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# THE QUANTITATIVE EVALUATION OF SOIL EROSION: A CASE STUDY OF UPPER BHIMA BASIN

By


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# C E R T I F I C A T E

This is to certify that, Dr. Sachin J. Deore (Professor, Department of Geography, S.N.D.T. Women's University) has successfully carried out the project work entitled "**The quantitative evaluation of soil erosion: A case study of upper Bhima Basin**" towards fulfillment of Major Research Project, funded by University Grants Commission, New Delhi. This work has been carried out at the Department of Geography, S.N.D.T. Women's University, Pune Campus, Pune.

This report contains the bonafide work carried out by him and the data supplemented from different sources is duly acknowledged.

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**ABBREVIATIONS:**

1. (AHP): Analytical Hierarchy Process
2. (AICRPDA): All India Co-ordinated Research Project on Dryland Agriculture
3. (AnnAGNPS): Annualized Agricultural Non- Point Source
4. (ARS):Agricultural Research Service
5. (ASTER DEM): Advanced Spaceborne Thermal Emission And Reflection Radiometer
6. (CCT): Continuous Contour Trenching
7. (CEI): Composite Erosion Index
8. (COWDEP): Comprehensive Watershed Development Programme
9. (CSWCRTI): Central Soil & Water Conservation Research & Training Institute
10. (Dd): Drainage Density
11. (DEM): Digital Elevation Models
12. (EI): Erosion Index
13. ($EI_{30}$): Erosivity Index
14. (EUROSEM): European Soil Erosion Model
15. (GIS): Geographical Information System
16. (ICAR): Indian Council of Agricultural Research
17. (IMD): India Meteorological Department
18. (LU/LC): Landuse / Landcover
19. (MERI): Maharashtra Engineering Research Institute
20. (MLH): Maximum Likelihood Algorithm
21. (MMF): Morgan-Morgan-Finney
22. (NBSSLUP): National Bureau of Soil Survey and Land Use Planning
23. (NRSC): National Remote Sensing Centre
24. (NWDPRA): National Watershed Development Program for Rainfed Agriculture
25. (ORP): Operational Research Projects
26. (Re): Elongation Ratio
27. (SCS): Soil Conservation Service
28. (SWAT): Soil and Water Assessment Tool
29. (USDA): U.S. Department of Agriculture
30. (USLE):Universal Soil Loss Equation
31. (WEPP): Water Erosion Prediction Project
32. (WRD): Water Resource Department

# CHAPTER 1: INTRODUCTION

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# CHAPTER 1

# INTRODUCTION

## 1.1. Introduction:

Soil is the fragile layer of the earth that anchors life. It supports the complex ecosystems on the earth and provides resources to man. Thus, proving to be of crucial importance to mankind. An increased demand of human being, for the sake of development is becoming very harmful to this crucial resource. For food production, infrastructural development, industrial set up, etc. the forests are being cleared rapidly. This results into the loosening and removal of the soil particles and ultimately bare open to the direct impact of wind and water. This accelerates the process of detachment, removal and transportation of soil particles leading to loss of the soil. The soil loss results into massive destruction of soil. It is one of the major cause of soil degradation.

The degradation of soil is a global issue. An estimated 175 million ha of lands in India, constituting about 53 % of total geographical area, suffers from deleterious effect of soil erosion and other forms of land degradation. Active erosion caused by water and wind alone accounts for 150 million ha of land, which amounts to a loss of about 5.3 metric tons of sub-soil. In addition, 25 million ha have been degraded due to ravines and gullies, shifting cultivation, water logging, salinity or alkalinity.

Scientific management of soil, water and vegetation resources on watershed basis is, therefore, very important to arrest rapid siltation in rivers, lakes and estuaries. A watershed is used as a unit for planning and management of land, water and other resources, and all inter-related factors such as physical, biological, technological, economic, socio-cultural and managerial etc. are considered together in a system framework (Singh, 1991).

It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds , which contribute to the maximum sediment yield would determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme.

There is considerable potential for the use of GIS technology as an aid to soil erosion inventory with reference to soil erosion modeling and erosion hazard assessment. A number of modeling approaches both empirical and physical processed – based are in vogue to quantitatively assess erosional soil loss. Input parameters in terms of spatial information on landuse / land cover could be obtained from multi-spectral RS data. GIS technique is very effective tool for integrating above inputs for modeling erosional soil loss.

Watershed has emerged as the focus of planning for agriculture and rural development especially for the fragile dryland, hilly and other stress areas since early 1980s. India is one of the very few developing countries in the world, which recognized the importance of conservation of soil as early as 1952 when the action for establishment of research and training facilities was initiated.

The All India Co-ordinated Research Project on Dryland Agriculture (AICRPDA) was launched with 23 cooperative centers representing arid to sub-humid climates and three major soil groups viz. alluvial, red and black soils in the country. During the process of formulation of the fifth Five Year Plan in 1972, Indian Council of Agricultural Research (ICAR) started three Operational Research Projects (ORP) pertaining to watershed management in the UP hills, Haryana and Karnataka. The basic lessons learnt through the implementation and evaluation of the ORPs on watershed were (i) the priorities perceived by the development agency are not necessarily the priorities set by the people inhabiting the watershed, (ii) the people in the watershed will participate emotionally if their economic security is assured, and (iii) people were willing to share the cost of development – through voluntary labour and other inputs if they are assured of the benefits accruing especially out of the Common Property Resources.

In India, the area for which watershed based technology may be suited is estimated between 5 and 12 million ha covering the states of Karnataka, Andhra Pradesh, Maharashtra, Madhya Pradesh and Gujarat (Ryan et al., 1982). Recognizing the importance of the watershed in dryland regions, 46 model watershed projects were taken up by the ICAR in 1982. The program envisaged that a micro-watershed would be taken up for the development in every block (Government of India, 1992).

The programmes implemented upto the Fifth Five Year Plan Period (1974 - 1979) were mainly beneficiary oriented with emphasis on sectoral approach later shifted to ecodevelopment in the sixth plan and the seventh Five Year Plan emphasized sustainable development and recognized the importance of watershed development as a means of integrated management of resources. The eighth plan further recognized the importance of people's participation in watershed development, and accordingly laid emphasis on involving farmers in planning, management and monitoring of watershed development programmes (Vimal Kishor, 1999).

Government of Maharashtra implemented the watershed development programme beginning with 1982 under Comprehensive Watershed Development Programme (COWDEP) which in 1986 developed into (Deshpande and Reddy, 1990, 1991) the National Watershed Development Program for Rainfed Agriculture (NWDPRA). Overall 380 watersheds were taken for development from each district. Deshpande and Narayanamoorty (1999) reported that hardly any plan for watershed management and action was made. The impact study of NWDPRA carried out by Deshpande and Rajshekaran (1995) highlighted that the interaction with the hill region environment seeks top priority in planning for watershed management. Increase in crop production, cropping intensity and optimum use of farm inputs are also of relevance as these are in the case of plains. Soil degradation, protecting land slides, deforestation, gully/ravine formations, however, need immediate attention. They clearly reported that the planning exercises of NWDPRA were extremely mechanical and concentrated more on agriculture as the major activity. The absence of participation of beneficiaries particularly in hill areas has caused skewed impact of the programme.

It is against this backdrop, the present study attempts to assess soil erosion risk in the Upper Bhima basin using the RS and GIS technology.

## 1.2. Significance of the Study:

Scientific management of land is the key aspect of sustainable agriculture. As land being the fixed resource and subject to degradation due to exploitative use, needs to be managed keeping in view the present and future needs. The perpetual flow of food, fibre and fuel can be sustained only if the productivity and quality of land is maintained. Integrated watershed management has been accepted as the most rational approach in preventing deterioration of ecosystem, restoration of degraded lands and improving the overall productivity for sustained use. It is an attempt at comprehensive investigation of environmental aspects of the watershed management in real-time perspective using remote sensing and GIS techniques.

A study would help improve understanding of relationship between environmental causative factors and soil loss. It would help estimate soil loss and map soil erosion risk zones for conservation and thereby, maximize benefits of soil erosion control from minimum inputs enhancing efficiency of process of restoring the resource base. The study highlights the relative contribution of causative factors to the soil loss. The recommendations shall be useful for controlling soil loss and in turn improving the crop yield at field as well as regional level. Extension workers of the Government Department of Agriculture, NGOs working in the field of watershed management may facilitate their programmes focusing the prioritized area using the prescribed guidelines for the respective area.

## 1.3. Study Area:

River basins are a useful unit of analysis to assess water resource availability and address challenges facing sustainable use because it is at this scale that hydrologic, agronomic and economic criteria can be integrated effectively into a framework that can be used to inform resource management policy (McKinney et al. 1999, Khan et al. 2008, Cook et al. 2011). The area selected for the study comprises the Upper Bhima basin, which covers the entire area of Pune district and part of adjacent district of Ahemadnagar and Satara. The river originates in Western Ghats at a place called '*Bhimashankar*' in Ambegaon taluka of Pune district. The river follows a straight south-easterly course and further confluences with river Krishna in Karnataka.

The basin is trapezoidal in shape with its axis aligning North-west to South-east. The Bhima basin is located on the northern border of Krishna basin and bounded by Western Ghats on West and by Harishchandra and Balaghat ranges on the north. The basin covers an area of 22828 sq. km.

River Bhima is the largest tributary of River Krishna which holds a special significance for the state of Maharashtra. River Bhima originates in Western Ghats in Maharashtra and it merges with Krishna river in Karnataka state, thus can be viewed as an independent basin in Maharashtra

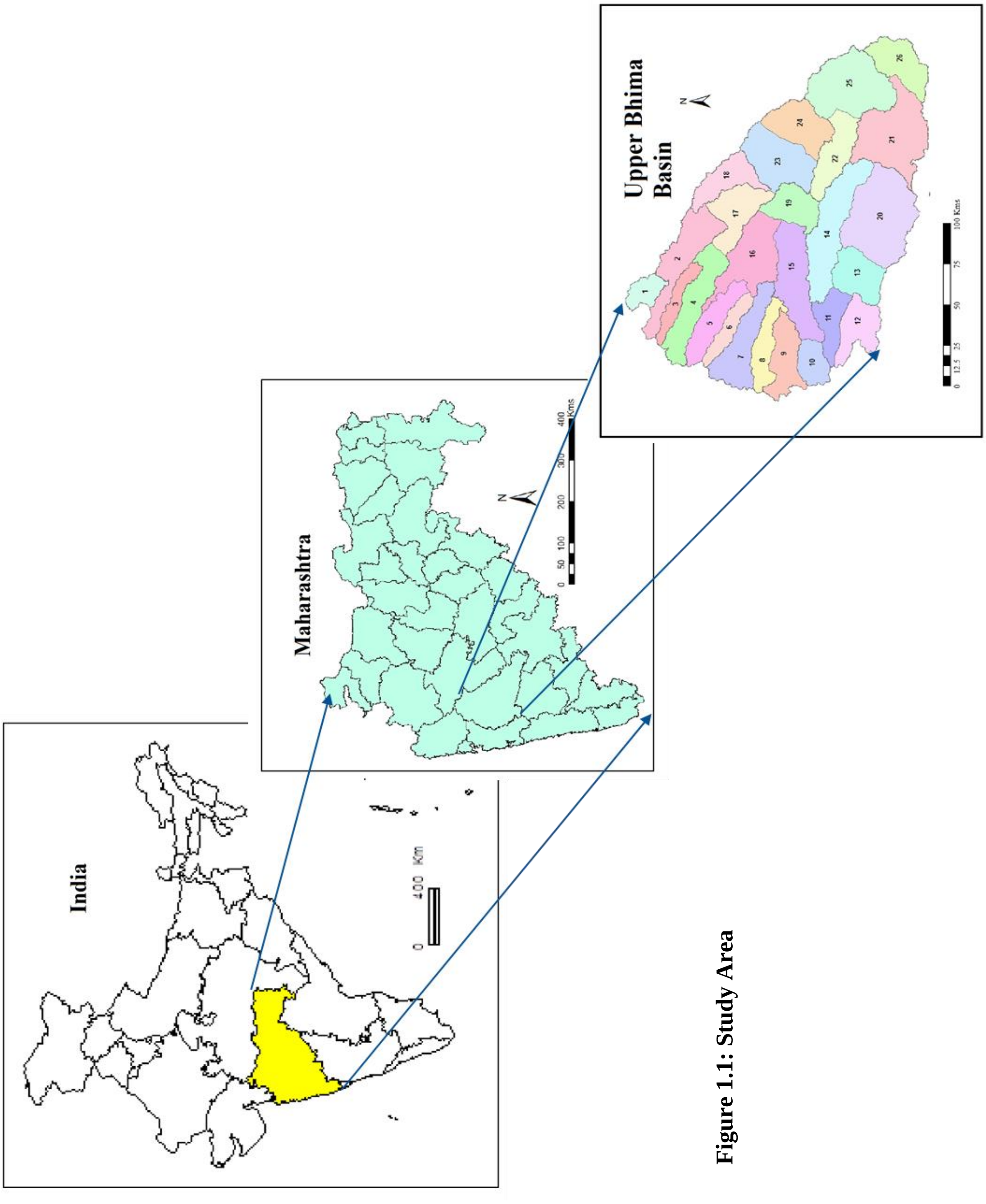


Figure 1.1: Study Area

The major tributaries of river Bhima are the Ghod, the Indrayani, the Mula-Mutha and the Nira. These all tributaries have their source in the heavy rainfall zone of the Western Ghat region. Thus all tributaries have reservoirs and dams constructed in their source region which provides a lifeline for the district.

The river Bhima is also referred to as *Chandrabhaga* especially at Pandharpur- the famous pilgrimage city, as it resembles the shape of the Moon. The river is closely woven with the spiritual fabric of the state.

## 1.4 Objectives of the Study:

The main objective of the proposed study is to evaluate the factors in soil erosion for the upper Bhima basin and to suggest soil conservation measures to control the soil loss.

The supportive objectives are:

1. Computation and mapping of the physical factors such as rainfall intensity, slope amount and length, morphometric attributes and soil erodibility in the Bhima basin

2. Assessment of areas under different land use/land cover categories

3. Estimation of potential soil loss.

4. Preparation of guidelines for soil conservation plan.

## 1.5. Review of Literature

The process of mathematically describing detachment, transportation and deposition of soil particle on land surfaces is called Soil Erosion Modelling. There are two basic types of erosion models. They are empirical and physically based or process based models. The empirical models were developed primarily from statistical analysis of erosion data. The best example of the empirical model is the Universal Soil Loss Equation (USLE). The Process-based models are intended to represent the essential mechanisms of controlling erosion. They represent a synthesis of the individual component, which affects erosion, including the complex interactions between various factors and temporal variability e.g. Morgan-Morgan and Finney Model (1982).

Soil erosion prediction models play an important role both in meeting practical needs of soil conservation goals and in advancing the scientific understanding of soil erosion processes (Nearing et al., 2007). Many researchers have attempted to develop erosion models considering the local conditions of the respective regions.

To develop a soil erosion model, one must have appropriate knowledge about the factors and parameters affecting soil erosion. It is also important to thoroughly investigate these parameters. The various factors affecting are rainfall, soil properties, land use, topography, etc. of the region. But to study these factors in their natural environment is very difficult as they are having very complex relationship with each other. Therefore, studies are conducted in small fields or plots, where the parameters are controlled by man. Such studies are called Experimental or Simulated studies.

The studies for the development of equation started in 1940's in Corn Belt (USA) by calculating the field loss. The empirical equations were developed for estimating average annual soil loss for different combinations of soil, slope, cropping management and conservation practices. A power relationship between soil loss and slope length was proposed by Zingg in 1940. Musgrav (1947) proposed an equation, which was adopted for the farm planning in the North Eastern State of the United States and for the computation of gross erosion from watersheds in flood abatement programmes.

In Lafayetti, Indiana (USA), a laboratory was established in 1953 to collect, summarise and combine runoff and soil loss data from more than 35 field stations. W.H. Wischmeier, D.D. Smith and their associates from the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Purdue University, developed an equation in 1965 called Universal Soil Loss Equation (USLE). It is an empirical model designed to predict long term average soil loss from a specific field or area under specified cropping and management system.

Along with Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), many erosion models such as Morgan-Morgan-Finney (MMF) (Morgan et al.,1984),Water Erosion Prediction Project (WEPP) (Flanagan and Nearing 1995), Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998), European  Soil Erosion Model (EUROSEM) (Morgan et al., 1998), and Annualized Agricultural Non- Point Source (AnnAGNPS) (Bingner and Theurer 2001) have been developed.

Recently, after the development of Geographical Information System (GIS) the scenario changed drastically. The use of remotely sensed data as input for the above mentioned models, along with GIS technology has proved to be very beneficial. It gives us the related information in pixel form, means the information obtained is at the pin point location. So that the conservation measures and suggestions can also be implemented directly to the location.

Amongst all these models, the USLE has remained the most practical method of estimating soil erosion potential for more than 40 years (Fox and Bryan 2000; Kinnell 2000), despite the fact that it has many limitations for application at catchment-scale (Tesfahunegn et al., 2014).

**National Status:** Soil conservation research in India started as early as 1923 with the establishment of dry farming scheme at Manjri near Pune (Kanitkar et al., 1960). The experiments carried out at Manjri from 1929 onwards to determine the quantity of rain water lost by runoff and the quantity of soil lost by erosion were laid out on the same plan as was followed by Duley and Miller in their classical experiments at Missouri in the USA. Later in the late I Five Year Plan and in early II Five Year Plan, eight Soil Conservation Research, Demonstration and Training Centres were established at Dehradun, Ootacamund, Chandigarh, Bellary, Kota, Vasad, Agra and Ibrahimpatnam. Besides, some State Governments, and other institutions have also done useful studies on these lines. At all these research stations, runoff plots of various sizes and gradients were established and studied for soil loss measurements (Gurmel Singh et al., 1981).

The integration of GIS and Remote Sensing techniques for soil erosion modeling is a very useful tool for estimating soil loss on local as well as global scale. For the State level planning, larger maps are required with voluminous data as input. Thus, the maps have been generated using USLE for 10 km x 10 km grid data for the states of West Bengal (Narain et al., 1993), Gujarat (Kurothe et al. 1997), Maharashtra (Kurothe et al., 2001), Tamil Nadu (Sikka et al. 2003), Delhi (Yadav and Mahapatra, 2007) and Haryana (Yadav and Sachdev 2008), Himachal Pradesh (Yadav and Sidhu 2010).These maps have been found to be very effective in identifying the severely affected areas and planning the conservation strategies.

Pratap Narain et al. (1993) estimated soil loss from 800 points on 10 km2 grid distributed over entire state of West Bengal using USLE and generated a soil erosion map of the State on 1: 250,000 scale. The information of soil properties, landuse, slope, vegetation and irrigation etc. were drawn from soil survey reports. They also made use of sediment data from small and medium watersheds and reservoirs. Erosion rates were processed using SPANS-GIS System reclassifying the map in six suitable soil loss classes. Soil erosion rates in the West Bengal ranged from <5 t/ha/yr in deltaic and dense forest region to more than 40 t/ha/yr in hilly regions having open forest. They suggested that 10 % area of the West Bengal (having > 20 t/ha/yr) was critical and should be treated on top priority, which could reduce the total silt load of the state by 34 percent. Depending upon the resources, priority area which was about 6 % (15-20 t/ha/yr) could be taken up for treatment of soil and water conservation measures. Thus treatment of 16 percent priority area would reduce the silt load to nearly 50 percent. They concluded that the soil erosion map of West Bengal will prove useful to planners, watershed managers and policy makers to develop appropriate landuse planning for achieving sustained productivity.

Rao et al. (1994) aimed at evolving a watershed prioritization scheme for conservation planning based on estimates of the sediment yield potentials of different sub-watersheds of the Salauli watershed of the Zuari river basin using the USLE. The watershed measuring 209 sq km is located in the Western Ghats, South Goa, India. IRS-1A LISS II data was assessed in terms of providing input on landuse/land cover and soil physiography-cum-soil information to the USLE model. Their results indicated that the average annual soil loss varies from 13.7 to 49.42 t/ha/yr and that the sediment yield potential of all the sub-watersheds, in general, exceeds the erosion tolerance limits (soil loss above 10 t/ha/yr from a unit area is considered as the erosion tolerance limit). Eighteen sub-watersheds were categorized into five category classes based on their soil loss potential, with a view to taking up conservation planning by the concern state departments.

Kurothe et al. (1997) estimated soil loss using the USLE from 1460 points on 10 X 10 km grid distributed over the entire state of Gujarat and generated a soil erosion map of the State. The computed values of soil loss were grouped in six classes which varied from slight (<5 t/ha/yr) in 71% area to very severe (40 t/ha/yr) in South Gujarat, where high intensity of rainfall is received on hilly slopes. They concluded that afforestation must be accelerated on the hill slopes in high rainfall areas to arrest the erosion. Catchment areas of major reservoirs deserve high priority. Erosion on the regions of moderate classes could be reduced by proper selection of crops and adoption of appropriate conservation practices.

Considering the inaccessibility in the mountainous areas, Shreshtha (1997), assessed the soil erosion in the middle mountain region of Nepal using MMF model. The applicability of an erosion model in mountainous terrain using GIS was verified by analyzing the effect of land use, slope exposition and terrace farming on soil erosion. The study demonstrated that the soil erosion can be modeled in mountainous areas.

