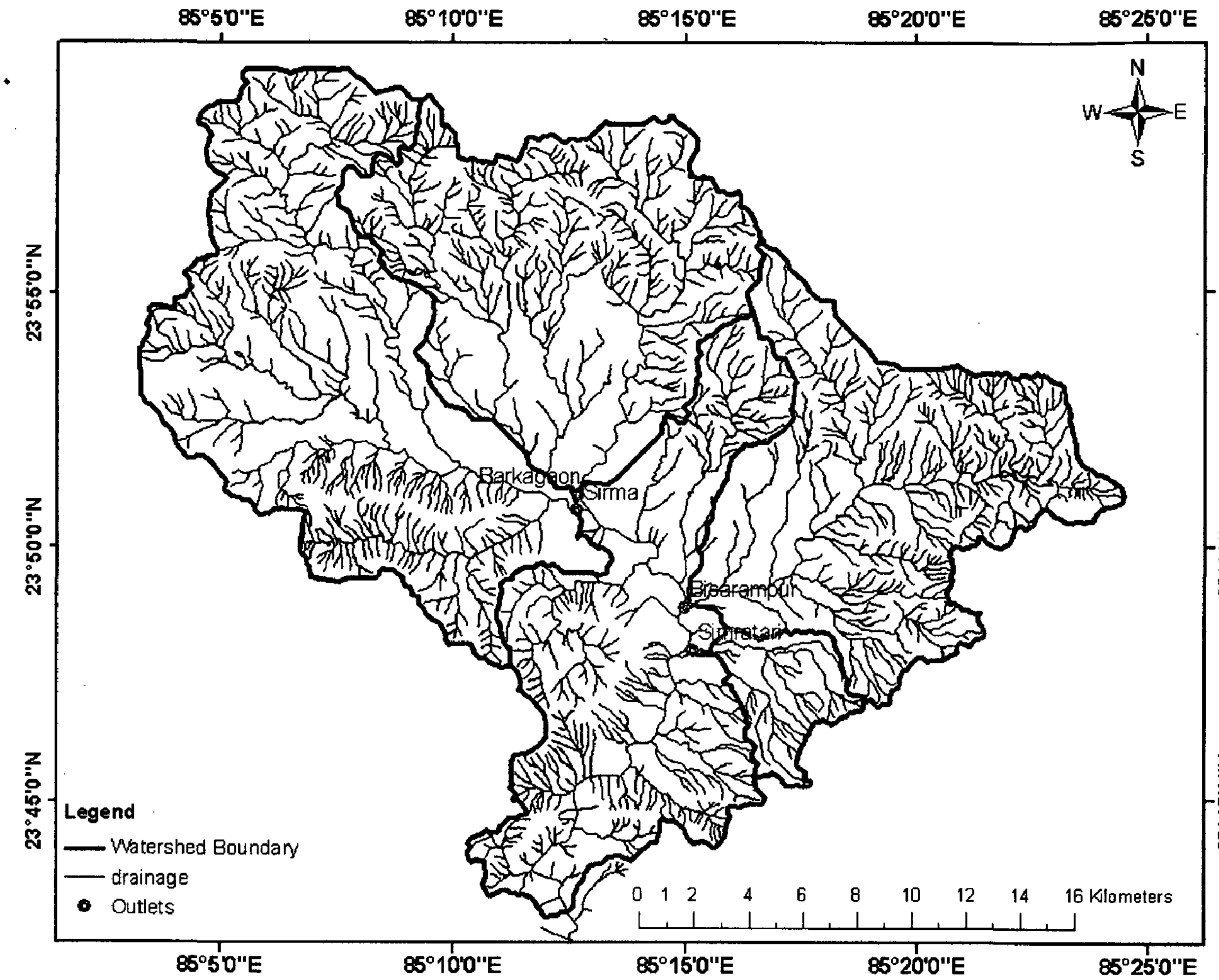

Fig. 4.2 Location map of gauging station and sub watersheds boundaries.

Table 4.1 Salient features of Sub-Watersheds in Haharo Sub catchment.

Serial No.	Particulars	Watershed Number			
		4/4 (Simratari)	4/3 (Bisrampur)	4/2 (Barkagoan)	4/1 (Sirma)
1	Size (sq.km.)	18.15	124.58	131.87	169.91
2	Longitude	85° 15' E to 85° 19' E	85° 15' E to 85° 24' E	85° 07 'E to 85°16' E	85° 04' E to 85°12' E
3	Latitude	23°45' N to 23°48' N	23°47' N to 23°56' N	23°51' N to 23°58' N	23°47' N to 23°59' N
4	Shape	Oval	Rectangular	Oval	Elongated
5	Soil type	Fine loam	Coarse loam	Coarse and fine loam	Fine loam
	(a) Loam	14.11%	10.40%	3.98%	2.58%
	(b) Silt loam	85.89%	89.59%	96.02%	82.61%

Serial No.	Particulars	Watershed Number							
		4/4 (Simratari)		4/3 (Bisrampur)		4/2 (Barkagoan)		4/1 (Sirma)	
	(c) Silt clay loam	—		—		—		14.81%	
6	Average slope in %	5.35		6.57		8.85		6.86	
7	Relief (m)	192.00		269.90		428.69		346.70	
8	Land use (%)								
	(i)Agriculture	48.57		33.33		24.88		27.05	
	(ii) Water body	2.89		1.13		0.88		1.36	
	(iii) Waste land	4.10		3.65		14.08		25.07	
	(iv) Settlement	9.17		4.68		2.26		1.88	
	(v) Forest	35.27		57.21		57.89		44.65	
9	Vegetation	Sheesham, Sal, Palash		Sheesham, Sal, Palash		Sheesham, Sal, Palash		Sheesham, Sal, Palash	
10	Method of measurement								
	(i)Rainfall	Std. R.G.		Std. R.G.		Std. R.G.		Std. R.G.	
	(ii) Runoff	Velocity-area		Velocity-area		Velocity-area		Velocity-area	
	(iii)Sediment	USDH-48		USDH-48		USDH-48		USDH-48	
11	Nature of stream	Ephemeral		Ephemeral		Ephemeral		Ephemeral	
12	Period of Record	1979-1989		1979-1990		1980-1985		1981-1985	
13	Missing Period	1981				1981			
14	Summary of data (Annual)	Max	Min	Max	Min	Max	Min	Max	Min
	(i)Rainfall (mm)	1392	548	1392	521	1186	567	1321	649
	(ii)Runoff(mm)	298	140	379	240	491	176	422	226
	(iii)Sediment production rate (tones/ha)	2.98	2.06	3.13	1.08	2.81	1.17	2.33	1.01
	(iv)Sediment yields(tones)	5403	3739	39009	13416	37111	15474	39633	17129
	(v)Mean SY (tones)	2.38		1.97		1.85		1.5	

Table 4.2 Rainfall, Sediment Yield and Sediment production rate of four watersheds, Samuel (1995).

Watershed no.	Name of Gauging station	Year	Rainfall (mm)	Sediment Yield (tonnes)	Sediment production rate (tonnes/ha)
4/1	Sirma	1982	649	17950.1	1.06
		1983	849	17129.4	1.01
		1984	1120	33570.5	1.98
		1985	723	19247.4	1.13
		1986	1321	39633.3	2.33
4/2	Barkagaon	1980	983	37111.3	2.81
		1981	773	24151.8	1.83
		1982	566	15474.4	1.17
		1983	770	17785.3	1.35
		1984	1186	27391.7	2.08
4/3	Bisarampur	1979	699	26487.4	2.13
		1980	983	39009.4	3.13
		1981	769	13416.5	1.08
		1982	567	20876.9	1.68
		1983	849	20836.2	1.67
		1984	1097	26731.3	2.15
4/4	Simratari	1979	699	3739.2	2.06
		1980	983	5403.2	2.98
		1981	841	4572.62	2.52
		1982	579	4718.2	2.60
		1983	849	4641.1	2.56
		1984	1098	5132.1	2.83
		1985	733	3690.6	2.03
		1986	1211	2626.0	1.45

CHAPTER 5

ANALYSIS AND DISCUSSION OF RESULTS

Observed information on rainfall and sediment outflow was available at 4 gauging stations depicted in Fig 4.2. Therefore the entire area is divided into four sub-watersheds defined at gauging station at Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3) and Simratari (4/4).

5.1 Morphometric analysis

Basic parameters: Geometric (area, perimeter, basin length) and stream parameters (stream length, stream order) were measured from topographic map using ArcGIS.

Geometric parameters

Area (A): The total drainage area of Haharo sub catchment was of 565km^2. The areas of each watershed are shown in Table 5.2. Watershed 4/4 is the smaller sub-basin (A=18.15 km2) and watershed 4/1 is bigger than the others (A=169.91 km2).

Perimeter (P): The perimeter is the total length of the drainage basin boundary. The perimeter of Haharo is 302 km, and the P of the four sub watershed is shown in Table 5.2. Sirma has the higher value (P>79 km) and coincides with the higher value of area (A), while the perimeter of Simratari is less (P<23 km) coincides with the lower value of area (A).

Basin length (L_b): The basin length corresponds to the maximum length of the basin and sub-basins. The basin length (L_b) of Haharo is 32.77 km and the values of L_b for the four watersheds are shown in Table 5.2. Sirma is the longest sub-basins (L_b>20 km) while Simratari has the minimum value of L_b (L_b<6 km).

Stream parameters

Stream length (L): The values of L for the four watersheds are shown in Table 5.2. Sirma has the longest Stream length (L=278.01 km) while Barkagaon has the minimum value of L (L=37.19 km).

Total number of stream of all order (N): The values of total number of stream of all order for each watershed are shown in Table 5.2. Sirma has the highest number of stream of all order (N=647) while Simratari has the minimum N (=71).

Stream order (Nu): Haharo is designated as a seventh order basin; Sirma (4/1), Barkagaon (4/2) 5^{th} order and Simratari (4/4) is of 4th order watersheds respectively and Bisarampur (4/3) is of 6 th order (Horton 1945; Strahler 1964). The R_b of the four watersheds varies from 1.81 to 2.45 (Table 5.1).

Determination of bifurcation ratio (R_b) of watersheds

Fig 5.1 shows stream ordering of various watersheds. Calculation on an average value of bifurcation ratio (R_b) for a given channel network can be made by determining the slope of the fitted regression of logarithm of numbers (ordinate) on order (abscissa).Regression of number of stream segments on stream order of watersheds Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3), Simratari (4/4) are shown in Fig 5.2. Average value of R_b of watersheds Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3), and Simratari (4/4) are shown in Table 5.1.

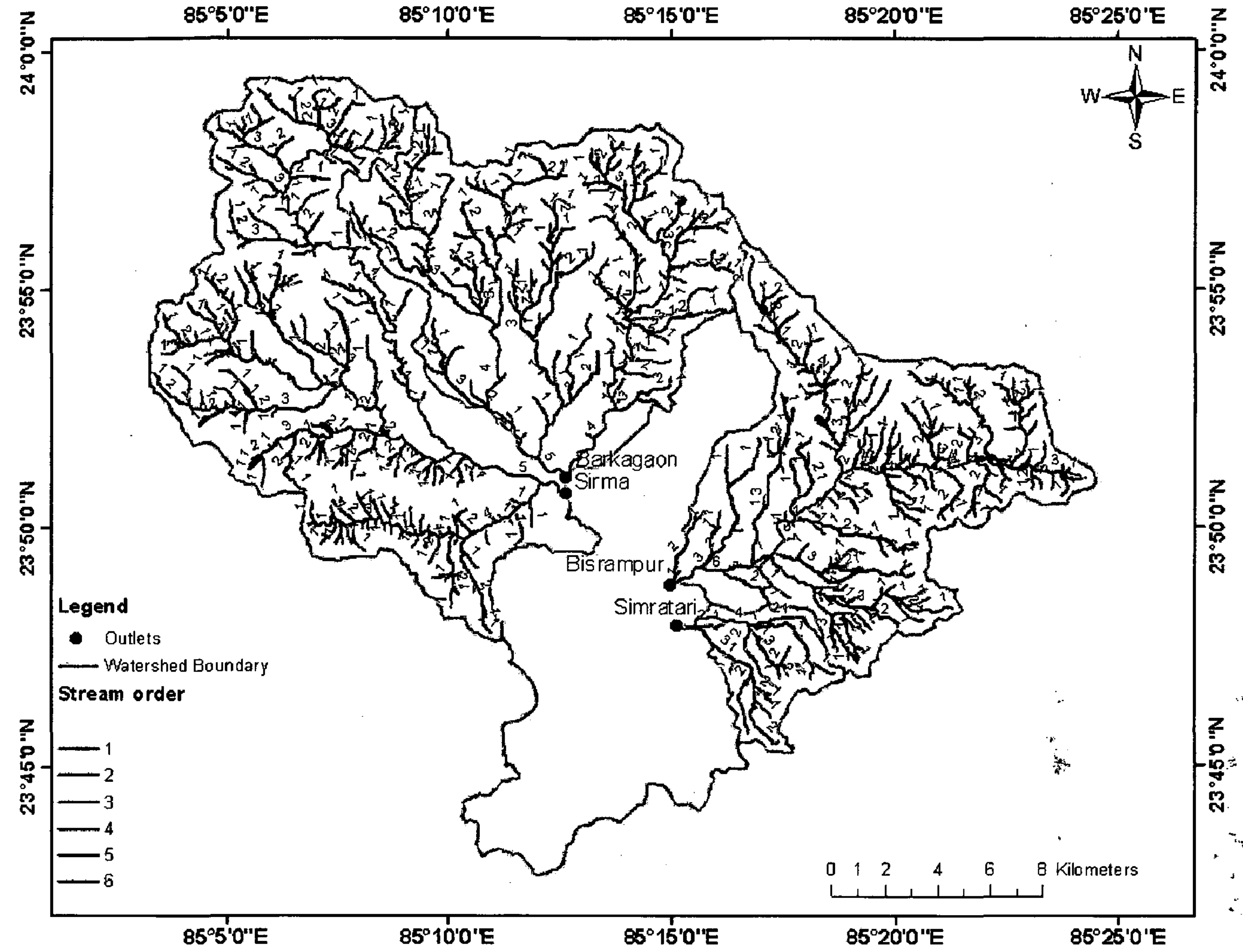

Fig 5.1 Haharo sub watershed drainage pattern with stream order

Table 5.1 Determinations of average value of R_b of watersheds.

