STUDY OF COMPARATIVE PERFORMANCE OF WEPP AND USLE MODEL FOR PREDICTION OF SOIL LOSS FROM KARLI RIVER CATCHMENT

A Thesis submitted to

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In the partial fulfillment of the requirements for the degree
of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
in
SOIL AND WATER CONSERVATION ENGINEERING
by

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(ENDPM 2016/100)

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	**Meanings**
%	Percent
<	Less than
>	Greater than
^{0}C	Degree Celsius
abs.	Absolute
A	Average annual soil loss
ARS	Agricultural Research Service
ASCII	American Standard Code for Information Interchange
C	Crop management factor
CAET a	College of Agricultural Engineering and Technology
CLIGEN	Climate Generator
CSA	Critical Source Area
Cm	Centimeter
DEM	Digital Elevation Model
E	East
Equ.	Equation
et.al	And others
FAO	Food and Agricultural Organisation
Fig.	Figure
GIS	Geographical Information System
Ha	Hectares
HR	Hour
HWSD	Harmonised World Soil Database
i.e	That is
i/p	Input
K	Soil erodibility factor
Km	Kilo meter

Km^2	Kilo meter square
LANDSAT	Land Satellite Imagery
LISS	Linear Imaging Self Scanning Sensor
LS	Slope length factor
LU/LC	Land use –Land cover
M	Million
m	meter
MJ	Megajoules
m/s	Meter/second
m^3	Meter cube
Max.	Maximum
Min.	Minimum
Mm	Millimeter
mm/hr	Millimeter per hour
MRSAC	Maharashtra Remote Sensing Application Centre
N	North
No.	Number
OFE	Overland Flow Element
PRISM	Parameter-elevation Regressions on Independent Slopes Model
resp.	Respectively
RS	Remote Sensing
R^2	Coefficient of Determination
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Services
SOI	Survey of India
Sq.	Square
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool

T	Tonnes
USLE	Universal Soil Loss Equation
USA	United States of America
USDA	United States Department of Agriculture
WEPP	Water Erosion Prediction Project
YR	Year

ABSTRACT

"STUDY OF COMPARATIVE PERFORMANCE OF WEPP AND USLE MODEL FOR PREDICTION OF SOIL LOSS FROM KARLI RIVER CATCHMENT"

By

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Soil erosion is a serious problem that seems from a combination of agricultural intensification, soil degradation and intense rainstorms. Erosion may also be exacerbated in the future in many parts of the world because of erotic climatic change results into more vigorous changes in hydrologic cycle. The different management theories, formulae, equations and models have been developed to predict the soil loss from the catchment.

In recent decades, models have been built (empirical, conceptual, or physically based) in order to represent and to quantify the processes of detachment, transport, and deposition of eroded soil, with the aim of implementing assessment tools for educational, planning and legislative purposes. Among the different models being used to predict the soil loss along with other important parameters the Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE) model are being widely used for the purpose therefore the study, “Study of comparative performance of WEPP and USLE models for prediction of soil loss from Karli river catchment” was under taken to predict the soil loss.

The present research work was conducted at Karli river catchment is located between the longitude 73.92^0 to 74.01^0 E and latitudes 16.04^0 to 16.10^0 N on the

western coast of India in the southern part of Maharashtra state. The total geographical area of study location is 4247.12 ha.

Data collected through Remote Sensing (RS) and Geographical Information System (GIS) was used in the study of land-use pattern and analysis relating the soil loss with loss of yield. With the help of RS and GIS data, Comparative performance of Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE) model were used for prediction of soil loss from Karli river catchment.

The WEPP model computed soil loss for 7 channels and 18 hill slopes of Karli river catchment. The GeoWEPP model run for Karli river catchment with contributing total area to outlet was 3978.75 ha. The average annual soil loss from hill slopes and channels was found to be 42.89 t/ha/yr and 8.78 t/ha/yr respectively, totally to 51.67 t/ha/yr. The WEPP model also calculated the sediment yield of Karli river catchment that is 17.92 t/ha/yr. The Water Erosion Prediction Project (WEPP) model predicted the 9.01 t/ha/yr more soil loss than the Universal Soil Loss Equation (USLE) model. It also overestimates the sediment yield than the government data by 9.80 t/ha/yr (Ahmadi *et al.*, 2011)

The Universal Soil Loss Equation (USLE) was used for estimation of soil loss from the watershed. The different parameters including soil loss and related were determined by using Remote Sensing data and Geographical Information System tools. The predicted soil loss by using USLE in the Karli river catchment was found to be 42.66 t/ha/yr and it is 9.01 t/ha/yr less than predicted by WEPP.

The R factor values were calculated using relationship between the daily rainfall and erosivity index of Wakawali region by developing regression equation. The average annual erosivity obtained for Dukanwadi station was 6635.65 MJ-mm/ha-hr-yr. Soil erodibility factor values were estimated using sand (%), silt (%), clay (%), organic matter content (%), structural code and permeability code of each village. Weighted soil erodibility factor for Karli river catchment was ranging between 0.040 to 0.041 t-ha-hr/ha-MJ-mm. The value of LS factor for Karli river catchment was found in the range of 1.81 to 4.53. The crop management factor associated with erosion losses is site specific. Detailed information on land use land cover was obtained by LANDSAT imageries and field survey. Crop management factor (C) values of Karli river catchment were ranging from 0.024 to 0.12. Considering support conservation practice factor value as 1, soil loss was estimated for Karli river catchment and its micro watersheds using USLE.

Along with the prediction of the soil loss by using WEPP model and its comparison with USLE model the sediment yield predicted by WEPP and observed data by Government department was also considered and for the purpose, The sediment data of Dukanwadi station from 2001-2010 was collected from Hydrology Project, Water Resource Department, Government of Maharashtra (India). According to the observed data, the average annual sediment yield was 8.12 t/ha/yr whereas the predicted sediment yield from the WEPP model was 17.92 t/ha/yr. which is 120 % more predicted than the observed data. The sedimentation also 15.71 % and 34.68% of predicted soil loss by WEPP and for the observed sediment yield and predicted sediment yield respectively. The similar statement is made and that is the sediment yield is 30 to 60% of soil erosion loss (Fernandez *et al*., 2003; Vemu *et al*., 2012; Richarde *et al*., 2014). According to comparative performance of Water Erosion Prediction Project (WEPP) model overestimates the soil loss value and sediment yield value than the Universal Soil Loss Equation (USLE) model and Government data respectively. WEPP model was best suitable model for Karli river catchment due to its less input files, less time consumption, ease to operate and understand, and less data requirement with minimum pre-processed data.

I. INTRODUCTION

Soil erosion is a serious problem that seems from a combination of agricultural intensification, soil degradation, and intense rainstorms. Erosion may also be exacerbated in the future in many parts of the world because of climatic change towards a more vigorous hydrologic cycle. Many planning and management theories and formulae have been developed in order to reduce soil loss from basins and as a result, sediment transport to hydrologic drainage networks. This latter phenomenon has a great deal of importance in optimizing policies for management of water resources, particularly when sediment is generated in such a way to seriously reduce the capacity of reservoirs. A Storage capacity of existing reservoirs is a valuable and non-renewable resource that must be protected from 'sediment danger' (Di/Silvio, 1996), and which can be restored only through costly periodic dredging. It is therefore desirable to predict distributions of soil loss, sediment yield, and sediment deposition upstream of a dam in order to plan structural works and other means for reducing the problem. Soil erosion resulting mainly from forest and agricultural land use, is associated mainly with environmental impacts as well as crop productivity loss in the latter (Lal, 1995; Pimentel *et al.,* 1995) which makes the understanding of the erosion process important to guarantee food security (Daily *et al.*, 1998) and environmental safety (Matson *et al.,* 1997).

Soil erosion is a complex phenomenon as it is governed by various natural processes and it, in turn, results in a decrease in soil fertility and reduction in crop yield. India is one of the few countries in the world to have estimated the loss of topsoil due to erosion. An estimated 175 Mha of land in India, constituting about 53% of the total geographical area (329 Mha), suffers from the deleterious effect of soil erosion and other forms of land degradation. Active erosion caused by water and wind alone accounts for 150 Mha of land, which amounts to a loss of about 5.3 million tonnes of sub-soil per year. In addition, remaining 25 Mha land has been degraded due to ravine, gullies, shifting cultivation, salinity, alkalinity, and waterlogging (Reddy 1999). In India the soil erosion rate was 5,334 million tonnes (16.35 t/ha/annum) of soil is detached annually; about 29% is carried away by a river into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the storage capacity. The remaining 61% is dislocated from one place to another (Narayana and Babu, 1983).

The process of soil erosion involves detachment, transport and subsequent of soil particles deposition (Meyer and Wischmeier, 1969). The consequence of soil erosion occurs both on-site and off-site (Morgan, 1986). On-site effects are particularly important on agricultural land, where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and the decline in soil fertility. The total estimated area of Maharashtra is 30.77 Mha. Among this total land area, 773.5 million tonnes (25.14 t/ha) of soil was lost due to soil erosion, were 94% of this erosion was mainly caused due to induction of water (Durbude, 2015). So it becomes essential to study the soil characteristics of various soil types, which are responsible for this phenomenon. The prevention of soil erosion, which means reducing the rate of soil loss to approximately that, which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation and this, in turn, requires a thorough understanding of the processes of erosion. The factors, which influence the rate of soil erosion, are rainfall, runoff, soil, slope, plant cover and the presence or absence of conservation measures (Morgan, 1986).

In recent decades, models have been built (empirical, conceptual, or physically based) in order to represent and to quantify the processes of detachment, transport, and deposition of eroded soil, with the aim of implementing assessment tools for educational, planning and legislative purposes (Renschler and Harbor,2002).

Empirical models have been and are still used because of their simple structure and ease of application, but as they are based on coefficients computed or calibrated on the basis of measurement and/or observation, they cannot describe nor simulate the erosion process as a set of physical phenomena. The most widely used empirical soil loss models are Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE) and Soil Loss Estimation Model for Southern Africa (SLEMSA). The Universal Soil Loss Equation (USLE) is the most widely used empirical erosion model (Wischmeier and Smith, 1965). It estimates soil erosion from an area simply as the product of empirical coefficients, which must, therefore, be accurately evaluated.

Physically based models simulate the individual components of the entire erosion process by solving the corresponding equations and so it is argued that they tend to have a wider range of applicability. Such models are also generally better in terms of their capability to assess both the spatial and temporal variability of the natural erosion processes. The most widely used physical based soil loss models are Water Erosion Prediction Project (WEPP), Soil and Water Assessment Tool, Soil, and Water integrated Model (SWIM), Hydrological Predictions for the Environment (HYPE), Watershed Erosion Simulation Programme, and Arial Nonpoint Source Watershed Environment Response Simulation (ANSWERS). The Water Erosion Prediction Project (WEPP) is a physically based erosion simulation model that, predicts soil loss and deposition using a spatially and temporally distributed approach (Foster and Lane, 1987; Nearing *et al.,* 1989a; Flanagan and Nearing, 1995). WEPP (Flanagan and Nearing, 1995) is a continuous simulation model that is able to predict spatial and temporal distributions of net soil loss and deposition for a wide range of time periods and spatial scales. WEPP requires four inputs *i.e.,* climate, topography, soil & vegetation and provides various types of outputs, including water balance, surface runoff, subsurface flow, and evapotranspiration.

The Universal Soil Loss Equation (USLE) only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems but is also applicable to non-agricultural conditions such as construction sites. The USLE can be used to compare soil losses from a tonnes particular field with a specific crop and management system to "tolerable soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning. The USLE has remained the most practical method of estimating soil erosion in the field and for estimating the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000), while other process-based erosion models have intensive data and computational requirements (Lim *et al.,* 2005). An environmental characterization of the physical (climate, pedology, topography) and human factors (agricultural and conservation practices) governing water erosion on the watershed unit scale was made based on the USLE (Vezina *et al.,* 2006). Created in the United States, the USLE is an erosion model designed to compute longterm average annual soil loss on a field scale (A) as the product of six major factors: rainfall erosivity (R), soil erodibility (K), slope length (L), steepness (S), cover and management practices (C) and conservation practices (P) (Wischmeier and Smith, 1978). Erosion prediction models can help address long-range land management planning under natural and agricultural conditions. Even though it is hard to find a model that considers all forms of erosion, some models have been developed specifically to aid conservation planners in identifying areas where introducing soil conservation measures would have the most impact on reducing soil loss (Angima *et al.,* 2003). In certain areas of research, though the USLE model was found best in adaptations it also faced certain critical problems (Gelagay *et al.,* 2016). Hence to overcome these problems, there arose a need for the development of the Revised Universal Soil Loss Equation (RUSLE) model.

This model was found beneficial in calculating the soil erodibility factor. In USLE, soil erodibility is characterized by a single number, while in RUSLE; a detailed procedure is implemented allowing for temporal variability. Experimental and field work had indeed demonstrated that soil erodibility could be highly variable. The developers of the RUSLE used the available experimental data to develop seasonal soil erodibility factors so that the model could determine the seasonal changes such as variations in soil moisture, freezing and thawing, and soil consolidation. Similarly, the calculation of the cover factor was refined in an attempt to improve the model's capability of accounting for temporal variations in soil cover as well as of the role of the various components of soil cover. Process-based models incorporated in a continuous soil-plant simulation model, such as the current WEPP model, are, in principle, applicable to even finer temporal scales, since such models simulate erosion using time-steps of seconds. This temporal resolution is large enough to simulate the variations in soil conditions, plant development and surface cover that may affect erosion rates that are updated between each event (Morgan and Nearing, 2011). United States Department of Agriculture (USDA) Agricultural Research Service (ARS) personnel and their co-operators initiated the Water Erosion Prediction Project (WEPP) in August 1985 to produce new-generation water erosion prediction technology for use by federal action agencies involved in soil and water conservation and environmental planning & assessment. At that time, the soil erosion prediction tool in widespread use was the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978); (Gilley and Flanagan, 2007) describe the events leading to the release of the USLE. While the USLE was used extensively to predict long-term average annual soil loss, it was a mature technology that could not easily be expanded to meet the ever-increasing needs of conservationists and environmental managers. For example, USLE was only applicable to detaching regions of a hill slope, and could not estimate sediment deposition or sediment delivery from fields to off-site channels or streams. In addition, USLE had no capabilities to estimate runoff, spatial locations of soil loss on a hill slope profile or within a small watershed, channel erosion, effects of impoundments, recurrence probabilities of erosion events, or watershed sediment yield. The WEPP model was developed to address all of these needs and to serve as a replacement for empirically based erosion prediction technologies like USLE.