Shakir Ali et al. (2001) used standard runoff plot data from 1956 to 1998 to evaluate various parameters of the USLE in south-eastern Rajasthan which constitute about 80 percent of total ravenous area of the state. They observed that more than 87 percent of erosive rainfall was received during crop season only. The seasonal and annual rainfall factor (R) was found to be 341.6 and 404.5 respectively. Crop season and annual soil erodibility factor (K) of clay soil under climatic condition of southeastern Rajasthan was found 0.15 and 0.11 t/ha/unit of EI30 (R) respectively. Cover and management factor (C) for row crops, legumes, and intercropping of row crops with legumes were about 0.52, 0.45 and 0.35 respectively. The C value of grasses ranged from 0.007 to 0.14, whereas natural cover has value of 0.15. They concluded that information generated on R, K, C and P factors of the USLE is useful in planning of soil and water conservation and watershed management programmes.

Bharat Bhushan and Khera (2002) had undertaken a study to assess the erosion hazard by using different erosion parameters and to delineate the priority areas for soil conservation of Patiala-Ki-Rao watershed situated at an elevation of 415 m ASL in foothills of Shiwaliks in the district Ropar of Punjab state. Based on the erosion survey, slope, rainfall erosion index and erosion intensity, these micro-watersheds were assessed for their potential erosion hazard. Using the information obtained regarding the exposure of tree roots, formation of pedestals and the size of rills and gullies, erosion risk assessment classes were established (based on the scoring system of William and Morgan, 1976). They reported that the predominant factors responsible for high erosion risk in the area were the steep slopes, high erodibility of soils and inadequate plant cover.

Shakeel and Kanth (2009), applied USLE for the quantitative estimation of soil loss of the Liddar river basin with a view to formulate suitable conservation measures for getting maximum sustained productivity of soil for a given land use. Verma et al. (2014), integrated the RUSLE model with GIS and Remote Sensing techniques to determine the soil erosion vulnerability in a part of Talwara block of Hoshiarpur district in Punjab.

Along with the improvement of resolution in remotely sensed data, the outputs generated were also of good quality. Saha et al., (2001) used LISS II digitally classified soil and land use/land cover maps, slope information (obtained from topographic maps) and rainfall-climatic data using the USLE to quantify spatial erosional soil loss in part of the Western Siwalik hills and its foothill areas. For the preparation of the thematic layers remotely sensed data was used. For generation of L.S. factor (Topography) the DEM data of SRTM (90m) resolution was used. Land cover factor was generated by NDVI and monthly rainfall was used for calculating erosivity factor. The highest erosion values were observed in very small areas of steep slopes and lower values at the terraced or dense forest areas.

Lu et al., (2004), applied RUSLE, remote sensing, and geographical information system (GIS) to the map the of soil erosion risk in Brazilian Amazonia. The C factor was developed based on vegetation, shade, and soil fraction images derived from spectral mixture analysis of a Landsat Enhanced Thematic Mapper Plus image. The climatic conditions were assumed same with no support practice in the study area. The rainfall–runoff erosivity (R) and the support practice (P) factors were not used.

Deore Sachin (2011) calculated annual soil loss based on annual average rainfall data of 1988 to 1998 using USLE to prioritize micro-watersheds (MWs) of Bhama basin, which is a major tributary of Bhima river in the upper Krishna basin. Average soil erosion rate for the entire basin is 17.1 t/ha/yr while for MWs, it varies from < 5 t/ha/yr to 88 t/ha/yr. Annual average soil loss for the entire basin is 17.1 t/ha/yr; for micro-watersheds, it varies from < 5 t/ha/yr to 88 t/ha/yr. Severe soil loss (>40 t/ha/yr) is observed both in the valley as well as in ridge region of the Bhama basin. The number of causative factors of soil erosion tends to decrease from source towards mouth. Particularly R and K are least influencing as rainfall decreases and clay proportion in soils increases downstream. Conservation and support practices are very scantily noted throughout the Bhama basin.

Multi-criteria decision making method based on Analytical Hierarchy Procedure was used to prioritize MWs of the Bhama basin by Deore Sachin (2005). Criteria were cover1-C1, cover 2-C2, rainfall erosivity-R, slope-S, erodible matter-T, drainage density-Dd and elongation ratio-Re. C1 comprises change in dense forest and double cropped area while the C2 refers to the change in the degraded forest and single cropped area during the period from 1988 to 1998; R as a measure of climatic influence on soil erosion; the least resistant particles in the soil are silt and very fine sand termed as T; S in percent; Dd an expression of dissection of a basin by streams; and Re as a measure of the basin shape were considered as the criteria.

Using the sub-class weights (Saaty, 1980) GIS aided analysis was done to generate micro-watershed wise area-weighted layers for all criteria which were then multiplied by the corresponding pairwise compared weights derived from AHP. The final output Composite Erosion Index (CEI) map was generated and was classified into six classes of erosion intensity.

The general relationship of criteria with erosion intensity observed by him is 1) From the source to mouth, influence of C1, C2, R and S decreases; number of significant criteria influencing CEI decreases and number of counterbalancing criteria on CEI increases. 2) None of the criteria is uniquely observed to be influencing erosion intensity from ridge to valley.

## 1.6. Data and Methodology:

### *1.6.1. Sources of Data:*

- Daily rainfall data from IMD and Hourly data from Water Resource Department (WRD), Maharashtra Engineering Research Institute (MERI), Nashik for a period from 1990 to 2014.
- Soil data from National Bureau of Soil Survey and land use planning and field work.
- Satellite data of LANDSAT TM and LANDSAT ETM of 30 m. resolution
- Elevation data of ASTER DEM

- Primary data by conducting Field work/ Ground Truthing.

## *1.6.2. Research Methodology:*

The quantitative evaluation of the factors in soil erosion and an assessment of soil loss will be done to suggest soil conservation measures to control the soil loss in the upper Bhima basin in Pune district, Maharashtra. This will be carried out through the following steps.

a) Delineation of the Bhima basin and watersheds.

b) Examination of the rainfall intensity and computation of rainfall erosivity

c) Analysis of soil samples to obtain variation in soil erodibility (K)

d) Estimation of Slope length and slope gradient (LS) obtained from DEM derived slope map using the topomaps.

e) Generation of landuse / landcover (LU/LC) map using ground truth to obtain impact of cover and conservation measures (CP) on the soil loss.

f) Estimation of potential soil loss at watershed level.

g) Analysis of morphometric attributes like drainage density (Dd) and elongation ratio (Re) of watersheds.

h) Estimation of Composite Erosion Index (CEI) at watershed level using multi-criteria analysis using weighted overlay analysis.

i) Prioritization of watersheds within the basin based on soil erosion risk and preparation of guidelines for soil conservation plan.

### 1.6.2.1. Rainfall Analysis:

***Statistical analysis:***

The daily rainfall data of 15 years obtained from IMD was analyzed. The erosivity index ($EI_{30}$) was determined for isolated rainfalls and classified as either erosive or non-erosive. The erosive event of more than 12.5 mm of total rainfall accumulation in 24 hours were used for computation. To obtain an approximate relationship between rainfall data and the rainfall erosivity, a regression analysis was performed.

***Spatio-temporal analysis:***

Multi-temporal rainfall data was analysed to study temporal variation of rainfall erosivity. The annual average and the annual rainfall zones were identified in GIS environment using spatial interpolation technique. Similarly, Rainfall erosivity map was prepared. The seasonal analysis was done using the monthly rainfall data.

#### 1.6.2.2. Soil Analysis:

***Field Work:***

A field work was conducted as a pilot study by collecting the soil samples. The K factor was also derived by collecting soil samples for few sites which were well distributed from source to mouth in respective watershed areas located in the upper Bhima basin. Soil samples were collected from top 5 cm (2 inches) layer of soil covering most of the geomorphic units from ridge to valley and from source to mouth. The samples were analysed in the laboratory to find out soil texture (sand, slit, and clay composition), structure, permeability and organic matter content. The corresponding K values for the soil types were identified from the soil erodibility nomograph (USDA 1978) by considering the particle size, organic matter content and permeability class.

***Laboratory Work:***

Soil map was generated from the data obtained from National Bureau of Soil Survey and Land Use Planning (NBSSLUP). The map was digitized manually in Arc GIS 9.3.

#### 1.6.2.3. Assessment of Soil Erodibility (K):

Texture, structure, permeability and organic matter content of the soil determine its ability to get eroded. The values of the soil parameters were obtained from the soil series (NBSSLUP). The Central Soil And Water Conservation Research And Training Institute, Dehradun and its centres have measured K values for some soils in India. Considering those values and the nomograph (Wischmeier and Smith 1978), K values were assigned.

In addition the data collected from NBSSLUP, Nagpur containing the physical properties of the soil was also used for analysis. The points were located on google earth considering the latitudes and longitudes provided in the soil series. The point data was exported to ARC GIS and the maps were prepared using the IDW-interpolation techniques.

100 K = 2.1 M 1.14 (10 - 4) (12 – a) + 3.25 (b –2) + 2.5 (c-3)

K = soil erodibility factor

M = percent silt x (100 – percent clay)

a = organic matter content

b = structure of the soil

c = permeability of the soil

#### 1.6.2.4. Topographical Analysis:

Relief map of the study area is obtained from ASTER data. The data was downloaded from the USGS site (*http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp*) in the month of January 2014. The tiles were mosaicked and the area was extracted. From the SOI toposheets, the physiography was verified. Spatial distribution of the rainfall erosivity with respect to elevation was studied.

The slope analysis was carried out using the ASTER DEM data of 30 m resolution. The slope in percentage and in degrees was computed in Arc GIS 9.3. The relationship between the slope steepness in percentages (Sp) and slope length in meters (L) was used to generate slope length map.

The combined LS factor layer was generated using the equation modified by Wischmeier and Smith (1978):

$$LS = (L / 22.1) * (65.41 \sin^2\theta + 4.56 \sin \theta + 0.065)$$

Where, LS is the slope length and gradient factor and θ is angle of the slope in degrees and L = 0.4 * Sp + 40

#### 1.6.2.5. Land Use Land Cover:

The LULC layer was derived using the Landsat ETM and Landsat ETM Plus data of October and November 2009. The data was downloaded from the USGS site (*http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp*). The image processing was done using ERDAS Imagine 13. The seven bands were first stacked together to get a multispectral image. Histogram matching was done to correct the radiometric differences. All scenes were mosaicked and the study area was extracted from it, which was further classified. The image interpretation can be carried out by two ways viz., Visual and Digital Analysis. We have followed a Digital Analysis in which the training sets of different areas were defined on spectral response pattern generated in different spectral bands. Based on these training sets, the supervised classification of the image was done using Maximum Likelihood Algorithm (MLH).

There are many classification schemes adopted by the researchers based upon the date as well as purpose. For the present analysis, the level I classification scheme of NRSC was followed. The LULC classification has been designed with a three level hierarchy based configuration, each level containing information of increasing speciality (NRSC 2006). The major classes comprises of Agriculture, Forest, Built Up, Barren and Water Body. Keeping in mind the purpose of study, agriculture was divided into Cultivated and fallow and the forest were classified as Dense forest and Degraded forest.

***Ground Truthing:***

Ground Truthing or field verification is an important component in mapping and its validation. But considering the extent of the study area and time constrain, it was impossible to check all details on ground. Therefore, the doubtful areas were identified and verified using the SOI toposheets and google earth images. The accessible and some of the areas were visited and actually verified.

Most of the classes were mixed up, for example, the built up and sediment deposit in river channel, forest and agricultural and built up with barren. They were verified and corrected by recoding.

***Accuracy Assessment:***

To verify the interpretation, the accuracy assessment was carried out. The points collected during ground truthing were used for the quantitative estimation of accuracy of Kappa statistics.

Overall Accuracy = (Total No of correctly classified pixels) / (Total No of pixels)

Producer Accuracy = (No of correct pixels in each class) / (No of reference pixels in each class)

User Accuracy = (No of correct pixels in each class) / (No of classified pixels in each class)

K = (ND – P)/ (N2 – P)

where, K = Kappa coefficient, N = Total number of pixels, D = Sum of diagonal elements i.e. sum of correctly classified pixels and P = Row total X column total

| **Land Use Land Cover categories** | **User Accuracy (%)** | **Producer Accuracy (%)** |
|---|---|---|
| Degraded Forest | 93.75 | 93.75 |
| Dense Forest | 97.4 | 91.4 |
| Agriculture cultivated | 88.89 | 100.0 |
| Agriculture Fallow | 85.71 | 85.71 |
| Barren lands | 73.2 | 84.6 |
| Waterbody | 100.0 | 99.6 |

***Table 1.1: Accuracy Assessment***

#### 1.6.2.6. Assessment of Cover Management (C):

The C factor in the upper Bhima basin indicates not only the land cover by the natural vegetation but also the land use under the crops. It also indicates the status of the land in an area. For each land use land cover, the C factors were attributed (Table 1.2).

In the present study, the C factors for each land-cover type are assessed using a land-cover classification based on Landsat TM and Landsat ETM database. Literature based on Indian as well as international studies was extensively referred while assigning these values. Central Soil and Water Conservation Research and Training Institute, Dehradun and Vasad has evaluated C factor for various crops (Kurothe, 1991-92; Nema, et al., 1978; Verma, et al., 1982). Also the C values for some crops were considered from Singh et al., 1981.

| **Land Use Land Cover** | **C Factor** |
|---|---|
| Agriculture Cultivated | 0.8 |
| Agriculture Fallow | 0.6 |
| Degraded Forest | 0.005 |
| Dense Forest | 0.003 |
| Barren | 0.5 |
| Water Body | 0.9 |
| Built Up Area | 0.25 |

***Table: 1.2: C Factor***

#### 1.6.2.7. Assessment of Supporting Conservation Practices (P):

The common supporting conservation practices adopted in the study area are terracing, contour bunding and field bunding and contour cultivation. The P values were assigned as per Singh, et al., 1990 and Kurothe, 1991-92. In addition, site suitability analysis is carried out using map overlay tool in Arc GIS 9.3. For this purpose the LULC and the slope were taken into consideration. The values of P-factor are assigned to the suitability classes in the range from 0.1 to 0.9., in which the highest values are assigned to areas with no conservation practices like barren lands on higher slopes.

#### 1.6.2.8. Estimation of soil erosion:

Two approaches were adopted for evaluation of soil erosion-proneness of watersheds viz. Universal Soil Loss Equation and Multi-Criteria Analysis. The USLE developed by Wischmeier and Smith (1978) is used in this study for estimation of soil loss in the Bhima basin. Some of the parameters of this model are achievable through remote sensing. Hence this model was chosen for this study. Soil loss for entire Bhima basin is calculated by generating various input layers in GIS environment.

***Approach 1: USLE Equation***

The soil erosion estimation was done by the multiplying the parameters derived above by the equation suggested by Wischmeier and Smith (1978) as below:

$$A = R * K * L * S * C * P$$

Where, A is computed soil loss (t/ha/yr), 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, and P the supporting practices factor.

Soil loss obtained for different rainfall zones is correlated with the rainfall erosivity to understand the influence of rainfall intensities under different land characteristics to understand the response of elevation, soil properties and land use land cover.

***Approach 2:***

The second approach is the Multi-Criteria Analysis using Analytical Hierarchy Process (AHP) applied for the prioritization of watersheds. The criteria were topographic (slope-S), morphometric (drainage density-Dd and elongation ratio-Re), climatic (rainfall erosivity-R), pedological (Silt+very fine sand content-T) and anthropogenic (Land use/ land cover – LU/LC). Sub-class weights were assigned (Saaty, 1980) for each criterion for each watershed. GIS-aided analysis was done for all criteria mentioned above to generate watershedwise area-weighted layers. Layers thus obtained were then multiplied by the respective pairwise compared weighting number derived from AHP and then added by linear combination using Boolean logic. The final output of Composite Erosion Index (CEI) map was generated and it was classified into the categories of erosion intensity. Prioritization of watersheds was done according to severity of watersheds to the erosion.

## 1.7. Framework of the Study:

The study is sequentially organized in present chapter wise scheme. The first Chapter 'Introduction' highlights the significance of the topic, aims and objectives, review of literature, scope and chapter wise scheme.

Second Chapter deals with the Geographical profile of the study region such as location and extent, physiography, drainage, climate, Land use land cover and Soils.

Third chapter elaborates the assessment soil erosion in the study area using USLE. Causative parameters viz. slope length, soil erodibility, status of land use land cover and assignment of C and P factor values are discussed in this chapter.

Chapter four discusses morphometric analysis and Multi criteria analysis.

The results are discussed in the concluding chapter fifth and are supported with the recommendations.

## CHAPTER 2: GEOGRAPHIC PROFILE OF UPPER BHIMA BASIN

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## CHAPTER 2

# GEOGRAPHIC PROFILE OF UPPER BHIMA BASIN

## 2.1 Introduction:

The basin is the natural integrator of variables such as precipitation, runoff, erosion and sediment discharge as they relate to input and output in an open hydrological system. Keeping this in view, basin characteristics like drainage density and elongation ratio of the Upper Bhima basin have been considered. Landuse / land cover also has a strong influence on the soil erosion.

Area selected for the study is upper Bhima basin, which covers entire part of the Pune district and some part of adjoining districts of Ahemadnagar and Satara. Upper Bhima basin covers an area of 22828 sq. km. In the upper Bhima basin, twenty six watersheds are delineated for the assessment of soil loss and to analyze impact of causative factors.

The River Bhima is the largest tributary of River Krishna which holds a special significance for the state of Maharashtra. River Bhima originates in Western Ghats in Maharashtra and it merges with Krishna river in Karnataka state, thus can be viewed as an independent basin.

In north the basin is bounded by the Godavari basin and by the Western Ghats in the west whereas the lower Bhima basin lies in the east and the sub basin of the river Krishna in the south.

## 2.2 Location and Extent:

Administratively the upper bhima basin covers the entire Pune District of Maharashtra, India (Figure 1.1). The river originates in Western Ghats at a place called '*Bhimashankar*' in Ambegaon taluka of Pune district. After its origin it flows towards East through Pune district for a length of 240 km. taking southeasterly turn the river then enters Ahmednagar district where it flows for 56 km. After that the river flows on border of Pune and Solapur district for about 96 km. It forms the natural boundary between the Pune district and Solapur district. The upper Bhima basin covers an area of 2282828.73 ha (19 $^{o}$1' N to 19 $^{o}$ 2' N latitude and 73 $^{o}$ 34' E to 73 $^{o}$ 45' longitude).

## 2.3 Physiography:

Physiography plays an important role in a study of a natural unit. It determines the distribution of climatic parameters like rainfall and temperature, natural resources like soils and forest as well as the economic activities in the region. All these factors have an impact on the overall development of the region.

The entire upper Bhima basin is underlain by the basaltic lava flows of upper Cretaceous to lower Eocene age. The basin mainly consists of the part of Western Ghat and Deccan Plateau

Upper Bhima basin covers entire Pune district, which can be divided physiographically in to three distinct belts as follows:

- Western belt
- Central belt
- Eastern belt

*1.* ***The western belt***

The western belt runs along the entire western border of the district. It mainly consists of the Sahyadri's or the Western Ghats. It stretches from 16 to 31 km east of Sahayadri. This region has extremely rugged terrain with lofty peaks, clear-cut ridges, steep slopes and deep ravines. These hills vary from 700 to 1300 meters in altitude. Some peaks rise to even more than 1300 meters.

*2.* ***The central belt***

This belt extends for about 30 km east of western belt across the tract whose eastern belt is roughly marked by a line drawn from Pabal in the north to south up to Purandhar through Pune. In this belt, the smaller chains of hills sink into the plains. The valleys become straighter, winder and the large spurs spread into plateaux.