watershed no	Total number of stream(N_u)of order(U)						Log Nu						slope of trend line	Bifurcation ratio
	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th		
Sirma (4/1)	307	138	111	80	11		2.49	2.14	2.05	1.90	1.04		0.321	2.094
Barkagaon (4/2)	207	116	64	54	6		2.32	2.06	1.81	1.73	0.78		0.34	2.188
Bisarampur (4/3)	248	127	75	29	21	14	2.39	2.10	1.88	1.46	1.32	1.15	0.257	1.807
Simratari (4/3)	36	19	14	2			1.56	1.28	1.15	0.30			0.389	2.449

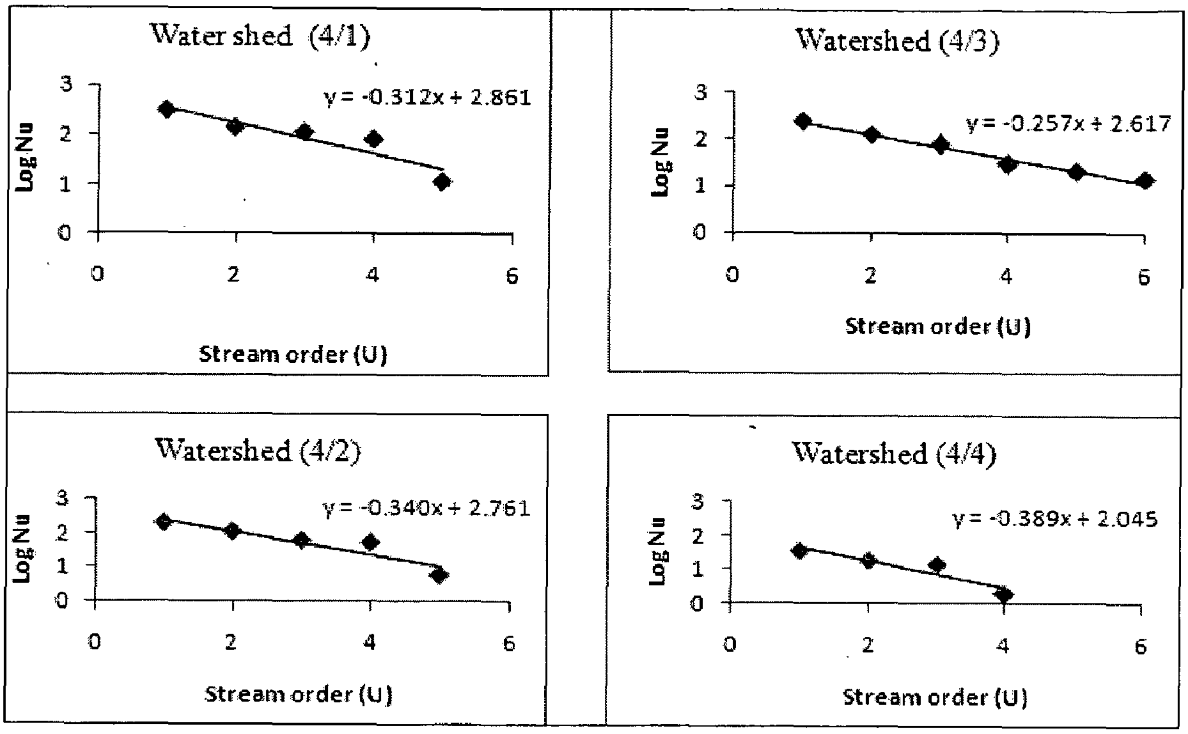

Fig-5.2 Regression of number of stream segments on Order of four watersheds

Derived parameters

Estimation of all the morphometric and basin shape parameters was done as per formula given in Table 3.1. Values of morphometric parameters are tabulated in Table 5.2.

Bifurcation ratio (R_b): The R_b of the four watersheds vary from 1.81 to 2.45 (Table 5.2). Usually these values are common in the areas where geologic structure does not exercise a dominant influence on the drainage pattern. Watershed 4/1 and 4/3 are elongated and rectangular shape respectively and that of 4/2 and 4/4 is oval. The effect of the elongate basin with high bifurcation ratio value would yield low but extended peak flow, where as the rotund basin with low bifurcation ratio value would produce a sharp peak (Chow, 1964).

Drainage density (D_d): The D_d of the four watersheds vary from 1.64 to 2.05 (Table 5.2). A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response. In general, low drainage density is favored in

Table 5.2 Geometric and morphometric parameters of watershed

Name of watershed	Geometric parameter			Stream parameter		Morphometric parameters				Basin shape parameters		
	Area in Km^{2} (A)	perimeter in Km (P)	Basin Length (L_b) in Km	stream length (L) in Km	Total no of Stream (N)	Bifurcation ratio R_b= ($N_u/N_{(u+1)}$)	Drainage density (D_d = L/A)	Stream frequency (F_s=∑N/A)	Drainage Texture (T)=D_d* Fs	Form factor (R_f=A/$(L_b)^2$	Circularity Ratio(R_c= 4πA/P^2)	Elongation Ratio Re= (2/L_b)*√(A/ π)
Sirma (4/1)	169.91	79.94	20.04	278.01	647	2.09	1.64	3.81	6.23	0.42	0.33	0.73
BarkaGaon (4/2)	131.87	58.28	15.45	218.52	447	2.19	1.66	3.39	5.62	0.55	0.49	0.84
Bisarampur (4/3)	124.58	64.33	16.67	234.7	514	1.81	1.88	4.13	7.77	0.45	0.38	0.76
Simratari (4/4)	18.15	23.39	6.69	37.19	71	2.45	2.05	3.91	8.02	0.41	0.42	0.72

regions of highly resistant or highly permeable subsoil materials under dense vegetative cover and where relief is low. High drainage density is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Chow, 1964). The D_d of the watersheds reveals that the nature of subsurface strata is permeable, which is a characteristic feature of coarse drainage as the density values are less than 5.

Stream frequency (Fs): The Fs values for the four watersheds vary from 3.39 to 4.13 (Table 5.2). According to Kale and Gupta, (2001) greater the drainage density and stream frequency in a basin, the runoff is faster, and therefore, flooding is more likely in basins with a high drainage and stream frequency.

Drainage texture (T): The value of T for four watersheds are shown in Table 5.2.The values are very well between 4 to 10 and therefore the watersheds are intermediate in texture (Smith 1950).

Form factor (R_f): The R_f for the four watersheds are ranging between 0.41 to 0.55 (Table 5.2). There is a low form factor in a basin that indicates less intense rainfall simultaneously over its entire area than an area of equal size with a large form factor (Gupta, 1999).

Circularity Ratio (R_c): The R_c for the watersheds 1 and 3 are below 0.39 and that of watersheds 2 and 4 are more than 0.41 (Table 5.2). Those values are indicative of the lack of circularity. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins.

Elongation Ratio (R_e): The R_e for the four watersheds vary from 0.72 to 0.84 (Table 5.2). All of those values are indicative of elongated shapes rather deviation from a circular shape.

5.1.1 Ranking of each watershed based on morphometric parameters and watershed prioritization

Ranking of each watershed is done depending on values of the morphometric and basin shape parameters. The highest value of each of the first four morphometric parameters (i.e., bifurcation ratio, drainage density, stream frequency, and texture ratio) among 4 watersheds was given a rating of 1, the next highest value was given a rating of 2, and so on as the morphometric parameters generally shows positive co-relation with soil erosion. The lowest value was rated last in the series of numbers.

For the shape parameters, the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as the basin shape parameters generally shows negative co-relation with soil erosion.

After the rating had been done based on every single parameter, these were averaged to arrive at a compound value for each watershed. Based on the average value of these parameters, the watershed having the least rating value was assigned the highest priority number of 1, the next highest value was assigned a priority number of 2, and so on. The watershed that got the highest value was assigned the last priority number. The same procedure was adopted by Chaudhary and Sharma (1998), Biswas et al., (2002) Singh et al., (2005), Jain and Goel (2002) and Pandey et al. (2007) for prioritization of watersheds of a catchment. The results of prioritization of watersheds based on morphometric parameters and comparison of the same with the observed sediment yield data are shown in Table 5.3. Fig 5.3a and 5.3b compare the result of prioritization based on morphometric analysis and observed sediment yield.

Table 5.3: Prioritizing watersheds based on morphometric parameters and observed sediment yield are shown in table below.

Name of watershed	Ranking based on parameters							Priority based on average rating and observed sediment yield value			
	R_b	D_d	F_s	T	R_f	R_c	R_e	Average rating	Priority	Observed Av. Sediment production rate(T/ha)	Priority
Sirma (4/1)	3	4	3	3	2	1	2	2.57	Medium	1.50	Low
Barkagaon(4/2)	2	3	4	4	4	4	4	3.57	Low	1.85	Medium
Bisarampur(4/3)	4	2	1	2	3	2	3	2.43	High	1.97	High
Simratari (4/4)	1	1	2	1	1	3	1	1.43	Very high	2.38	Very high

5.1.2 Discussion

It is observed from the result (Table 5.3) that among the four watersheds 4/4 is the highest priority area where conservation measure has to be taken first. Watershed 4/3 falls under next higher priority watershed. Watershed 4/1 is the medium priority area and watershed 4/2 is the low priority area. The major factors that contribute to soil erosion potential in these watersheds were analyzed. The catchment has overall loamy soil so soil has equal influence for the entire four sub watershed. For the very high priority watersheds 4/4, has the lowest slope of 5.35% among the watersheds of the catchment and it is nearest to the main outlet of the catchment so it has the largest flow convergence therefore subjected to high sediment yield. Moreover the land use pattern (Agricuture-48.5%, Forest-35 %,) is also responsible for higher soil erosion compare to others. Of the high priority watershed 4/3 is the 2nd nearest to the main outlet of the catchment and 2nd highest 33.33% agricultural land may be the main reason for high erosion rate. Mainly