Due to worldwide use of Universal Soil Loss Equation (USLE) which predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system, and management practices. But this empirical model having some certain limitations which were overcome in Physical process based WEPP model, which computed the soil erosion for hillslope area at finer scale with less time required. So it needs to study the comparative performance between the USLE and WEPP Model. In Maharashtra state the Konkan region was bestowed by world recognized unique biodiversity but highly vulnerable to erosion. The total geographical area of Konkan was 30763.39 ha which was having average annual soil loss of 38.90 t/ha/yr (Natural Resources Atlas of Konkan, 2018). So this kind of study was very essential for the Konkan region. With this background study entitled "Study of comparative performance of WEPP and USLE models for prediction of soil loss from Karli river catchment"

In natural resources conservation studies, soil erosion is highly dependent on the degree of erodibility of particular soil along with factors. Any model for computing potential soil loss from an area must deal with a large number of variables, *i.e.* parameters concerning vegetation, management, soil, topography, and climate. When available spatial data are geo-referenced and can be put in the form of maps, Geographic Information Systems (GIS) allows simpler and faster data and parameter management. Therefore, GIS can make soil erosion studies easier, especially when repeated applications of similar and complex procedures are required (Amore *et al.*, 2014). The GIS is gaining importance as a powerful tool for the management of information in agriculture, natural resources assessment, environmental protection, and conservation. There is considerable potential for the use of GIS technology as an aid to soil erosion inventory with reference to soil erosion modeling and erosion hazard assessment. A number of modeling approaches both empirical and physical process based are in vogue to quantitatively assess erosion by soil loss. GIS technique is a very effective tool for integrating inputs for modeling of soil loss.

The soil erosion depends on rainfall and geomorphological characteristics of a catchment. Both of these parameters have large variability due to the spatial variation of rainfall and catchment heterogeneity. Remote Sensing (RS) and Geographic Information Systems (GIS) techniques make it possible to measure these hydrologic parameters on spatial scales. The RS and GIS techniques have become valuable tools, especially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage (Parveen and Kumar, 2012). With the advance of RS, it becomes possible to measure hydrologic parameters on spatial scales while GIS integrates the spatial and analytical functionality for spatially distributed data. Therefore in this study remote sensing and GIS technique were used to estimate average annual soil erosion for the watershed. Data collected through RS and GIS was also used in the study of land-use pattern and analysis relating the soil loss with loss of yield. With above-mentioned study entitled was undertaken with the following objectives

1. To predict soil loss by using WEPP model.
2. To predict soil loss by using USLE model.
3. To compare performance of WEPP and USLE models.

II. REVIEW OF LITERATURE

This chapter deals with the review of study carried out by various investigators on the applications of Remote Sensing (RS) and Geographical Information System (GIS) for estimation of soil loss by using WEPP and USLE models and compare their performance.

2.1 Estimation of soil loss using WEPP model

Foster *et al.,* (1985) developed the new-generation water erosion prediction technology WEPP model by the USDA-ARS at National Soil Erosion Research Laboratory in Indiana, USA. as a replacement for empirically based erosion prediction technologies, The WEPP model simulates many of the physical processes important in soil erosion, including infiltration, runoff, raindrop and flow detachment, sediment transport, deposition, plant growth, and residue decomposition.

Flangen *et al.,* (1995) applied the WEPP erosion model for continuous simulation computer program which predicted soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flow in small channels, and sediment deposition in impoundments. The WEPP model computed spatial and temporal distributions of soil loss and deposition, and provided explicit estimates of when and where in a watershed or on a hill slope that erosion has occurred so that conservation measures shall be selected to most effectively control soil loss and sediment yield.

Pieri *et al.,* (2007) studied the comparison between WEPP-simulated and field-measured sediment yields indicate that WEPP tends to under-predict erosion for 1999–2004 at Centonara Watershed, southeast of Bologna, Italy. WEPP does not generate any erosion events, whereas the experimental monitoring system detected 15 events. The observed annual sediment yield, ranging 0.02 – 0.15 t ha^{-1} for this time period, was very low. For 2005, WEPP predicted an erosion rate of 0.18 t ha^{-1}, exclusively as a result of the large and intensive storm event on September 16, 2005, and the experimental system detected an event rate of 1.68 t ha^{-1} and an annual rate of 2.14 t ha^{-1}. The consistent under-prediction of sediment yield by WEPP may be attributed to the lack of calibration of the soil erodibility parameters.

Yuksel *et al.*, (2008) applied the GeoWEPP model for computing sediment yield and runoff from Orcan Creek watershed in Kahramanmaras region, Turkey. The average Root Mean Square Error (RMSE) between observed and predicted average annual sediment yield and runoff were 2.96 and 8.43, respectively. The index of agreement was 0.98 and 0.99 for sediment yield and runoff, respectively, which indicated that the model predictions provided good results.

Ahmadi *et al.*, (2011) studied the efficiency of WEPP model to predict runoff and sediment yield at catchment scale in a semi-arid area. Continuous simulations have been conducted between 1996 and 2005 in Orazan Watershed, Tehran province, Iran. Comparison between predictions and measurements indicated that WEPP under-estimated sediment volumes of 23% and over-estimates runoff volumes of 27%. Results showed that sediment yield and runoff outputs we relatively well predicted but lack of input data to run WEPP model was an important challenge in Iranian conditions.

Ebrahimpour *et al.*, (2011) computed annual sediment load of Lui watershed of Langat River in peninsular Malaysia. The estimated sediment load was 0.57 t ha^{-1} yr^{-1} which was almost half of the predicted annual value of 1.1 t ha^{-1} yr^{-1}. Correlation between predicted and measured sediment load was 0.48 indicating that WEPP model overestimated sediment load.

Kumar *et al.*, (2011) Computed the surface runoff and soil loss simulated in a mini watershed (57 ha) of Sitlarao watershed is located in the Doon valley of Himalayan region in Dehradun district, India, using the WEPP watershed model. The Measured surface runoff of mini watershed was validated with WEPP simulated surface runoff for selected rain events. The surface runoff generated for rain events of low to medium rain intensity by WEPP model matched with observation ($r^2 = 0.69$) while its performance was poor for high rain intensity. Simulated and measured runoff from all the rain events comprising low to high rain intensity showed low regression coefficient ($r^2 = 0.25$).

Landi *et al.*, (2011) applied the Water Erosion Prediction Project (WEPP) and Geographic Information System (GIS) models to estimate the average soil loss in the Halahijan watershed in Khuzestan Province, Iran, one of the priority areas for soil erosion control in Iran. Results indicated that, the soil loss estimated by the WEPP model ranged from 15.10 to 28.20 Mg ha^{-1} yr^{-1} with an average soil loss of 21.8 Mg ha^{-1} yr^{-1} in the study area. The soil loss estimated by WEPP model highly correlated with data estimated by MPSIAC (R_2 = 0.97). The soil erosion in this region could be attributed to rainfall intensity (which ranged from 16 to 88 mm hr^{-1}), and high surface runoff (which ranged from 48562 to 80963 m^3). Results also revealed that, the WEPP model was suitable for estimating soil loss in complex watersheds.

Dehvari Abdolhamid (2014) estimated surface runoff and sediment yield in different slope and management systems in a 13-year simulation period of three small watersheds, with areas between 4594 to 19325 m^2 within Lucknow River basin, Ontario, Canada, which were delineated using LiDAR DEM. The measured sediment yield (0.15 and 0.17 t ha^{-1} yr^{-1}), which was computed using suspended load data of Lucknow hydrometric station, was less than mean predicted value (0.42 t ha^{-1} yr^{-1}) simulated by the WEPP model.

Bavor and Genson-Torrefranca (2016) applied the WEPP model on the Upper Inabanga Watershed which was the catchment basin of the Malinao Dam Reservoir, Philippines. The WEPP model was applied to assess erosion at watershed and farm-scale levels. Erosion was predicted using simulated conventional and, alternatively, conservation-oriented agriculture practices, in terms of on -site and off-site effects of the agricultural practices. From instrumented trial, hill slopes, sediment yield decreased from 32.8 t ha^{-1} to 12.8 t ha^{-1} under conventional farming to conservation-oriented practices. At the watershed level under current land use, this was translated into a decrease in sediment discharge from 11.9 t ha^{-1} to 10 t ha^{-1}. With land use change in which 58% of the watershed area was allocated to agriculture cultivation, conservation oriented practices decreased sediment discharges from 32.1 t ha^{-1} to 3.9 t ha^{-1}.

Gonzalez *et al.,* (2016) computed the effect of discretization on the hill slope sediment yield estimation of two large watersheds viz. Rincon and Tres Pasos are located in the Serrano river basin of the Chile. The hill slope sediment yield estimates ranged from 5.1 to 9.3 t ha^{-1} yr^{-1} in the Tres Pasos watershed and from 11.8 to 20.9 t ha^{-1} yr^{-1} in Rincon, while the maximum sediment yield from a hill slope ranged from 44 to 59.7 t ha^{-1} yr^{-1} in Tres Pasos and from 66.4 to 78.5 t ha^{-1} yr^{-1} in Rincon.

Han et al., (2016) applied the WEPP model at Liudaogou watershed, Shenmu, Iran to simulate soil erosion both at the slope and watershed scales. Analysis showed that the simulated values at the slope scale were very close to the measured. However, both the runoff and soil erosion simulated values at the watershed scale were higher than the measured. At the slope scale, under different coverage, the simulated erosion was slightly higher than the measured. When the coverage is 40%, the simulated results of both runoff and erosion were best. At the watershed scale, the actual annual runoff of the Liudaogou watershed was 83 m^3; sediment content was 0.097 t m^{-3}, annual erosion sediment 8.057 t and erosion intensity was 0.288 t ha^{-1} yr^{-1}.

Reis *et al.*, (2017) applied the GeoWEPP model was used to estimate sediment yield and runoff from Keklik watershed, which was located 12 km from Kahramanmaras in the eastern Mediterranean region of Turkey. The digital maps of the input files required for GeoWEPP model were generated using GIS tools. The estimated average annual sediment discharge and delivery of watershed were 34533.5 tonnes and 44.2 t ha^{-1}, respectively. This study indicated that GeoWEPP model could provide decision makers with quick estimation of sediment yield from large watersheds with high accuracy.

Yusuf *et al.*, (2018) applied the WEPP model in Cikapundung watershed, West Java Province, Indonesia. The total runoff volume, hill slope soil loss, and sediment yield under existing condition were approximately 410 mm, 359 t ha^{-1} yr^{-1} and 217 t ha^{-1} yr^{-1} respectively. While regional planning scenario was produced total runoff, hill slope soil loss, and sediment yield of 399 mm, 21 t ha^{-1} yr^{-1}, and 10 tons/ha/year, respectively. The 2030 predicted land cover was generating the highest average sediment yield approximately 2190 t ha^{-1} yr^{-1}. The regional planning was the best scenario in reducing hill slope, soil loss and sediment yield in Cikapundung watershed, approximately 94% and 95%, respectively.

2.2 Estimation of soil loss using USLE model

Wischmeier and Smith (1978) developed a Universal Soil Loss Equation (USLE) method for plot scale soil loss estimation, including all the relevant terrain and climatic factors like topography, soil types, rainfall etc. This method was given by the formula, A = R K L S C P, where, A = average annual soil loss in tons/ha, R = rainfall erosivity factor and is equal to $\sum$ EI/100, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = crop management factor and P = supporting conservation factor.

Shiono *et al.,* (2002) estimated the soil loss of crop fields on a local scale was carried out using the Universal Soil Loss Equation (USLE) and Geographic Information System (GIS) tools. The study site covered 3,009 ha in Kanto, Japan, comprising 11,544 crop fields. The estimated soil loss rate under the current cropping conditions was found to range from 0.2 to 70.6 t ha^{-1} yr^{-1}, averaging 10.5 t ha^{-1} yr^{-1}. A distribution map of the rate indicated the fields where conservation measures should be taken. The study suggested that combining the USLE with GIS tools was likely to be useful for estimating soil loss on a local scale for soil conservation planning.

Devatha *et al.,* (2007) studied the annual soil loss using USLE model for Kulhan watershed of Shivnath basin, sub-basin of Mahanadi basin (Chhattisgarh), India using RS and GIS techniques. It was observed that the soil erosion for Kulhan watershed was very less (0.1783 ton/ha/year) because slope of the study area was gentle undulating about 10.49% and most of the area (78%) was occupied by agricultural land. It was found that 83.97% of total area was under slight erosion risk class and only 0.45% of total area was under very high severe class which was observed near the bank of mainstream line of the watershed.

Brhane and Kirubel (2009) estimated average annual soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego Watershed, Northern Ethiopia. Results showed that the lowest soil loss was estimated on flat plains (< 2% slope) about 1.59 t ha^{-1} yr^{-1}, which was less than the minimum tolerable soil loss (2 tons ha-1 y-1) for the country. However, the highest soil loss was from steep slopes (30-50%) which was 35.43 t ha^{-1} yr^{-1}, about twice the maximum tolerable soil loss (18 t ha^{-1} yr^{-1}). The average soil loss rate at watershed level was 9.63 t ha^{-1} yr^{-1} about half of the maximum tolerable soil loss. The implication was the contribution of the implemented SWC measures in decreasing the rate of soil erosion is encourage able as compared to the results related to high soil loss estimated in the past studies.

Kefi *et al.,* (2009) predicted the soil loss by using combination of USLE Model and GIS for three different watersheds of Tunisia which were Batta, Boulabouz and Koukat watershed. Results showed that the predicted soil loss by using USLE model were 16.75, 5.18 and 0.39 t ha^{-1} yr^{-1} for selected three watersheds respectively.

Londhe *et al.,* (2010) evaluated morphometric characteristics and Universal Soil Loss Equation (USLE) parameters using remote sensing and GIS for prioritization of miniwatersheds in Subranerakha Subcatchment (Jharkhand), India. Based on the integration of LS, R, K, C and P factors of USLE in GIS, seven classes of estimated actual soil loss i.e. negligible (80 t ha^{-1} yr^{-1}), very slight (25 t ha^{-1} yr^{-1}), slight (510 t ha^{-1} yr^{-1}), moderate (1015 t ha^{-1} yr^{-1}), moderately severe (1520 t ha^{-1} yr^{-1}), severe (2040 t ha^{-1} yr^{-1}), very severe (4080 t ha^{-1} yr^{-1}) and extremely severe (>80 t ha^{-1} yr^{-1}) were identified. Most of the area of mini watersheds was come under very severe soil loss class.