*3.* ***The eastern belt***

In this region, the hills slowly sink into the plain. The tablelands become lower and more broken. This area comes under rain shadow. The breaded and more levelled valleys stripped off most of their beauty by the dryness of the air. The soils are bare,

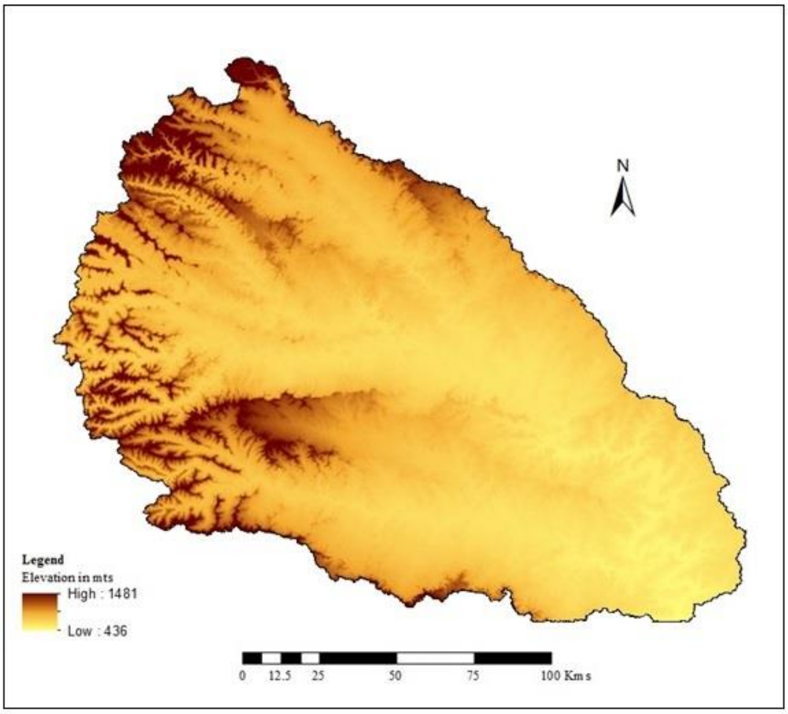


**Figure 2.1 Relief (Upper Bhima Basin)**

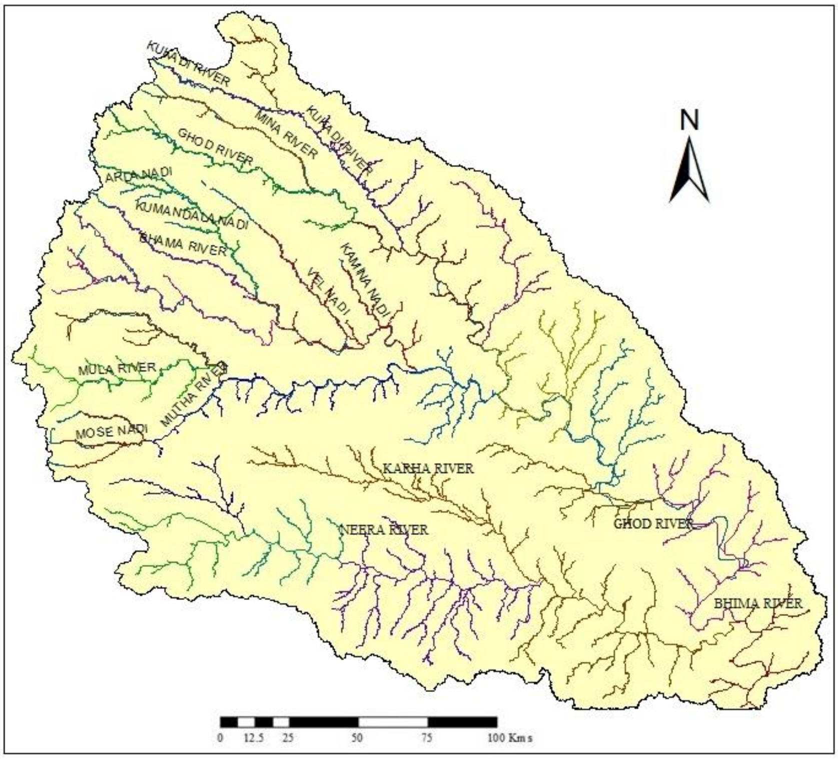


**Figure 2.2 Drainage (Upper Bhima Basin)**

looks yellow with stunning spear grass and black with boulders and sheets of basalts, except in rainy season. The low lands, though somewhat less bleak are also bare (District Gazetteer, 1954).

## 2.4 Drainage:

Administratively Bhima river drains complete Pune district. The major tributaries of river Bhima are Ghod, Indrayani, Mula - Mutha and Nira. All these rivers originate in the Sahyadris and flow east and southeast across the district. These rivers are seasonal. They are flooded during the rainy season and they shrink to a narrow thread in broad stretches of gravel in the summers.

All the rivers have most semi-dendritic drainage pattern and the drainage density is quite high. Based on geomorphological setting and drainage pattern the upper Bhima basin is divided into 26 watersheds.

1. **The Bhima - Ghod River System**:

The Bhima - Ghod River System drains the northern, north-eastern and eastern part of the district. Bhima River has a total length of about 355 km and Ghod river has a drainage of about 196 km. The source of the river Bhima is at the famous place Bhimashankar located at a height of about 914.40 meters above the sea level. Further, east with a general course to the southeast, it flows through the very narrow and rugged valley. At Tulapur village, it bends to the south, skirting the Haveli Tahsil, and after receiving waters from the Vel river below place of Talegaon-Dhamdhere and it turns again northeast to Mahalungi village. Then the Mula-Mutha joins it and run south of the Ranjangoan village. From Ranjangoan village the Bhima runs southeast with a winding course of about 22.52 K.M. Still, on the eastern border of the district, From the left it receives waters of the Ghod. Finally, at the extreme southeast of the district, after a deep southward bend round the east of Indapur, the Nira joins it from the right. Bhama, Ghod, Vel, Indrayani, Mula-Mutha, and Nira are main six tributaries of the Bhima.

***River Ghod:***

The Ghod’s origin is near Ahupe village on the crest of the Sahyadris. From Ghodegaon it runs east-southeast, passing through the large villages of Ghodegaon and Vadgaon on the north boundary of Khed. It is joined by the R. Mina from the left. Further at about 40 km it joined by river Kukadi and still further at a distance of about 32 km, it joins river Bhima. At Pargaon village the Mina, whose source joins it to the valley changes in the level plain place of Kavthe. Kukdi, Pushpawati and Mina are tributaries of Ghod River.

***Vel:***

The source of Vel is Dhakale in a spur of the Sahyadris near Khed. It flows southeast nearly parallel to the R. Bhima, and meets Bhima after a course of nearly 64.36 Kms.

***Bhama:***

Bhama River falls from the right into Bhima near the village of Pipalgaon. The Bhama source is in the Sahyadris about 9.65 Kms South of Bhimashankar.

***Kukadi:***

The R. Kukdi rises at Pur, west of Chavand near the Nane pass in the northeast corner of the district. It runs southeast by the town and fort of Junnar to Pimpalvandi. Kukadi River joins Ghod at Northeast of the Sirur camp on the eastern border of the Sirur Tahsil.

***Pushpawati's*** source is near the Malsej pass at the north-west corner of the Junnar Tahsil. It flows down to Madhner by the village of the Pimpalgaon-jaga and Udapur, nearly parallel to the Mina River, and then joins the Kukdi at the Yedgaon village.

The ***Mina*** is originated from the eastern slope of Dhak in the west of Junnar and flows east through the rich valley. In the land of the Kusur village at its source, the dam known as the Tambnala dam crosses the river. From this, the Mina flows to Narayangaon on the Pune-Nashik road. There is also a dam at Vaduj southeast of Kusur. Past Narayangaon, where a bridge crosses it, the Mina joins Ghod at Pargaon.

***River Indrayani:-***

The Indrayani originates in Kurvande village at the head of the Kurvande pass on the crest of the Sahyadri. Past the village of Nane till it is joined on the left by the Andra. It then enters the open country, passes through Dehu, and after keeping southeast, turns north and meets the Bhima near Tulapur.

Andra is a tributary of Indrayani. It source on the Sahyadris is near the Savle passes. It flows southeast and joins the Indrayani on its north bank near the village of Rajpura.

***2. Mula – Mutha River System:***

The Mula or Mula Mutha is formed stream's origin at various points along the crest of the Sahyadris between the souths of the Bhor pass. It passes east to Pune receiving on Pavna on the left. At Pune the Mutha on the right, then under the name of the Mula - Mutha wined east till Ranjangaon sandals village. It then reaches the Bhima.

The source of Pavana River is on the crest of the Sahyadris south. It forms the southern border of the Indrayani valley and includes the fortified summits of Lohagad and Visapur. First, it flows forwards east along the winding vale of Pavna till. It turns southeast, and after a winding course joins Mula from the north near Dapudi.

The Mutha originates in a mass of hills on the edge of the Sahyadris. The Mutha flows through the Bhor Tahsil. After entering the Pune district the current of the river checked by the great Khadakvasla dam. Below the dam the Mutha flows northeast past the Parvati hill by the northwest limit of the city of the Pune, till it joins the Mula at a point known as the Sangam.

***3. The Karha Nira River System:***

In the Bhor Tahsil in the spur of the Sahyadris the fort of Torna is the source of Nira River. It flows northeast till it reaches the southern border of Poona. The Shivaganga joins it from the north. From this, it turns east and forms the southern boundary of the district separating it from Satara North and Solapur. It finally falls into the Bhima at the southeast corner of the district near Narsingpur. Karha and Shivganga are tributaries of Nira River.

The Karha originates east of Sinhagad and further it flows in the southern part of the district by nearly touring the south boundry of Saswad anb Baramati tahsils. It fall in to theNira.

The Shivganga is originates is on the south slopes of Sinhagad and flows east till Shivapur and then south to Nasrapur, Then Nasrapur, under the name of Ganjavni, it flows southeast for about and falls into the Nira near Kenjal in Saswad.

## 2.5 Climate:

The climate is influenced mainly by the physiography of the region. The climate of the Western region of the upper Bhima basin is cool, whereas the Eastern part is hot and dry. The region belongs to tropical sub-humid in the west to semi-arid in the east with three distinct seasons Viz., summer, rainy, and winter.

The winter season is from December to about the middle of February followed by summer season, which lasts up to May. June to September is the south-west monsoon season, whereas October and November constitute the post-monsoon season (District Gazetteer Series 1954, Rao Y.L.P. 2004, Gupta 2011 and Patak S.K.2011). Annual mean rainfall decreases from west to east from about 2800 mm to less than 400 mm marked with July Maximum. This region receives its rainfall during the southwest monsoon season.

### 2.5.1 Temperature

The climate of the study area is on the whole is agreeable. The winter season is from December to about the middle of February followed by summer season which last up to May. During winters, the weather is pleasant with clear skies and gentle breeze. The average temperature of the upper Bhima basin during this period is between 12°C – 25°C.

June to September is the south-west monsoon season, whereas October and November constitute the post-monsoon season. The mean minimum temperature is about 12°C and mean maximum temperature is about 39°C.

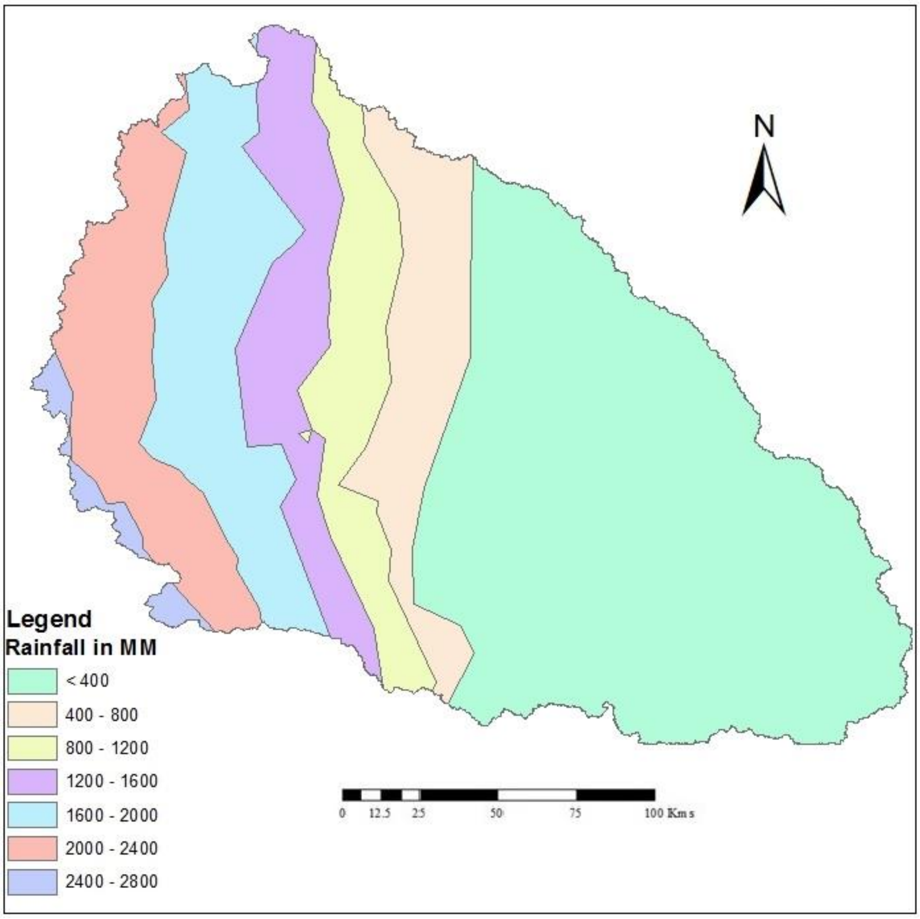


**Figure 2.3: Rainfall Distribution (Upper Bhima Basin)**

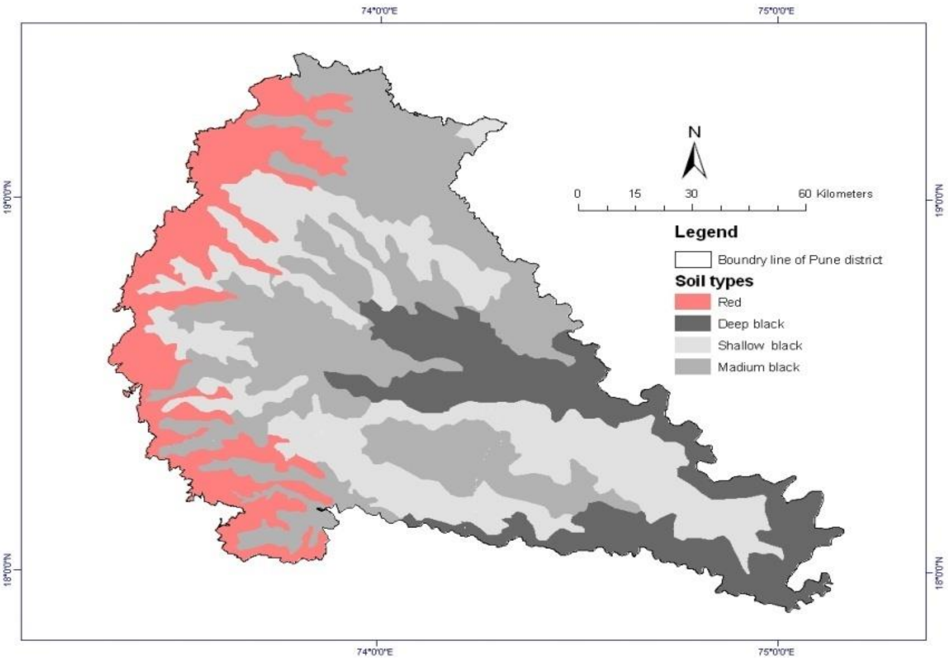


**Figure 2.4: Soil Types-Pune District**

April and May are the hottest months in the basin. Western Side of the basin is cool, whereas the Eastern part is hot and dry. The daily range of temperature is highest in the Eastern part of the basin, where the summers are relatively hotter and winter is relatively colder. The daily range in temperature is the least during the month of July and August. This is owing to the fact that the amount of solar radiation received in July is relatively less as compared to April or May, due to cloud cover and due to the considerable loss of heat energy as wet surfaces get evaporated. Thus, the daily temperature comes down and night temperature becomes steady, as terrestrial heat is unable to escape due to the water vapour present in the atmosphere.

Humidity is low during the summer months due to increase in evaporation. The variations in humidity during this period are high. Water vapor is condensed due to falling nighttime temperatures and the daytime temperatures are high.

### 2.5.2 Rainfall:

Most of the rain is received by the Southwest monsoon winds during the summer. Total 87% of rain falls during the monsoon months. The monsoon arrives in the month of June, with the maximum intensity of rainfall during the month of July followed by August.

The western margin of the basin falls in the highest rainfall zone of more than 2000 mm. Physiography of this area shows a hilly and undulating terrain, with altitude ranging above 1000m. Medium rainfall zone comprises of administrative tahsils of Bhor, Ambegaon, Junnar, Khed, Haveli, Pune city and Purandhar where the rainfall ranges from 800 – 1500 mm. The lowest rainfall zone, which is the dry and semi-arid region consists of Shirur, Daund, Indapur and Baramati tahsils. The rainfall in this region is less than 800 mm as it falls in the rain shadow zone.

## 2.6 Soils:

Soil has divided into two classes, namely back and red (Fig.2.4). In some place, one class of soil blends to another in varying proportions and in turn modified by sand, gravel, lime salts and other ingredients (Rao Y.L.P. 2004, Gupta 2011 and Patak S.K.2011).

***Black soil:***

The black soil, Kali, is generally black or nearly black. It is commonly found in layers several feet deep. The black soil belongs to the plain, comprising the eastern portion of Rajgurunager, Sirur, Dhond, Saswad Tahsils and the whole of Baramati, Indapur Tahsil. The black soil by the side of rivers and large streams is usually of great and uniform depth. It is sometimes found injured by getting mixed with lime nodules, and occasionally from the action of water or the presence of mineral salts. It becomes stiff and clayey except in years of heavy rainfall, which lessens its richness. Excellent black soil of small and varying depth, with its surface covered with black basalt stones, found on the tableland. Black soils are richer than either red or coarse gray soils. It is futher classified in to medium, shallows and deep black soil.

***Medium black soil:***

This soil has developed along the secondary minor drainage system of the area and along intermediate gradients areas. It is developed in localized isolated patches on the plateau regions. The capacity of internal drainage of such soil is good. It is mostly found to occur on piedmont plain. This soil's is base saturated with calcium as the predominant exchangeable caption. This soil is found in Junnar, Ambegaon, Haveli, Shirur Baramati, Vadgaon Tahsils.

***Shallow black soil**:*

This soil has a coarse texture and characterized by low fertility. It is found on the plateau between the coastal plain and the foot of a mountain range and erosion surfaces. The best red soil is found near Pabal, midway between Khed and Sirur where ploughing also has to be deep. The red soils of Pabal are a mixture of sand with smaller quantity of clay, and though very powerful, it requires great labour. Shallow black soil is found in south of Ambegaon, Paud, Saswad, Haveli, Daund and in medial side of Rajgurunager, Indapur and Saswad Tahsils.

***Deep black soil:***

This soil found in vast stretches in river valleys. It soil is more fertile than medium black soils. The structure is granular in the surface layer and becomes cloudy with angular shining wedge shaped surface at lower depths. Deep black soil is found in Haveli, Daund, Baramati and Inapur Tahsils.

***Lateritic soil:***

Covers a considerable area in the study area and it is found in the western portions of the basin comprising in the Tahsils of Junnar, Ghodegaon, Rajgurunager, Vadgaon, Paud, Velhe and Bhor. It is particularly suited for the cultivation of *Bajri*, *Matki*, groundnuts. There are three varieties of red soil namely, pure red, upland and sandy. The pure red is lighter and richer. The upland is of reddish soil thickly spread over the rock and classified into two classes according to depth and quantities of sand.

## 2.7 Land Use and Land Cover:

Land use refers to the man's activities and various uses which are carried out on land. Land cover refers to the natural vegetation, water bodies, rock, soil, etc. Although land use is generally inferred based on cover, yet both the terms are related and interchangeable. Intensive land use changes and unsustainable use of forest resources have put considerable pressure on land resources.

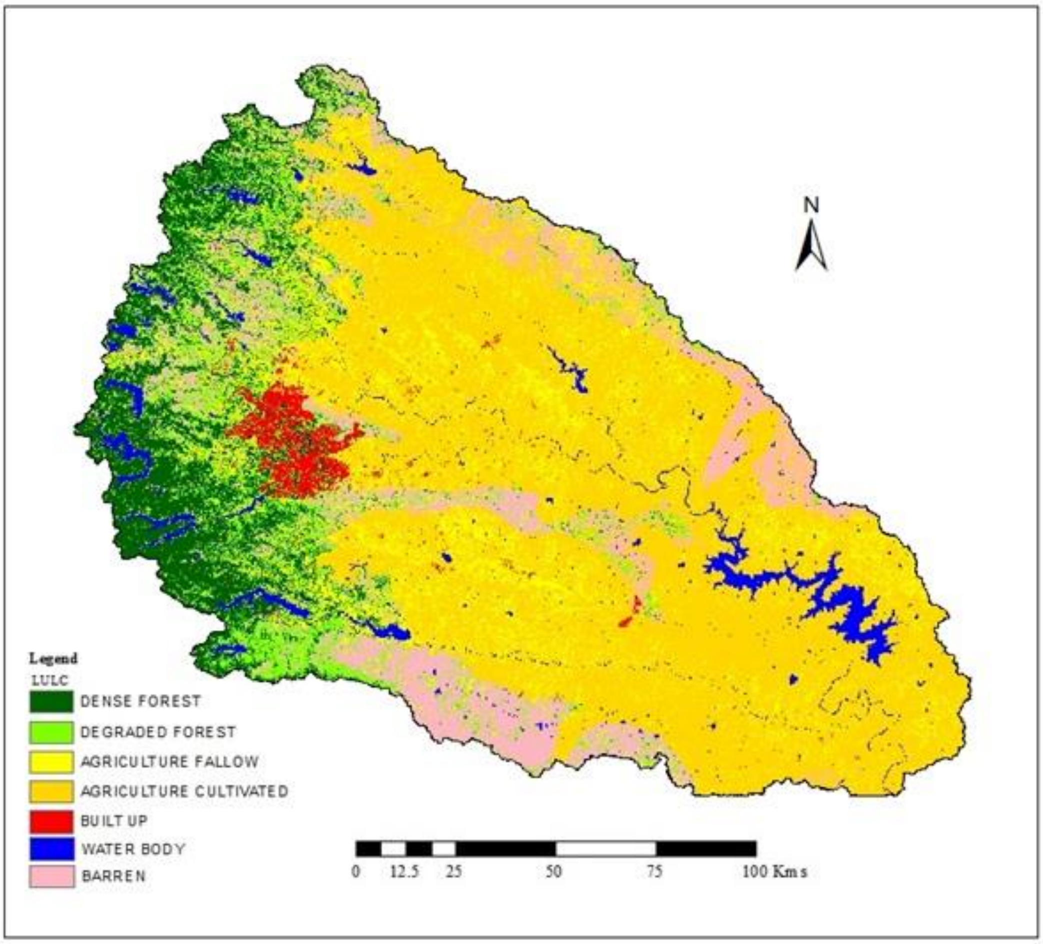


**Figure 2.5: Land Use/ Land Cover**

## Agriculture:

The upper Bhima basin is basically an agricultural region. Agricultural potential of this region primarily depends on texture and thickness of soil, terrain and the amount and duration of rainfall. Agricultural Lands are the lands primarily used for farming and for production of food, fiber, and other commercial and horticultural crops. The mountainous terrain on the western part of the basin, the slopes at the base of the Sahyadri ranges, the extensive plateau areas without a thick soil cover and lateritic soils have restricted the area under cultivation. Even the area that cultivated suffers from infertile soil and deficiency of moisture as a large part of the Eastern portion of the study area receives rainfall less than 600 mm.