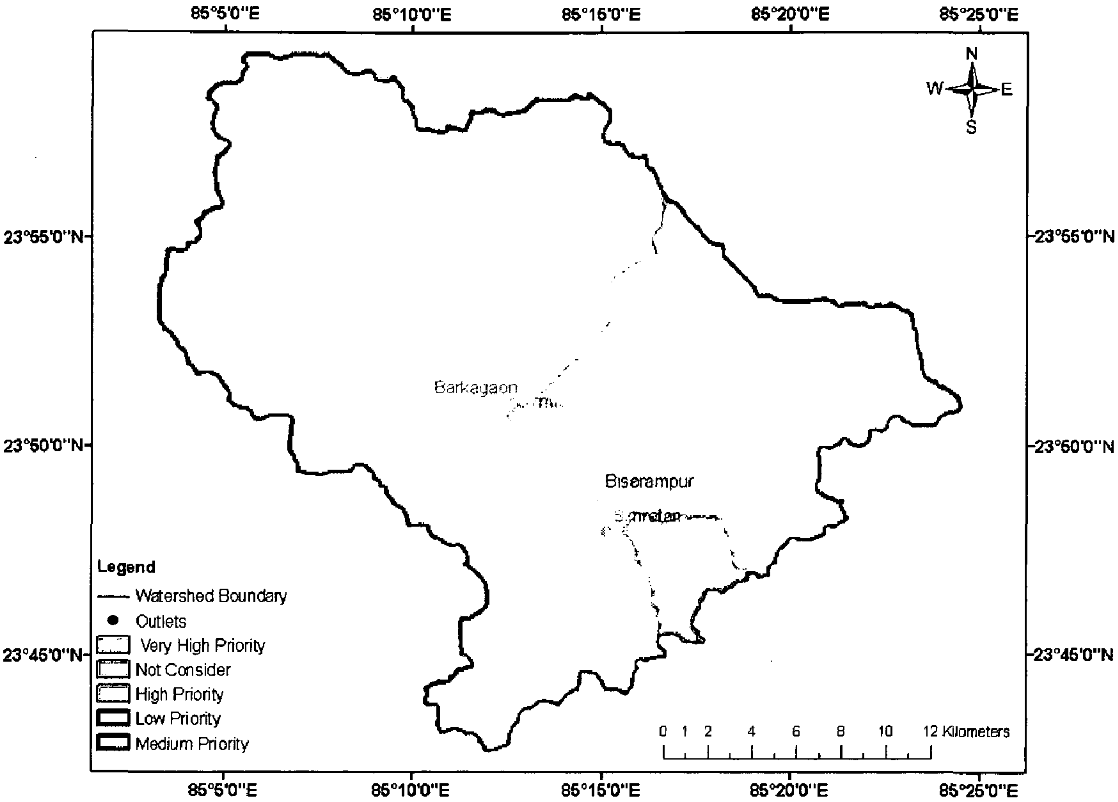

Fig 5.3a Priority of watershed based on Morphometric parameters

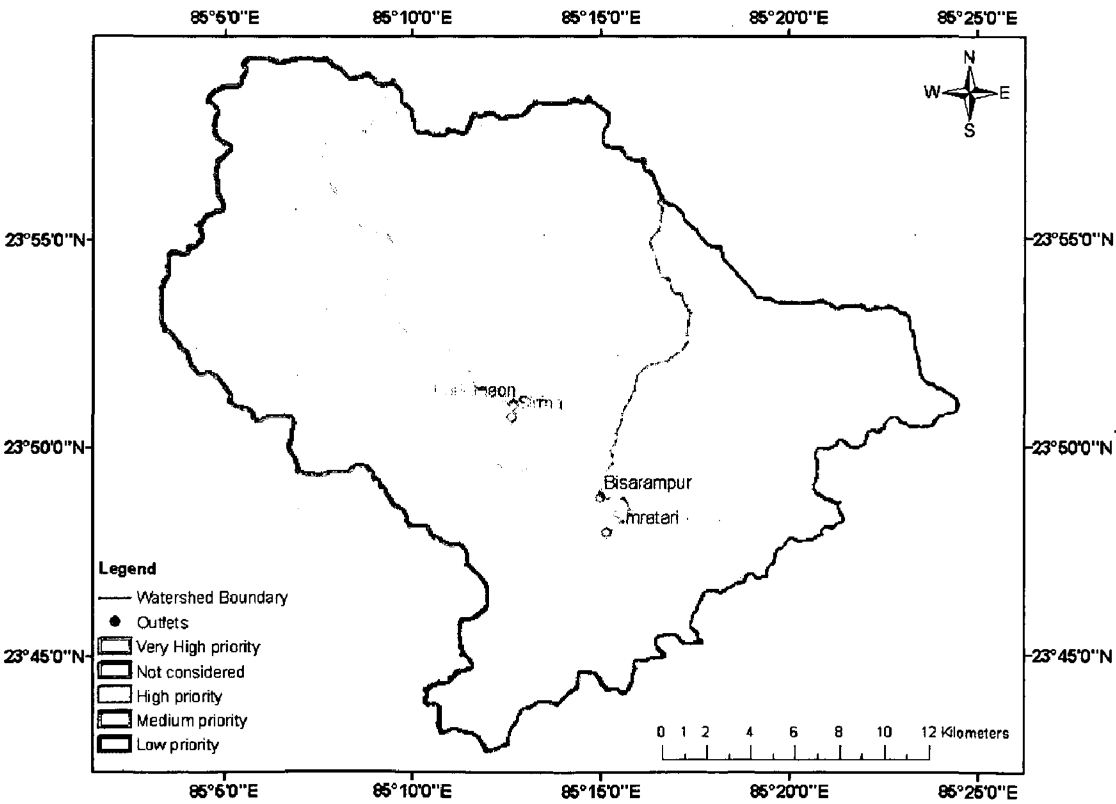

Fig 5.3b Priority of watershed based on observed sediment yield value.

high percentage of wasteland and low forested area are the main reason for medium priority of watershed 4/1. Watershed 4/2 as having low morphometric and high basin shape parameters value is prioritize as low priority. It is also justified from the land use of the watershed as it has more than 57% forested area. It has also been observed that watershed more nearer to the main outlet of the catchment is more prone to soil erosion. Attempt was made to establish relationship between average index value with land use pattern, average slope of the watersheds and the same are shown in Fig 5.4. It can be seen from Fig. 5.4 that with the increase in forested area soil erosion decreases and with the agriculture area it shows the reverse co-relation as conventional. But with percentage of average slope (rolling topography of 5 to 9%) it shows totally reverse result with general convention.

The results obtained above were compared with the observed sediment yield from these sub-watersheds. It was found that the order of priority arrived at using morphometric analysis does not correspond fully with observations. Watershed 4/4 and 4/3 are identified as very high priority and high priority watershed respectively from morphometric analysis as observed from the sediment yield data and others are showing reverse result. This is due to non-utilization of hydrologic parameters like rainfall, runoff etc., this methodology has its own limitations of quantifying absolute sediment production rate from the catchment. It is therefore found that morphometry based analysis have inherent limitations and may result in assignment of erroneous priority to watersheds. Also this method lacks details about within watershed variability of sediment source areas.

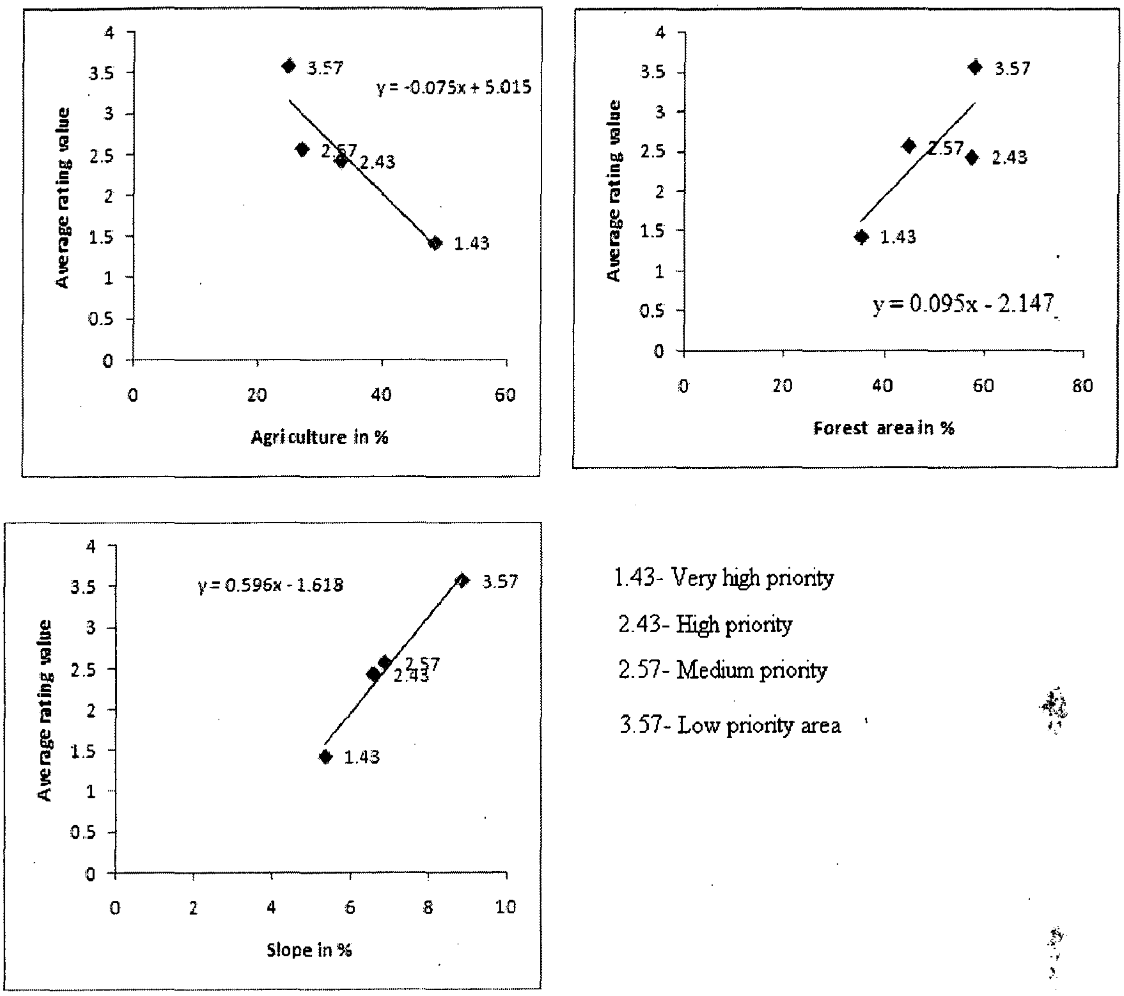

Fig 5.4: Relationship with various land use pattern and average slope and priority watersheds.

5.2 USLE based spatially distributed Watershed prioritization

5.2.1 Generation of input GIS data base: In order to compute gross soil erosion in grid sized areas, maps for factors appearing in eq. 3.1 are generated using methodology outlined in chapter 3.

5.2.1.1 Rainfall erosivity (R) factor: Annual values of rainfall erosivity factor are calculated using regression equation 3.4 following Rambabu et al. (2004) for Indian catchment. R-factor of sub watersheds for different years is shown in table 5.4. Fig 5.5 shows the R factor layer map for the year 1982 as illustration.

Table 5.4 Annual rainfall and rainfall runoff erosivity (R) factors of watersheds.

Watershed no.	Name of Gauging station	Year	Rainfall (mm)	Annual rainfall erosivity(R)	Average annual rainfall	Average annual rainfall erosivity factor (R)
4/1	Sirma	1982	649	328.12	932.40	435.81
		1983	849	404.12		
		1984	1120	507.10		
		1985	723	356.24		
		1986	1321	583.48		
4/2	Barkagaon	1980	983	455.04	855.60	406.63
		1981	773	375.24		
		1982	566	296.58		
		1983	770	374.10		
		1984	1186	532.18		
4/3	Bisarampur	1979	699	347.12	827.33	395.89
		1980	983	455.04		
		1981	769	373.72		
		1982	567	296.96		
		1983	849	404.12		
		1984	1097	498.36		
4/4	Simratari	1979	699	347.12	874.13	413.67
		1980	983	455.04		
		1981	841	401.08		
		1982	579	301.52		
		1983	849	404.12		
		1984	1098	498.74		
		1985	733	360.04		
		1986	1211	541.68		

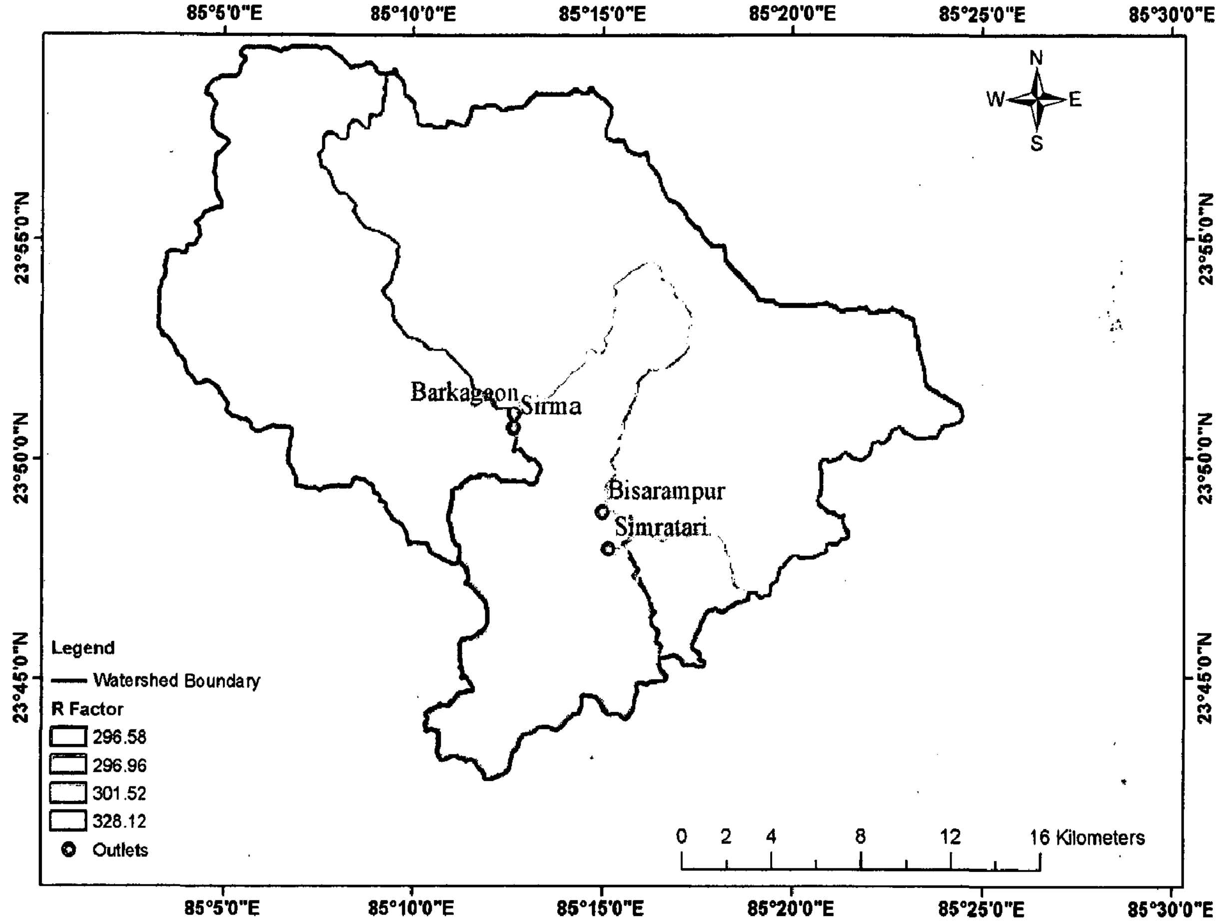

Fig 5.5: Rainfall erosivity (R) factor map of the year 1982

5.2.1.2 Soil erodibility (K) factor: Using the methodology described earlier, map for K-factor is generated. Areal extent of different soil types present in different sub-watersheds and assigned value of K-factor for each soil category is given in Table 5.5. Fig 5.6 depicts spatial distribution of different soil types for Haharo sub-catchment.