Sheikh *et al.,* (2011) Computed the soil erosion rate at watershed scale Universal Soil Loss Equation (USLE) erosion model has been used on IEL7 watershed of Lidder Catchment in Himalayan Region, India. The annual soil loss predictions range between 0 and 61 tons ha^{-1}. Average soil loss was highest (26 t ha^{-1} yr^{-1}) in agriculture area and lowest soil loss rate was found in forest area (0.99 t ha^{-1} yr^{-1}). For horticulture and plantation the soil loss rates were 1.47 and 5.39 t ha^{-1} yr^{-1} respectively. For pasture, fallow and scrub the soil loss rates were 25.47, 28.39 and 35.76 t ha^{-1} yr^{-1} respectively.

Junakova and Balintova (2012) predicted the annual soil loss in the Tisovec river catchment, located in the east of Slovakia, in Bardejov district. The area of this watershed was about 6.0 km^2 with annual average discharge 0.045 m^3/s. Results showed that the total average annual soil loss from the arable land and also soil loss from the whole watershed of the Tisovec river. The average annual soil loss represented was approximately 2026 t yr^{-1}.

Parveen *et al.,* (2012) determined the soil erosion rate of Upper South Koel basin (Jharkhand), India, as a function of land topography, soil texture, land use/land cover, rainfall erosivity, and crop management and practice in the watershed using the Universal Soil Loss Equation (for Indian conditions), remote sensing imagery, and GIS techniques. The rainfall erosivity R-factor of USLE was found that 546 MJ mm/ha-hr-yr and the soil erodibility K-factor varied from 0.23-0.37. Slopes in the catchment varied between 0% and 42% having LS factor values ranging from 0-21.

The C factor was computed from NDVI values derived from Landsat data. The P value was computed from existing cropping patterns in the catchment. The annual soil loss estimated in the watershed using USLE was 12.2 tonnes ha^{-1} yr^{-1}.

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

Ghosh *et al.* (2013) estimated the assessment of soil loss of the Dhalai river basin, Tripura, India using USLE. The whole study area was subdivided into 23 sub watersheds in order to identify the priority areas in terms of the intensity of soil erosion. Each sub-watershed was further studied intensively in terms of rainfall, soil type, slope, land use/land cover and soil erosion to determine the dominant factor leading to higher erosion. The average annual predicted soil loss ranged between 11 and 836 t/ha/year. Low soil loss areas (<50 t/ha/year) was mostly been recorded under densely forested areas.

Amara *et al.,* (2014) applied the USLE equation to assess soil erosion and suggest possible intervention strategies to address soil loss in Singhanhalli-Bogur Micro watershed of Dharwad District in northern transition zone of Karnataka, India. The average annual soil loss was 27 tonnes ha^{-1} yr^{-1}. About 574 ha of the study area was under slight erosion, 118 ha under moderate erosion and 53 ha under severe erosion. The soil loss under different land use ranged from 7 tonnes ha^{-1} yr^{-1} under forest to 40 tonnes ha^{-1} yr^{-1} under agriculture. The soil loss under plantation and open scrub land use were 8 and 26 tonnes ha^{-1} yr^{-1} respectively.

Wolka *et al*. (2015) studied that soil erosion risk assessment in the Chaleleka wetland watershed, Ethopia. Results showed that 13.6 percent of the study area has a soil loss value less than 10 t/ha/year with the remaining area experiencing a higher soil loss. Moderate soil loss (10–20 t/ha/year) was observed in 15.5 percent of the watershed, covering the sub-watersheds in Upper Wesha, upper Hallo, and lower Lango. The soil loss severity class of high to very high (20–45 t/ha/year) occured in 17.3 per cent of the total study area.

Belasri and Lakhouili (2016) estimated the annual soil loss using the Universal Soil Loss Equation (USLE), remote sensing (RS) and geographic information system (GIS) of Oued El Makhazine watershed, Morocco. GIS data layers including, rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were computed to determine their effects on average annual soil loss in the area. The resultant map of annual soil erosion showed maximum soil loss of 735 t ha^{-1} yr^{-1}, about 65.25% (1575 km^2), of the watershed ranges between 0 and 95 t ha^{-1} yr^{-1}.

Bera Amit (2017) studied that the soil erosion was a most severe environmental problem on Muhuri river basin of Tripura state, North east India having an area of 614.54 Sq.km. In this study USLE parameters such as the daily rainfall data (2001-2010) of 6 rain gauge stations were used to predict the R factor. Soil erodibility (K) factor in Basin area ranged from 0.15 to 0.36. The average annual predicted soil loss ranged between 0 to and 650 t ha^{-1} yr^{-1}. Low soil loss areas 70 t ha^{-1} yr^{-1} of soil erosion were found along the main course of Muhuri River.

2.3 Comparative Performance of WEPP and USLE models

Tiwari *et al.,* (2000) studied the sixteen-hundred years of natural runoff plot data of for verification and validation of WEPP including most of the data used to develop Universal soil loss equation (USLE) for United States. WEPP predictions of soil loss from natural runoff plots at 20 different locations were compared to measured data and existing technology (*i.e.*, USLE and RUSLE). WEPP recorded a model efficiency of 0.71 compared to 0.80 and 0.72 for the USLE and RUSLE respectively. While the USLE and RUSLE exhibited better model efficiency than WEPP, it could be attributed to availability of more refined and site specific input parameters for the empirical model.

Amore *et al*., (2004) studied the results of the application of two soil erosion models, both spatially distributed, to three large Sicilian basins upstream of reservoirs, Italy. Each basin was subdivided into hill slopes, using three different classes of average area, in order to estimate the scale effect on the sediment yield evaluation. The first model was the empirical Universal Soil Loss Equation (USLE), and the other one was the physically based model of the Water Erosion Prediction Project (WEPP). A Geographical Information System (GIS) was used as a tool to handle and manage data for application of the models. Computed sediment yields were compared with each other and with measurements of deposited sediment in the reservoir, and for these cases the WEPP estimates better approximated the measured volumes than did the USLE.

Cecilio *et al*., (2004) analysed RUSLE and WEPP models for a small watershed located in Vicosa, minas Gerais state, Brazil. Results showed that, the runoff and soil loss measured were very low, due to high infiltration rate and vegetable covering conditions. In WEPP simulations two values were used for the hydraulic conductivity (K0): one measured in field (scenario A) and another calculated using WEPP internal procedures (scenario B). The runoff calculated by WEPP in scenario A was very close to measured value. In scenario B, the annual runoff amount was over-predicted. RUSLE model simulated a very low value of soil loss and, therefore, close to the field observed. WEPP, in scenario B, also simulated a small soil loss, although greater than that one simulated by RUSLE. In scenario A, WEPP simulated soil loss equal to zero, which was close to the observed value. Both models satisfactorily estimated soil loss for the analysed conditions, although RUSLE performed better. In WEPP, the water loss was simulated better using measured K0, suggesting that WEPP internal procedures should be carefully used for Brazilian conditions.

Laflen *et al*., (2004) applied three different models to predict the annual soil loss of 20 hill slopes and 15 small watersheds of United States. Over a very wide range of conditions, WEPP performed about as good as replicated small plots and about as good as USLE and RUSLE when comparisons were made. It was a major finding, for WEPP model which was developed from basic relationships constructed similarly to how one would build a building – piece by piece – using the attributes of the pieces and the best understanding of the linkages between the pieces so that the model would replicate the real world. WEPP was not calibrated, nor were locally derived parameters based on measurements used. When the results using WEPP were compared to results using USLE and RUSLE, which we based on locally derived parameters and developed from the data set on which they were tested, and WEPP does as well there was a very strong indication that in un-calibrated comparisons, WEPP would perform very well as compared to USLE and RUSLE technology.

Kim *et al.*, (2007) studied the implementation of two soil erosion models, the empirical Universal Soil Loss Equation (USLE) and the physical-based model of the Water Erosion Prediction Project (WEPP) for the erosion assessment in Korea. The results of the study were that better erosion prediction was obtained using the WEPP model since it illustrated a higher degree of spatial variability than USLE in topography, precipitation, soils, and crop management practices. There was a little variability between the estimates in Chun-Cheon (r^2=0.6841) and Jeon-Ju (r^2=0.8891).

Shen *et al.*, (2009) performed a study to simulate runoff and sediment yield for the Zhangjiachong Watershed in the Three Gorges Reservoir Area in China, in this study, two widely used models – the Water Erosion Prediction Project (WEPP) and the Soil and Water Assessment Tool (SWAT) were applied. The models were run and the simulated runoff and sediment yield values were compared with the measured runoff and sediment yield values. In the calibration period, the model efficiency (E_{NS}) values for the WEPP and SWAT were 0.864 and 0.711 for runoff, and 0.847 and 0.678 for sediment yield, respectively. In the validation period, the ENS values for WEPP and SWAT were 0.835 and 0.690 for runoff, and 0.828 and 0.818 for sediment yield, respectively. The results of ENS and the other criteria indicated that the results of both models were acceptable. WEPP simulations were better than SWAT in most cases, and could be used with a reasonable confidence for soil loss quantification in the Zhangjiachong Watershed.

Demeny *et al*., (2010) studied the area having loessy sand parent material. Intensive arable farming, high compaction and small infiltration rate resulted in high erodibility. WEPP and USLE model were used to provide information from various sources and also to compare the efficiency of the models on a slope of intensive arable farmland. The results showed that on the upper and middle slope sections, WEPP calculated more soil loss than USLE, while at the bottom of the slopes WEPP calculated much more soil loss than USLE. On-site investigations proved that the lower part of the slope was sedimented, so USLE was closer to reality at the bottom of the slope.

Gelencser *et al*., (2010) studied the WEPP and USLE model to prove their efficiency on a slope of intensive arable farmland, close to the Koppany Creek, Hungary. The results showed that on the upper and middle slope sections WEPP calculated more soil loss than USLE, while at the bottom of the slopes WEPP calculated much more soil loss than USLE. On-site investigations proved that the lower part of the slope was sedimented so USLE was closer to reality at the bottom of the slope.

Wade *et al*., (2012) studied the comparison of the sediment trap data with the USLE-forest, RUSLE2, and WEPP-road erosion models for evaluation of bladed skid trail BMPS at Reynolds Homestead Forest Research and Extension Center in Patrick County, Virginia. Model predictions indicated that all models were suitable for ranking erosion rates for the skid trail closure treatments for simple hazard or BMP ratings. However, the older and simpler USLE-Forest and RUSLE2 models had satisfactory NSE and PBIAS values, whereas WEPP-Road did not. Results indicated that WEPP-Road needs additional enhancement with regard to skid trail parameters before it could be effectively used for erosion prediction on bladed skid trails.

Chandramohan *et al*., (2015) studied the evaluation of three soil erosion models i.e. Modified Universal Soil Loss Equation (MUSLE), Unit Sediment graph (USG) and Water Erosion Prediction Project (WEPP). The models were tested on small watersheds within the Pamba River basin of Kerala, India, using the data on observed rainfall-runoff-sediment yield events. Three watersheds were selected with varying land use types, topography and drainage density. Three erosion models were applied for the same rainfall events and the results were compared with the observed sediment yield values. It was seen that the USG predicted the rate of sediment yield better than the other two models. Even though WEPP was a physically distributed model, the large and detailed data requirement, which was impractical in studies of this scale, affected its prediction accuracy.

2.4 Critique of Reviews

From the present literature, it is observed that research work has been carried out on computation of soil erosion, Sediment Yield, Runoff and other different parameters to check the suitability of different models. Soil degradation has reached alarming proportions in many parts of the world, especially in tropics and subtropics. It also leads to decreased agricultural productivity. Hence, efficient management of natural resources viz. soil and water is the major challenge for agricultural scientists, planners and farmers to ensure food, water and environmental security for present future generations.

Konkan region is the part of Maharashtra which having higher soil erosion through runoff, extreme weather conditions, hilly terrain and undulating topography. Due to soil erosion and runoff rich fertile topsoil erodes. Thus, prediction of soil loss, Sediment yield, and to compare the empirical and physical models to check the suitability for the region.

Also research has been done on assessment of the soil erosion by WEPP and USLE using geospatial techniques like Remote Sensing (RS) and Geographical Information System (GIS). WEPP is a continuous simulation model that is able to predict spatial and temporal distributions of net soil loss and deposition for a wide range of time periods and spatial scales. WEPP model useful for to compute soil loss, Sediment yield and other several values at finer scale. But the WEPP model was overestimates and underestimates the soil loss and sediment yield value.

So Universal Soil Loss Equation (USLE) and use of Geographical Information System (GIS) and Remote Sensing (RS) helps to estimate soil loss. USLE was found useful for computing long term soil loss with empirical for different soil erosion classes in many parts of the world.

Mainly research has been done on comparative performance on WEPP and USLE model to compute the soil loss and to check the model suitability for study area.

III. MATERIALS AND METHODS

This chapter deals with the description of the study area, data collection, the procedure adopted for estimation of soil loss by using WEPP and USLE models with the help of Remote Sensing (RS) and Geographical Information System (GIS) for Karli river catchment.

3.1 Study area

The present research work was conducted at Karli river catchment, Taluka-Kudal, District – Sindhudurg, Maharashtra. The Study area is located between the longitude 73.92^0 to 74.01^0 E and latitudes 16.04^0 to 16.10^0 N on the western coast of India in the southern part of Maharashtra state as shown in (Fig 3.1). The total length of the Karli River is 56 km^2. The total geographical area of study location is 4247.12 ha. It is on the eastern side of the Western Ghats forming the narrow strip of land of about 40 km between the Sahyadri on the east and the Arabian Sea on the west. It is highly hilly and undulating, being cut up by many east-west trending ridges, some of which reach right to the coast.

3.2 Rainfall

The area under investigation receives average annual rainfall of about 3,287 mm. geologically; the area is endowed with a variety of lithological types ranging in age from Achaean to Recent. Lithotypes like gneisses, quartzite, and schist are exposed while Cretaceous basaltic flows of Deccan Volcanic are present at higher elevations.