About 48 % of area is under cultivation. The cultivable land comes under two main categories namely, dry cropland and irrigated land. Dry cropland depends on the monsoon which are further divided in early monsoon and post monsoon. There are many rivers originated in the Western Ghats which have many dams constructed across them. The irrigated areas are irrigated with the help of these dams canals and reservoirs.

The region experiences high rainfall in western part and less rainfall in east part. The dams like Panshet, Varasgaon, Pavna, Mulshi, Temghar etc. have been constructed in Sahyadri region mainly for irrigation purpose. The more irrigated land is available at the eastern part of the district where canal and well / lift irrigation is the main source of the irrigation. There are sufficient wells and bore wells to irrigate the land. Fertility is more in Baramati, Indapur, Daund and Shirur Tahsil because soil is deep black along Nira River. Irrigation provides double or triple crops.

**Forest:**

The Sahyadri has a cool climate. It varies to the east of Sahyadri. The higher area has high rainfall where lateritic soil is found. These conditions are very good for the growth of plant and hence there are more forest areas. As the altitude decreases in the eastern part of the upper Bhima basin, rainfall also decrease due to which thorny forest can be seen in eastern part of the study area.

About 11 % of area is under dense forest cover. The forest can be classified according to the nature of their forest species as evergreen, deciduous, xerophytes or thorny, etc. Evergreen forests observed in the heavy rainfall area of the west, occupying the higher elevation of the Sahyadri main ridge and extending to some distance on the outlying spurs of the eastern flanks. In its undisturbed state at the higher elevations, where soil and crop react to set up a stable composition

Deciduous forests is a narrow belt along lower slope of Sahyadri. There is a gradual change from scrub to deciduous species as one advance into the central zones. Here the forest characteristics take on a marked change from evergreen in the western region to dry deciduous. Today due to gradual but continual deterioration in physical factor and due to repeated unauthorized hacking of immature teak tree and sapling along with other non-teak species for fuel or sale, mature tree growth of teak and other tree species are hardly seen.

The degraded forests and the scrubs consists of nearly 9 %. The region with an average rainfall below 600 mm is thorny scrub forest.  This type of forest is found in the eastern part of the basin. Forest are scattered and are in isolated pockets which are surrounded by villages and subjected to excessive grazing and browsing and is typical of the extremely dry condition of the eastern region which is also a drought prone area. The vegetation characterized by stunted growth of Neem, Babul, Hivar, and Bor.

Plants provide a protective canopy that lessens the impact of raindrops on the soil, thereby reducing soil erosion. Roots help to hold the soil in place. They provide shade that prevents the soil becoming too dry (Rao Y.L.P. 2004, Gupta 2011 and Patak S.K.2011).

**Barren Lands:**

About 13 per cent of area is under barren lands. They are observed in irregular to discontinuous shape with a linear to contiguous or dispersed pattern. They are located on steep isolated hillocks and hill slopes in the Sahyadri ranges and also on the hillocks in the central and eastern part of the basin. Barren lands are associated with barren or exposed rocky or stony wastes, rock out crop, mining and quarrying sites surrounding Pune urban region.

**Built-Up Area:**

Built-Up Area is an area of human habitation developed due to non-agricultural use and that has a cover of buildings, transport and communication, utilities in association with water, vegetation and vacant lands. It covers 1.8 per cent of total geographical area of the upper Bhima basin. The major urban settlement in the study area is a city of Pune, a district headquarter, which is extending fast due to rapid growth of industrialization. Vicinity of western part of the study area towards Mumbai, an economic capital of the country is causing more use of land for non-agricultural purposes.

## CHAPTER 3: ASSESMENT OF SOIL EROSION: USLE

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## CHAPTER 3

# ASSESMENT OF SOIL EROSION: USLE

### 3.1 Introduction:

The USLE was developed as a tool to assist soil conservators in farm planning. A conservator used the USLE to estimate soil loss on specific slopes in specific fields. In situation of the estimated soil loss being exceeded the acceptable limits, the USLE provides guidelines to the conservator and farmer in choosing a practice(s) that would control erosion adequately while meeting the needs and expectations of a farmer. Thus, the USLE helped to tailor erosion control practices to specific sites. The USLE is used to assess the soil erosion in the present study which predicts the soil loss at the given specific sites as a product of six major factors which had made it very popular. It allows one to predict average soil erosion for each feasible alternate combinations of crop cover and management practices in association with specific soil type, rainfall pattern and topography.

This chapter aims at quantitative assessment of soil erosion in the upper Bhima basin using the Universal Soil Loss Equation.

### 3.2. Universal Soil Loss Equation (USLE):

The factors affecting soil erosion are having very complex relationship with Soil erosion. Therefore, its study becomes difficult in natural environment. So considering all these things, the universal soil loss equation (USLE) developed by Wischmeier and Smith (1978) was used in this study for assessing the soil loss in the upper Bhima basin.

$$A = R * K * L * S * C * P$$

| | | |
|---|---|---|
| Where, A | = | Soil Loss in tons/ha/year |
| R | = | Rainfall Erosivity factor |
| K | = | Soil Erodibility factor |
| L | = | Slope Length factor |
| S | = | Slope Gradient factor |
| C | = | Cover Management factor |

P = Conservation Practice factor

All the layers viz. R, K, LS, C and P were generated in GIS environment and were crossed to obtain the product, which gives annual soil loss (A) for the upper Bhima basin..

### 3.2.1 Rainfall Erosivity (R) Factor:

The aggressiveness of the rain to cause erosion is termed as Rainfall erosivity. This concept was first introduced by Wischmeier and Smith in 1958 to encapsulate the climatic influence on soil erosion in such a way that, when other variables are held constant, rate of soil loss is directly proportional to the level of rainfall erosivity. It is commonly known as R factor of USLE. The erosivity depends upon the Kinetic energy of the storm and its 30 minute maximum intensity. As rain drop falls from the sky it has tremendous force which can break away small portions of soil and can lead to erosion. When the drop hits the soil surface, it compresses the soil and removes particles and aggregates of soil. Bigger the size of the rain drop, greater will be the impact with which it will strike the land.

Study area displays significant regional variations which is responsible for the differences in distribution, duration and intensity of rainfall which ultimately controls the erosivity. The rainfall in the basin varies from 400 mm in the driest part to over 2800 mm in the hilly areas of the Western Ghats. The Western Ghat hills receives 2400 to 2800 mm, majority of the western part of the basin 1600 to 2400 mm, the central part 400 to 800 mm, the eastern slopes of hills 800 to 1200 mm and the eastern margin of the upper Bhima basin receives less than 400 mm rain (Figure 3.1).

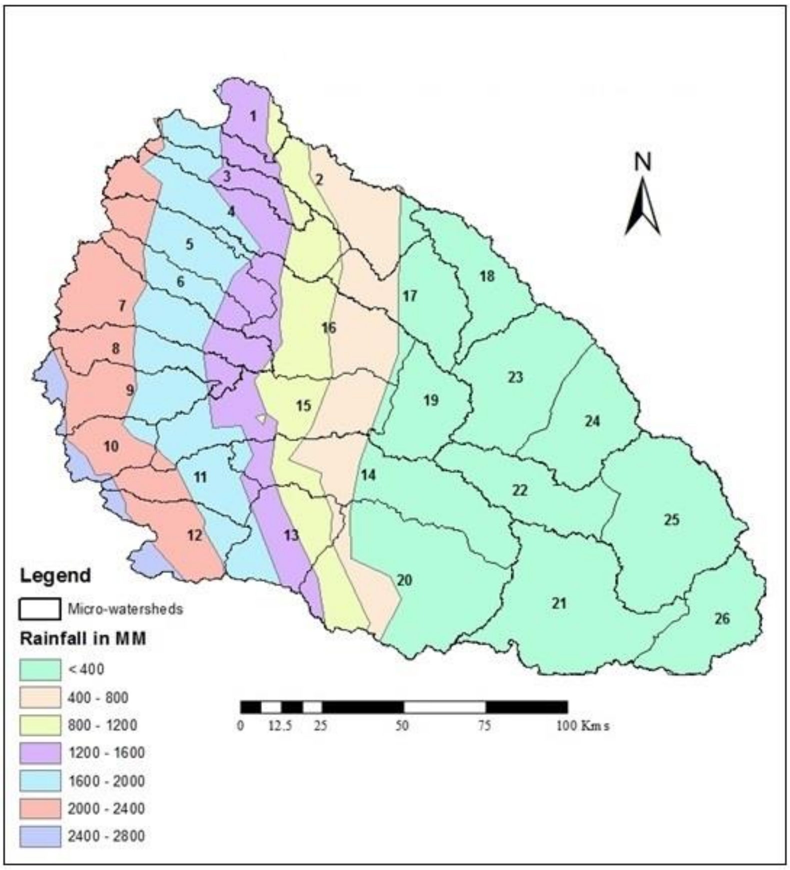


**Figure 3.1: Distribution of Rainfall**

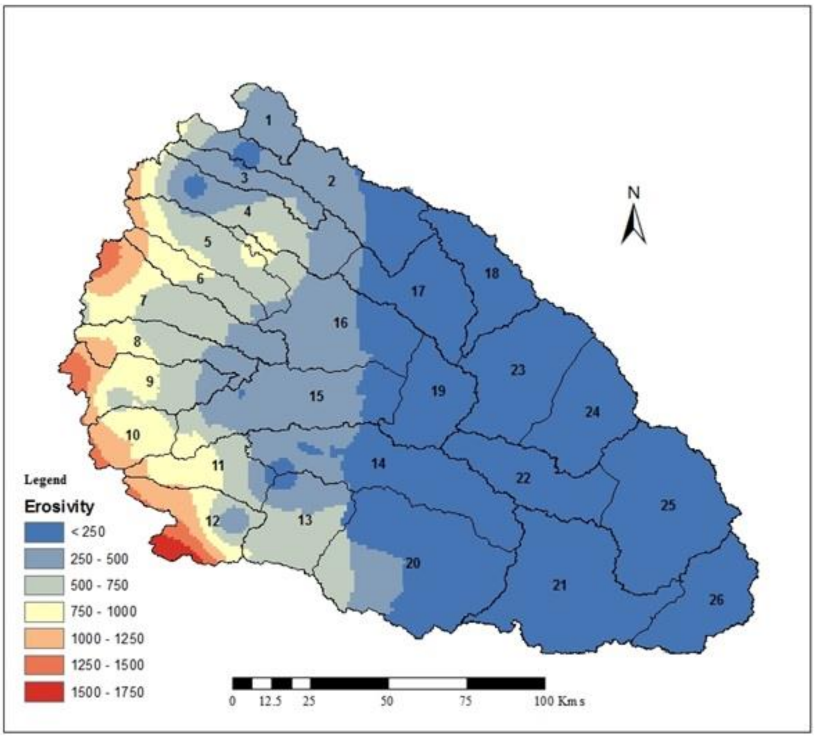


**Figure 3.2: Rainfall Erosivity (R)**

The spatial distribution of erosivity factor follows the rainfall pattern. It ranges from 250 to more than 1500 depending upon the location of the station and season. Erosivity values are less than 250 in the entire area of eight watersheds located to the east of the basin, major parts of four watersheds and in few patches of two watersheds located in the central part of the study area (Figure 3.2). Major portion of watersheds in the central part of the basin shows erosivity values between 250 and 500. Eastern parts of western watersheds number 4 to 12 shows 500-700, whereas western part of these watersheds has erosivity of 1250-1500 with extreme values of more than 1500 in the hilly area located south west of watershed 12.

Western hilly region in the range of 1500-1750 as a result of the orographic high intensity rains received during the South-West monsoon. The annual rainfall in these region ranges from 2000-2800 mm and is mostly received during June to September. While the lee ward side of Western ghats with 1200-1600 mm rainfall shows R-value 500 to 750. Eastern part of the basin is semi-arid, which receives rainfall upto 400 mm. This region shows low erosivity values less than 250. The low erosivity in this area explain the low rainfall under rain shadow conditions. Higher erosivity values are observed in the area with high amount of precipitation, intensity and kinetic energy of rain.

### *3.2.2. Soil Erodiblity (K) Factor:*

Erodibility of soil is a major consideration in developing sound management practices for agricultural, forest and other landuses. This chapter assesses the erodibility status of soils in Upper Bhima basin.

There are different soil types around the world having varying characteristics. One of their properties is their soil erodibility.  Vulnerability of the soils to get eroded is referred to as erodibility of soils. It is the function of both the physical characteristics of soils and the land management practices. However, effects of physical properties can be evaluated more precisely compared to the effects of the management practices. Some soils are much more susceptible to erosion than others. Soil erodibility is a function of complex interaction of physical and chemical properties of soils affecting detachability, transportability and infiltration capacity.

For the spatial distribution of the soil erodibility, the scale from very low to very high is used to characterize the concentration of an element in the soil sample based on the mean and standard deviation. The major portion of the basin falls in low to moderate erodibility class. Very high K is observed in the south western part of the basin and in more proportion towards eastern part (Fig 3.3.) and moderate erodibility is surrounding this high erodibility zone. The north western region of the study area shows low erodibility. It is dependent upon the texture and chemical composition of the soil and the way these affect its shear strength, aggregate stability and tendency to surface crusting.

The percentage of sand and silt present in the soil determines soil texture. Soil texture is a measure of the particle size distribution in a soil. Large particles are resistant to transport because of the greater force required to entrain them and that fine particles are resistant to detachment because of their cohesiveness. The percentage of sand particles in the soils in the basin varies from less than 10 percent to 83 percent. Very high K is observed in the south eastern part of the upper Bhima basin covering major portion of watershed number 21 and adjacent parts of watersheds 25 and 26, central part of watershed 11 located south west of the study area. This is as a result of the high proportion of erodible matter i.e. silt + fine sand present in the soil. The least resistant particles are silts and fine sands, thus soils with high silt content are highly erodible. The soils with 40 to 60% silt content are the most erodible (Richter and Negendank 1977).

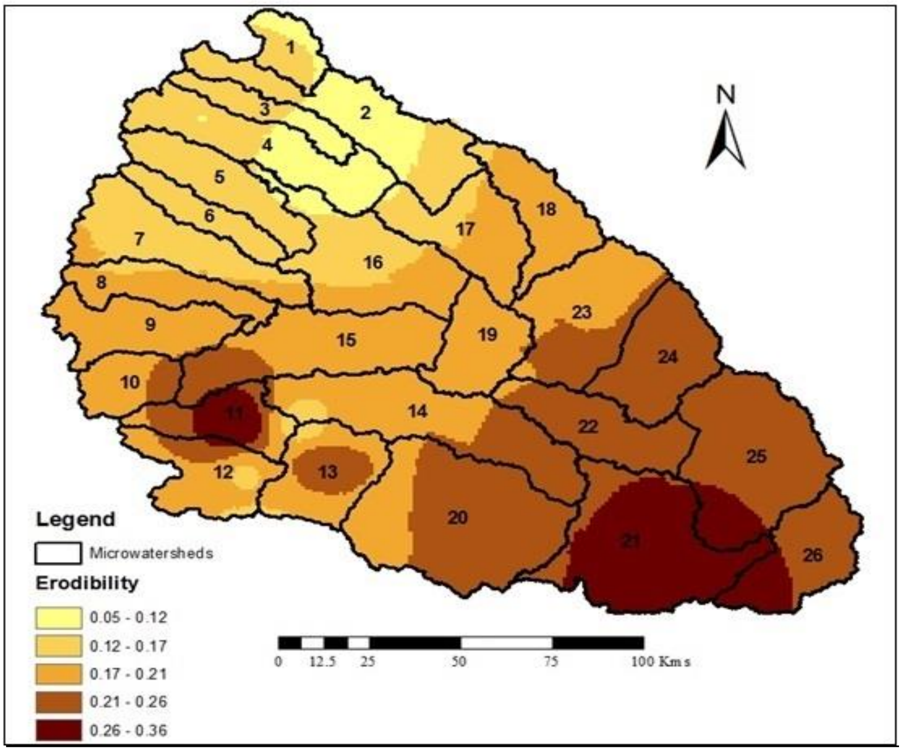


**Figure 3.3: Soil Erodibility (K)**

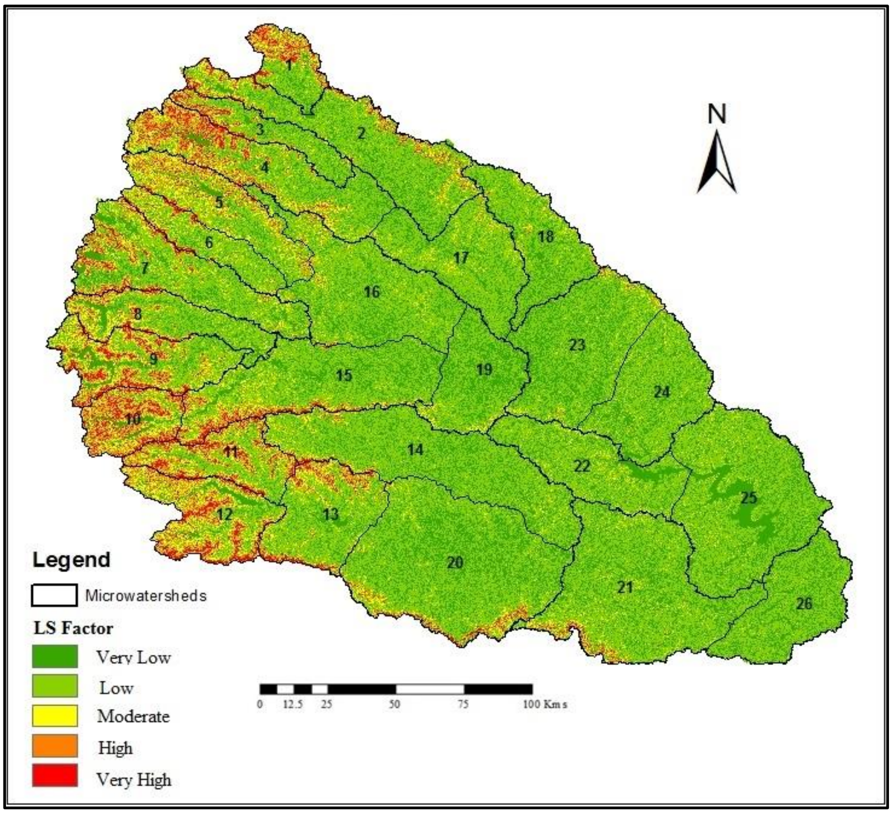


**Figure 3.4: Slope Length LS Factor**

Texture directly influences the infiltration rate of water. In the coarse textured soils, the water infiltrates quickly resulting into less runoff and ultimately into decrease in the soil carrying capacity of the water. Silt particles are most easily detached so silty soils are more prone to water erosion. Soil has an inherent resistance to erosion and the erosive agent must attain a critical or threshold condition for detachment to occur. The low OM content and high amount of sand in the soil have been responsible for moderate to high erodibility of soils in the region surrounding high erodibility. For water erosion the critical velocity increases with increasing grain size for particle sizes above 0.20 mm because of the greater force required to dislodge the larger and heavier particles. Below this grain size, critical velocities increase with decreasing particle size for cohesive materials but decrease slightly for cohesion less particles.

By virtue of its binding action, organic matter helps stabilize loose soils against erosion. Soils with less than 3.5% organic content can be considered erodible (Evans, 1980). Organic matter has a variable influence on the soil, affecting both its chemical and physical properties. The effect of organic matter on physical properties relates largely to its availability to bind soil particles together. The organic constituents of the soil influences the aggregate stability. Organic Matter content is observed very high in the western ghat region, as a result of forest and vegetation present in this area. Whereas, the central parts of the basin especially, watersheds 14 to 19, the matter content is moderate. In both the regions the erodibility is low to moderate. The eastern region of the basin shows high percentage of erodible matter compared to Western ghat region resulting into high erodibility. The role played by organic material depends on its origin. Soil organic matter has a strong bearing on erodibility. The organic material from grass and farmyard manure contributes to the stability of the soil aggregates, peat and undecomposed hulm merely protect the soil by acting like mulch and do little to increase the aggregate strength (Ekwue et al., 1993).