Table 5.5 Area of Soil class in percent of each watershed and K factor

Soil class	Watershed 1	Watershed 2	Watershed 3	Watershed 4	
	Area (%)	Area (%)	Area (%)	Area (%)	K factor
Loamy	2.58	3.98	10.41	14.11	0.0527
silt loam	82.61	96.02	89.59	85.89	0.0395
Silt clay loam	14.81				0.0382

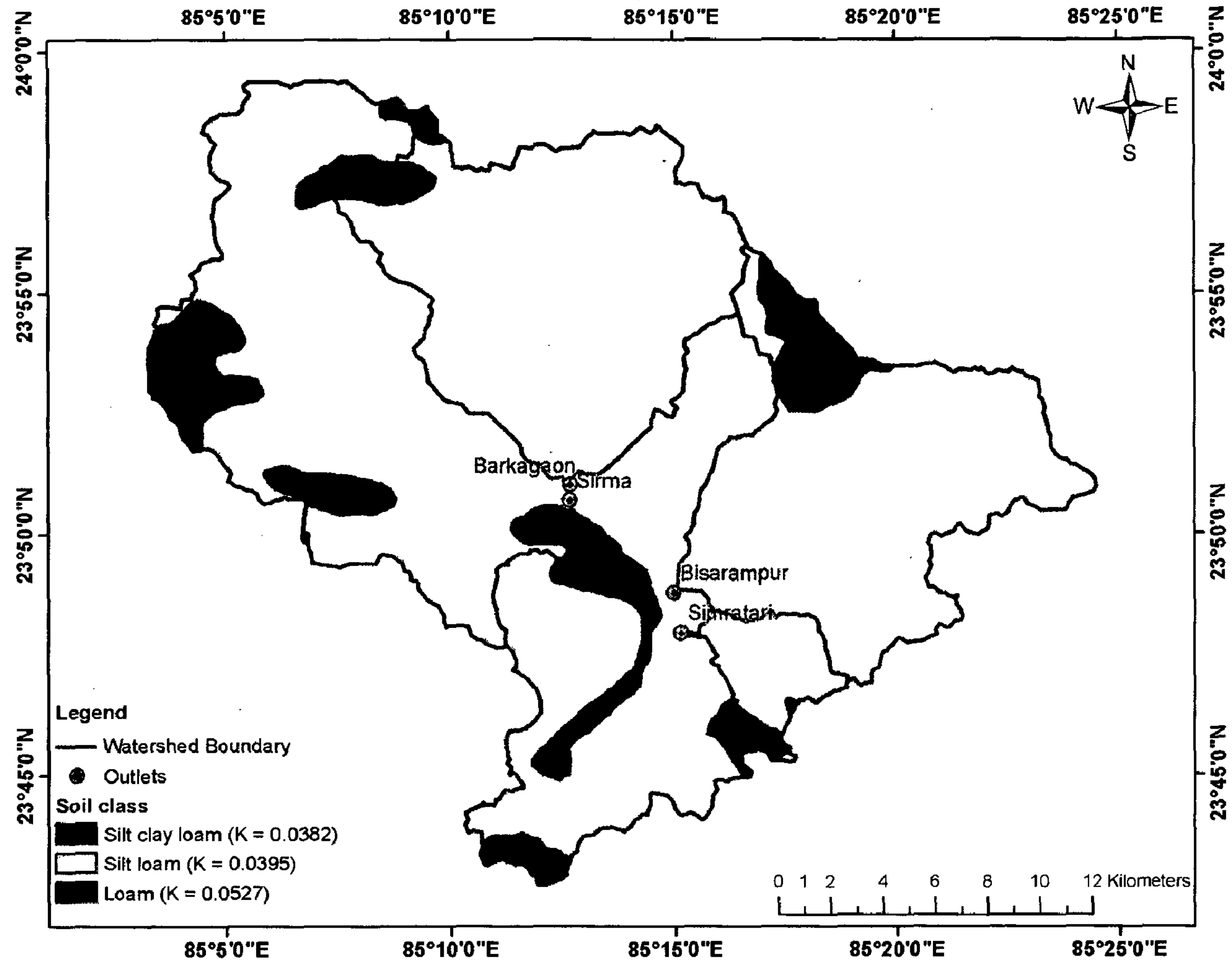

Fig 5.6: Soil erodibility (K) factor map of the Haharo sub catchment.

5.2.1.3 Length and slope Steepness or Topographic factor (LS): For computation of LS factor, a DEM of the watershed was prepared by interpolating digitized contour map and is given as Fig. 5.7. Topographic factor (LS) is calculated by eq. 3.9 following Moore & Willson (1992) for the upslope contributing area less than the channel initiation threshold and for the upslope contributing catchment area equal to channel initiation threshold for over land cell and channel cell respectively. Fig 5.8 shows the topographic (LS) factor map layer of the Haharo sub catchment.

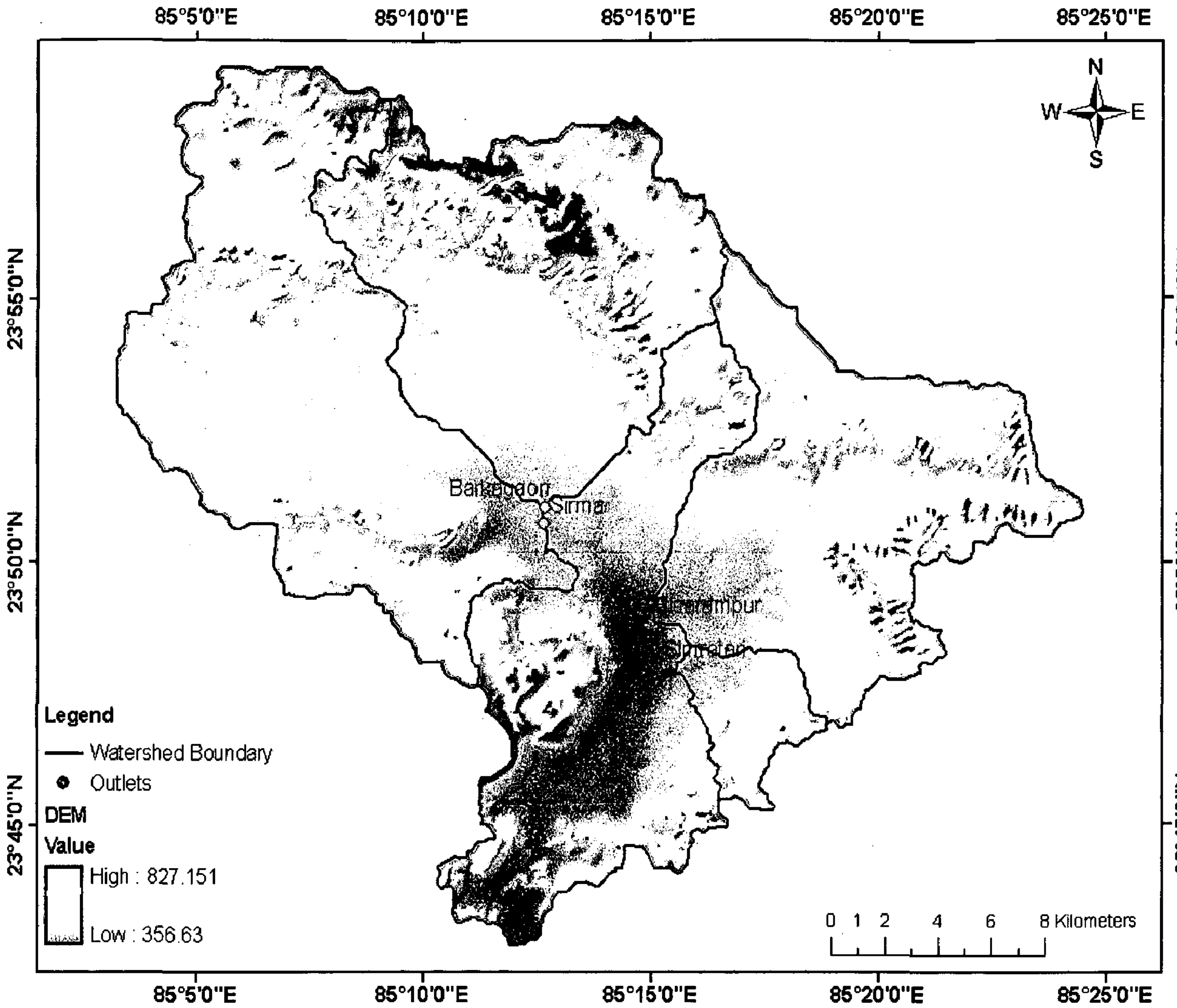

Fig 5.7 Digital elevation model of Haharo catchment

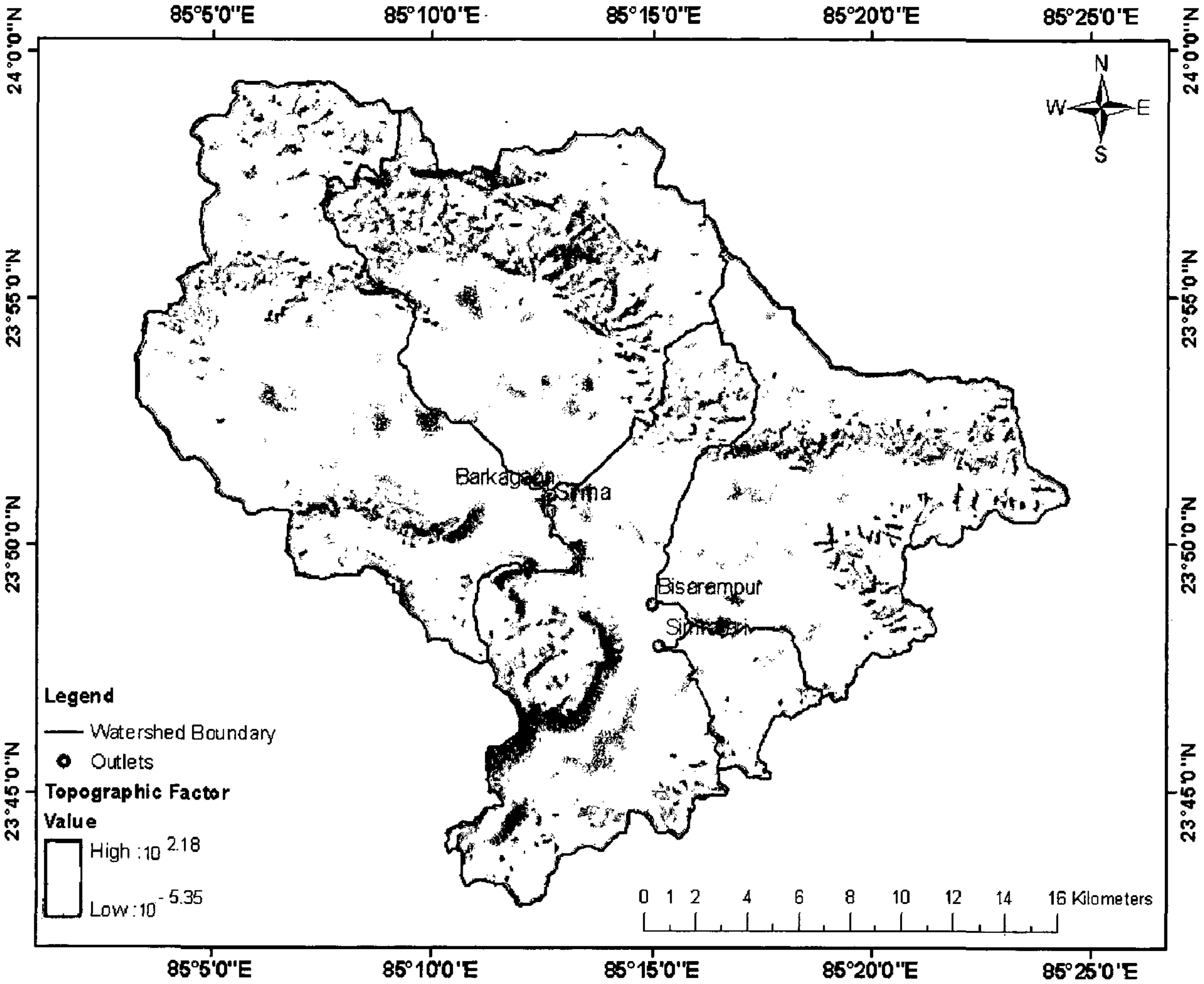

Fig 5.8 Topographic (LS) factor map layer of the Haharo sub catchment.

5.2.1.4 Cropping management (C) factor: The Haharo sub catchment was classified into degraded forest, agriculture, settlement, water body and wasteland. The percentage of various land use of the four watersheds and the values for the C factor based on the land cover categories, were assigned to individual cells was shown in Table 5.6 as proposed by Jain et al., (2001), Singh et al., (1981), Singh and Phadke, (2006), Ahmed et al., (2000) and Deore, (2005). This was then converted to the C factor layer map of USLE model in ArcGIS corresponding to C value of each cover type as described in methodology in chapter 3. Fig 5.9 shows the land use land cover map of the study catchment.

5.2.1.5 Support conservation practice factor (P): P factor map was prepared from Land use/land cover map. The Haharo sub catchment was classified into degraded forest, agriculture, settlement, water body and wasteland. Based on the management practice verified from the Google earth image that in the study area, no major conservation practices are followed except low height bund specifically these bunded fields are limited to agricultural areas only. The P factor value was taken equal to 1 for all land use and land cover categories.