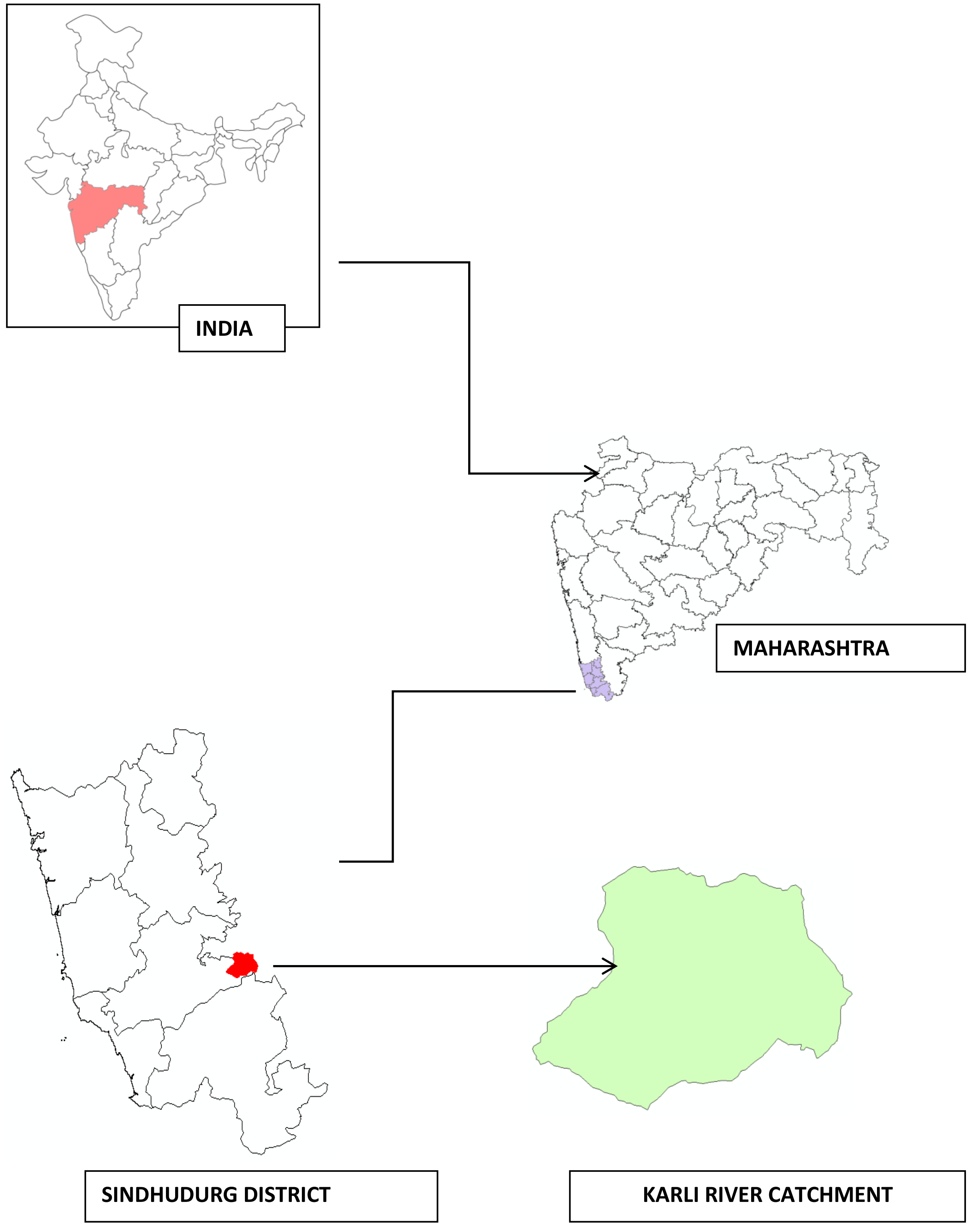


Fig. 3.1 Location map of the study area

3.3 Data collection and Pre-processing for Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE) Model

The data collection for WEPP and USLE Models were collected from various different sources. WEPP model required less preprocessing file as compare to USLE model. USLE model required all files should be preprocessed. The Toposheets for Karli river catchment, Tal-Kudal, Dist-Sindhudurg, Maharashtra was collected from Survey of India (www.soinakshe.uk.gov.in). The following data were used to compute soil loss by using WEPP and USLE model for the Karli river catchment.

3.3.1 Data requirement for Water Erosion Prediction Project (WEPP) Model

The following data were used to compute soil loss by using WEPP model for the Karli river catchment.

1. Daily rainfall data from 1990 to 2013 (24 years) of Dukanwadi station which was near to the study area, Tal-Kudal, Dist-Sindhudurg was used to prepare climate input file for WEPP model. It was collected from Water Resources Department, Hydrology Project (www.mahahp.gov.in).
2. Harmonised World Soil Database (HWSD) was used as soil input file for WEPP model. It was collected from Food and Agricultural Organisation (http://www.fao.org).
3. The slope input file for WEPP Model was created from the Digital Elevation Model (DEM) of the study area was prepared using CartoDEM data. It was collected from Bhuvan website portal (http://bhuvan.nrsc.gov.in).
4. Satellite images used for preparation of management input file for WEPP model were downloaded from LANDSAT data (http://ftp.glcf.umd.edu).

3.3.2 Data Requirement for Universal Soil Loss Equation (USLE) Model

The following data were used to compute soil loss by using USLE model for the Karli river catchment.

1. Daily rainfall data of Dukanwadi station has been used from (1990-2013) 24 years data to compute annual rainfall erosivity (R factor). It was collected from Water Resources Department, Hydrology Project website portal (www.mahahp.gov.in).
2. The different soil parameters such as sand, silt, clay and organic carbon of Kudal Taluka was collected from, Estimation of Erodibility at Selected Locations in Konkan Region to compute soil erodibility (K factor) for USLE model (Thawakar, 2014).

3. The slope length map for USLE Model was created from the Digital Elevation Model (DEM) of the study area was prepared using CartoDEM data. It was collected from Bhuvan website portal (http://bhuvan.nrsc.gov.in).
4. Landsat Satellite images used for preparation of Land Use/Land Cover (LULC) map for USLE model were downloaded from LANDSAT data portal (http://ftp.glcf.umd.edu).
5. Crop cover data of Kudal Taluka was collected from the Taluka Agriculture Office, Kudal, Dist-Sindhudurg, (Maharashtra) to obtain the crop cover management (C factor).

3.3.3 Input files for Water Erosion Prediction Project (WEPP) Model

The Water Erosion Prediction Project (WEPP) Model required four input files such as Slope input file, Climate input file, Soil input file, and, Management input file. In WEPP model only management input file were required preprocessed as Land Use/Land Cover (LULC) raster file. The Input files for Water Erosion Prediction Project (WEPP) Model for Karli river catchment were shown in Table 3.1.

3.1. Input files for Water Erosion Prediction Project (WEPP) Model

Sr. No.	Data Collected and Pre-processed	Input Files
1.	Digital Elevation Model (DEM) Collected from USGS Earth Explorer portal	Slope Input file
2.	Rainfall data collected from Water Resources Department, Hydrology Project	Climate input file
3.	Harmonised World Soil Database (HWSD) data collected from Food and Agricultural Organisation Portal	Soil erodibility file
4.	Landsat image Collected from Landsat imageries portal	Management input file

3.3.4 Input files for Universal Soil Loss Equation (USLE) Model

The Universal Soil Loss Equation (USLE) required five input files such as Rainfall erosivity factor, Soil erodibility factor, Slope length factor, Crop management factor, and Conservation practice factor. The Input files for Universal Soil Loss Equation (USLE) for Karli river catchment were shown in Table 3.2.

3.2. Input files for Universal Soil Loss Equation (USLE) Model

Sr. No.	Data Collected and Pre-processed	Input Files/map
1.	Rainfall data collected from Water Resources Department, Hydrology Project	Rainfall erosivity map
2.	Soil data collected from Thawakar Thesis (2014)	Soil erodibility map
3.	Digital Elevation Model (DEM) Collected from USGS Earth Explorer portal	Slope length map
4.	Landsat image Collected from Landsat imageries portal	Crop management map
5.	Raster file collected from Bhuvan portal	Conservation practice map

3.4 Software and System

Arc-GIS 10.2.2, GeoWEPP 10.2, and WEPP 2012.8 were used for data creation, data analysis and output generation which were available at Dr. B.S.K.K.V., Dapoli. Arc-GIS is advanced tool used for mapping, geographic analysis, spatial analysis, hydrology, overlay analysis, data editing etc. GeoWEPP is a GIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into WEPP and generation of GIS data from WEPP output.

3.5 Watershed delineation

Watershed is a hydrological unit from which runoff resulting from precipitation flows past a single point into a large stream, river, lake or pond. It is an ideal unit for management of natural resources like land, water and vegetation. Watershed delineation plays an important role in watershed management. Arc-GIS software was used for the purpose of watershed delineation using CartoDEM data. The shape file generated through watershed delineation of the study area was used for clip satellite images for further processing. Also Toposheets has been used to validate karli river catchment which were downloaded from Survey of India Toposheets (1:50,000 scale) U4 and T16. Toposheets provide information related to the location, drainage network and contours. Flowchart for the watershed delineation is presented in Fig 3.2. Watershed delineation map as shown in Fig 3.3.

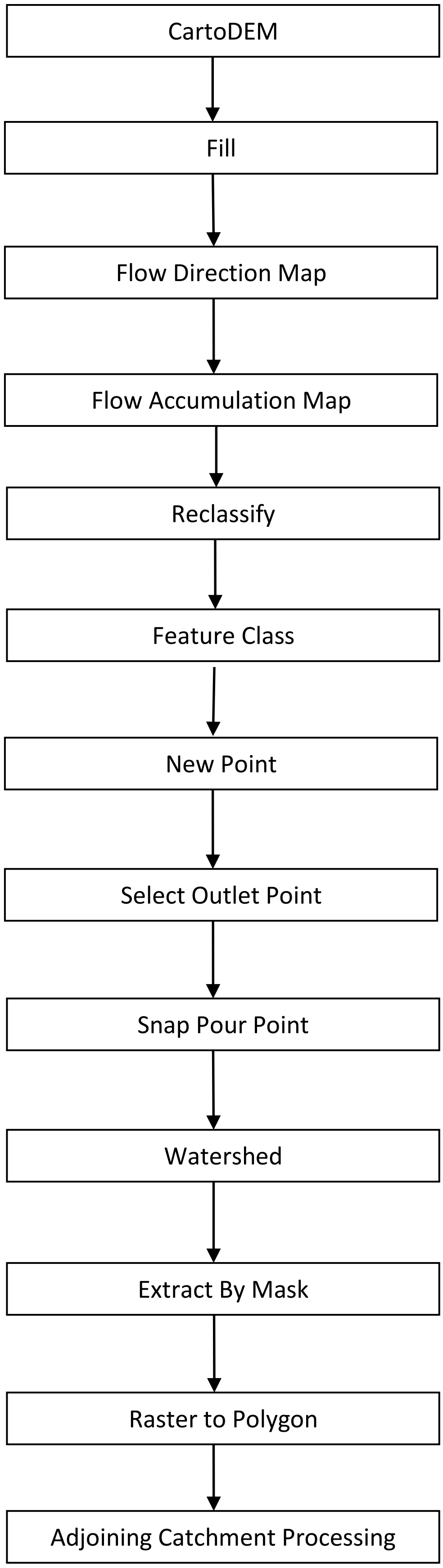


Fig 3.2 Flowchart for the watershed delineation

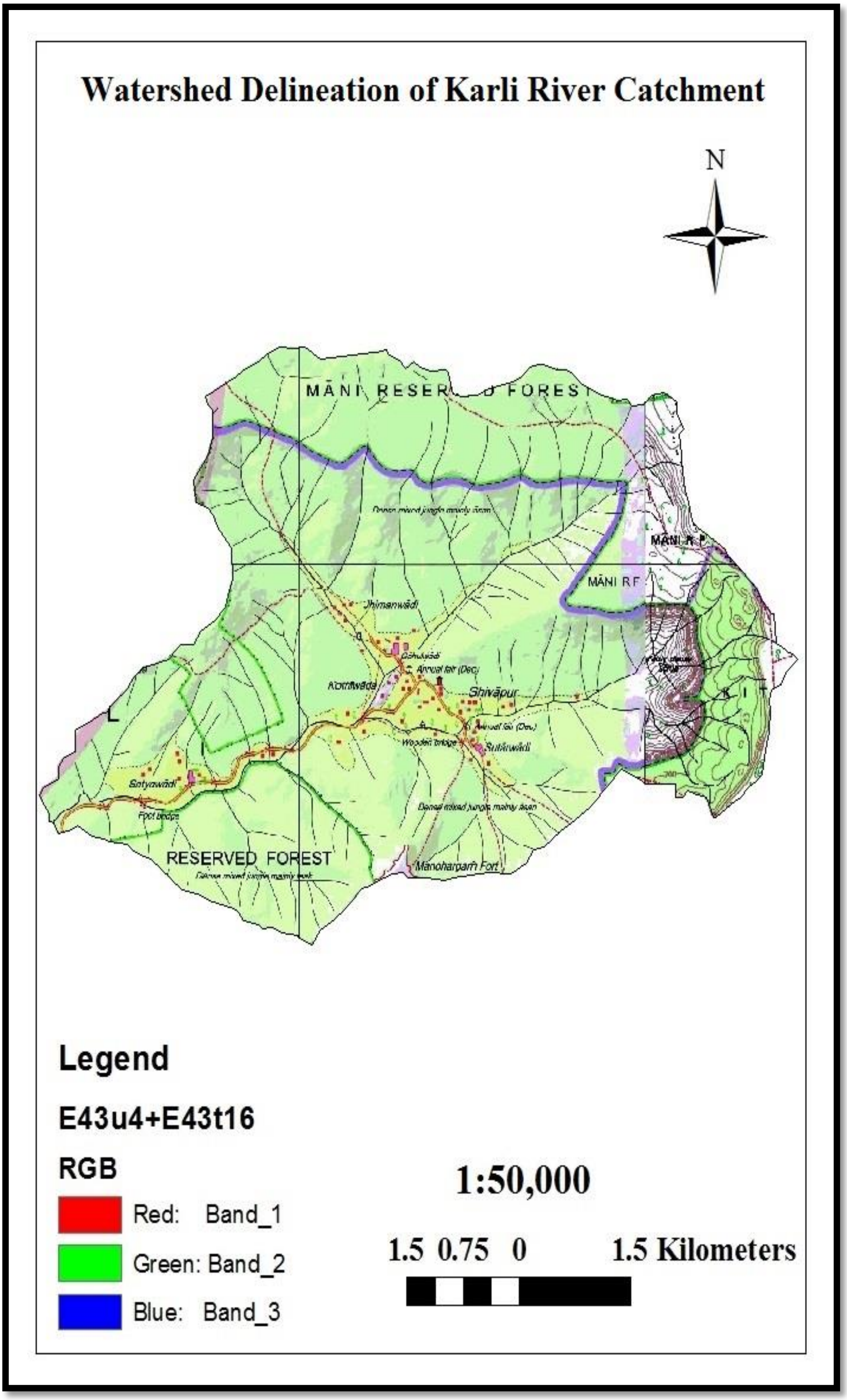


Fig.3.3 Watershed Delineation map of Karli River Catchment

3.6 Preparation of Land Use/ Land Cover map

Land use/Land cover is one of the most important thematic inputs in watershed study as it provides the present status of land utilization and its pattern. Flowchart for the generation of LU/LC map as shown in Fig 3.4.