But it is not always applicable. Some soils with very high organic matter particularly peats, are highly erodible by water and wind whereas others with very low organic matter can become very hard and therefore stronger under dry conditions. The clay particles combine with organic matter to form soil aggregates or clods and it is the stability of these clods which determines the resistance of the soil. Aggregation in soils depends primarily on the cohesive nature of the finer particles and on natural forces that organize and retain them in specific structural units, or peds, of definable shape and size. The differences in erosional behaviour of soils are primarily due to degree of aggregation of finer particles. The manner in which soil particles are assembled in aggregate form is called as structure of the soil. Structure may be designated as blocky, prismatic, platy, granular and structure less. The structure of soils in the study area is angular blocky. Blocky and platy structures are more erodible. Very fine granular structure is stable; does not break down under cultivation and a high infiltration capacity. The good structural grades like granules reduce runoff. The strength of soil aggregates is important, as strong peds resists the impact of raindrops.

The antecedent moisture has a significant effect on erosion. At low moisture content, the soil behaves as a solid and fractures under stress but with increasing moisture content it becomes plastic and yields inflow without fracture; the change in behavior is termed the plastic limit. With further wetting the soil reaches its liquid limit and starts to flow under its own weight. The interaction between the moisture content of the soil and chemical composition of both soil water and clay particles are rather complex. It could be due to this fact that, silt and sand proportion is considered as parameter of texture in the USLE to determine soil erodibility.

### *3.2.3. Topographical (LS) Factor:*

Topographic Factor – LS is the expected ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9% under otherwise identical conditions (Wischmeier and Smith, 1965). Hillslope gradient (S) and length (L) factors are sometimes combined into a topographic factor (LS) while estimating soil erosion. Topographic (LS) Factor was estimated from a digital elevation model in the present study. With the incorporation of Digital Elevation Models (DEM) into GIS environment, the slope gradient (S) and slope length (L) was determined accurately and combined to form a topographic factor LS. 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 to begin, or the runoff water enters a well-defined channel (Smith and Wischmeier, 1957).

Eastward flowing Bhima and her major tributaries clearly indicates that, the upper Bhima basin is sloping gently eastwards. The larger part of the basin area is under lands having LS-value less than one. High LS values are restricted to steep slopes with longer length covering ridges in major water divides of the basin. A very less part of the area is having very high LS values of more than 15. The LS-values increased with increase in length and degree of the slope. Moderate LS values from 5 to 10 are observed in the Western Ghats region. In the Western Ghats, the ranges attain varying heights of about 1300 m resulting in very steep slopes. The eastwards running offshoot branches from the main ranges also shows steep to very steep slopes. On the leeward aspect, the amount of effective rain dropped steadily with slope, to half of the meteorological rain at a slope of 100 % (Agassi et. al. 1990).

The slopes in the northern part of the study are moderate whereas they are moderately steep to steep in the southern part (Fig. 3.4). The central basin area shows gentle slopes and covers most of the area. The entire basin has few smaller plateaus and river valley plains of the tributaries. In the extreme eastern part the upper Bhima basin shows gentle to moderate slopes. The soil losses increase with the increase of the slope length and steepness, conditions where the surface flow reaches high-speeds.

The overland flow velocity that determines soil detachment and transport capacity, increases on longer slope lengths and strongly influences the inter-rill erosion rate Chaplot and Bissonnais (2003).

Very high to high length and slope gradient (> 17) is observed as the predominant LS factor in five watersheds (Figure 3.4). All of them are located in the main ridge where height is above 1100 m. They are observed in isolation in the northern (WS 4) and southern portion (WSs 10, 11, 12) of the basin. Soil loss under very high and high LS impact would be severe.

Average LS factor is reported by three watersheds having varying locations (watersheds 17, 18, 23) in the ridge towards northern portion of the basin. It is interesting to note that their slope (moderate) and elevation characteristics are similar.

More than 90 per cent of remaining watersheds are categorized as low and very low length and slope gradient factor. They are spread on all geomorphic units like ridge top, cliffs, inter-cliff zones, pediments and valley fills throughout the basin.

Number of watersheds has high elevation and steep slope resulting in high LS factor, however, the areal coverage in their respective geographical area is small. The description of the watersheds on the basis of magnitude of LS factor is based on predominance of LS class in it.

The slope length to where deposition begins can be used to compute soil loss on the upper eroding portion of a slope. However, the slope length for the lower eroding portion does not begin where deposition ends but starts where runoff originates which flows across the lower portion. Therefore the entire slope length must be used to compute soil loss on the lower portion of slope.

The velocity of the runoff water increases rapidly on the steeper lands and thereby increases immensely its soil carrying capacity. If the soil is not perfectly flat, rain splash will also produce the movement of soil particles down the slope due to diffusion. But even in the case of flat soils the detached particles will be available for transport by other erosion agents such as surface runoff.

Soil losses increase more rapidly as gradient increases than as length increases. The gradient of a hillslope profile is defined as the change in elevation per change in horizontal distance, expressed in percent or in degrees.

### 3.2.4 Cover Management (C) Factor:

The cropping management factor, C as proposed by Wischmeier and Smith (1978) is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean tilled fallow on identical soil and slope and under the same rainfall. The Cover management factor indicates not only the land cover by the natural vegetation but also the land use under the crops. It also indicates the status of the land in an area. Land use Land cover (LULC) layer is generated using satellite data. Values are assigned to the classes to obtain C factor map of the study area.

#### 3.2.4.1 Land use Land cover:

Intensive land use changes and unsustainable use of forest resources have put considerable pressure on land resources. The major classes comprises of Agriculture, Forest, Built Up, Barren and Water Body. Keeping in mind the purpose of study, agriculture was divided into Cultivated and fallow and the forest were classified as Dense forest and Degraded forest. The identified classes are defined as follows as per NRSC norms.

***Agricultural Lands*** are the lands primarily used for farming and for production of food, fiber, and other commercial and horticultural crops. Agriculture is the primary occupation in the study area. It includes land under crops (irrigated and unirrigated, fallow, plantations etc.). It has been categorized as cultivated and agricultural fallow. Out of the total geographical area about 61.6 per cent of the land is under cultivation (Table 3.5). The cultivated areas are the areas with standing crop as on the date of satellite overpass. Around 48 % of area was under cultivation. Cropped areas appear to be in bright red to red color with varying shape and size in a contiguous to non-contiguous pattern. The agriculture is dominated almost in the entire basin area except in the Western Ghats region. They prominently appear in the irrigated areas irrespective of the source of irrigation. They are widely distributed in different terrains.

The lands, which are taken up for cultivation but are temporarily allowed to rest, un-cropped for one or more seasons are ***agriculture fallow***.

***Dense Forest:***

The forests constitute about 20.5 per cent and are dominant in the Western part of the basin. These are the areas bearing an association predominantly of trees and other vegetation types (within the notified forest boundaries) capable of producing timber and other forest produce. Based on the canopy cover or density they are categorized as the dense and degraded forests. The dense forest category includes all the areas where the canopy cover or density is more than 40%. It appears in bright red tones. The western margin of the basin including Western ghats is dominated by luxuriant evergreen forest. This region is having relatively high rainfall.

On eastern side of ghats, after a transitional belt of low trees, thorny bushes predominate, except on some hill slopes. This area is occupied by different types of forests such as deciduous (moist and dry) and thorny nature. These are the degraded forests which appear in dark red to pink tones of varying sizes. The size can be irregular and discontinuous occupying medium relief mountain or hill slopes within the notified areas. The canopy cover or density ranges between 10 to 40 per cent only. Out of the total area, they cover an area of about 9.6 per cent.

***Barren Lands:***

These are rock exposures of varying lithology often barren and devoid of soil and vegetation cover. They cover around 12.5 % out of total geographical area. They occur amidst hill-forests as openings or as isolated exposures on plateau and plains. These lands are easily discriminated from other categories of wastelands because of their characteristic spectral response. They appear in greenish blue to yellow to brownish in colour depending on the rock type. They vary in size with irregular to discontinuous shape with a linear to contiguous or dispersed pattern. They are located on steep isolated hillocks and hill slopes in the Sahyadri ranges. They are also observed in the central and eastern parts of the study area. They are associated with barren or exposed rocky or stony wastes, rock out crop, mining and quarrying sites surrounding Pune urban region.

***Water Bodies:***

This category includes areas with surface water, either impounded in the form of ponds, lakes and reservoirs or flowing as streams, rivers, canals etc. These are seen clearly on the satellite image in blue to dark blue or cyan colour depending on the depth of water. Multipurpose dams are constructed at various locations in the upper Bhima basin. Area occupied by water stored in these reservoirs led to 3.6 % of total area under water bodies. Along with their tributaries, the rivers Ghod, Bhama and the Indryani drains major part of upper Bhima basin.

***Built-Up Area:***

Total built up area is around 1.8 %. It is an area of human habitation developed due to non-agricultural use and that has a cover of buildings, transport and communication, utilities in association with water, vegetation and vacant lands. It appears in cyan color in the image. The major citiy identified is Pune, a district headquarter.

**3.2.4.2 C Factor :**

The C factor indicates not only the land cover by the natural vegetation but also the land use under the crops. It also indicates the status of the land in an area. For each land use land cover C-factors were attributed (Table 3.1) and the spatial distribution of cover and management factor C in the upper Bhima basin is mapped out (Fig. 3.5).

| LULC Category | C Factor | Area (%) |
|---|---|---|
| Agriculture Cultivated | 0.8 | 48.59 |
| Agriculture Fallow | 0.6 | 12.98 |
| Degraded Forest | 0.005 | 09.63 |
| Dense Forest | 0.003 | 10.88 |
| Barren | 0.5 | 12.53 |
| Water Body | 1.0 | 03.59 |
| Built Up Area | 0.25 | 01.79 |

***Table 3.1: Area under different LULC Category and C Factor***

The cover management (C) 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 rainstorm with respect to seeding and harvesting date in the locality. Dense forest, degraded forest, cultivated area and agriculture fallow were assigned a C factor value of 0.003, 0.006, 0.2, 0.8 and 0.6 respectively (Table 3.1). In the mechanized agricultural techniques, the soils get compact during the seed bed preparation the interactive effect of the crops during the growing season, the loosing process takes place at the time of harvesting and the influence of the weather during the non-production season. Thus improper and wrong agricultural practices results in more erosion. The short periods of rough fallow in a rotation generally led to lose much less soil than the basic, clean tilled, continuous fallow conditions. The canopy protection of crops not only depends on the type of vegetation, the stand, and the quality of growth, but it also varies greatly in different months or seasons. Therefore, the overall erosion-reducing effectiveness of a crop depends largely on how much of the erosive rain occurs during those periods when the crop and management practices provide the least protection.

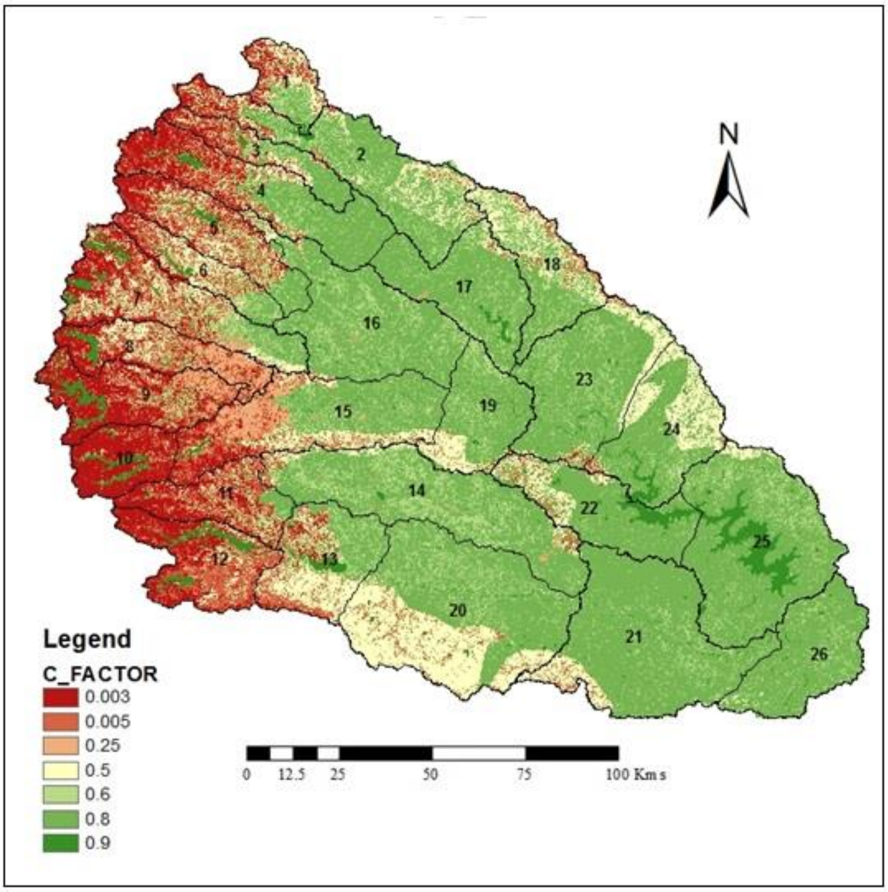


**Figure 3.5: C Factor**

The barren lands are unprotected throughout the rainy season and hence are given the C value of 0.5 and water body as 1 to nil out the effect during calculation.

Watersheds with dense forest cover in the source region (4, 9 to 12), have a C Factor of 0.003 (Figure 3.5) covers an area of about 11%. . Eastern slopes of the watersheds located towards west (watersheds 5 to 12) are predominated by degraded forest having C Factor 0.006 covering an area of about 9.6%. Largest number of watersheds covering more than 60% area is observed to have agriculture as a predominant class with C values of 0.6 and 0.8. Rest of the cover classes have not appeared as predominant LU/LC in any of the watersheds.

### 3.2.5 Conservation Practice (P) Factor:

The problem of conserving soil is of great importance in regions of low and uncertain rainfalls. Severe erosion occurs in the sub-humid and per-humid hilly areas due to high rainfall. In addition to these natural causes, overgrazing, deforestation and improper management of land are the other anthropogenic factors leading to soil erosion. In order to restore the soil status, agronomic and mechanical support measures are implemented. Presence of soil conservation practices in the region is duly considered in the USLE by including support conservation practice factor (P).

Cover and management effects cannot be independently evaluated because their combined effect is influenced by many significant interrelations. Different agricultural uses require different soil management practices. Various practices adopted in the area are contour bunding, graded bunding or contour terraces, strip cropping and bench terracing for agricultural lands and continuous contour trenching (CCT) structures, stone bunds and live bunds are observed on the sloping forested areas.

The values of P-factor ranges from 0.1 to 0.9, in which the highest values are assigned to areas with no conservation practices like barren lands and fallow lands. The hill-slope areas with degraded forest are supported by Continuous Contour Trenching structures (CCTs) and at a very few sites by live bunds. Effect of CCT, live bunds and check-dams is reported mainly in reduction in runoff which in turn reduces transport of the particles, but not affect much splash erosion.

Watershed-wise distribution of P Factor is presented in the Figure 3.6. Support practices are isolated and are located in individual fields throughout the basin and hence the predominant P factor for almost all the watersheds has been very high as 1.0. Contouring is practiced along 9 to 12 % slope where degraded forest cover is a major land cover in watersheds 5 to 11. Contouring as the conservation measure is adopted along 10 % slope under degraded forest cover class in watersheds 5 and 6 in the source region of the Bhima.

## 3.3. Assessment of Soil Erosion:

The erosion process can be both constructive and destructive. Erosion is primarily responsible for the variations in topography as it erodes the elevated surface and which simultaneously constructs alluvial plains. It is aggravated due to human intervention through indiscriminate felling/cutting of trees, mining, cultivation of marginal lands and over grazing etc., thus altering natural ecosystem.

In the present study, the quantitative soil loss through erosion in the study area was assessed with the help of universal soil equation by generating the layers viz. R, K, LS, C and P in GIS environment and multiplying them to obtain the annual soil loss (A) in tonnes per hectare per year.

The study area is classified into seven classes of soil erosion:

- Very Low (< 05 t/ha/yr)
- Low (05 – 10 t/ha/yr)
- Moderate (10 – 20 t/ha/yr)
- High ( 20- 30 t/ha/yr)
- Very High ( 30- 50 t/ha/yr)
- Severe ( 50- 70 t/ha/yr)
- Extremely Severe (> 70 t/ha/yr)

Majority of the area about 12749 Sq. KM. (55 %) is under low to moderate erosion classes covering most part of the study area. About 3382 Sq. KM (14.8 %) area is under the very low erosion class which is mainly covering the central and eastern part of the upper Bhima basin. The table 3.2 and figure 3.6 indicates distribution of the watersheds of upper Bhima basin according to soil loss intensity.

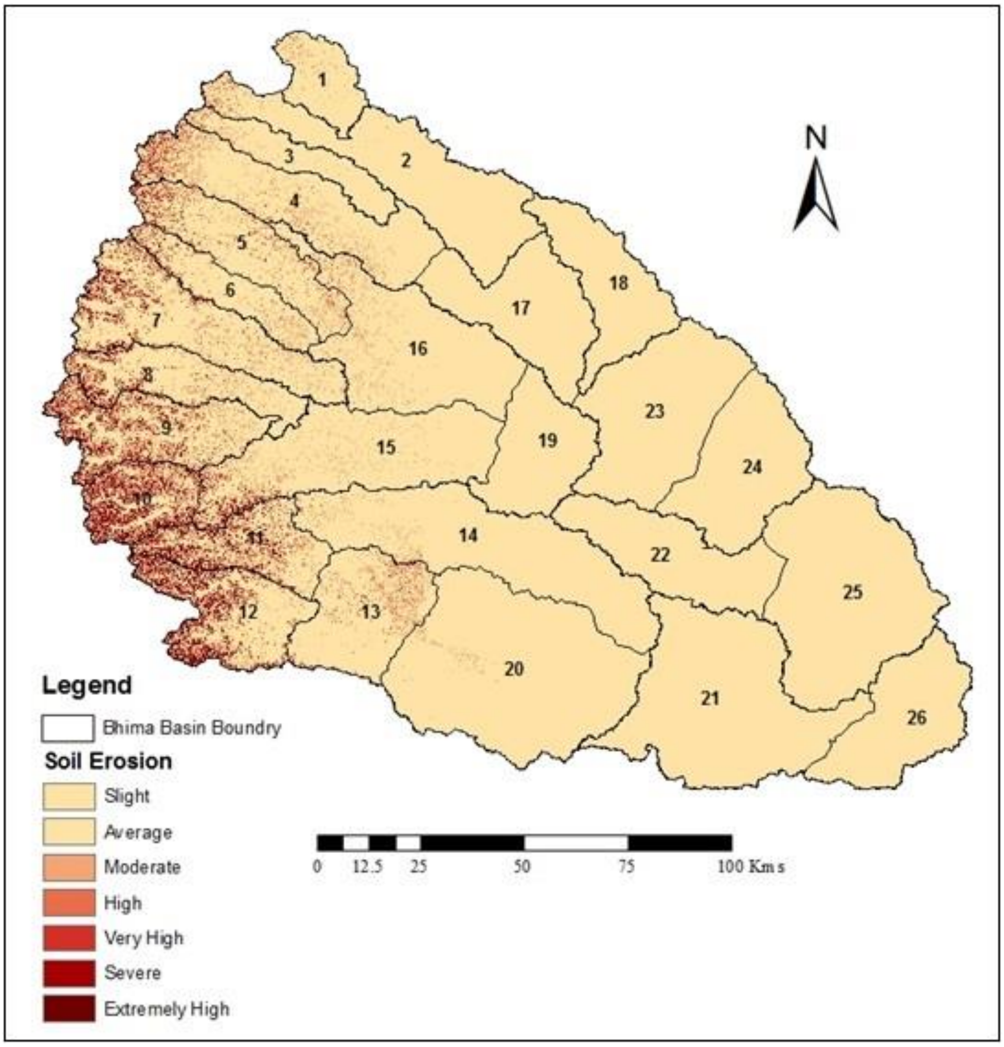


**Figure 3.6: Soil Erosion (USLE)**

| Priority Class | Category | Watersheds | No. | Area (ha) | Area (%) |
|---|---|---|---|---|---|
| P1 | Extremely Severe | 10, 11, 12 | 3 | 165418.0 | 7.2 |
| P2 | Severe | 9 | 1 | 73034.0 | 3.2 |
| P3 | Very High | 5, 6, 7, 8 | 4 | 259903.1 | 11.4 |
| P4 | High | 4, 13 | 2 | 172279.9 | 7.5 |
| P5 | Moderate | 1, 3, 15, 16 | 4 | 303742.5 | 13.3 |
| P6 | Low | 2, 14, 17, 19, 20, 21, 25, 26 | 8 | 970204.5 | 42.5 |
| P7 | Very Low | 18, 22 ,23, 24 | 4 | 338246.7 | 14.8 |
| | | Total | 26 | 2282828.7 | 100 |

***Table 3.2: Classification of watersheds***

As per these estimates, major area is under low (42.5 %) erosion class followed by moderate and very low erosion class (14.8 and 13.3% respectively). The area under very high class is 11.4 per cent while the area under high and extremely severe class is around 7 per cent.