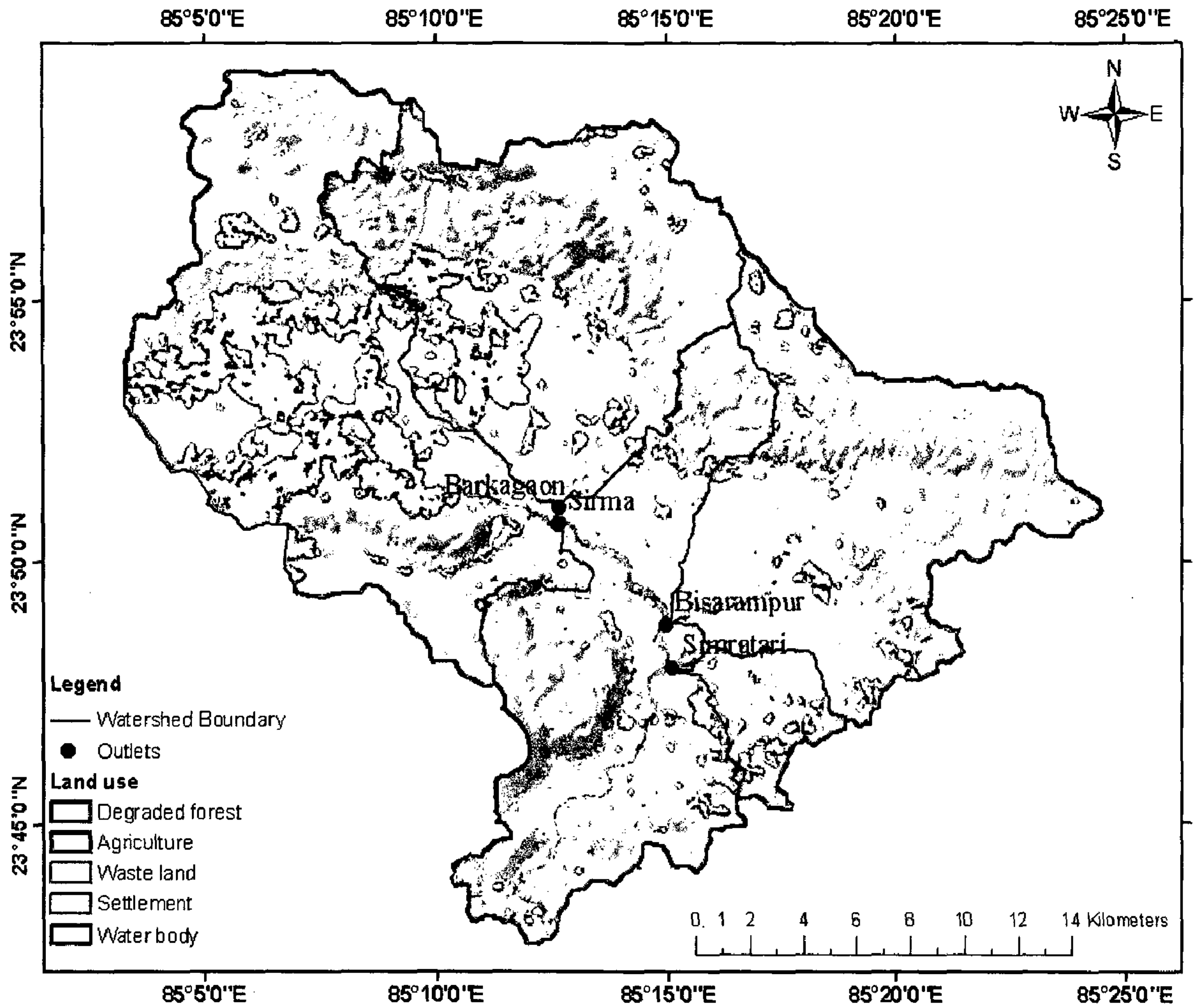

Fig 5.9 Land use land cover map of the Haharo catchment.

Table 5.6 percentage of various land use four watersheds

Land use	Watershed 1	Watershed 2	Watershed 3	Watershed 4	Value of	
	Area (%)	Area (%)	Area (%)	Area (%)	C factor	P factor
Agriculture	27.05	24.88	33.33	48.57	0.40	1.0
Water body	1.36	0.88	1.13	2.89	1.00	1.0
Waste land	25.07	14.08	3.65	4.10	0.65	1.0
Settlement	1.88	2.26	4.68	9.17	0.80	1.0
Degraded Forest	44.65	57.89	57.21	35.27	0. 03	1.0

5.2.2 Generation of erosion potential map: The K, LS, C and P map layers as shown in above figures are multiplied in ArcGIS to get erosion potential map. The composite term KLSCP represents the soil erosion potential of different grid cells of the Haharo sub catchment. Fig 5.10 shows the erosion potential map of the study area.

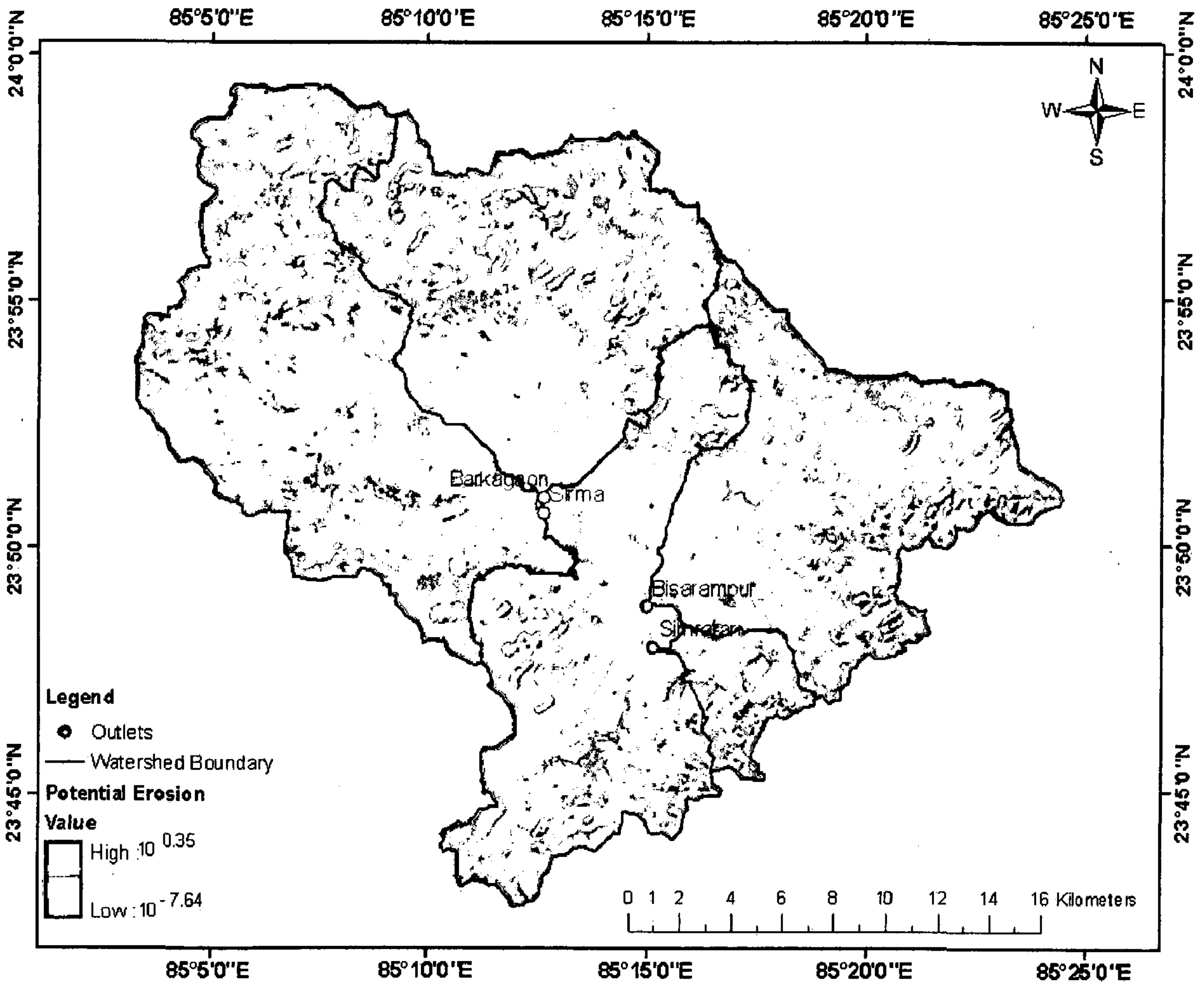

Fig 5.10 Erosion potential map of the catchment.

5.2.3 Estimation of gross erosion potential: R factor layer of each year is multiplied with the prepared erosion potential map (KLSCP) layer of the study area in ArcGIS to produce gross erosion of individual cells. Such maps were prepared for all years used for analysis. Fig 5.11a and 5.11b shows the gross erosion map for the year 1982 and 1984 as illustration. It can be seen from these figures that most areas are showing low erosion and high erosion is observed at the waste land and agricultural land areas, near the first order streams and high topographic (LS) factor value areas.

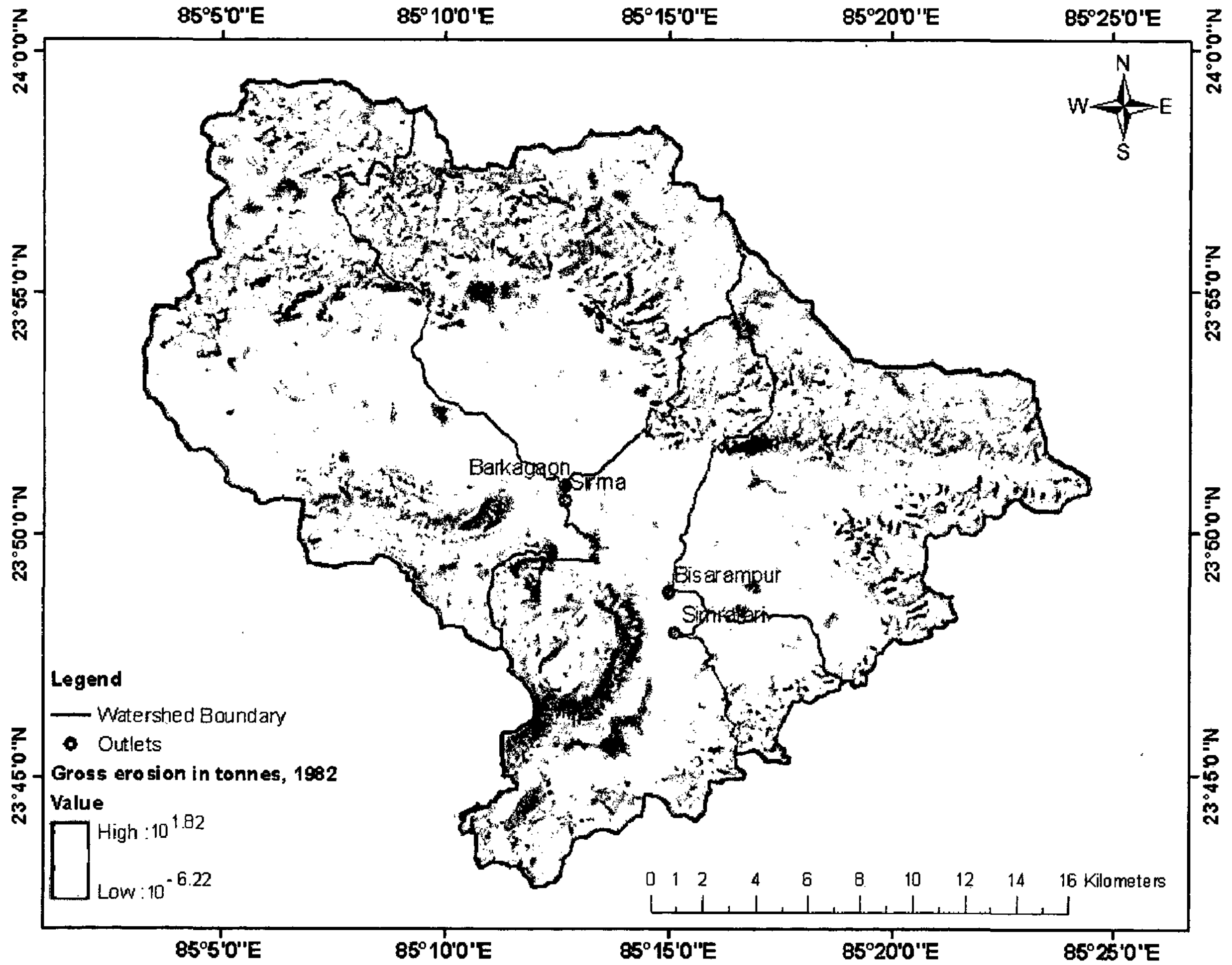

Fig 5.11a: The gross erosion map for the year 1982.

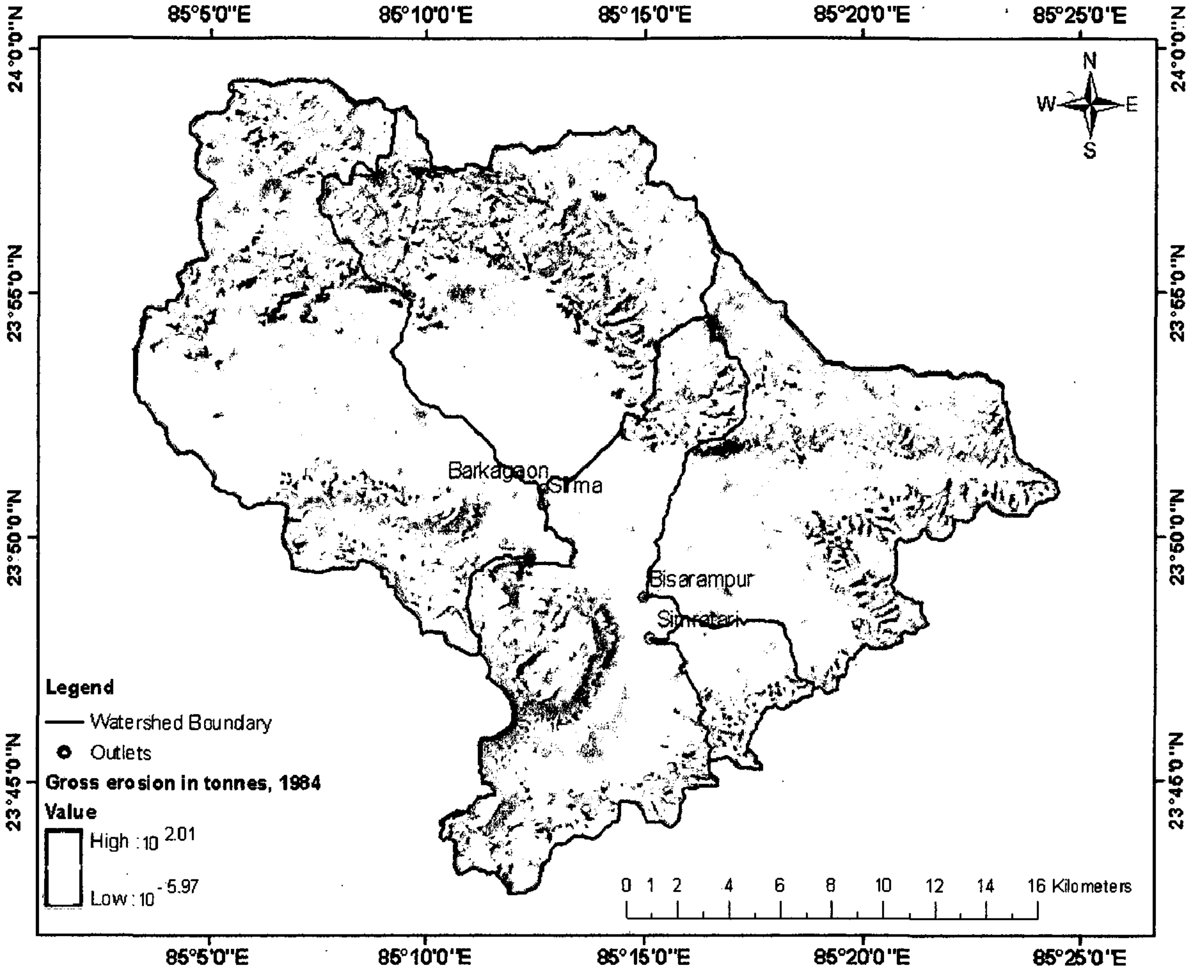

Fig 5.11b: The gross erosion map for the year 1984.