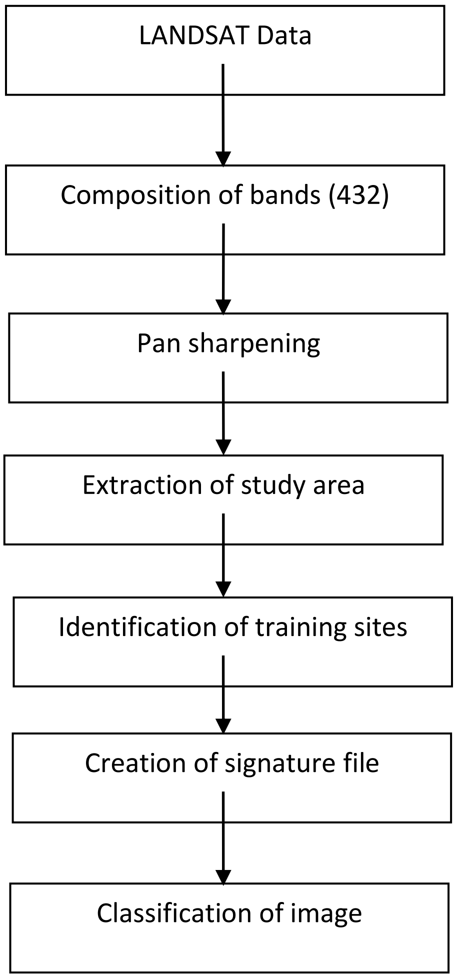


Fig 3.4 Flowchart for the preparation of Land Use/Land Cover map

The land use and land cover characteristics of the study area was described using land use/land cover (LU/LC) maps. Both the models required land use/land cover map as input parameter.

The LU/LC in the Karli river catchment was classified into five classes: (i) Water bodies (ii) Build up (iii) Agriculture (iv) Barren and (v) Forest. Highest per cent area was found under forest class (59.8 %), followed by agricultural (20.38 %), barren (15.31 %), build up (3.59 %) and water bodies (0.80 %).

The land use and land cover classes of Karli river catchment were shown in table 3.3 and land use and land cover map shown in fig 3.5.

Table 3.3 Land Use/ Land Cover (LU/LC) classification of the study area

Sr. No.	Land Use/Land Cover	Area (ha)
1.	Water bodies	34.26
2.	Build up	152.62
3.	Agricultural	865.64
4.	Barren	650.58
5.	Forest	2544.02
	Total	**4247.12**

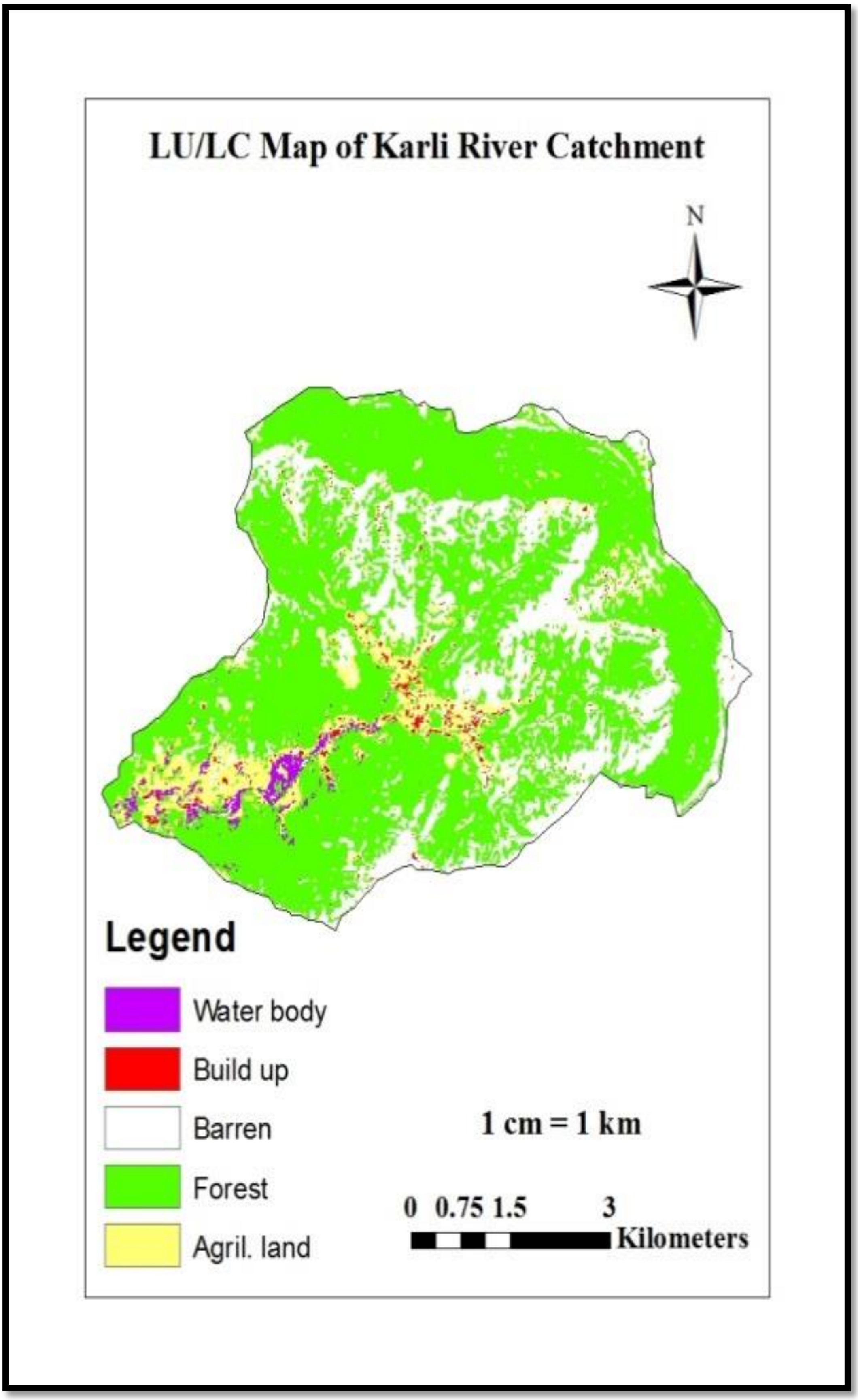


Fig.3.5 Land Use /Land Cover (LU/LC) map of Karli river catchment

3.7 Soil Erosion-Water Erosion Prediction Project

The Water Erosion Prediction Project (WEPP) was initiated in 1985, by the USDA (Nearing, 1998). It is a continuous process-based erosion prediction model which can compute runoff and soil loss along a slope. The hill slope version of WEPP can also estimate the watershed runoff and sediment yield under different land use and soil types (Flanagan and Nearing, 2000).

The WEPP model represents a new soil erosion prediction technology which is based on the fundamentals of infiltration theory, soil physics, hydrology, plant science, hydraulics, and erosion mechanics (Nearing, 1998). Like most of the soil erosion model, the erosion component of WEPP is based firmly on a steady state continuity equation which is composed of inter-rill and rill erosion. Inter-rill erosion is considered to be independent of distance that is to say inter-rill erosion occurs at a constant rate down the slope. Rill erosion is positive for detachment and negative for deposition. Each of these parameters is calculated on a per rill area basis, thus the sediment load is solved as soil loss per unit rill area. One difference between the WEPP model and other models is that, the sediment continuity equation is applied within rills rather than using uniform flow hydraulics. The WEPP model was developed by an interagency of scientists to replace the Universal Soil Loss Equation (USLE) and has been widely used in world. WEPP was continuous simulation model that is able to predict spatial and temporal distributions of net soil loss and deposition for a wide range of time periods and spatial scales. The hill slope version computes erosion along a single slope profile, while the Watershed version can be used to assess soil loss at the catchment scale. In this latter case the watershed is idealized with multiple hill slopes, channels and impoundments. The model is composed of several components, taking into account climate, hydrology and water balance, plant growth with residue decomposition and agricultural practices, soil composition and consolidation (Flanagan and Nearing, 1995).

The WEPP works in continuous as well as single-storm simulation mode. This model is considered to possess the state-of-the-art knowledge of the erosion science, and has become an important tool for runoff and sediment estimation (Lane *et al.*, 1997). WEPP requires four inputs *i.e.*, climate, slope, soil & management and provides various types of outputs, which include water balance, surface runoff, subsurface flow and evapotranspiration, soil detachment and deposition at points along the slope, sediment delivery and vegetation growth.

3.7.1 Preparation of input files for Water Erosion Prediction Project Watershed Model Application

The WEPP model requires four inputs files such as Slope, Climate, Soil and Management were as follows

3.7.1.1 Slope input file

The slope file is generated based on parameters such as slope length, orientation, and steepness which are provided for each Overland Flow Element (OFE). This is a region of homogeneous soil, crop and management within the hill slope. Slope parameters for OFEs were derived from the Digital Elevation Model. The Digital Elevation Model (DEM) was used to prepare CartoDEM of the study area. DEM was projected into UTMs and converted into ASCII files format in ArcGIS was used as Slope input file for GeoWEPP tool. The DEM is used to delineate the channel network, determine the sub-catchments in the Karli river catchment, and generated the hill-slope information (slope, length, etc.) in GeoWEPP tool. GeoWEPP generates a network based on DEM using two parameters: the Critical Source Area (CSA) and the Minimum Source Channel Length (MSCL). Both of these parameters are dependent on the resolution of the DEM and outlet point selected. The WEPP model computed soil loss for 7 major channels and 18 sub-catchments/hills of Karli river catchment as shown in (Fig 3.6).

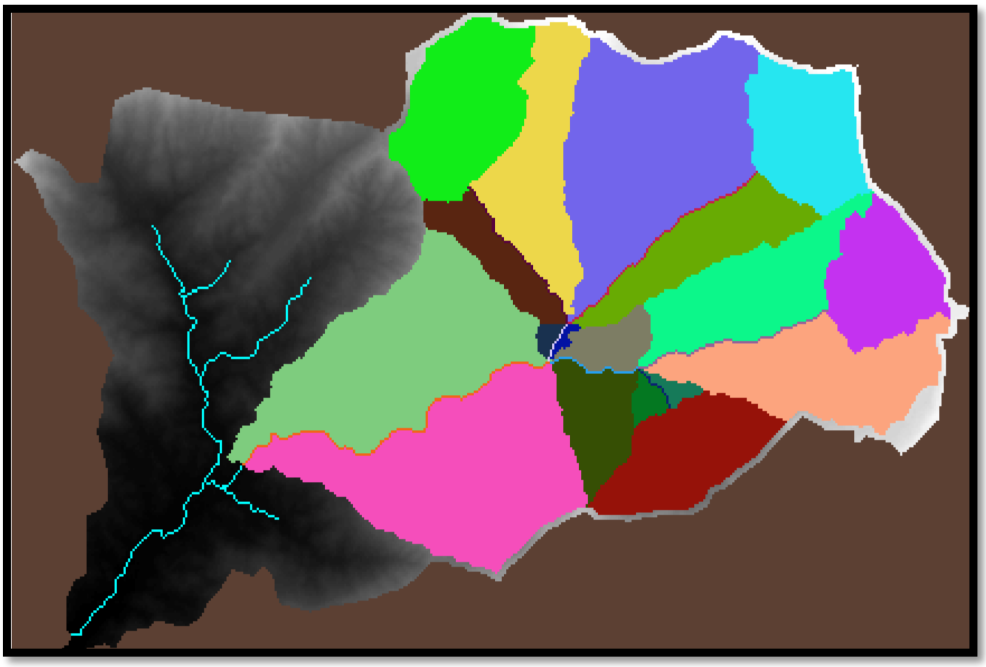
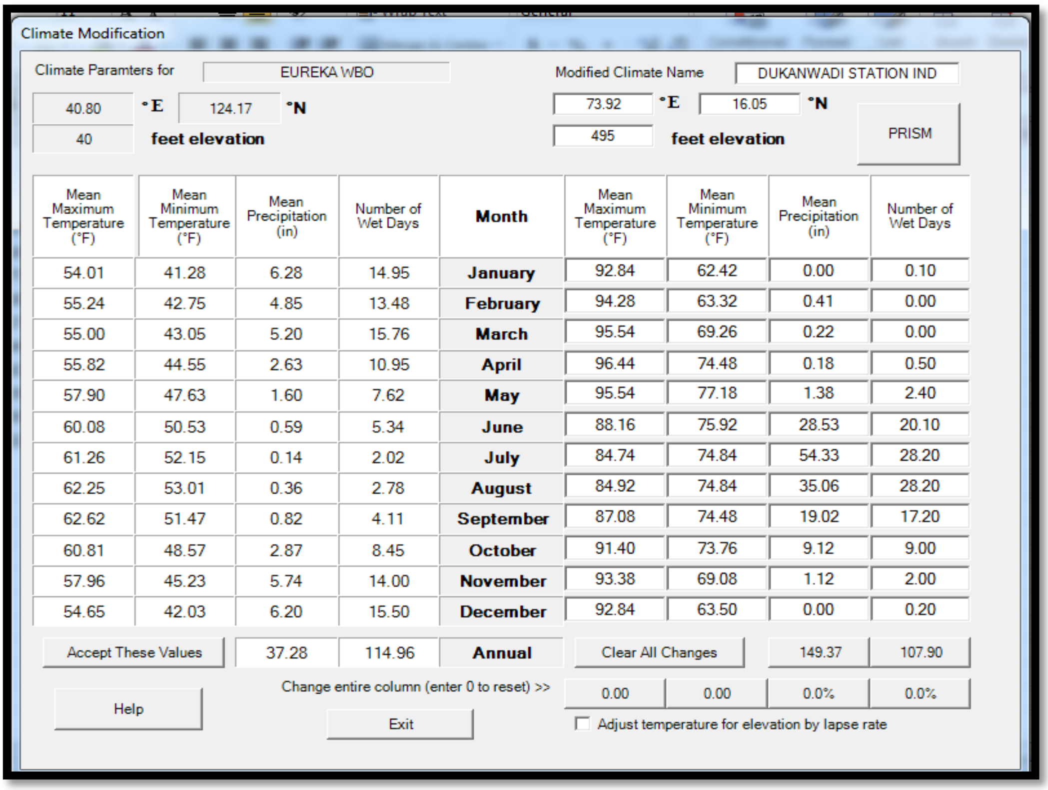


Fig 3.6 Digital Elevation Model is used to delineate the channel network, and determine the sub-catchments/hill-slope for Karli River Catchment

3.7.1.2 Climate input file

Climate data for the considered period was used for continuous simulating. Meteorological data such as maximum and minimum temperature, relative humidity, solar radiation and wind velocity were collected from Dukanwadi station of the Karli river catchment. WEPP accepts climate input files including the Climate Generator (CLIGEN) programs generate climate data in the format accepted by the model using observed meteorological database. Parameter-elevation Regressions on Independent Slopes Model (PRISM) allows you to modify an existing WEPP Climate parameter file – the files WEPP uses to generate the climate events for a simulation. PRISM allows you to make modification to the GeoWEPP climate parameter files so that it can more closely match the climate found in selected study area as shown in (Fig 3.7).