High erosion is observed in western and hilly parts of the basin. The potential soil loss is typically greater along the steeper slope and in the areas with poor vegetation cover. The grass land and dense forest areas of the upper Bhima basin are least vulnerable to soil erosion. A spatial location of the high soil erosion areas has been identified in the regions having high hills accompanied by heavy rainfall.

Other high soil erosion areas are dispersed throughout the central part of the basin and are typically associated with the land-use classes which have high erosion potential such as the higher elevation ranges, isolated pockets of open and dense forests which have been cleared for agriculture and horticultural crop lands. In this study, the highest amount of soil loss has been identified in the fallow and agricultural lands. Also urbanization and construction of roads in this area have affected the topography and increased the soil loss.

Very high, severe and very severe classes cover 238452 ha. (10 %) area which is restricted to western parts and hilly areas of other parts of the basin. Severe and Very severe soil erosion is observed in the Western Ghats accompanied by steep slope, high intensity rains and deforestation or cultivation are responsible for such exceptionally high values of soil loss. Very severe soil erosion in these areas is attributed to highest rainfall in the basin, steep slopes and fragile geology coupled with cultivation on the private land.

## 3.4. Prioritization:

Watershed management has assumed importance in India in view of the reported loss of storage capacity of a number of major reservoirs due to increasing siltation. In addition, there is a need to preserve the soil-water-vegetation ecosystem in river valleys in harmony with resource exploitation and development programmes. The large financial and manpower commitments involved in treating watersheds require a selective approach. Identification of smaller hydrological units is needed for more efficient and better targeted resource management programmes. This has created renewed interest in erosion surveys and sediment yield prediction studies to identify problem area with relatively high sediment yield potential so as to take up conservation measures on priority basis (Rao et al., 1994).

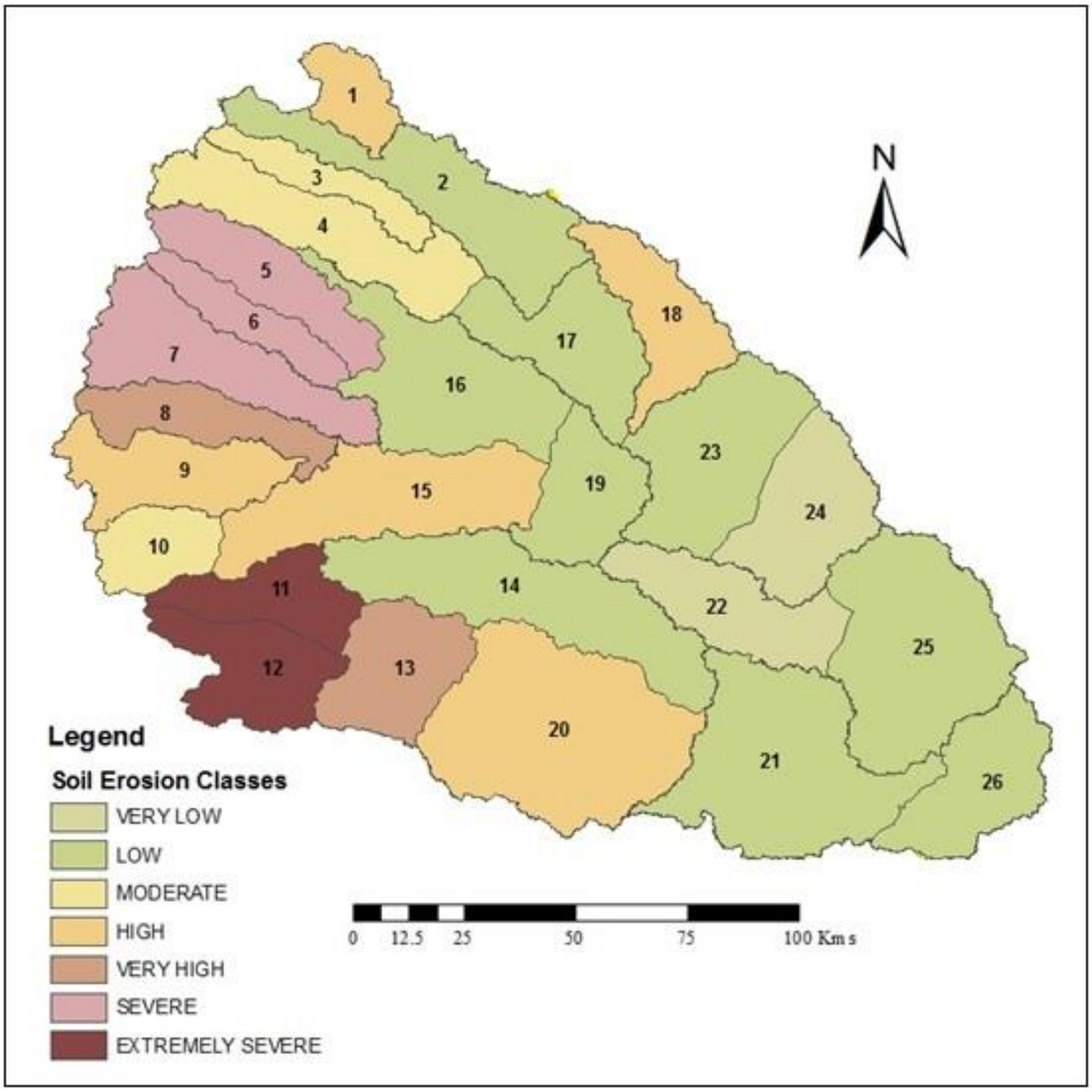


**Figure 3.7: Soil Erosion categories based on USLE**

Watershed characterization, prioritization and creation of database manually through conventional methods is time consuming, tedious and there are difficulties in handling large areas and data. Voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of GIS techniques. GIS facilitates creation of computerized database in the form of maps, map manipulation, composite map generation, area statistics calculation etc. much faster and more accurately. The information on sediment yield and the priority classification of watersheds help in taking up soil conservation measures on the priority basis.

The highest priority is seen for the watersheds 10, 11 and 12 covering 165418 ha area which should be adopted urgently under the conservation programme (Table 3.2). Severely to very high eroded area amounts to 332937 ha (14 % of the total basin area) comprising 5 watersheds. Area under high and moderate erosion together (6 watersheds) accounting for 21% of the basin area. This is the area highlighted by the analysis needs implementation of erosion control measures.

Fifty Seven percent area (1308451 ha) spreading over 12 watersheds is low to very low soil loss regime which is the least

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# CHAPTER 4

# MULTICRITERIA MODELING OF SOIL EROSION

## 4.1 Introduction:

Erosion destroys the land resources which are very precious. It results in the problems like siltation of reservoirs, deposition of unfertile material on the fertile agricultural lands leading to the loss of fertile soil. Accelerated soil erosion caused by water is an increasing global problem that threatens sustainable agricultural production (Oldeman 1994).

It is very important to conserve the available land resource by implementing proper conservation measures. Appropriate knowledge of quantity of soil loss will help for proper framing of conservation policies. Analyzing soil erosion risk is an important task, especially in vulnerable areas. Erosion risk maps of areas are required to plan land-use and soil conservation measures. But, for this it is very essential to study the factors responsible for soil erosion. Soil erosion prediction models play an important role both in meeting practical needs of soil conservation goals and in advancing the scientific understanding of soil erosion processes (Nearing et al., 2007). The soil erosion modelling can be used as predictive tool for assessing soil loss for conservation planning and project planning, soil erosion inventories and for formulating regulations.

Many attempts have been done by various researchers to quantify soil erosion. Reliable soil loss estimation is a valuable design extension and planning tool (Singh et al. 1981). Modeling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. There are two basic types of erosion models. They are empirical and physically based or process based models. The empirical models were developed primarily from statistical analysis of erosion data. The best example of the empirical model is the Universal Soil Loss Equation (USLE). The Process-based models are intended to represent the essential mechanisms of controlling erosion. They represent a synthesis of the individual component, which affects erosion, including the complex interactions between various factors and temporal variability e.g. Morgan-Morgan and Finney Model (1982). In the present study, an attempt has been made to estimate the soil erosion using multi-criteria modelling.

The GIS is found to be a technique that provides scope to incorporate multiple criteria in an order of hierarchical importance in a given situation and also provides greater flexibility and accuracy for land use planning.

Although planners have conducted similar exercises in the past using manual methods, with the help of GIS these tasks performs much faster. The combination of multi-criteria analysis with GIS is a new trend in land use planning exercises. Least suitable areas for development and/or conservation are important for decision making. At that time planner needs to exert in judgment to decide whether land should be developed or conserved. Multi-criteria modelling and GIS together provide a powerful tool in decision-making process. The Weighted Overlay is one of the most used approaches for overlay analysis to solve multi-criteria problems such as site selection and suitability models.

This chapter elaborates the multi-criteria analysis done for decision making regarding prioritization of watersheds based on their vulnerability to soil erosion for application of conservation measures.

This chapter elaborates multi-criteria analysis done for the prioritization of watersheds based on their vulnerability to soil erosion.

## 4.2 Data and Methodology:

The expert systems are computer programs that simulate the problem-solving skills of one or more human experts in a given field and provide solutions to a problem. These systems express inferential knowledge by using decision trees. The expert decision trees are based on the scientific background (theoretical description) and results of experiences and discussions with human experts (practical experience), and thereby reflect available expert knowledge. A systematic landuse planning by using the concept of compatibility of multiple landuses was introduced by Mc Harg (1968). According to him the factors affecting land and its relative resource potential are different and, therefore, it is difficult to think of optimizing them for a single use. The land can be optimized for multiple compatible uses. He introduced simple matrix system for determining the degree of compatibility. The idea of multi-criteria decision making was based on this concept.

The recent developments in Geographical Information Systems have drawn upon concepts of the multi-criteria methodology. Methods of multi-criteria evaluation (Carver, 1991) have been developed to provide a user with the means to determine new attributes that indicate alternative responses to problems involving multiple and conflicting criteria. This section presents the methodology of multi-criteria analysis based on weighted overlay approach used to estimate erosion intensity in the upper Bhima basin.

Mc Harg (1968) introduced a systematic landuse planning by using the concept of compatibility of multiple landuses. He mentioned that the factors affecting land and its relative resource potential are different and, therefore, it is difficult to think of optimizing them for a single use. The land can be optimized for multiple compatible uses. He introduced simple matrix system for determining the degree of compatibility. The idea of multi-criteria decision making was based on this concept. Recent developments in Geographical Information Systems have drawn upon concepts of the multi-criteria methodology. Methods of multi-criteria evaluation (Carver, 1991) have been developed to provide a user with the means to determine new attributes that indicate alternative responses to problems involving multiple and conflicting criteria. This section presents the methodology of multi-criteria analysis used in estimation of erosion intensity in the Upper Bhima basin.

### 4.2.1 Data used:

To perform multi-criteria analysis for soil erosion modeling in the upper Bhima basin, the criteria have been derived from various sources as follows:

ASTER DEM data was used to derive physiography, drainage and morphometric parameters like drainage density, elongation ratio and slope of the watersheds.
Rainfall erosivity was obtained from daily rainfall data.
Proportion of erodible matter in the soils were obtained from soil survey analysis.

The LULC layer was derived using the Landsat ETM and Landsat ETM Plus data of October and November 2009. Weights are assigned to respective classes using the literature based on Indian as well as international studies.

## 4.2.2 Methodology

The methodology used in the MCA is the Weighted Overlay Analysis

#### 4.2.2.1 Criteria used:

The basin is the natural integrator of variables such as precipitation, runoff, erosion and sediment discharge as they relate to input and output in an open hydrological system. Keeping this in view, basin characteristics like drainage density and elongation ratio of the Upper Bhima basin have been considered. Canopy percentage resulted from landuse / land cover also has a strong influence on the soil erosion. Relevance of the criteria selected for the multi-criteria analysis is presented below:

1. Land Use/ Land Cover (LU/LC): Information on landuse permits a better understanding of the land utilization aspects on cropping pattern, fallow land, forest and wasteland and surface water bodies, which have varying response to falling rain drops and to the process of detachment of soil particles.

2. Rainfall Erosivity: As rainfall has pronounced effect on the soil erosion, rainfall erosivity as a measure of climatic influence on soil erosion has been considered.

3. Erodible Matter (Texture): Soil texture is a measure of the particle size distribution in a soil. Large particles are resistant to transport because of the greater force required to entrain them and that fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silt and very fine sand, which are termed as an erodible matter (Particle size: 0.002 to 0.1 mm).

4. Slope: Although there is little doubt that runoff plays a critical role in soil erosion and sediment movement downslope, the use of runoff characteristics is not consistent with the notation of rainfall erosivity as a measure of climatic influence on water erosion, because runoff depends on the topography and soil properties in addition to the rainfall regime, thus often having much greater spatial variability within the catchment than rainfall (Yu and Neil, 2000). Slope in percent is, therefore, chosen as one of the criteria.

5. Drainage Density: Drainage density is an expression of dissection of a basin by streams and is related to other characteristics such as rock and soil type, vegetation, climate and infiltration, which have influence on soil erosion.

6. Elongation Ratio: The elongation ratio is considered as a measure of the basin shape which is related to runoff characteristics.

### *4.2.3 Analytical Hierarchy Process (AHP)*

Saaty (1980) forwarded Analytical Hierarchy Process (AHP) as a multi-criteria decision support that uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user. Numerical ratings with its verbal description of judgment given by Saaty are shown in Table 4.1.

| Numerical ratings | Verbal Description of Judgment |
|---|---|
| 1 | Equally preferred |
| 2 | Equally to moderate preferred |
| 3 | Moderately preferred |
| 4 | Moderately to strongly preferred |
| 5 | Strongly preferred |
| 6 | Strongly to very strongly preferred |
| 7 | Very strongly preferred |
| 8 | Very strongly to extremely strongly preferred |
| 9 | Extremely strongly preferred |

***Table 4.1 AHP – Numerical Ratings with Description of Judgment***

### 4.2.4 Layer generation of the criteria:

GIS aided analysis has been done to obtain a map for each criterion. On the basis of the range (Minimum and maximum value) sub-classes were formed and weights from 1 to 9 were assigned to each sub-class depending on the importance of the sub-class in the soil loss.

#### *4.2.4.1 Land use/ Land cover (LU/LC):*

The LULC layer derived using the Landsat ETM and Landsat ETM Plus data of October and November 2009 (Section 1.4) has been used for the analysis. In the context of soil erosion, LU/LC classes viz. Agriculture, Forest, Built Up, Barren and Water Body were considered.. Keeping in mind the purpose of study, agriculture was divided into Cultivated and fallow and the forest were classified as Dense forest and Degraded forest.

The LU/LC reflects the combined effect of canopy cover. Considering the density of trees forest is classified as dense forest and degraded forest having different response to soil loss. Agricultural land is classified as cultivated and fallow. The barren lands are unprotected throughout the rainy season and hence are given the value of 9 and water body as 1 to nil out the effect during calculation.
The canopy protection of crops not only depends on the type of vegetation, the stand, and the quality of growth, but it also varies greatly in different months or seasons.

| **Land Use** | **Weight** |
|---|---|
| Dense Forest | 1 |
| Degraded Forest | 6 |
| Agricultural Cultivated | 3 |
| Agriculture Fallow | 7 |
| Barren Lands | 9 |
| Built Up Area | 1 |
| Water Body | 1 |

***Table 4.2: Ratings for LU/LC criteria***

The range under the LU/LC is rated in 9-point weighing scale appropriately as per their contributions to the soil losses (Table 7.6). Watershed-wise weighted maps for LU/LC was generated.

*4.2.4.2 Rainfall Erosivity (R), Slope (S) and Erodible Matter (T) criteria:*

A rainfall erosivity map based on rainfall data for a period from1990 to 2014 was created. A slope map was generated from the ASTER DEM data of 30 m resolution DEM. A textural analysis was carried out and a layer of silt and very fine sand i. e. erodible matter was prepared. The ranges of these criteria are rated by 9-point weighing scale (Table 4.3, 4.4, 4.5).

| Rainfall | Erosivity | Weight |
|---|---|---|
| < 400 | < 250 | 1 |
| 400 – 800 | 250 – 500 | 2 |
| 800 – 1200 | 500 – 750 | 5 |
| 1200 – 1600 | 750 – 1000 | 6 |
| 1600 - 2000 | 1000 – 1200 | 7 |
| 2000 – 2400 | 1250 – 1500 | 8 |
| 2400 - 2800 | 1500 – 1750 | 9 |

***Table 4. 3: Ratings for Erosivity criteria***

| Slope | Class | Weight |
|---|---|---|
| Gentle | > 5 | 1 |
| Moderate | 5 – 7.5 | 2 |
| Moderately Steep | 7.5 – 10 | 4 |
| Steep | 10 – 12.5 | 5 |
| Very Steep | < 12.5 | 6 |

***Table 4. 1: Ratings for Slope criteria***

*4.2.4.3 Drainage Density:*

Drainage density (Dd) (km/km$^2$) as defined by Horton (1932) is the total length of streams in km ($\sum$ L) within a basin divided by the drainage area in km$^2$ (A). Length of streams, area and perimeter for each watershed were obtained using *Strahler.avx* extension of Arc-view GIS 3.2a (Jeff Jenness, 2004). The range of Dd values was assigned 1 – 9 weights which is presented in the Table 4.5.

*4.2.4.4 Elongation Ratio:*

Shape of a drainage basin as it is projected upon the horizontal datum plane of a map, may conceivably affect stream discharge characteristics. Schumm (1956) expressed basin shape as the elongation ratio (Re), which is used in the present study. It is the ratio of diameter of a circle with the same area (km$^2$) as the basin (A) and the maximum length (m) of the basin (L) from mouth to the headwater divide along the main channel. Measuring tool available in the Arc-view GIS 3.2a is used to measure maximum length of the basin for each watershed. Sub-classes for Re are assigned the weights as mentioned in the Table 4.5

### *4.2.5 Multi-criteria analysis:*

*4.2.5.1 The Weighted overlay analysis:*

Overlay analysis is a group of methodologies applied in optimal site selection or suitability modeling. It is one of the most used approaches for overlay analysis to solve multi-criteria problems. This technique is applied for a common scale of values to diverse and dissimilar inputs to create an integrated analysis.

Overlay analysis often requires the analysis of many different factors. Soil loss is the result of various factors like rainfall, soil properties, land use, topography, etc. of the region. For scientific planning of soil conservation the relationship between soil loss and these factors must be investigated thoroughly. These parameters are having very complex relationship with soil erosion. Hence, its study becomes very difficult in natural environment.

Therefore, each input raster is weighted according to its importance or its percent influence. The weight is a relative percentage, and the sum of the percent influence weights which is equal to 100. Since the input criteria layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion has to be reclassified into a common preference scale of 1 to 9. Thomas Saaty in 1976, introduced this scale, which was very simple to use and have hundreds of reported applications in many areas.

Layers of weighted drainage density, elongation ratio; change detection in landuse/ land cover, rainfall erosivity and proportion of erodible matter in soils were generated and used in multi-criteria analysis. Further area-weighted maps were generated for all these criteria for each watershed and the index of Erosion (EI) is calculated for each watershed.

*4.2.5.2 Map algebra:*

All area-weighted criteria layers obtained above are then multiplied to get Composite Erosion Index (CEI)

The algebraic operation performed on seven layers is as below:

CEI = LU/LC * R * S *T *Dd *$R_e$

Where CEI is Composite Erosion Index

The final output map indicates watershed-wise Composite Erosion Index that relates to the erosion intensity of the unit area under the relative contribution of the given criteria.

| **Weights** | **Erodible Matter (%) (T)** | **Drainage Density (Dd)** | **Elongation Ratio (Re)** |
|---|---|---|---|
| 1 | < 8 | < 1 | < 0.5 |
| 2 | 8 to 12 | ---- | ---- |
| 3 | 12 to 16 | 1 to 2 | 0.5-0.7 |
| 4 | 16-20 | ---- | ---- |
| 5 | 20-24 | 2 to 3 | ---- |
| 6 | 24-28 | 3 to 4 | 0.7-0.9 |
| 7 | 28-32 | 4 to 5 | 0.9-1.1 |
| 8 | 32-36 | 5 to 6 | > 1.1 |
| 9 | >36 | > 6 | ---- |

***Table 4.5 Weights and ratings for criteria***

## 4.2.6 Prioritization of Watersheds:

Prioritization of watersheds was done on the basis of Composite Erosion Index. The range of CEI values is classified, which generated 7 classes of erosion intensity varying from very low to extremely severe (Table 4.6).

| Sr. No. | Priority category | Description |
|---|---|---|
| 1 | P1 | Extremely Severe |
| 2 | P2 | Severe |
| 3 | P3 | Very High |
| 4 | P4 | High |
| 5 | P5 | Moderate |
| 6 | P6 | Low |
| 7 | P7 | Very Low |

***Table 4. 6: Soil erosion categories according to Composite Erosion Index***

## 4.3 Results and Discussion:

### 4.3.1 Criteria used in the analysis:

#### 4.3.1.1 Morphometric influence on the soil erosion

A drainage basin provides a convenient and functional unit for the description of landforms and the measurement of inputs and outputs of energy from the sun and kinetic energy from water (Chorely and Kenndey, 1971). Therefore it is appropriate to analyze morphological characteristics of basin while interpreting the vulnerability of basin to soil erosion.

The drainage pattern of upper Bhima is dendritic and it is the seventh order stream. A drainage basin can be characterized by linear, areal, and relief elements.