5.2.4 Computation of spatially distributed transport capacity: The Normalized Difference Vegetation Index (NDVI) layer was prepared in ERDAS imagine image processor software from the Landsat satellite image after doing geometric correction and reprojection to same coordinate system of other maps. Then the layer of spatially distributed transport capacity coefficient (K_{TC_i}) is prepared using eq. 3.12. For this the value of scaling factor β in the equation is determined through calibration. Calibrated value of the scaling factor β is found to be equal to 1 for the study area. An upslope contributing area per unit length of contour (A) and slope map were prepared in ArcGIS.

Transport capacity of overland flow was calculated for each year from the relationship stated in equation 3.10 by multiplying the R factor of each year with other factors appearing in eq. 3.10 in ArcGIS. Fig 5.12a and 5.12b shows the transport capacity of overland flow map for the year 1982 and 1984 as illustration. As can be seen from these figures, the high transport capacity occurs in areas having steep slopes and in the channel cells.

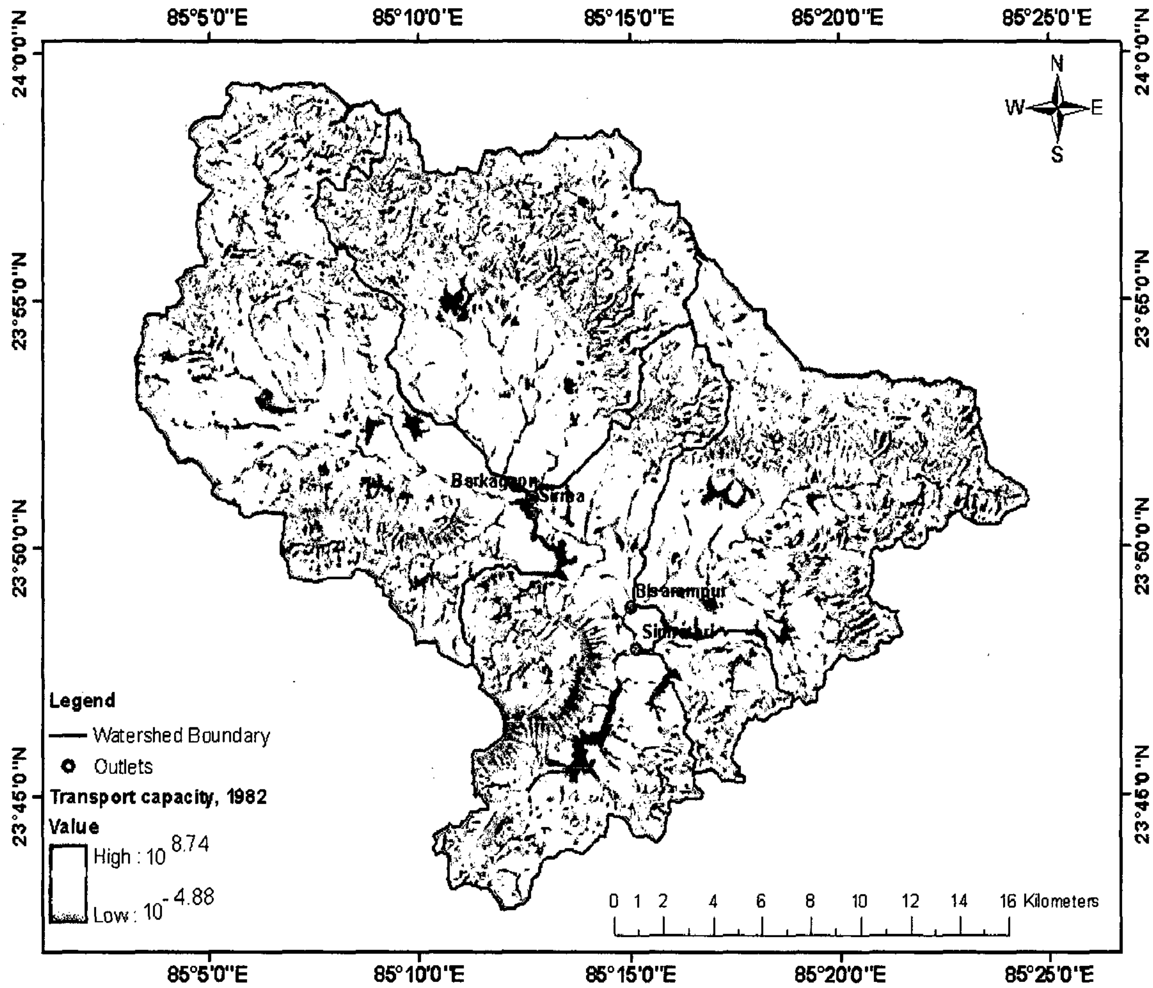

Fig 5.12a: The transport capacity of overland flow map for the year 1982.

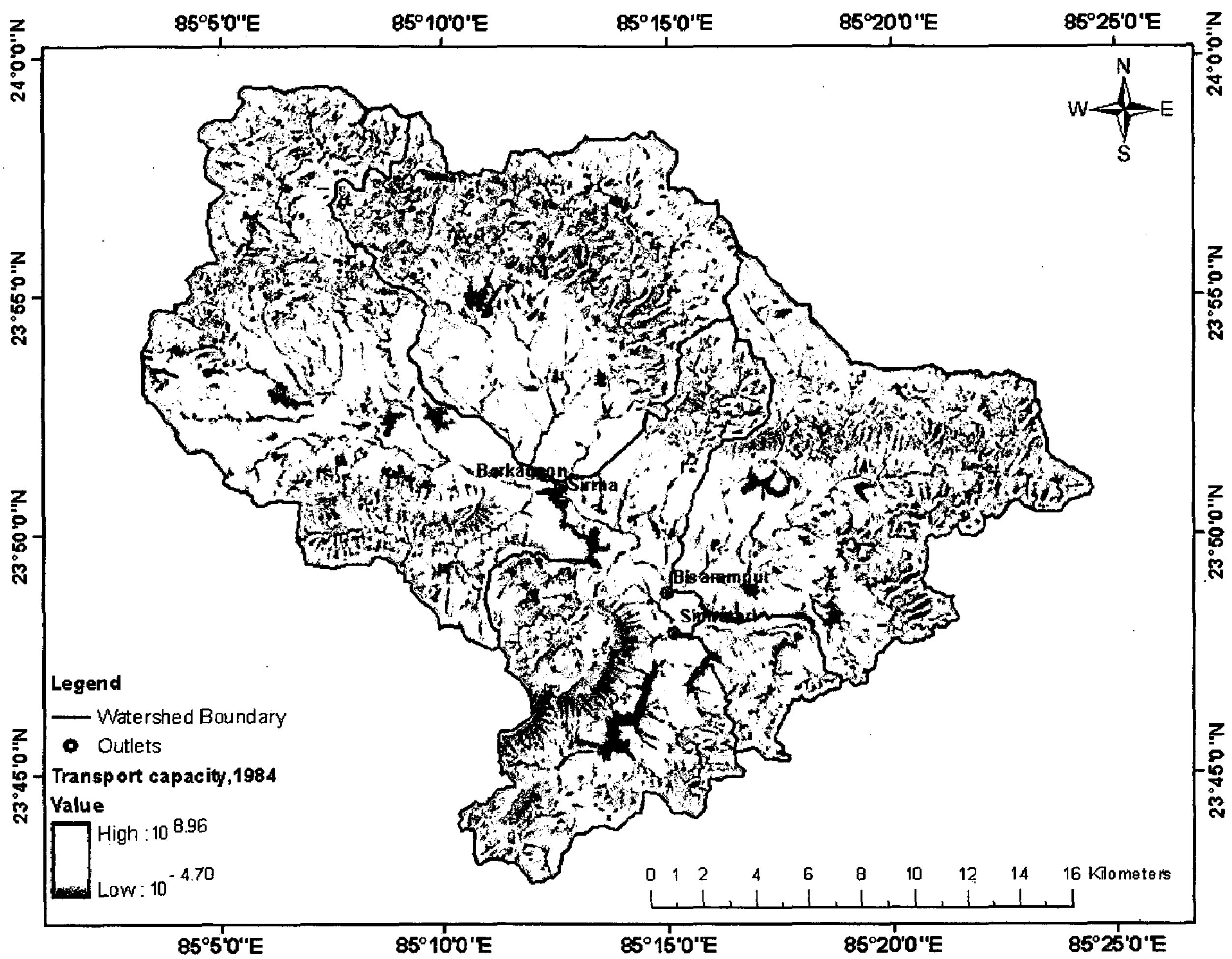

Fig 5.12b: The transport capacity of overland flow map for the year 1984.

5.2.5 Computation of transport limiting sediment accumulation and outflow: Gross erosion and transport capacity of overland flow map is created using the equations 3.1 and 3.10 respectively as described above for each year. Also a flow direction layer was prepared from generated DEM in ArcGIS. Using Eq. 3.13 and 3.14, the gross erosion was routed following derived drainage direction limited by transport capacity computed earlier (Tarboton, 1991) in ArcGIS to get sediment yield at the outlets of the sub-watersheds and catchment. Above procedure produces maps of sediment deposition and transport limited sediment accumulation (sediment yield). This process was repeated for all years of data used in the analysis. Fig 5.13a and 5.13b shows the sediment yield map for the year 1982 and 1984 as illustration. Comparison of predicted sediment yield with the observed sediment yield for all year from 1979 to 1986 for each watershed is shown in Table 5.7. It is seen from Table 5.7 that the percentage of error in the estimated sediment yields from the observed values varies in the range of (-) 23.22% (over prediction) to (+) 36.12% (under prediction) excluding data point for the year 1981 of watershed no 4/3 and for the year 1986 of watershed no 4/4 showing larger variations (Table 5.7) and are ascribed to probable uncertainties in observations. The under-prediction or over-prediction limits for the USLE model simulation are within ±40% from the measured values and are considered as the acceptable levels of accuracy for the simulations. The USLE model was also validated by plotting the estimated sediment yield against the observed values of sediment yield as shown in Figure 5.14. It can be seen from Figure 5.14 that the points obtained by plotting the estimated values against the observed values are very close to 1:1 line indicating that their differences are not significant. The best fit line between the data have high coefficient of determination (R^2 value) of 0.868 which shows that they are closely related by a straight line. Thus the present method can be successfully used for estimation of sediment yield from Haharo sub-catchment.

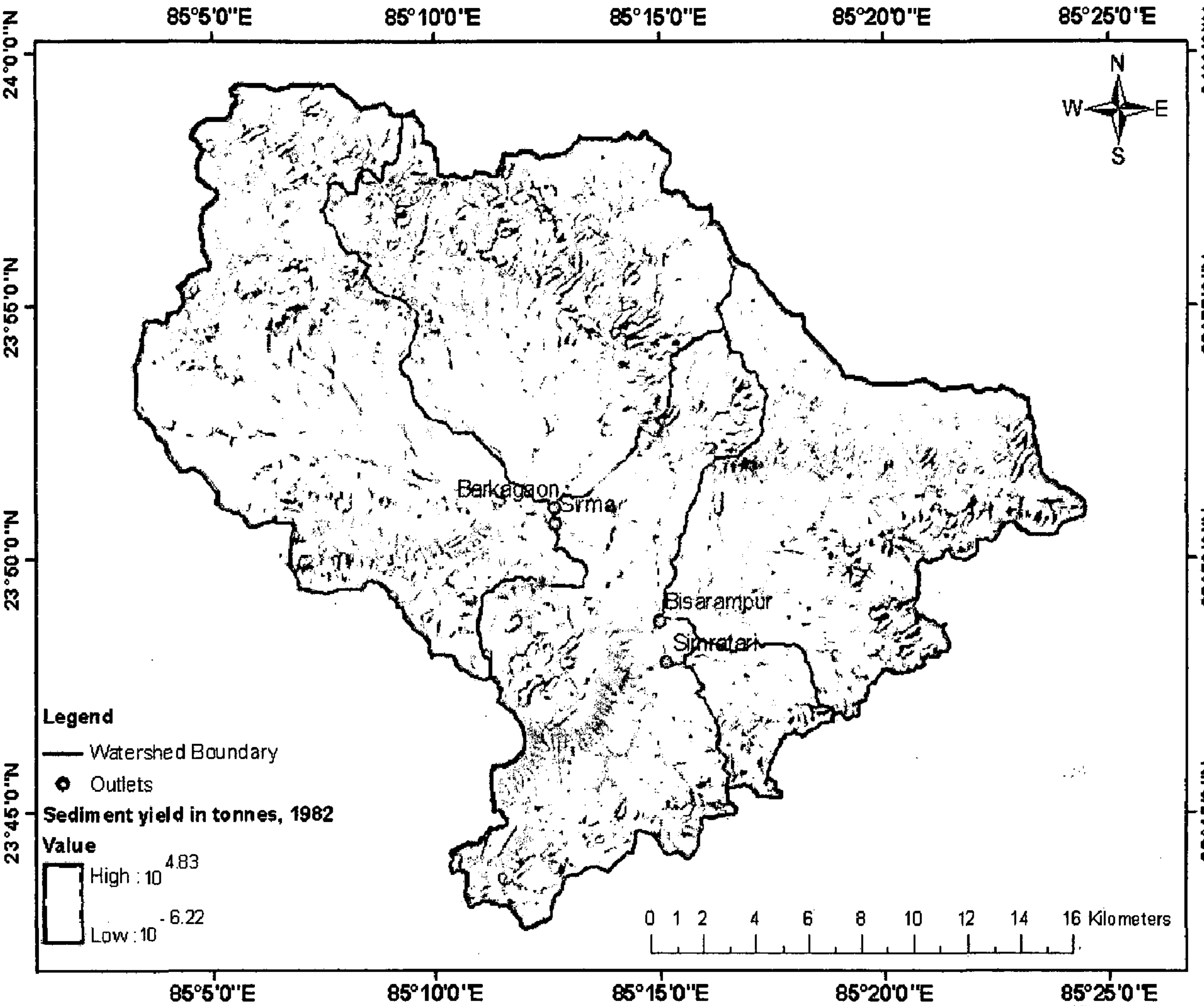

Fig 5.13a: Sediment outflow from each grid for the year 1982.