Climate Modification

Climate Paramters for EUREKA WBO — Modified Climate Name DUKANWADI STATION IND

40.80 °E 124.17 °N — 73.92 °E 16.05 °N — PRISM

40 feet elevation — 495 feet elevation

Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of Wet Days	Month	Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of Wet Days
54.01	41.28	6.28	14.95	January	92.84	62.42	0.00	0.10
55.24	42.75	4.85	13.48	February	94.28	63.32	0.41	0.00
55.00	43.05	5.20	15.76	March	95.54	69.26	0.22	0.00
55.82	44.55	2.63	10.95	April	96.44	74.48	0.18	0.50
57.90	47.63	1.60	7.62	May	95.54	77.18	1.38	2.40
60.08	50.53	0.59	5.34	June	88.16	75.92	28.53	20.10
61.26	52.15	0.14	2.02	July	84.74	74.84	54.33	28.20
62.25	53.01	0.36	2.78	August	84.92	74.84	35.06	28.20
62.62	51.47	0.82	4.11	September	87.08	74.48	19.02	17.20
60.81	48.57	2.87	8.45	October	91.40	73.76	9.12	9.00
57.96	45.23	5.74	14.00	November	93.38	69.08	1.12	2.00
54.65	42.03	6.20	15.50	December	92.84	63.50	0.00	0.20
Accept These Values		37.28	114.96	Annual	Clear All Changes		149.37	107.90

Change entire column (enter 0 to reset) >> 0.00 0.00 0.0% 0.0%

Help — Exit — Adjust temperature for elevation by lapse rate

Fig 3.7 Climate Modification for Dukanwadi station of Karli river catchment

3.7.1.3 Management input file

The management input file is generated for different land use types like agriculture, barren, residential regions, forest open water etc). LANDSAT-8 data was used to prepare various land use classes and convert into ASCII file format in ArcGIS. The WEPP Management input file input was prepared in look up table of GeoWEPP Model as shown in (Fig 3.8).

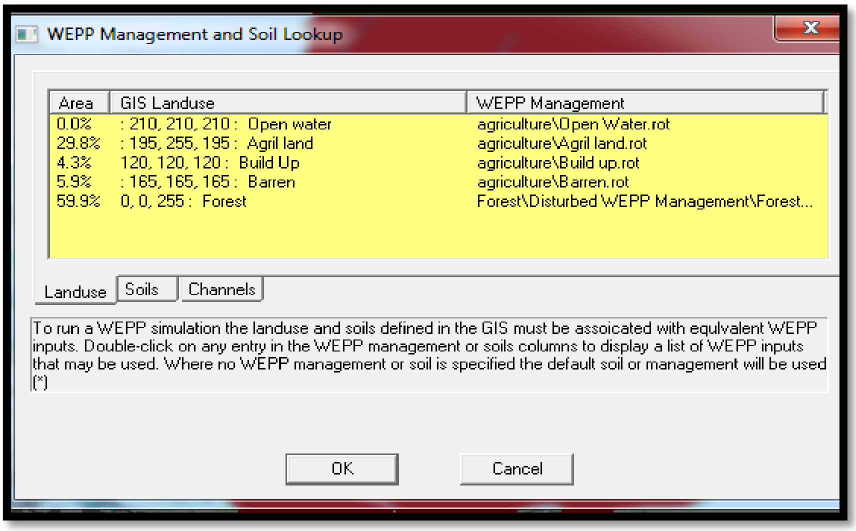


Fig 3.8 WEPP Management Lookup file displaying land management information and Select a Management file

3.7.1.4 Soil input file

In WEPP model required parameters in the soil input file are soil texture (% sand, silt, and clay) and physicochemical properties, soil characteristics for each hill slope, including type of soil, hydraulic conductivity, bulk density, organic matter percentage, etc. The Harmonized World Soil Database (HWSD) was used to prepared soil input file for GeoWEPP model. A default Sandy clay loam value for studied area was extracted from the WEPP database (Flanagan and Livingston, 1995) as shown in (Fig 3.9)

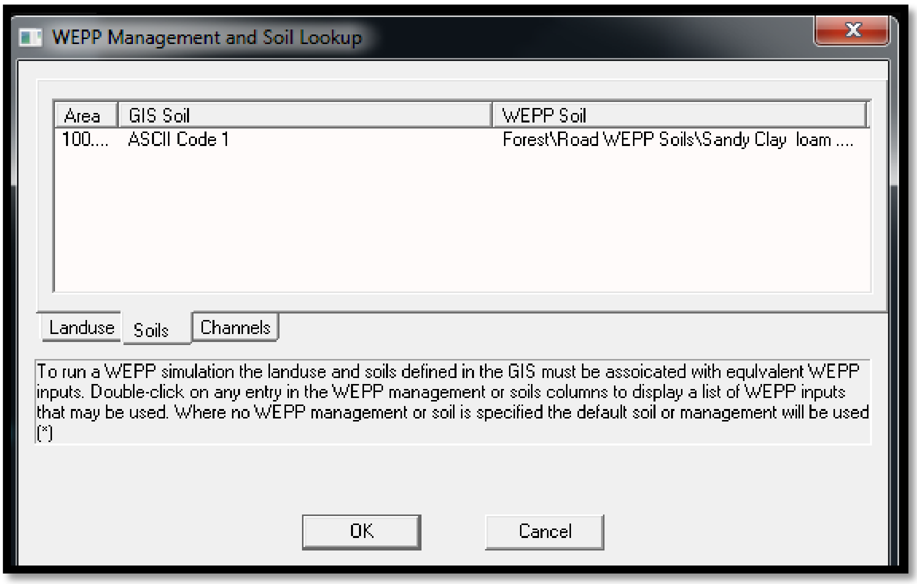


Fig 3.9 Soil Lookup File displaying soil information

3.8 Soil Erosion-Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith, (1978) and their associates from the U.S Department of Agriculture (USDA), Agricultural Research Service (ARS), Soil Conservation Services (SCS) and Purdue University. The USLE was proposed for estimating sheet and rill erosion sediments losses from cultivated fields. The USLE and its predecessors were meant as field-level conservation planning rather than research tools, and were therefore structured to be 'user friendly' for USDA programs in the Soil Conservation Service (SCS) and designed for adapting erosion-control practices to the needs of specific fields and farms. This empirical equation, based on a large mass of field data, computes sheet and rill erosion as annual average soil loss (t/ha/yr) using the values representing the four major types of factors affecting erosion. These factors are climatic, soil, topographic, land use and management. The equation given by Wischmeier & Smith (1978) is,

$$A = R \times K \times L \times S \times C \times P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.1)$$

Where, A is computed soil loss (t/ha/yr),

R is the rainfall erosivity factor (MJ-mm/ha-hr-yr),

K is the soil erodibility factor (t-ha-hr/ha-MJ-mm),

L is the slope length factor (m),

S is the slope steepness factor,

C is the crop cover-management factor and

P is the conservation practice factor.

Although the USLE was developed for use on cropland, by the early 1970s, it was being applied to rangeland and disturbed forestland. Other land uses where the USLE has been applied include urban construction areas, recreational sites, highway embankments, mine tailings, and even coal piles. Such widespread applications resulted from the technical soundness of the USLE and the lack of alternative simpler models for planning conservation programs to control soil erosion. It is an equation that, estimates average annual soil loss by sheet and rill erosion on those portions of landscape profiles where erosion, but not deposition, is occurring. It neither estimates deposition at the toe of concave slopes, nor the sediment yield at a downstream location. Also, it does not include ephemeral gully erosion. As an empirical equation derived from experimental data, the USLE adequately represents the first order effects of the factors that influence sheet and rill erosion.

3.8.1 Rainfall Erosivity (R) Factor

3.8.1.1 Concept of rainfall erosivity

Wischmeier and Smith (1958) derived the rainfall and runoff erosivity factor from research data from many sources. Renard et al. (1997) states that the numerical value used for R in USLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain. The rainfall runoff erosivity factor (R) derived by Wischmeier appears to meet these requirements better than any of the many other rainfall parameters and groups of parameters tested against the plot data. Raindrops while falling acquire kinetic energy and on impact, the kinetic energy is used up in detaching the soil particles. Energy is required to break the soil aggregates, splashing them and subsequently carrying them with runoff. Surface runoff as it flows down the slope, gains kinetic energy, which is responsible for the scouring action on the land surfaces. Wishmeier and Smith (1978) recommended that at least 20 years of rainfall data be used to accommodate natural climatic variation.

3.8.1.2 Computation of rainfall erosivity factor (R)

The rainfall – runoff erosivity factor is defined as the mean annual sum of individual storm erosion index values. To compute storm EI30, continuous rainfall intensity data are needed. It is defined as the product of kinetic energy and the maximum 30 minute intensity and shows the erosivity of rainfall events. It is given by

$$R = \frac{KE \times I_{30}}{100} \qquad \ldots\ldots\ldots\ldots (3.2)$$

Where,

R = Rainfall erosivity factor (MJ-mm/ha-hr-yr),

EI_{30} = Erosivity index,

I_{30} = Maximum 30 minute rainfall intensity of the storm,

KE = Kinetic energy of storm (MT/ha-cm),

= 210.3 + 89 *log I*

I = Rainfall intensity (cm-hr).

3.8.1.3 Computation of R factor using daily data

The EI_{30} was closely related to the intensity of every storm and also with the depth of rainfall occurred in that storm. The daily precipitation and EI_{30} data of Wakawali station were used for regression analysis (Yadav and Mhatre, 2005) and regression equation was obtained for computing the daily erosivity index. The following equation implies the correlation between daily rainfall and daily Erosivity Index.

$$Y = 0.3339x^{1.50} \qquad \ldots.. (3.3)$$

Where, Y = Daily erosivity index,

x = Daily precipitation.

The coefficient of determination obtained was 0.7624. This regression equation was used to estimate daily precipitation and EI_{30} data. Daily rainfall erosivity values of Dukanwadi station was estimated by using regression equation.

3.8.1.4 Creation of rainfall erosivity (R) map

In Arc GIS the R factor is computed by putting the Coordinates of the gauging station for Karli river catchment was obtained from Google Earth map. Then these longitude, latitude value are written in excel and then imported into Arc GIS. The average annual erosivity values for Dukanwadi station (1991-2013) were the summation of daily erosivity values of station. Average annual erosivity values of these Dukanwadi station was assigned to respective polygon to get rainfall erosivity (R) map.

3.8.2 Soil erodibility (K) factor

3.8.2.1 Concept of soil erodibility

Soil erodibility factor (K) is defined as the average rate of soil loss per unit of rainfall erosivity index from a unit plot (Zhang, *et al*., 2004). Soil erodibility (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input, as measured under a standard condition. The standard condition is the unit plot, 22.13 m long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hill slope (Weesies, 1998). K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil erodibility factors (K) are best obtained from direct measurements on natural runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Romkens 1985). For satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years (Loch et al., 1998). Therefore, considerable attention has been paid to estimating soil erodibility from soil attributes such as particle size distribution, organic matter content and density of eroded soil (Wischmeier et al., 1971). Nomograph used to determine the K factor for a soil, based on its texture; % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability.

3.8.2.2 Computation of soil erodibility (K)

Soil erodibility equation is statistically accurate and technically valid but has proven too complex as an operational tool for a technician to solve. Direct determination of the K factor requires long- term measurements of soil loss, which is costly and time-consuming. Hence the K-factor was calculated by using the formula was used given as below (Wischmeier and Smith, 1978 and Renard *et al.*, 1997)

$$K = \left\{\frac{\left[2.1 * 10^{-4}\, M^{1.14} (12-a) + 3.25\,(b-2) + 2.5\,(c-3)\right]}{100}\right\} * 0.1317 \ldots\ldots\ldots\ldots (3.4)$$

Where,

K = soil erodibility factor (t-ha-hr/ha-MJ-mm)

M = (% silt + 0.7 * % sand) * (100 - % clay)

a = organic matter content

= (Organic carbon * 1.724)

b = structure of the soil

c = permeability of the soil

In present study, the different soil parameters such as sand, silt, clay and organic carbon were collected from M. Tech. thesis (Thawakar, 2014). Based on these data parameters required for erodibility estimation (Equation 3.4).

3.8.2.3 Creation of soil erodibility (K) map

Soil parameters such as sand, silt, clay and organic carbon were collected (Thawakar, 2014). Based on these data soil parameters required for estimation of erodibility were determined using above relationships and models. K factor values for 6 villages of the Kudal Taluka were calculated by using Eqn. 3.4. Soil erodibility factor (K) value was assigned to each village of Kudal Taluka in ArcGIS 10.2.2. The Inverse Distance Weighted (IDW) Technique was used for interpolation to get Soil Erodibility (K) map of study area.

3.8.3 Slope Length and Slope Steepness (LS)

The effect of topography on soil erosion is accounted for by the LS factor in USLE, which combines the effects of a slope length factor, L, and a slope steepness factor, S. In general, as slope length (L) increases, total soil erosion and soil erosion per unit area increase due to the progressive accumulation of runoff in the downslope direction. As the slope steepness (S) increases, the velocity and erosivity of runoff increase. It is generally accepted that the erosion increases with increasing slope length, as the greater accumulation of runoff on longer slopes increases its detachment and transport capacities.

3.8.3.1 Slope length factor (L)

The relationship between the slope steepness in percentages (Sp) and slope length in meters (L) are used to generate slope length map. It is given by

$$L = 0.4 \times (Sp + 40) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where,

L = slope length (m) and

Sp = slope steepness (%)

By applying equation 3.5 the resultant map was prepared in Arc GIS 10.2.2 for slope length.