***Linear Drainage Basin Characteristics***: The stream network in a drainage basin was examined quantitatively by Horton (1945) in terms of stream order, stream length etc. which are measured for all 26 watersheds in upper Bhima basin. Most of the watersheds have second and third – order streams while some of them have fifth – order streams, and a very few have first-order streams. Stream length across the watersheds in the upper Bhima basin is varying widely from 1.0 km to 13 km.

***Areal Drainage Basin Characteristics*****:** There are areal measures of drainage basin that may be related to both stream flow and sediment yield. These measures include drainage area, basin shape and drainage density. Drainage area is an important hydrological integrator for runoff and sediment yield. The area has been calculated for each watershed which is varying from 32027 ha to 187521 ha.

If the basin is elongated then the value approaches unity. In such case, it has a larger perimeter but smaller drainage area compared to a circular because a circle provides a maximum area with a minimum perimeter. The lag time, or time for concentration of flow from tributaries to the main channel, is more in elongated and narrow basins than in circular basins. In the upper Bhima basin all the watersheds have $R_e$ ranging from 0.2 to 1.2 indicating that majority of them are elongated basins. Drainage density in the upper Bhima basin varies from 0.6 to 6.8 with the mean of 2.3. Various studies carried out by Hadley and Schumm (1961) have revealed that drainage density is directly related to sediment yield. Slope in the basin is observed upto 45 %. On the basis of the magnitude of slope the geomorphic features from ridge to valley are upper cliff slope, middle moderate slopes, lower moderate to gentle slopes, pediment, terraces and valley fills.

#### 4.3.1.2 Climatic influence on the soil erosion

When other variables are held constant, rate of soil loss is directly proportional to the level of rainfall erosivity (Wischmeier and Smith, 1958). Further, as stated by Morgan (1996) erosivity data can be used as an indicator of regional variations in erosion potential. This is a crucial climatic parameter that determines erosion-proneness of a watershed. Maximum rainfall erosivity is found in the watersheds in the source region located in the western part (~ 2000) and it decreases towards the east of the upper Bhima basin (~ 250).

#### 4.3.1.3 Pedological influence on the soil erosion

Erodibility of soils is referred to as the vulnerability of the soils to get eroded. Soil texture is a measure of the particle size distribution in a soil. It is important to note that as proportion of silt and very fine sand in the soil increases the erodibility increases (Deore, 2005). Ellison (1947) and Baver (1966) have highlighted that fine sand being least resistant to splash action, detachment increases as the fine sand content of soil increases.

Maximum erodible matter is observed in patches in the lower part of the basin and in the watersheds 11 towards south western part. Moderate proportion of erodible matter in soils is found in the valley portion of entire basin while its low amount is observed in the source, and middle portion of the basin.

#### 4.3.1.4 Influence of LU/LC on the soil erosion

If the area under dense forest is more, vulnerability to soil erosion decreases. In contrast, as the area under degraded forest is more, vulnerability to soil erosion also increases. Under this consideration, weights are assigned to respective classes.
Agricultural fallow area is vulnerable to erosion process, as the soil is exposed to rain during increased rain drop impact in the monsoon season. Agricultural area under cultivation is observed to be protected. Barren lands are most vulnerable to soil loss.
Watersheds (4, 9 to 12), having dense forest cover are observed in the source region covers an area of about 11%. Out of the total area of 9.6% under degraded forest, eastern slopes of the watersheds located towards west (watersheds 5 to 12) are predominated by degraded forest. Largest number of watersheds covering more than 60% area is observed to have agriculture as a predominant class. Barren lands are seen spread in the central and eastern parts of the study area.

### 4.3.2 Multi-criteria Decision Making (MCDM):

Decision analysis is a set of systematic procedures for analyzing complex decision problems. The basic strategy is to divide the decision problem into small, understandable parts; analyze each part; and integrate the parts in a logical manner to produce a meaningful solution. Much of the development in the field of decision analysis has been in the areas of operational research and management sciences, in which the decision making process is of key importance for functions such as investment, logistics, allocation of resources etc. Decision making itself, however, is broadly defined to include any choice or selection of alternative courses of action, and is, therefore, of importance in many fields in both the social and natural sciences (Roy et al., 2000).

Decision problems which interest geographers and spatial planners involve a set of geographically defined alternatives, from which choice of one or more alternatives is to be made on the basis of multiple, conflicting and incommensurate evaluation criterion. The alternatives are geographically defined. Accordingly, many real-world spatial planning and management problems give rise to GIS based MCDM or area weighted analysis. In the present study for estimation of erosion intensity in the upper Bhima basin, seven criteria have been used which are LU/LC, Rainfall erosivity, Erodible matter, Slope, Drainage density and Elongation ratio.

**4.3.2.2 Area weighted analysis:**

Geographic Information System (GIS) is a computer-based system that is used to store and manipulate geographic information. This technology has developed so rapidly over the past two decades and it is now accepted as an essential tool for the effective use of geographic information. All six criterion layers are integrated in the weighted linear combination equation in GIS to derive Composite Erosion Index.

***Climatic parameters:***

Rainfall erosivity as a climatic criterion is observed to decrease from the west to east. It is highest (9) in the watersheds 9 and 12 located south west and west in the study area. watersheds 4 to 12 located in the western ghat region shows high erosivity with weight of 8. Large part of the study area (watersheds 17 to 26 and eastern parts of watersheds 2 and 14 to 16) comes under low erosivity values (Figure 4.1).

***Pedologic parameters***:

Area weighted layer indicating proportion of erodible matter (silt + very fine sand) brings out high pedological adverse influence in the watersheds 11 towards west and 21 towards east, both located in the south part of the basin. watersheds (20, 22 to 26) located towards east in the basin has high values for erodible matter. Low amount erodible matter is observed in the north-western part of the study area (watersheds 1 to 7 and western parts of watersheds 16, 17).

***LU/LC parameters:***

Barren lands covering total area of 13 percent with highest weights are observed on the slopes of the northern divide of the upper Bhima basin spread in the watersheds 2, 18, 23 and 24; central parts in watersheds 15 and 22; and towards southern divide in watersheds 13 and 20. Agriculture area is spread almost in the entire study area (60 %) with less concentration in the western part of the basin. Cultivated area with the weight of 3 is observed mainly in the central and western parts of the basin covering majority of the watersheds (Figure 4.3). Agricultural fallow with the weight of 7 covers an area of 13 percent, concentrated in the eastern parts (watersheds 21 to 25).

Dense forest covers an area of about 11% observed predominately in the watersheds 4, 9 to 12 in the western parts of the basin whereas eastern slopes of the watersheds located towards west (watersheds 5 to 12) are having good coverage of degraded forest.

***Morphometric parameters:***

Morphometric criteria refer to drainage density and elongation ratio of the watersheds. Above average Dd is observed in the western parts of the upper Bhima basin. . Rest of the basin is marked by below average Dd. High $R_e$ is noted in the watersheds 2 to 8 located in the western part and watershed 14 in the central part of the study area.

DEM derived slope is weighted by criteria slope class and area under its influence. Watersheds located in the western region of the study area are flanked by high slope values. High slope is observed in the regions in the vicinity of both north and south divides of the upper Bhima basin (Figure 4.4). Low slope values are seen in the valley region extending over wider areas in the eastern parts of the basin.

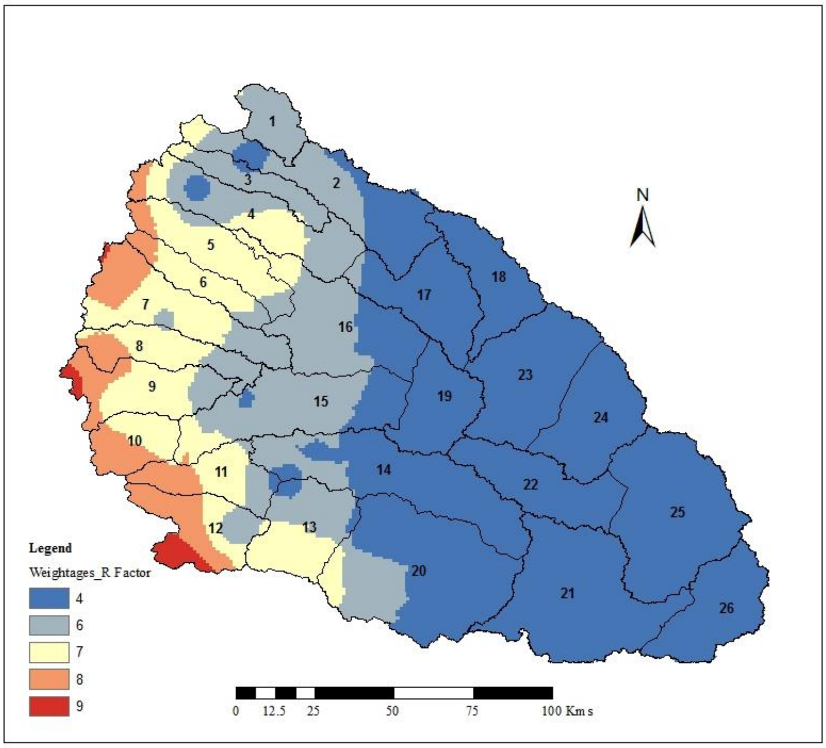


**Figure 4.1: Erosivity Criterion**

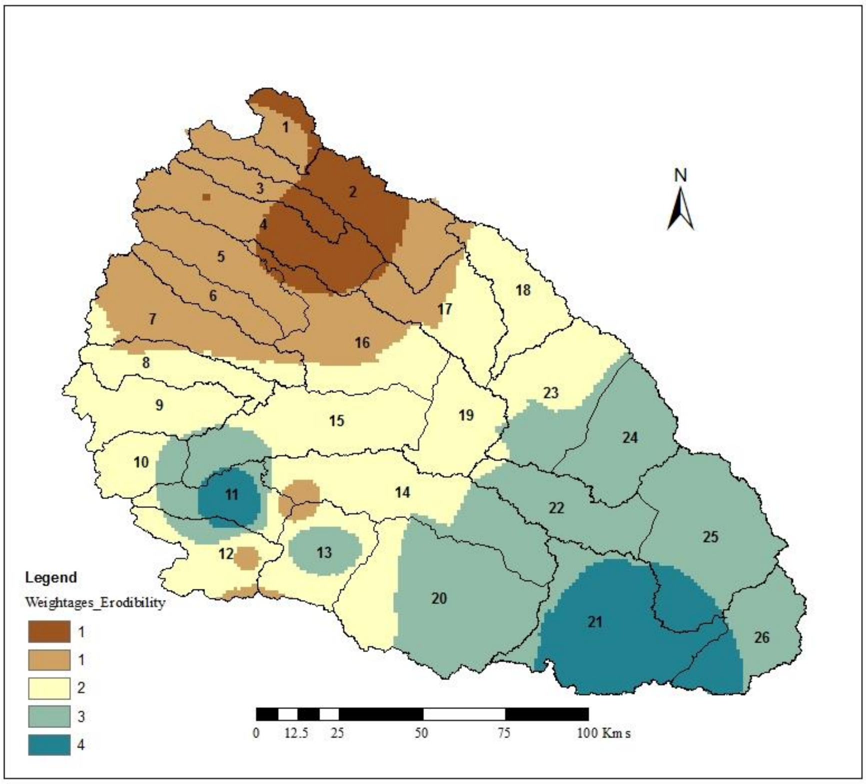


**Figure 4.2: Erodibility Criterion**

## 4.4.3 Composite Erosion Index (CEI):

The weight and rating system used for soil erosion intensity map is based on the relative importance of various causative factors derived from field knowledge and related literature.

### 4.3.3.1 Watershed-wise CEI:

Watershed-wise CEI is presented in Table 4.7 indicates that 2 watersheds are under ‘extremely severe’ category. The area covered under this category is 121265 ha (5%). They are located in the south west part of the basin, whereas three watersheds covering 9% (203613 ha) of the total area are located in the western part of the study area are under ‘severe’ category. Topographically they are found in ridge and pediment. It is important to note that all the 6 factors are above average in most of these watersheds causing high erosion intensity. More area under degraded forest have led the intense soil erosion. Moderately sloping conditions with very high proportion of erodible matter in the soils under high rainfall erosivity increase the erosion intensity. Morphometric properties of these watersheds are characterized by moderate to high Dd and $R_e$.

‘Very high’ category is represented by 2 watersheds (6%) covering 129639 ha area situated in the western and south part of the upper Bhima basin. Their location is observed on different topographic units.

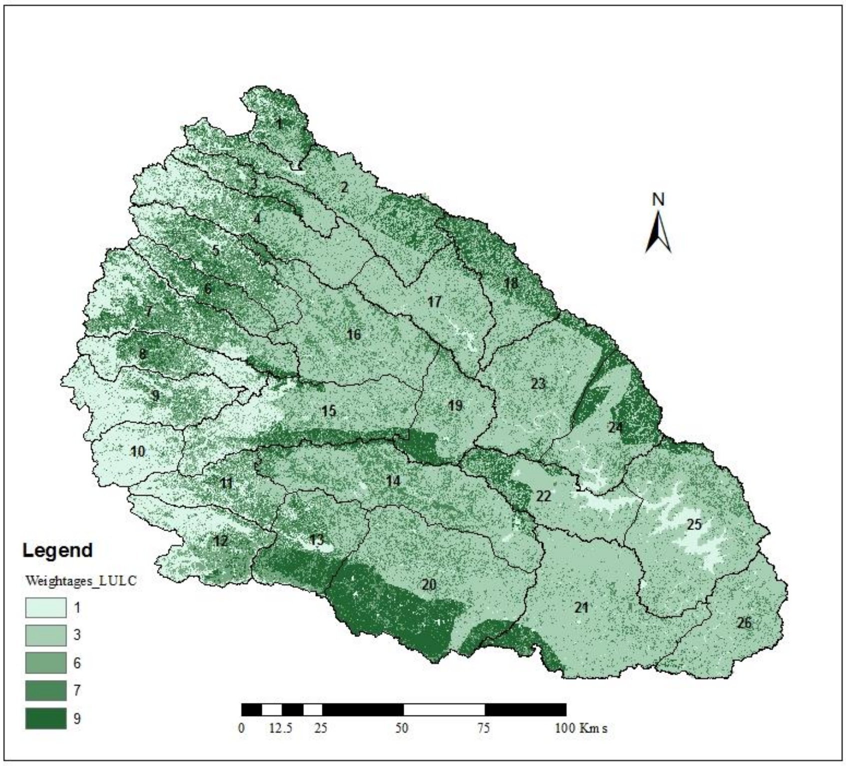


**Figure 4.3: LULC Criterion**

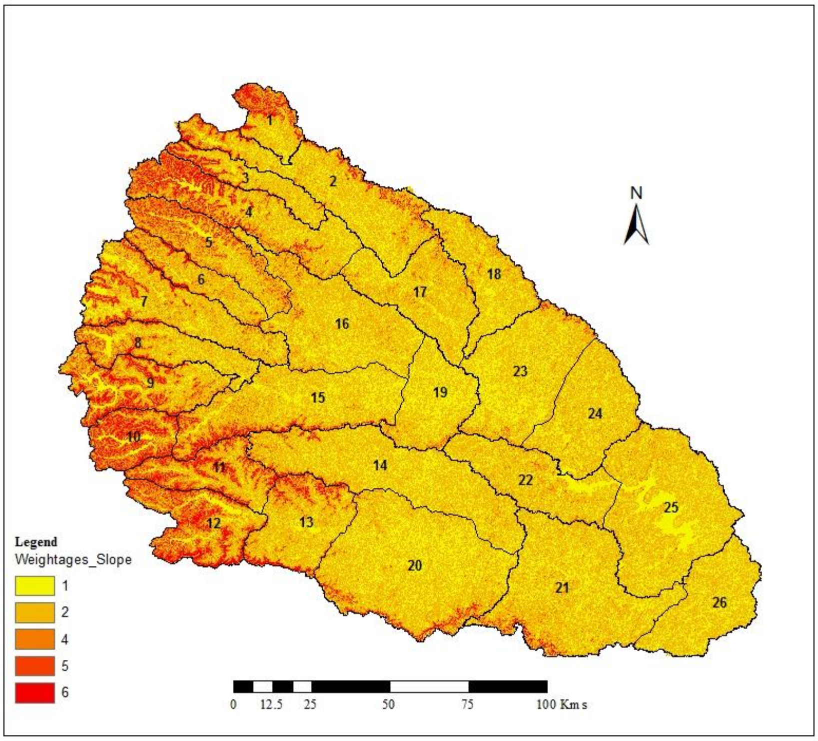


**Figure 4.4: Slope Criterion**

Five watersheds occupying 476836 ha area (21%) under ‘high’ category have spread in western, and central part of the study area on various geomorphic units like ridge zone, lower slopes, pediments and valley fills. Watershed (1) region are characterized high rainfall erosivity, erodible matter and elongation ratio. watersheds (8 and 15) in the western and central part of the basin also experience high erosion intensity due to greater area under degraded forest. These watersheds show high R, T and $R_e$, as against the counterbalancing forcing of the rest of the criteria. Remaining 2 watersheds from the high erosion intensity category are located in the slopes of north and south divides of the upper Bhima basin. They exhibit interplay of high C1, C2, T and $R_e$ vis-a- vis low R, slope and Dd.

| **Priority Class** | **Category** | **Watersheds** | **No.** | **Area (ha)** | **Area (%)** |
|---|---|---|---|---|---|
| P1 | Extremely Severe | 11, 12 | 2 | 121265.6 | 5.3 |
| P2 | Severe | 5, 6, 7 | 3 | 203613.8 | 8.9 |
| P3 | Very High | 8, 13 | 2 | 129639.5 | 5.7 |
| P4 | High | 1, 9, 15, 18, 20 | 5 | 476836.9 | 20.9 |
| P5 | Moderate | 3, 4, 10 | 3 | 178674.3 | 7.8 |
| P6 | Low | 2, 14, 16, 17, 19, 21, 23, 25, 26 | 9 | 1009932.1 | 44.2 |
| P7 | Very Low | 22, 24 | 2 | 162866.3 | 7.1 |
| | | Total | 26 | 2282828.7 | 100 |

***Table 4. 7: Categorization and Prioritization of watersheds according to CEI***

watersheds (3, 4 and 10) from the western part of the basin experiences ‘moderate’ erosion intensity category extending over an area of 178674 ha (8 %) in the basin. Number of counterbalancing criteria (C1, C2, Dd and T) have increased, which control soil erosion occurring under the influence of high R and S criteria.

About 51 % watersheds experience ‘low’ to ‘very low’ erosion index. Low erosion index in watersheds (2, 14, 16 to 19, 21, 23, 25, 26) is the result of high R, S and $R_e$, which are effectively controlled by the cover, texture and drainage density criteria and, therefore, CEI in these watersheds is low.

Two watersheds located in the north eastern part of the upper Bhima basin are categorized in the ‘very low’ erosion intensity. These watersheds experience erosion losses due to average to high Dd and $R_e$ while the remaining criteria are insignificant.

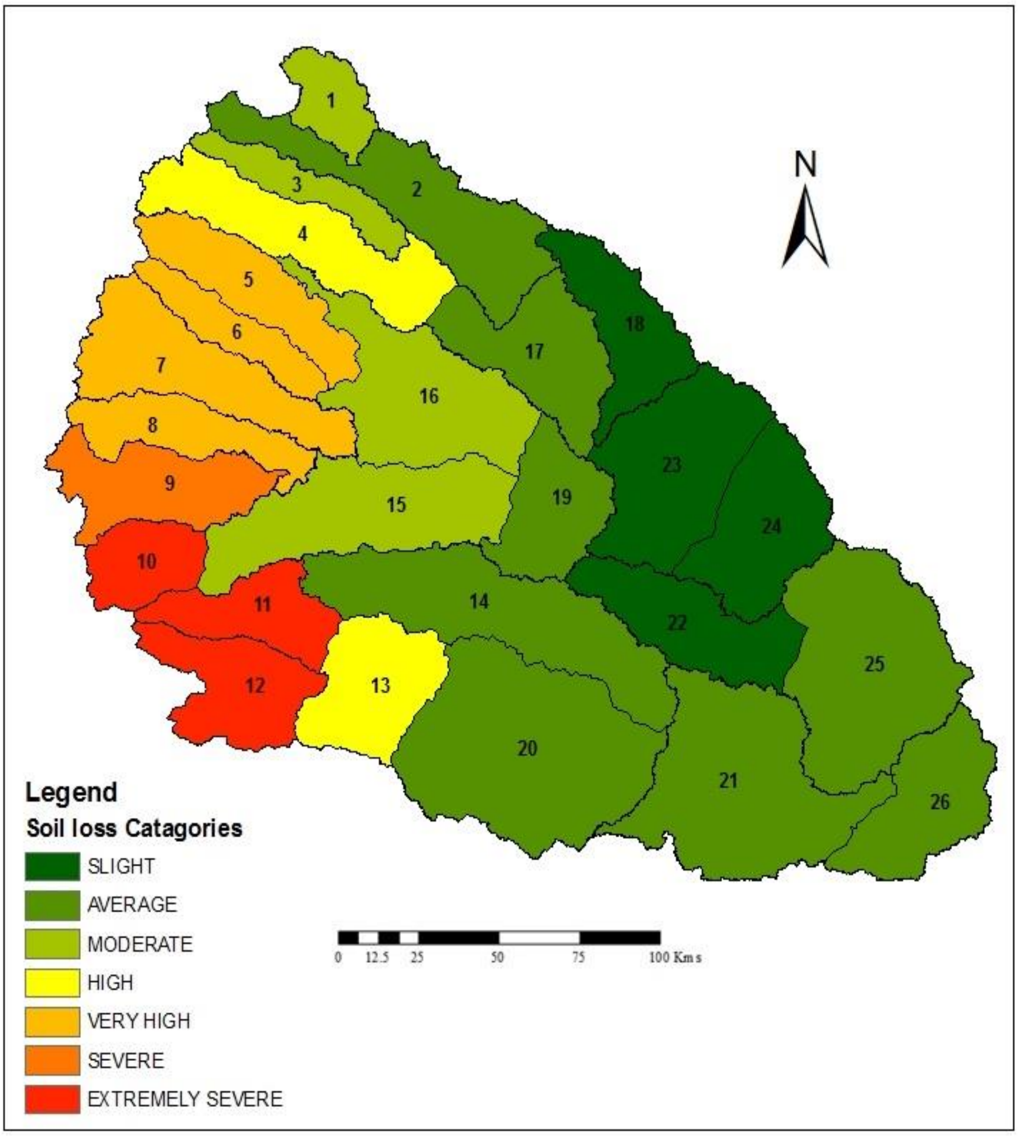


**Figure 4.5: Classification of Watersheds based on CEI**

### 4.3.5 Decision-making and Prioritization:

Analyzing soil erosion risk is an important task, especially in vulnerable areas. Erosion risk maps of areas are required to plan landuse and soil conservation measures. Many mapping methods exist to fulfill this requirement (De Jong and Riezebos, 1992 and Fu and Gulinck, 1994). Each method usually accounts for the following erosion controlling factors: climate characteristics, soil properties, topography and land management (Morgan, 1986). These factors are often highly variable in space and time, which makes erosion risk mapping a complicated task (Deore, 2005).