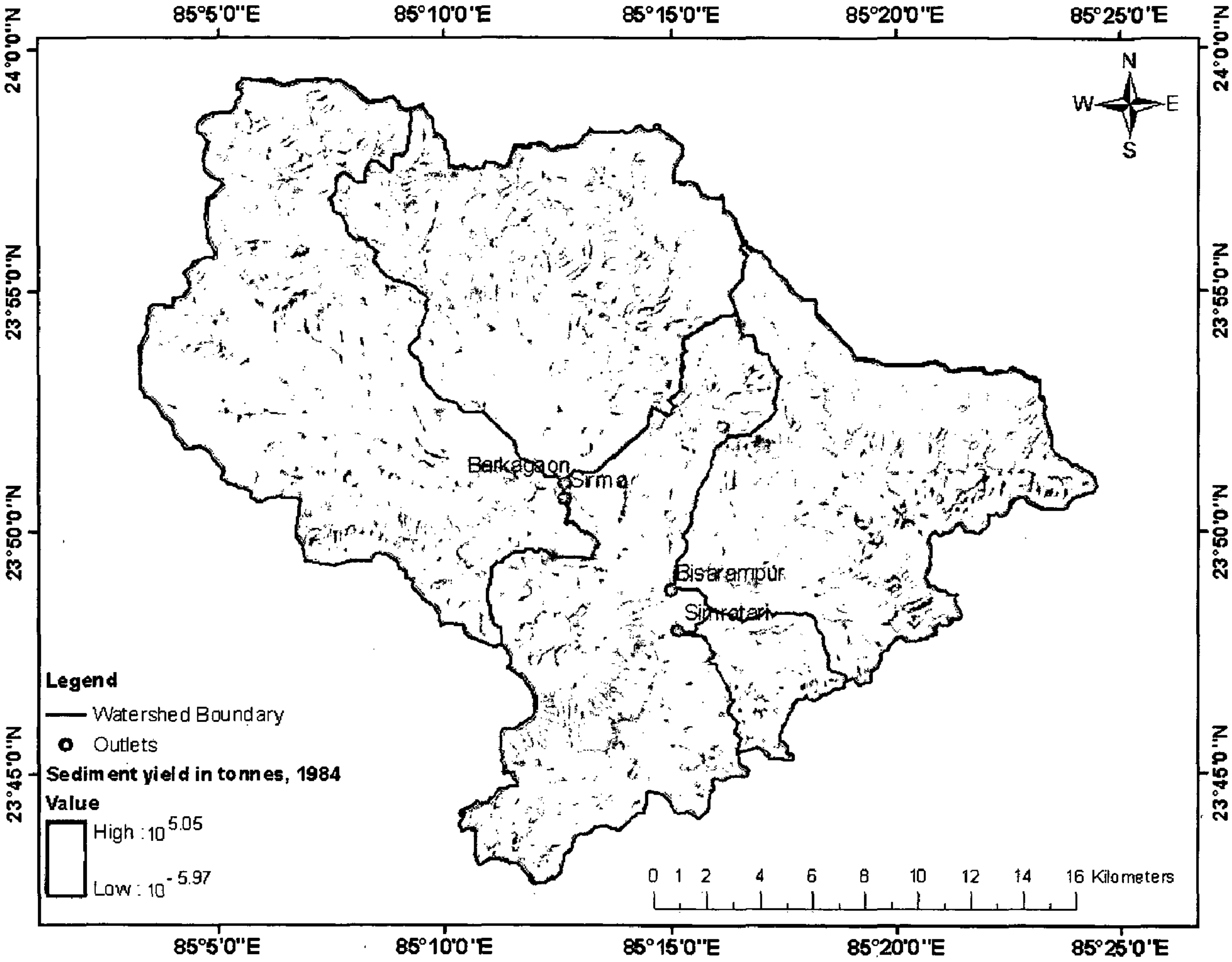

Fig 5.13b: Sediment outflow from each grid for the year 1984.

Table 5.7 comparisons between observed and predicted value for all the watersheds.

Watershed no.	Name of Gauging station	Year	Rainfall (mm)	Annual rainfall erosivity(R)	Observed sediment yield(t)	Predicted sediment yield(t)	%Error
4/1	Sirma	1982	649	328.12	17950.1	17137.1	4.53
		1983	849	404.12	17129.0	21106.7	-23.22
		1984	1120	507.10	33570.5	26486.8	21.10
		1985	723	356.24	19247.4	18607.1	3.33
		1986	1321	583.48	39633.2	30475.0	23.11
4/2	Barkagaon	1980	983	455.04	37111.3	24115.8	35.02
		1981	773	375.24	24151.8	19886.7	17.66
		1982	566	296.58	15474.4	15718.0	-1.57
		1983	770	374.10	17785.3	19826.4	-11.48
		1984	1186	532.18	27391.7	28203.7	-2.96
4/3	Bisarampur	1979	699	347.12	26487.4	19919.0	24.80
		1980	983	455.04	39009.4	26112.0	33.06
		1981	769	373.72	13416.5	21446.6	-59.85
		1982	567	296.96	20876.9	17041.6	18.37
		1983	849	404.12	20836.2	23188.5	-11.29
		1984	1097	498.36	26731.3	28598.0	-6.98
4/4	Simratari	1979	699	347.12	3739.2	3470.0	7.20
		1980	983	455.04	5403.2	4549.0	15.81
		1981	841	401.08	4572.6	4008.6	12.33
		1982	579	301.52	4718.2	3014.1	36.12
		1983	849	404.12	4641.1	4039.8	12.96
		1984	1098	498.74	5132.1	4984.2	2.88
		1985	733	360.04	3690.6	3604.2	2.34
		1986	1211	541.68	2626.0	5416.0	-106.25

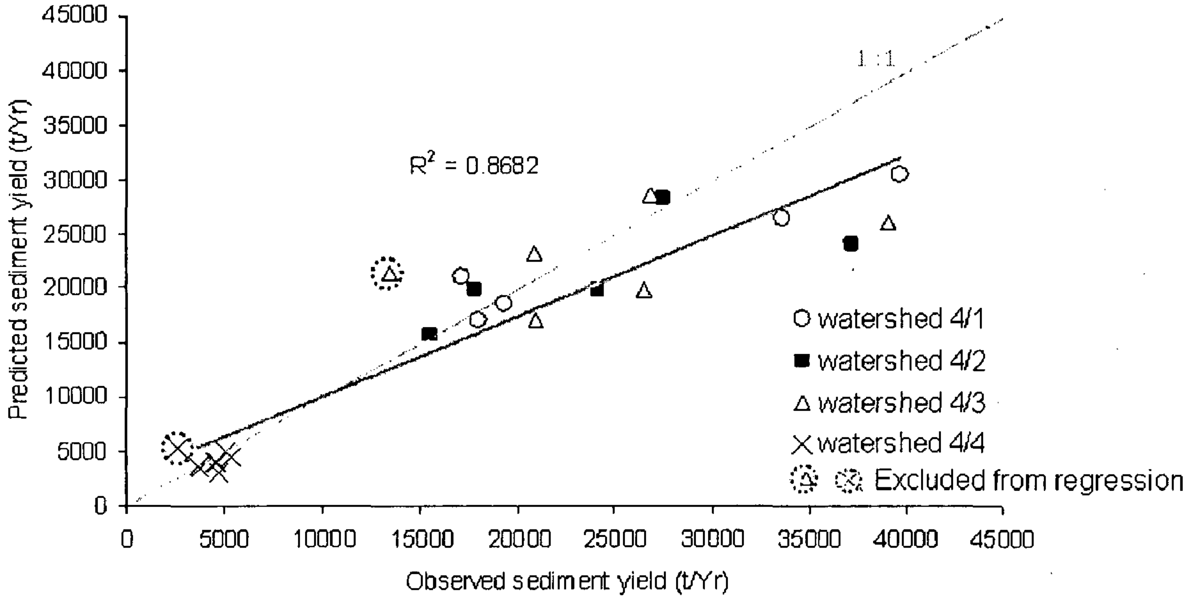

Figure 5.14 Plotting of predicted values against the observed values

5.2.6 Identification of priority areas (sediment source and sinks): A net erosion map is calculated by subtracting the deposition rates for each grid cell from the gross erosion rates for each grid cell. Negative values on the net erosion map are the areas where sediment deposition occurs (i.e. true sediment deposition), whereas positive values correspond to grid cells with net sediment erosion. Consequently, different total values of erosion and net soil loss can be defined. Finally, annual sediment yields estimated on a cell basis and all the grid cells of the watershed was regrouped into the following scales of priority: Slight (0 to 5 t $ha^{-1}yr^{-1}$), Moderate (5 to10 t ha−1yr−1), High (10 to 20 t ha−1yr−1),Very High (20 to 40 t ha−1yr−1), Severe (40 to 80 t ha−1yr−1) and Very Severe (>80 tha−1yr−1) erosion classes as per the guidelines suggested by Singh et al., (1992) for Indian conditions. Fig 5.15a, 5.15b, 5.15c showing the net erosion for the year 1982, 1983 and 1984 respectively as illustration.

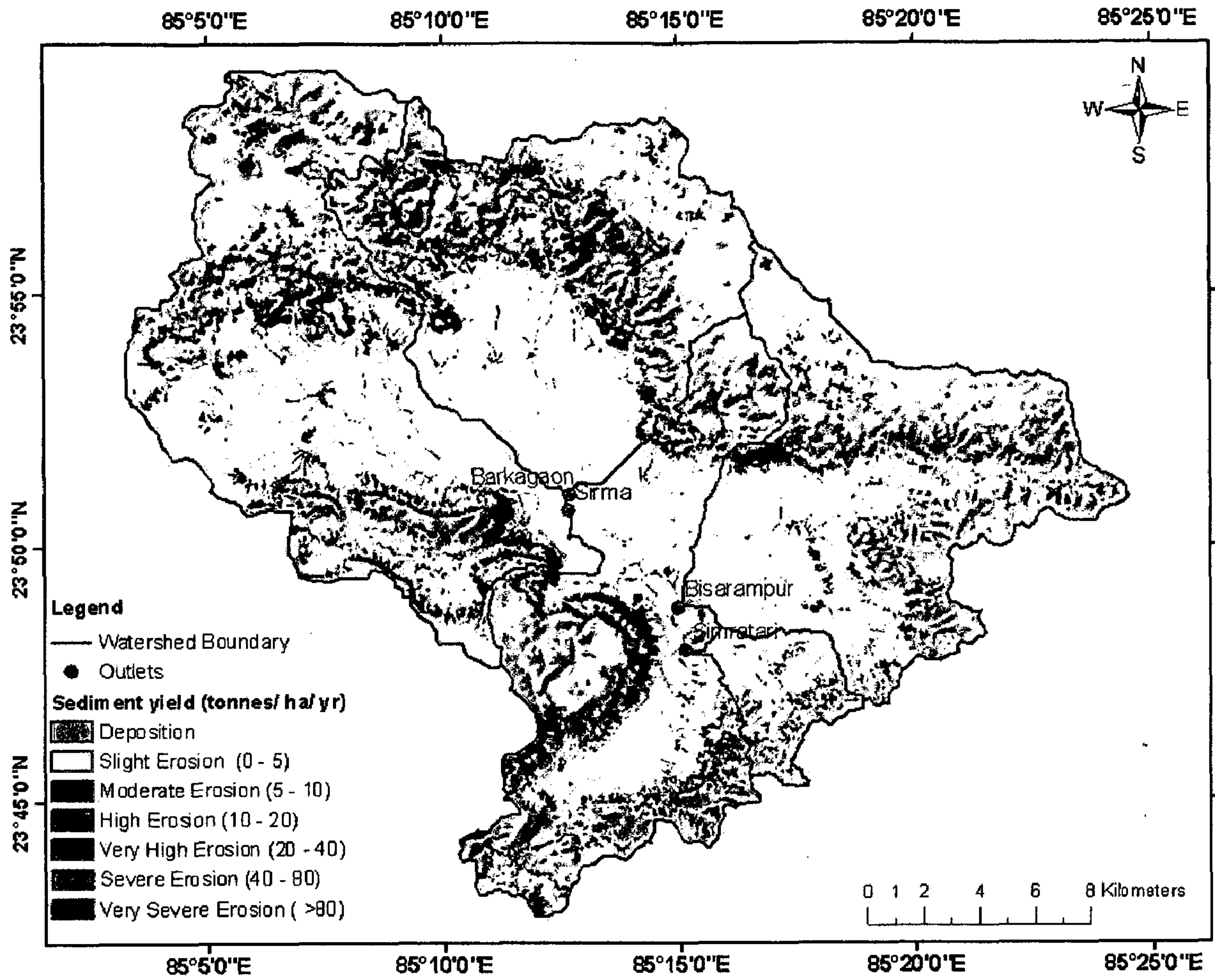

Fig 5.15a Net erosion map for the year 1982.