3.8.3.2 Topographic Factor (LS)

Although Slope length (L) and Slope steepness (S) factors will be determined separately, the procedure has been further simplified by combining the L and S factors together and considering the two as a single topographic factor (LS) (Wischmeier and Smith, 1965). Combined LS factor was generated for the following conditions

i) For slopes up to 21 %, the equation given by (Wischmeier and Smith, 1978)

$$LS_1 = (l/22.1)^{m} \times (65.4 \sin^2\theta + 4.56 \sin\theta + 0.065) \quad \ldots\ldots\ldots\ldots (3.6)$$

Where,

LS_1 = topographic factor,

M = exponent factor varying 0.2 to 0.5,

θ = angle of the slope and

l = slope length (m)

ii) For slope steepness of 21 % or more, the equation is

$$LS_2 = (l/22.1)^{0.7} \times (6.432 \times \sin(\theta^{0.79}) \times \cos(\theta)) \quad \ldots\ldots\ldots\ldots (3.7)$$

Where,

LS_2 = slope length in gradient factor,

θ = angle of the slope and

l = slope length (m).

3.8.3.3 Creation of topographic factor (LS) map

Digital Elevation Model (DEM) of the study area was used to generate slope map, which was downloaded from Shuttle Radar Topography Mission (SRTM) images (http://.srtm.csi.cgiar.org). The Digital Elevation Model (DEM) is the continuous representation of elevation values over a topographic surface by regular array of altitude, referenced to a common datum. Slope maps of the study area in percentage and in degree were prepared by using Arc GIS 10.2.2. These maps were used to calculate LS factor of study area.

3.8.4 Crop Management Factor (C)

The cover management factor (C) represents the effects of vegetation, management, and erosion control practices on soil loss. As with other USLE factors, the C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot as defined in earlier chapters. The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). USLE uses a sub factor method to compute Soil Loss Ratios (SLR), which are the ratios of soil loss at any given time in the cover management sequence to soil loss from the standard condition. The sub factors used to compute a soil loss ratio value are prior land use, forest cover, surface cover, surface roughness, and soil moisture.

3.8.4.1 Creation of crop management factor (C)

The cloud free satellite data downloaded from LANDSAT imageries (ftp.glcf.umd.edu) was used in the present study to prepare LU/LC map. Values for particular land use class were assigned to study area from existing literature (Table 3.4). These values were assigned to respective land use/land cover class map in ArcGIS 10.2.2 to get C factor map.

Table 3.4. Land Use/Land Cover and Crop management factor value (C)

Land use/land cover	C value
Forest (Rasool *et al*. 2014)	0.04
Barren land (Rasool *et al*. 2014)	0.034
Built-up (Rasool *et al*. 2014)	0.024
Horticultural crops (Pal and Samanta, 2011)	0.1
Oilseeds (Panagos *et al*. 2015)	0.28
Rice (Panagos *et al*. 2015)	0.15

3.8.5 Conservation Practice Factor (P)

Support Practice Factor (P) in RUSLE model is account for the ratio of soil loss with a specific support practice to corresponding soil loss with upslope and downslope tillage. These practices essentially effect erosion by adjusting the flow pattern, steepness, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster 1983). The support practices for cultivable lands are including contouring, strip-cropping, terracing, and subsurface drainage. While on dry land or rangeland area, soil disturbing practices to result storage of moisture and reduction of runoff considered to be as support practices mechanisms.

3.8.5.1 Creation of Conservation Practice Factor (P) map

Conservation practice factor would be decided based on treatments taken up in various parts of the watershed. Karli river catchment was not taken up for any conservation treatments in the past. So, conservation practice factor (P) was considered as 1 for Karli river catchment which was untreated.

IV. RESULTS AND DISCUSSION

This chapter deals with the results of the study of soil loss from Karli river catchment by using WEPP and USLE models, using GIS map. Chapter includes results of various parameters as rainfall erosivity factor, soil erodibility factor, topographic factor, crop management factor and support conservation practices factor in USLE equation for estimation of average annual soil loss from Karli river catchment.

4.1 Water Erosion Prediction Project (WEPP)

GeoWEPP 10.2 is an ArcGIS 10.2.2 extension that provides a set of procedures, tools, and utilities for the preparation of GIS data for import into WEPP and generation of GIS data from WEPP output. After launching GeoWEPP initially input DEM is mainly required. Soil and land use/land cover files are also required as input for start processing as shown in fig 4.1. If one of file from land use/ land cover and soil file are not available then the default file has been used.

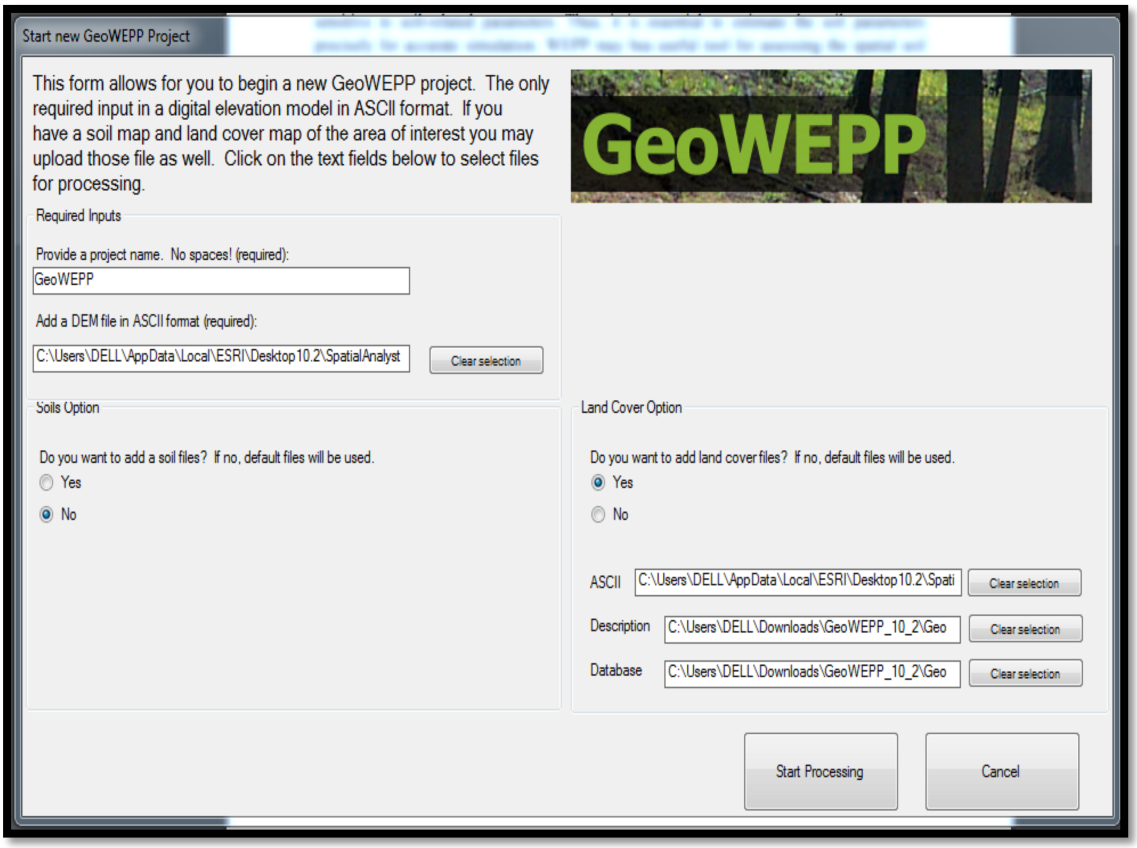


Fig 4.1 Input DEM, Soil and land use/land cover files as input for GeoWEPP

4.2 Watershed delineation

The Automatic Watershed Delineation command accesses the dialog box used to import topographic maps and delineate the watershed. Watershed is a hydrological unit from which runoff resulting from precipitation flows past a single point into a large stream, river, lake or pond. Watershed delineation plays an important role in watershed management. Delineated watershed is based on outlet point with the help to specify the outlet point of watershed tool.

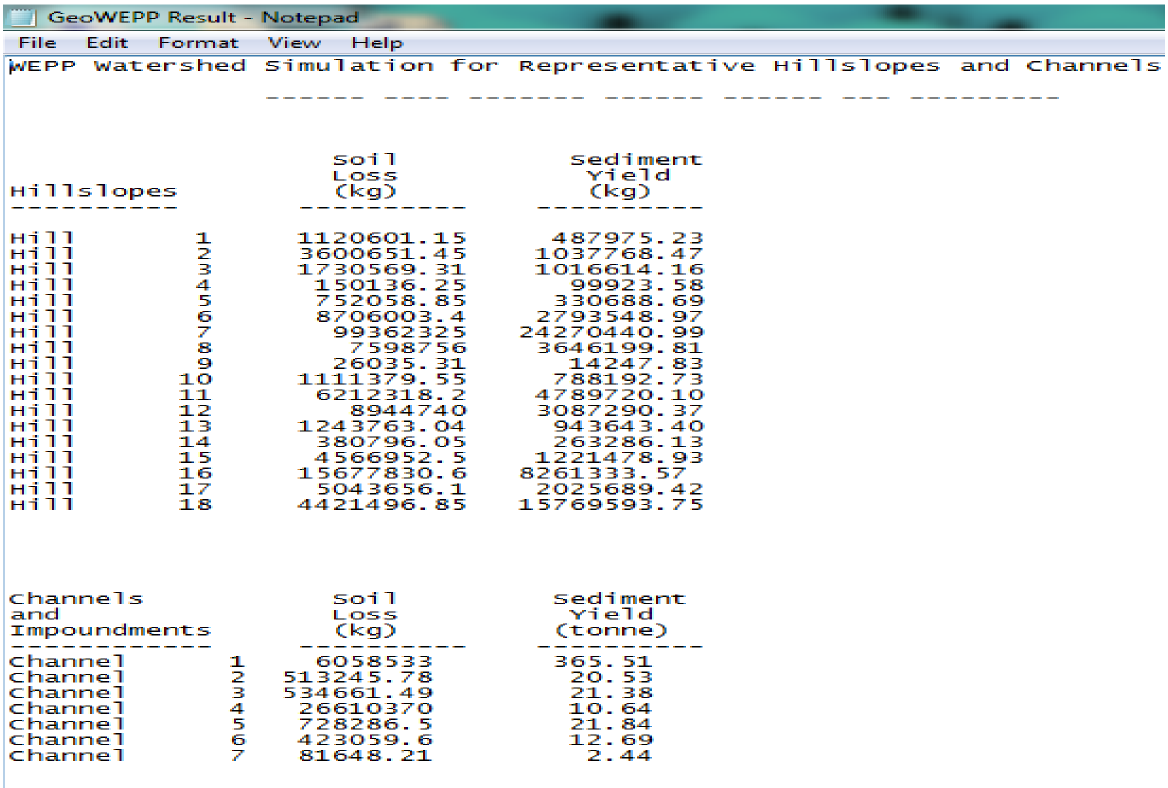
The automatic delineated watershed area was 39.78 km^2 which was less than actual area of Karli river catchment 42.17 km^2. The WEPP model delineate the watershed according to slope input file from which elevation data, soil input file from which soil properties data, and mainly management input file from which land use class area data. so in this model the raster input file of Slope, Soil, and Management input file are all matched with all one another data then and then it has delineate proper area of watershed but due to soil input file which having less area than required area, the model not read the all these three input file carefully and do not match data with each other, it has delineate the less area.

The WEPP model required the Specifying the Universal Transverse Mercator (UTM) zone for data and study area which was WGS 1984 UTM zone 43N for Karli River Catchment.

4.3 Water Erosion Prediction Project (WEPP) model Run

In WEPP model, after the delineation of watershed GeoWEPP model required Climate file of 24 years (1990-2013) for run the GeoWEPP model successfully. GeoWEPP delineated the Karli River catchment in 7 channels and 18 hills. Each channel and hill was assign the Land Use/Land Cover (LULC) as management input file and soil data as soil input file separately to run each hill slopes and channel successfully.

WEPP model calculated the average annual soil loss and average annual sediment yield for each channel and hill slopes separately. The WEPP watershed simulation for representative each hill slopes and each channels as shown in fig 4.2, Table 4.1, and Table 4.2.



```
GeoWEPP Result - Notepad
File   Edit   Format   View   Help
WEPP Watershed Simulation for Representative Hillslopes and Channels
                      ------ ---- -------- ------ ------ --- ----------

                                  Soil             Sediment
                                  Loss              Yield
Hillslopes                        (kg)              (kg)
----------                    -----------       -----------

Hill          1          1120601.15          487975.23
Hill          2          3600651.45         1037768.47
Hill          3          1730569.31         1016614.16
Hill          4           150136.25           99923.58
Hill          5           752058.85          330688.69
Hill          6           8706003.4         2793548.97
Hill          7            99362325        24270440.99
Hill          8             7598756         3646199.81
Hill          9            26035.31           14247.83
Hill         10          1111379.55          788192.73
Hill         11           6212318.2         4789720.10
Hill         12             8944740         3087290.37
Hill         13          1243763.04          943643.40
Hill         14           380796.05          263286.13
Hill         15           4566952.5         1221478.93
Hill         16          15677830.6         8261333.57
Hill         17           5043656.1         2025689.42
Hill         18          4421496.85        15769593.75


Channels                          Soil             Sediment
and                               Loss              Yield
Impoundments                      (kg)             (tonne)
------------                  -----------       -----------
Channel        1        6058533          365.51
Channel        2      513245.78           20.53
Channel        3      534661.49           21.38
Channel        4       26610370           10.64
Channel        5       728286.5           21.84
Channel        6       423059.6           12.69
Channel        7       81648.21            2.44
```

Fig 4.2 WEPP watershed simulation for representative hill slopes and channels

From figure 4.2 and Table 4.1 it was recoded that the soil loss and sediment yield from 7 channels was observed to be 8.78 t/ha/yr and 0.12 t/ha/yr respectively. From Table 4.1, it was seen that, the average annual soil loss was minimum in channel 7 that is 0.02 t/ha/yr and maximum in channel 4 that is 6.68 t/ha/yr. the average annual sediment yield was minimum in channel 7 that is 0.0006 t/ha/yr and maximum in channel 1 that is 0.09 t/ha/yr.

Table 4.1 WEPP watershed simulation for 7 channels

Sr. No.	Channels Name	Channels soil loss (t/ha/yr)	Channels sediment yield (t/ha/yr)
1.	Channel 1	1.52	0.09
2.	Channel 2	0.13	0.005
3.	Channel 3	0.13	0.005
4.	Channel 4	6.68	0.002
5.	Channel 5	0.18	0.005
6.	Channel 6	0.10	0.003
7.	Channel 7	0.02	0.0006
	Total	**8.78**	**0.12**

Similarly, The WEPP watershed simulation delineated the Karli river catchment in 18 sub-catchments/hills. From Table 4.1, it was seen that, the maximum average annual soil loss and sediment yield was in hill slope 7 that is 24.98 t/ha/yr and 6.10 respectively and the minimum average annual soil loss and sediment yield was in hill slope 4 that is 0.04 t/ha/yr and 0.02 t/ha/yr respectively.