About 41 % of the watersheds in the upper Bhima basin are in ≥high CEI category. Among them 2 watersheds covering 5 % of the total area located in the south western part of the upper Bhima basin were identified as the most vulnerable to the erosion processes.

In the lower basin again severe and very high erosion categories are not reported; the reason is very low rainfall erosivity due to the pronounced rainshadow effect of the Western Ghats. Against this, watersheds in the middle basin are prone to soil erosion hazard where integration of rainfall erosivity, degradation of vegetal cover, inappropriate crop landuse and high proportion of transported and then accumulated erodible matter in the soils have been found active.

A general notion among the conservators in India is that the source areas of any basin are intensely eroded due to intense rainfall under monsoon regime and steep slopes.

## CHAPTER 5: RESULTS AND DISCUSSION

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# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 Summary:

An increasing population, deforestation, improper methods of agriculture, uncontrolled grazing and unplanned use of natural resources is leading to irreversible degradation of soil. Soil erosion is the dominant cause of soil degradation at a global scale (Scherr 1999, Morgan 2005). Therefore, to preserve our existing soil resources, proper relationship of the parameters affecting must be studied. The continuous evaluation and monitoring of these parameters will ensure the appropriate solutions for the soil conservation efforts. Therefore, an attempt has been made to assess soil erosion in upper Bhima basin. The Remote sensing and GIS technology are best suited for this purpose as it has ability for assessing the potentials and limitations of the factors affecting soil erosion.

River basins are a useful unit of analysis to assess water resource availability and address challenges facing sustainable use because it is at this scale that hydrologic, agronomic and economic criteria can be integrated effectively into a framework that can be used to inform water management policy (McKinney et al. 1999, Khan et al. 2008, Cook et al. 2011). Although it can be difficult to obtain basin-wide data, and significant aggregation and generalization are required, it is nevertheless useful in understanding the wider economic implications of any strategy or intervention.

In view of the above, an attempt has been made in this study to suggest soil conservation measures to control the soil loss in the upper Bhima basin. This is carried out by following the steps given below:

1. Computation and mapping of the physical factors such as rainfall intensity, slope, morphometric attributes and soil erodibility in the upper Bhima basin
2. Assessment of areas under different landuse/land cover categories remotely sensed data in GIS environment.
3. Estimation of potential soil loss using USLE.
4. Multicriteria modeling using weighted overlay analysis.
5. Prioritization of watersheds within the basin based on soil erosion risk.
6. Preparation of guidelines for soil conservation plan.

The results obtained in this research would help to improve understanding of relationship between environmental causative factors and soil loss, which would be useful for planning proper soil conservation measures in the upper Bhima basin.

## 5.2 Results and Discussion:

Important findings obtained from these studies have been discussed in this section.

### 5.2.1 Rainfall Erosivity:

The daily rainfall data of 15 years obtained from IMD was analysed. Daily rainfall values are taken as the individual storm events and the minimum value of erosion index i.e. EImin is computed. Study area displays significant regional variations which is responsible for the differences in distribution, duration and intensity of rainfall which ultimately controls the erosivity. The rainfall in the basin varies from 400 mm in the driest part to over 2800 mm in the hilly areas of the Western Ghats. The Western Ghat hills receives 2400 to 2800 mm, majority of the western part of the basin 1600 to 2400 mm, the central part 400 to 800 mm, the eastern slopes of hills 800 to 1200 mm and the eastern margin of the upper Bhima basin receives less than 400 mm rain.

The spatial distribution of erosivity factor follows the rainfall pattern. It ranges from 250 to more than 1500 depending upon the location of the station and season. Major portion of watersheds in the central part of the basin shows erosivity values between 250 and 500. Eastern parts of western watersheds number 4 to 12 shows 500-700, whereas western part of these watersheds has erosivity of 1250-1500 with extreme values of more than 1500 in the hilly area located south west (watershed 12).

Western hilly region in the range of 1500-1750 as a result of the orographic high intensity rains received during the South-West monsoon. The annual rainfall in these region ranges from 2000-2800 mm and is mostly received during June to September. While the lee ward side of Western ghats with 1200-1600 mm rainfall shows R-value 500 to 750. Eastern part of the basin is semi-arid, which receives rainfall upto 400 mm. This region shows low erosivity values less than 250. The low erosivity in this area explains the low rainfall under rain shadow conditions. Higher erosivity values are observed in the area with high amount of precipitation, intensity and kinetic energy of rain.

### 5.2.2 Soil Erodibility:

Soil erodibiliy (K) refers to the inherent susceptibility of soils to erosion by rainwater and runoff and it is a function of complex interaction of physical and chemical properties of soils affecting detachability, transportability and infiltration capacity.

Very high K is observed in the south western part of the upper Bhima basin and in more proportion towards eastern part and moderate erodibility is surrounding this high erodibility zone. The north western region of the study area shows low erodibility. It is dependent upon the texture and chemical composition of the soil and the way these affect its shear strength, aggregate stability and tendency to surface crusting.

Soil texture is a measure of the particle size distribution in a soil. The percentage of sand particles in the soils in the basin varies from less than 10 percent to 83 percent. Very high K is observed in the south eastern part of the upper Bhima basin covering major portion of watershed number 21 and adjacent parts of watersheds 25 and 26, central part of watershed 11 located south west of the study area. This is as a result of the high proportion of erodible matter i.e. silt + fine sand present in the soil.

The organic constituents of the soil influence the aggregate stability. Organic Matter content is observed very high in the western ghat region, as a result of forest and vegetation present in this area. In the study area the sub-angular blocky structure of soil was observed which refers to intersection of surfaces with rounded edges, a common feature where clay content is high. The intensity of K factor in the upper Bhima basin is following the increasing proportion of erodible matter associated with decreasing clay and OM content in the soils.

### 5.2.3 Topographic Factor:

The erosive impact of rainfall varies as per the physiographic set-up of the region. Slope is particularly an influencing component, with two characteristics the steepness and the length of the slope. Slope length is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition to begin, or the runoff water enters a well-defined channel. The slope analysis was carried out using the ASTER DEM data of 30 m resolution. The slope in percentage and in degrees was computed in Arc GIS 9.3 which was used to determine accurately the combined single topographic factor (LS).

The LS-values increased with increase in length and degree of the slope. Moderate LS values from 5 to 10 are observed in the Western Ghats region, where the ranges attain varying heights of about 1600 m resulting in very steep slopes. The eastwards running offshoot branches from the main ranges also shows steep to very steep slopes.

The slopes in the northern and southern part of the study are moderate. The central basin area shows gentle slopes and covers most of the area. The entire basin has few smaller plateaus and river valley plains of the tributaries. In the extreme eastern part the upper Bhima basin shows gentle to moderate slopes. The soil losses increase with the increase of the slope length and steepness, conditions where the surface flow reaches high-speeds.

### 5.2.4 Cover management and support practice factor:

LULC layer was generated according to NRSC norms using Landsat data. The major classes comprises of Agriculture, Forest, Built Up, Barren and Water Body. Keeping in mind the purpose of study, agriculture was divided into cultivated and fallow and the forest were classified as dense forest and degraded forest. . The values of C were assigned as 0.003, 0.006, 0.2, 0.8 and 0.6 for the dense forest, degraded forest, cultivated area and agriculture fallow respectively.

Agriculture is the primary occupation in the study area. Out of the total geographical area about 61.6 per cent of the land is under cultivation. The forests constitute about 20.5 percent and are mainly dominated in the dominant in the Western part of the basin. Based on the canopy cover or density they are categorized as the dense and degraded forests. The Western Ghats is dominated by luxuriant evergreen forest. On eastern side of ghats, after a transitional belt of low trees, thorny bushes predominate, except on some hill slopes. This area is occupied by different types of forests such as deciduous (moist and dry) and thorny nature

Barren lands occur amidst hill-forests as openings or as isolated exposures on plateau and plains covering an area of 12.5%. They are located on steep isolated hillocks and hill slopes in the Sahyadri ranges. They are also observed in the central and eastern parts of the study area. They are associated with barren or exposed rocky or stony wastes, rock out crop, mining and quarrying sites surrounding Pune urban region, whereas total built up area is around 1.8 percent.

The C factor indicates not only the land cover by the natural vegetation but also the land use under the crops. Watersheds with dense forest cover in the source region have a C Factor of 0.003 covers an area of about 11%. . Eastern slopes of the watersheds located towards west (are predominated by degraded forest having C Factor 0.006 covering an area of about 9.6%. Largest number of watersheds covering more than 60% area is observed to have agriculture as a predominant class with C values of 0.6 and 0.8. The barren lands are unprotected throughout the rainy season and hence are given the C value of 0.5 and water body as 1 to nil out the effect during calculation.

Presence of soil conservation practices in the region is duly considered in the USLE by including support conservation practice factor (P). Referring to the ground truth and GIS developed slope information, P factor map was generated. Nearly half of the area of the upper Bhima basin is under P factor of 1.0 indicating widespread lack of supporting practices in areas. The hill-slope areas with degraded forest are supported by Continuous Contour Trenching structures (CCTs) and at a very few sites by live bunds. Contouring is practiced along 9 to 12 % slope where degraded forest cover is a major land cover in watersheds 5 to 11.

### 5.2.5 USLE and Prioritization of watersheds:

The soil erosion was calculated by R, K, LS and CP factors and the soil erosion rate (t/ha/yr) is worked out for each watershed. A spatial location of the high soil erosion areas have been identified in the regions having high hills and heavy rainfall. Severe and Very severe soil erosion is observed in the areas receiving intense rain accompanied by steep slope, and deforestation or cultivation is responsible for such exceptionally high values of soil loss. Very severe soil erosion in some areas is attributed to steep slopes and fragile geology coupled with cultivation on the land. The factors affecting soil erosion are having very complex relationship with Soil erosion.

Majority of the area about 12749 Sq. KM. (55 %) is under low to moderate erosion classes covering most part of the study area. About 3382 Sq. KM (14.8 %) area is under the very low erosion class which is mainly covering the central and eastern part of the upper Bhima basin. Area under low erosion class is 42.5 % followed by moderate and very low erosion class (14.8 and 13.3% respectively). The area under very high class is 11.4 per cent while the area under high and extremely severe class is around 7 per cent.

A spatial location of the high soil erosion areas has been identified in the regions having hill slopes accompanied by heavy rainfall and are typically associated with the land-use classes which have high erosion potential such as the higher elevation ranges, isolated pockets of open and dense forests which have been cleared for agriculture and horticultural. In this study, the highest amount of soil loss has been identified in the fallow and agricultural lands. Severe and Very severe soil erosion is observed in the Western Ghats accompanied by steep slope, high intensity rains and deforestation or cultivation are responsible for such exceptionally high values of soil loss. Very severe soil erosion in these areas is attributed to highest rainfall in the basin, steep slopes and fragile geology coupled with cultivation on the private land.

**Prioritization of Watersheds (USLE):**

The highest priority is seen for the watersheds 10, 11 and 12 covering 165418 ha area which should be adopted urgently under the conservation programme. Severely to very high eroded area amounts to 332937 ha (14 % of the total basin area) comprising 5 watersheds. Area under high and moderate erosion together (6 watersheds) accounting for 21% of the basin area. This is the area highlighted by the analysis, needs implementation of erosion control measures. Fifty Seven percent area (1308451 ha) spreading over 12 watersheds is low to very low soil loss regime which is the least prioritized category.

Rainfall is the cardinal factor in determining vulnerability of watersheds to soil erosion in the upper Bhima basin where rainfall gradient is steep decreasing from west to eas

### 5.2.6 MCA and Prioritization of Watersheds:

Multi-criteria decision making method based on weighted overlay analysis was used in the present study to prioritize watersheds of the upper Bhima basin. Criteria were land use/land cover (LU/LC), rainfall erosivity-R, slope-S, erodible matter-T, drainage density-Dd and elongation ratio-Re. R as a measure of climatic influence on soil erosion; the least resistant particles in the soil are silt and very fine sand termed as T; S in percent; Dd an expression of dissection of a basin by streams; and Re as a measure of the basin shape were considered as the criteria.

The CEI indicating intensity of soil erosion considered for prioritization of watersheds for selection and implementation of conservation measures and plan appropriate landuse to minimize the soil losses in them. Watersheds under 'extremely severe' category located in the south west part of the basin covering an area of 121265 ha (5%), whereas three watersheds covering 9% (203613 ha) of the total area are located in the western part of the study area are under 'severe' category. More area under degraded forest has led the intense soil erosion. Moderately sloping conditions with very high proportion of erodible matter in the soils under high rainfall erosivity increase the erosion intensity. Morphometric properties of these watersheds are characterized by moderate to high Dd and $R_e$.

'Very high' category is represented by 2 watersheds (6%) covering 129639 ha area situated in the western and south part of the upper Bhima basin, whereas watersheds occupying 476836 ha area (21%) under 'high' category have spread in western, and central part of the study area on various geomorphic units like ridge zone, lower slopes, pediments and valley fills. These watersheds show high R, T and $R_e$, as against the counterbalancing forcing of the rest of the criteria.

Watersheds experiencing 'moderate' erosion intensity extend over an area of 178674 ha (8 %). Number of counterbalancing criteria have increased, which control soil erosion occurring under the influence of high R and S criteria.

About 51 % watersheds experience 'low' to 'very low' erosion index, which is the result of high R, S and $R_e$, which are effectively controlled by the cover, texture and drainage density criteria and, therefore, CEI in these watersheds is low.

It is important to note that watersheds in the south west part of the basin are prone to soil erosion hazard where integration of rainfall erosivity, degradation of vegetal cover, inappropriate crop landuse and high proportion of accumulated erodible matter in the soils are the major criteria aggravating erosion processes.

**Prioritization of Watersheds (MCA):**

Analyzing soil erosion risk is an important task, especially in vulnerable areas. Erosion risk maps of areas are required to plan landuse and soil conservation measures. Causative factors of erosion are often highly variable in space and time, which makes erosion risk mapping a complicated task. About 41 % of the watersheds in the upper Bhima basin are in ≥high CEI category. Among them 2 watersheds covering 5 % of the total area located in the south western part of the upper Bhima basin were identified as the most vulnerable to the erosion processes.

In the lower basin again severe and very high erosion categories are not reported; the reason is very low rainfall erosivity due to the pronounced rainshadow effect. Watersheds in the middle basin are prone to soil erosion hazard where integration of rainfall erosivity, degradation of vegetal cover, inappropriate crop landuse and high proportion of transported and then accumulated erodible matter in the soils have been found active. A general notion among the conservators in India is that the source areas of any basin are intensely eroded due to intense rainfall under monsoon regime and steep slopes.

## 5.3 Conclusions:

The spatial distribution of erosivity factor follows the rainfall pattern. Study area displays significant regional variations which is responsible for the differences in distribution, duration and intensity of rainfall which ultimately controls the erosivity. Higher erosivity values are observed in the area with high amount of precipitation, intensity and kinetic energy of rain.

The percentage of sand particles in the soils in the basin varies from less than 10 percent to 83 percent. Organic Matter content is observed very high in the western ghat region, as a result of forest and vegetation present in this area. Sub-angular blocky structure of soil was observed in the study area which refers to intersection of surfaces with rounded edges, a common feature where clay content is high. The intensity of K factor in the upper Bhima basin is following the increasing proportion of erodible matter associated with decreasing clay and OM content in the soils.

The erosive impact of rainfall varies as per the physiographic set-up of the region. The soil losses increase with the increase of the slope length and steepness, conditions where the surface flow reaches high-speeds.

Agriculture is the primary occupation in the study area. A growth and expanse of vegetal cover at the time of rains, however, reduces the actual soil loss. The canopy protection of crops not only depends on the type of vegetation, the stand, and the quality of growth, but it also varies greatly in different months or seasons. Nearly half of the area of the upper Bhima basin is under P factor of 1.0 indicating widespread lack of supporting practices in areas.

Qualitatively seven soil erosion classes namely very low, low, moderate, high, very high, severe and very severe were identified in the upper Bhima basin. High soil erosion areas has been identified in the regions having hill slopes accompanied by heavy rainfall and are typically associated with the land-use classes which have high erosion potential such as the higher elevation ranges, isolated pockets of open and dense forests which have been cleared for agriculture and horticultural. Steep slope, high intensity rains and deforestation or cultivation are responsible for Severe and Very severe soil erosion.

The general relationship of criteria with erosion intensity observed in the Multi-criteria analysis shows that, from west to east, number of significant criteria influencing CEI decreases and number of counterbalancing criteria on CEI increases and none of the criteria is uniquely observed to be influencing erosion intensity in the complete study area.

***MCA / USLE approach:***

MCA identified 2 watersheds while USLE 03 watersheds in the ‘extremely severe’ category. Critical examination of these two approaches with respect to severe category highlighted that 1 watershed out of 3 USLE watersheds were placed in moderate category MCA. This watershed reported high proportion of dense forest and morphometric attributes of watershed resulted in its inclusion in the MCA ‘moderate’ category. The USLE approach did not account morphometric attributes.

USLE identified 04 watersheds in the severe category out of which 1 watershed was reported by MCA to very high category. Though organic matter content is high in this watershed, erodible matter content and morphometric attributes place it in very high category of MCA. Morhometric characteristics and erodible matter are not included in the USLE.

MCA, in our opinion will be better provided the temporal trend in rainfall erosivity could be included as a criterion. The future research would aim to analyze erosion intensity status of watersheds using the trend in rainfall weighted by intensity as well as recurrence. Such an approach would provide effective indicator of soil erosion intensity.

## 5.4 Recommendations:

A study would help improve understanding of relationship between environmental causative factors and soil loss. It has estimated soil loss and mapped soil erosion risk zones for conservation. It would help to maximize benefits of soil erosion control from minimum inputs enhancing efficiency of process of restoring the resource base. The study highlighted the relative contribution of causative factors to the soil loss which has helped to give proper guidelines for eosion control and frame appropriate conservation strategy (agronomic and engineering). The recommendations shall be useful for controlling soil loss and in turn improving the crop yield at field as well as regional level. Extension workers of the Department of Agriculture, Government of Maharashtra, NGOs working in the field of watershed management may facilitate their programmes focusing the prioritized area using the prescribed guidelines for the respective area.

The practical methods of soil and water conservation fall into two important classes, viz. agronomic and mechanical measures. The table given below indicates the watershedswise recommended conservation practices.

**Key**

| | | | |
|---|---|---|---|
| **A** | Contour Farming | **G** | Bench Terraces |
| **B** | Mulching | **H** | Contour & Peripheral bunding |
| **C** | Strip Cropping | **I** | Gully Ploughing |
| **D** | Contour Bunding | **J** | CCTs |
| **E** | Diversion Terraces | **K** | Afforestation |
| **F** | Retention Terraces | | |

*Table 5.1 Conservation Plan*

| Watershed | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | * | * | * | * | | * | | | | | |
| 2 | | * | | | | | | | | | |
| 3 | * | * | * | * | | * | | | | | |
| 4 | * | * | * | * | | | * | * | * | * | |
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## PHOTOGRAPHS


**Photo 1: Dense Forest**

**Photo 2: Degraded Forest**

**Photo 3: Barren Lands**


**Photo 4: Agricultural land – Cultivated**


**Photo 5: Agricultural land – Fallow**

**Photo 6: Contour Farming**

**Photo 7: Stony Bunds**

**Photo 8: Continuous Contour Trenches (CCTs)**