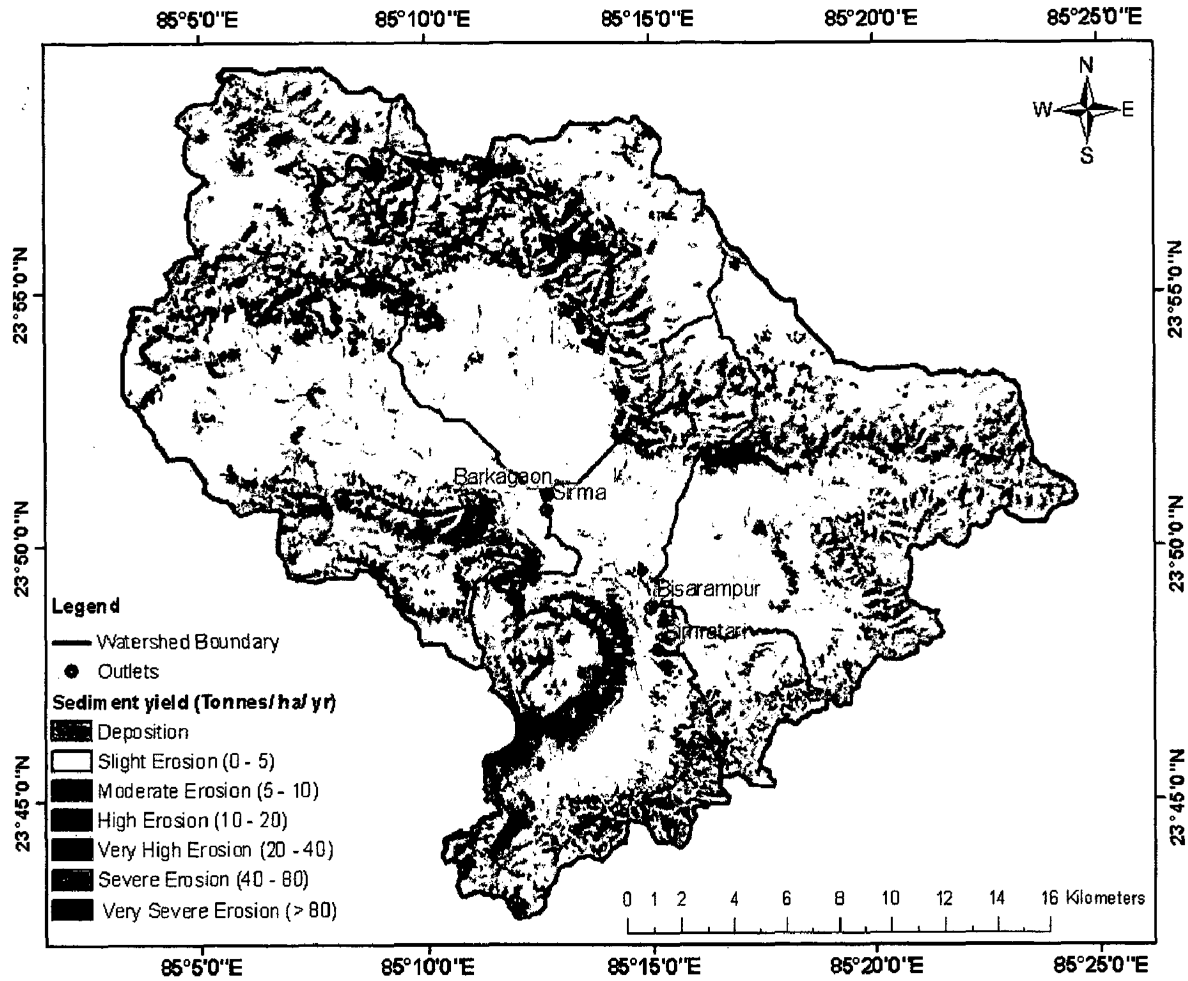

Fig 5.15b Net erosion map for the year 1983.

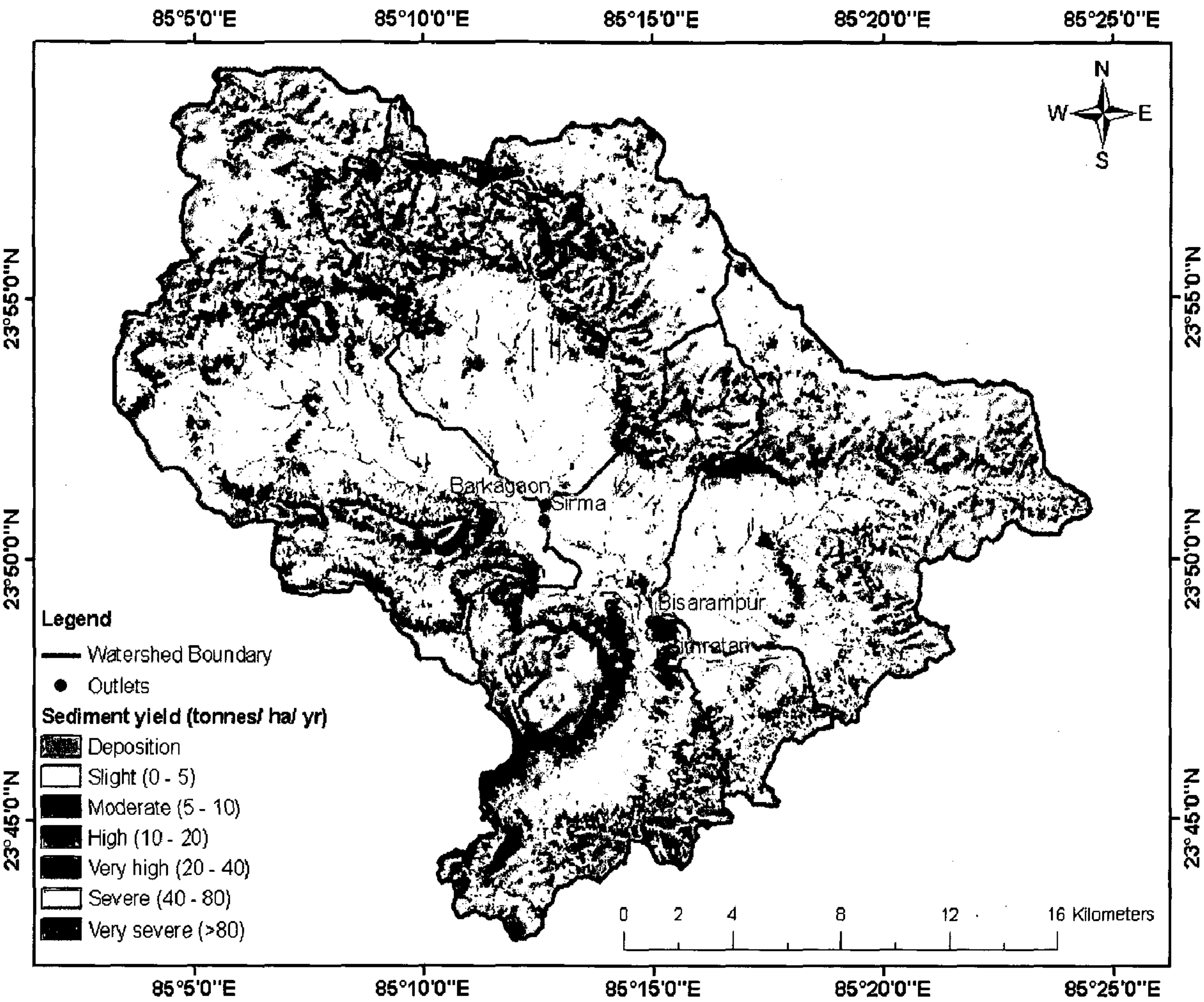

Fig 5.15c: Net erosion map for the year 1984.

5.2.7 Discussion: The above Figures5.15a, 4.15b and 5.15c show the magnitude and spatial distribution of net soil erosion and net deposition in the Haharo watershed on a cell basis. Observation shows that the areas with steep slopes with agriculture and waste land as land use and areas having first order stream are identified as high true net erosion zone i.e. more than 5 t $ha^{-1}yr^{-1}$, indicated that they have undergone severe erosion due to undulating topography and faulty method of cultivation practices. In fact, topography plays a critical role in controlling soil movement in a watershed. From Table 5.8 it is observed that the area under slight erosion class is ranging from 75% to 87%. Total areas covered by moderate, high, very high, severe and very severe erosion zones are varying from 12% to 25% and can be called as under critical erosion prone area (Table 5.9). Therefore, these areas need immediate attention from soil conservation point of view. Depending upon priority levels, the watershed area should be treated with suitable vegetative and structural measures. For effective watershed planning, there must be a close coordination of vegetative and structural control measures and best combination should be decided to tackle the problems of watershed in an integrated manner. Table 5.10 shows the total sediment yields from the USLE model in Million Tons for the year 1979 to1986.

Table 5.8 Area under different classes of soil erosion in Haharo watershed for the year 1979 to1986.

Sediment yield in tonnes/ ha	1979	1980	1981	1982	1983	1984	1985	1986
	% area	% area	% area	% area	% area	% area	% area	% area
deposition	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
0-5	85.04	80.1	83.27	86.90	82.73	77.77	82.89	75.06
5-10	7.93	10.55	8.88	6.79	9.19	11.65	9.22	12.82
10-20	3.16	4.50	3.61	2.82	3.74	5.28	3.62	6.22
20-40	1.78	2.19	1.94	1.62	1.99	2.38	1.95	2.64
40-80	0.92	1.22	1.04	0.80	1.08	1.36	1.03	1.52
> 80	0.33	0.59	0.42	0.24	0.45	0.73	0.44	0.90

Table 5.9 Percent area needs priority attention in Haharo watershed for the year 1979 to1986.

	Sediment yield in tonnes/ ha	1979	1980	1981	1982	1983	1984	1985	1986
Prioritization	deposition	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
	0-5	85.04	80.1	83.27	86.90	82.73	77.77	82.89	75.06
Area requiring attention	>5	14.12	19.05	15.90	12.27	16.45	21.40	16.26	24.11

Table 5.10 Total sediment yield of Haharo watershed for the year 1979 to1986.

Year	1979	1980	1981	1982	1983	1984	1985	1986
Sediment yield in Million tonnes	43.74	57.33	48.24	41.36	50.93	63.90	44.82	73.53

CHAPTER 6

SUMMARY AND CONCLUSIONS

Deterioration of soil in the study area can be controlled effectively by adopting watershed treatment measures if spatial distribution of soil erosion is known. In the present study vulnerable areas contributing to soil erosion in spatial domain have been determined using two different approaches i.e. Morphometric analysis and USLE model coupled with transport limited sediment delivery. Geographic Information System (GIS) ArcGIS was used to efficiently manage spatially discretized data such as topography, soil, land use/ land cover etc, for sediment yield modeling and for quantification of heterogeneity in the topographic and drainage feature of a catchment. ERDAS imagine image processor software was used to analyze remote sensing data for generating land use/land cover data and other factors. The use of GIS and remote sensing data enabled the quantitative estimation of morphological parameters and determination of the spatial distribution of the USLE parameters.

Various thematic layers representing different factor of USLE were generated and overlaid to compute spatially distributed gross soil erosion maps for the Haharo sub-basin, DVC, (India). An empirical relation is proposed and demonstrated for its usefulness for computation of land vegetation dependent transport capacity factor by linking it with normalized difference vegetation index (NDVI) derived from satellite data. The concept of transport limited accumulation was formulated and used in ArcGIS for generating maps for transport capacity, gross soil erosion was routed to the catchment outlet using hydrological drainage paths resulting in generation of transport capacity limited sediment outflow maps. Such maps provide the amount of sediment flowing from a particular grid in spatial domain. A comparison of the observed and computed sediment yield reveals the proposed method to compute sediment yield with reasonable accuracy. Further, maps for deposition of sediment were also generated for identification of areas vulnerable to silt deposition in the catchment. The deposition of sediment was found to occur at grids where transport capacity was low, mostly lying by the sides of some of the stream reaches. Superimposition of sediment deposition map over gross erosion map led to areas vulnerable to soil erosion and deposition. Such maps are important in planning conservation and control measures.

The proposed USLE based approach was found to be mimicking sub-watershed-scaled soil losses quite realistically and logically thereby suggesting its immense application potential for priority area identification in the test watershed. As, in contrast to the proposed USLE model, the morphometric analysis assigned reverse priorities to about 50% of the test sub watersheds therefore it is concluded that the morphometric analysis method of watershed prioritization techniques could not account for realistically the impact of varied rainfall, land uses and soil types, found in the subwatersheds, on their soil erosion generating potential. Thus the proposed USLE based modeling approach proved useful tool for identification of priority areas, for soil management, within the test catchment.

Based on present study, following specific conclusions can be drawn:

1. Remote sensing and GIS can play significant role in generating thematic inputs for models used for erosion estimation and in prioritization of watersheds.
2. Morphometric analysis based approach is found not to realistically identify vulnerable watersheds.
3. Proposed empirical relation for computation of land vegetation dependent transport capacity factor can be used to compute spatially distributed value of parameter K_{TC} indicates strong influence of vegetative cover on reduction of transport capacity of the cell areas.
4. Areas showing higher transport capacity coincide with steep head water areas and channel areas in the catchment and smaller transport capacity values are mainly associated with the overland regions that surround the confluence of the main stream with the smaller order streams and flatter land areas found in the cultivated valley lands in the catchment.
5. The proposed method produces satisfactory estimates of sediment outflow from catchment with ± 40% deviation from observations.
6. Spatially computed soil removal from most of the catchment area is limited to 0-5 tons/hectare/year except to few pockets which produce more sediment yield.
7. Deposition of sediment resulted at grids where transport capacity was low, mostly lying by the sides of some of the stream reaches in valleys and at places where steep slope converges into flatter slopes.

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