Table 4.2 WEPP watershed simulation for different hill slopes/ sub-catchments

Sr. No.	**Hill slopes**	**Hill slopes Soil Loss (t/ha/yr)**	**Hill slopes Sediment yield (t/ha/yr)**
1.	Hill 1	0.28	0.12
2.	Hill 2	0.91	0.26
3.	Hill 3	0.44	0.25
4.	Hill 4	0.04	0.02
5.	Hill 5	0.19	0.08
6.	Hill 6	2.19	0.70
7.	Hill 7	24.98	6.10
8.	Hill 8	1.91	0.92
9.	Hill 9	0.006	0.003
10.	Hill 10	0.28	0.20
11.	Hill 11	1.56	1.20
12.	Hill 12	2.25	0.78
13.	Hill 13	0.31	0.24
14.	Hill 14	0.09	0.07
15.	Hill 15	1.15	0.31
16.	Hill 16	3.94	2.08
17.	Hill 17	1.27	0.50
18.	Hill 18	1.11	3.96
	Total	**42.89**	**17.80**

The GeoWEPP model run for Karli river catchment with contributing total area to outlet was 3978.75 ha. The Average Annual total hill slopes and channels soil loss was 42.89 t/ha/yr and 8.78 t/ha/yr respectively. Average Annual total channel soil loss and sediment discharge from outlet was 34949.80 t/yr and 18472.4 t/yr respectively for watershed. The WEPP model also calculate the sediment yield of Karli river catchment was 17.92 t/ha/yr. WEPP model computed average annual soil loss from Karli river Catchment was 51.67 t/ha/yr with having the sediment delivery ratio of 0.270. The soil loss and sediment yield for Karli river catchment by using WEPP Model as shown in fig 4.3.

Average Annual Delivery From Channel Outlet:

Total contributing area to outlet	=	3978.75	ha
Avg. Ann. total hillslope soil loss	=	170650069.6	tonnes/yr
Avg. Ann. total channel soil loss	=	34949.80	tonnes/yr
Avg. Ann. sediment discharge from outlet	=	18472.4	tonnes/yr
Avg. Ann. Soil loss from watershed	=	51.67	T/ha/yr
Avg. Ann. Sediment yield from watershed	=	17.92	T/ha/yr
Sediment Delivery Ratio for Watershed	=	0.270	

Sediment Particle Information Leaving Channel:

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	50.0	0.085
2	0.010	2.65	0.0	100.0	0.0	0.0	0.510
3	0.030	1.80	0.0	77.8	22.2	11.1	0.386
4	0.300	1.60	75.3	13.4	11.4	5.7	0.011
5	0.200	2.65	100.0	0.0	0.0	0.0	0.007

Distribution of Primary Particles and Organic Matter in the Eroded Sediment:

type	fraction
clay	0.172
silt	0.812
sand	0.016
organic matter	0.086

Index of specific surface = 84.51 m**2/g of total sediment
Enrichment ratio of specific surface = 1.71

Fig 4.3 Soil Loss and Sediment Yield for Karli River Catchment by using Water Erosion Prediction Project Model

4.4 Average Annual Soil Loss using Water Erosion Prediction Project Model

The average annual soil loss and soil erosion rates (t/ha/yr) were estimated for Karli river catchment by GeoWEPP model. Soil, climate, management and slope files were generated in GeoWEPP and were used as input in the WEPP model, which gave average annual soil loss and soil erosion rates of the study area. The WEPP model computed soil loss for 7 major channels and 18 sub-catchments/hills of Karli river catchment. The average annual soil loss from 7 major channels and 18 sub-catchments/hills was 8.78 t/ha/yr were and 42.89 t/ha/yr respectively. The average annual soil loss from study area was 51.67 t/ha/yr and average annual sediment yield was 17.92 t/ha/yr. The average annual soil loss map has been prepared and is shown in fig 4.4.

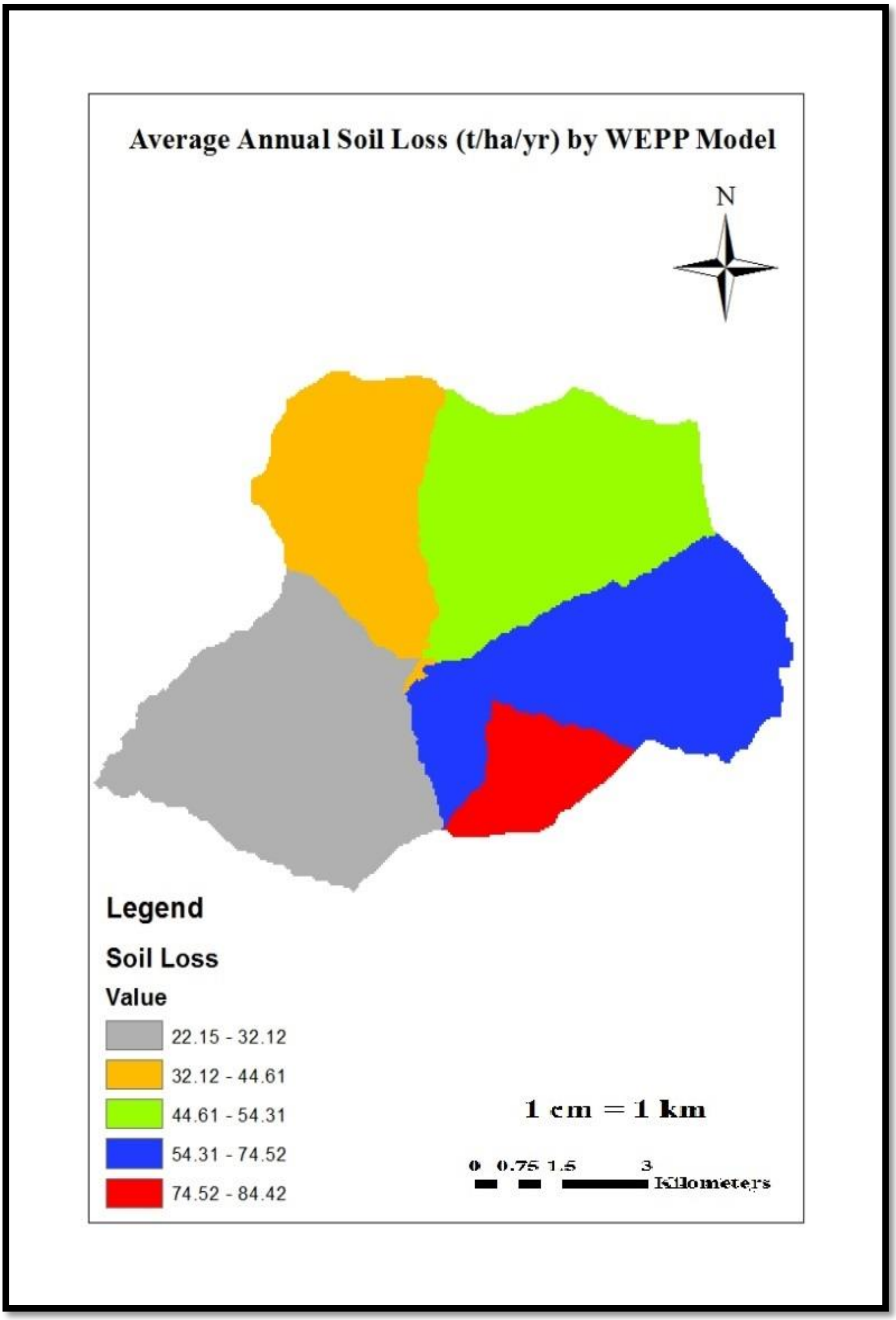


Fig 4.4 Average annual Soil Loss map of Karli River Catchment by Water Erosion Prediction Project Model

4.5 Universal Soil Loss Equation (USLE) parameters

The desired parameters of USLE model for Karli river catchment were calculated as follows.

4.5.1 Rainfall erosivity (R) factor

In the present study, for determination of R factor, the 24 years data of Wakawali station (1990-2013) has been used for Karli river catchment, Tal–Kudal, Dist-Sindhudurg. The annual rainfall of Dukanwadi station showed significant variation from year to year. During the period of analysis (1990-2013), annual rainfall varied from 2717.22 to 4815.77 mm. The average annual rainfall of Dukanwadi station was 3488.70 mm. similar values of annual erosivity ranges from 5065.3 to 10333.08 MJ-mm/ha-hr-yr. The average annual erosivity obtained for Dukanwadi station was 6635.65 MJ-mm/ha-hr-yr. The average annual erosivity values for Dukanwadi station were shown in Table 4.3. The average annual erosivity value for Karli River catchment was used to prepare R-map of study area as shown in (Fig. 4.5).

Table 4.3 Annual Erosivity factor (R) value for Dukanwadi Station (Sindhudurg)

Year	**Annual Erosivity (MJ-mm/ha-hr-yr)**	**Year**	**Annual Erosivity (MJ-mm/ha-hr-yr)**
1990	7245.35	2002	5856.14
1991	8829.66	2003	3485.95
1992	5453.95	2004	5190.54
1993	7133.55	2005	6159.85
1994	7746.75	2006	8072.40
1995	6509.76	2007	6704.42
1996	5938.08	2008	5065.03
1997	7415.75	2009	5882.08
1998	6500.74	2010	4440.81
1999	5473.92	2011	9013.97
2000	8548.95	2012	7390.26
2001	4864.66	2013	10333.08
Average Annual erosivity was 6635.65 MJ-mm/ha-hr-yr			

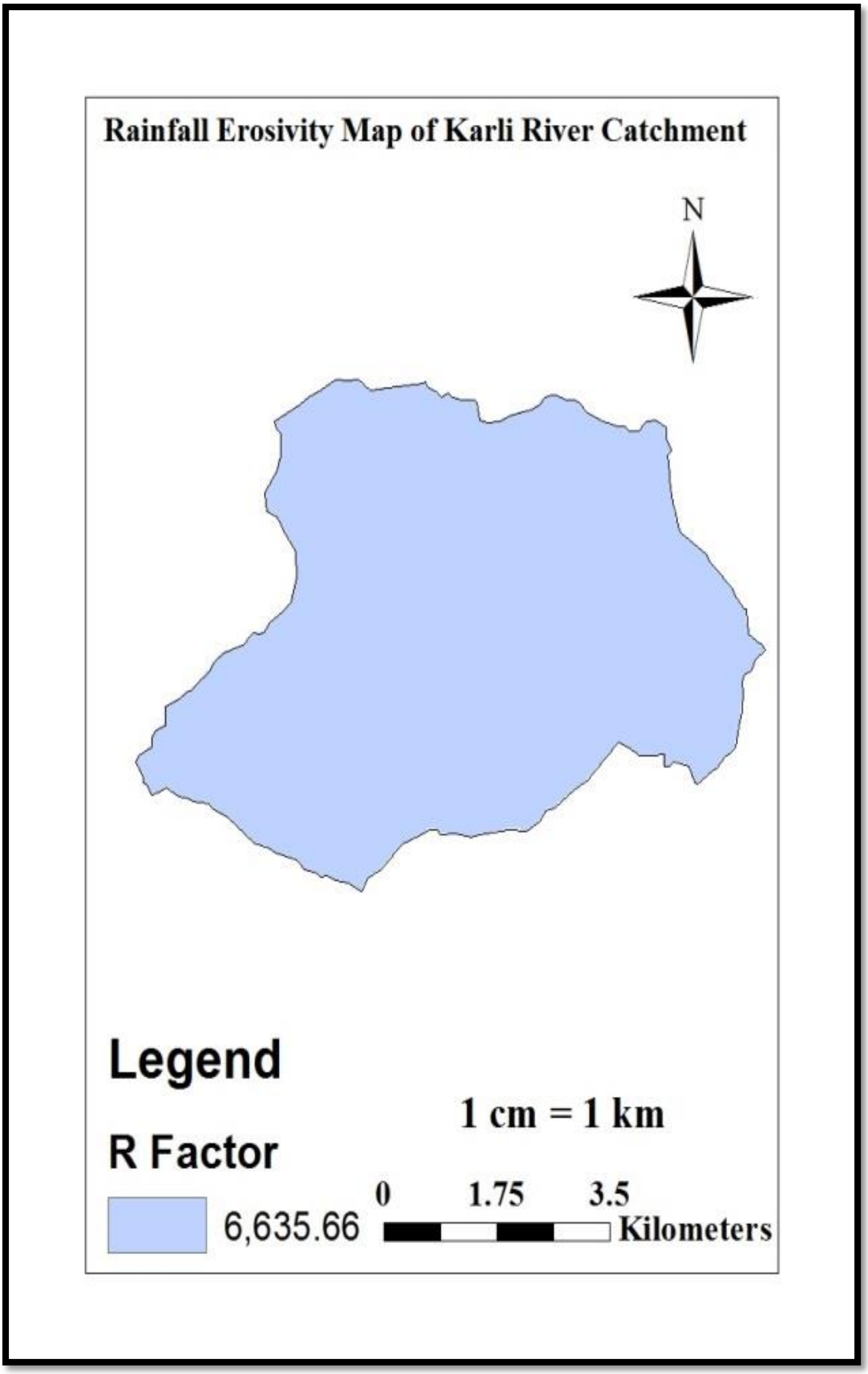


Fig 4.5 Rainfall erosivity map of Karli River Catchment

4.5.2 Soil Erodibility (K) Factor

The parameters like texture, structure, organic matter content and physic-chemical properties were very significant in determining soil erodibility. Soil erodibility factor were calculated for 6 villages of Kudal Taluka, Sindhudurg district, where the data of sand, silt, clay and organic carbon were available (Thawakar, 2014). Estimated per cent distribution of sand in soils of Kudal Taluka was found to vary from 37.94 to 42.48 % with a mean value of 40.21 %. Kudal Taluka soils have silt content in the range of 18.72 to 21.98 % with the mean value of 20.35 % and clay content varied from 20.59 to 23.74 % with the mean value of 22.16 %. In general, textural classes for Kudal Taluka were found to be in the category of sandy clay loam type. In Kudal Taluka, Organic Carbon (OC) was found to be in the range of 1.51 to 3.04 per cent with the mean value of 2.27 per cent. Organic Matter (OM) content in soil of Kudal Taluka varied from 2.6 to 5.2 per cent with the mean value of 3.9 per cent. Hydraulic Conductivity (HC) of soil was determined by using the SPAW model. Hydraulic conductivity of soil for Kudal Taluka is varied from 2.89 to 16.02 cm/hr as shown in Table 4.4. The permeability of soils of 6 villages Kudal Taluka, Sindhudurg district, was obtained from hydraulic conductivity of soil. The permeability class have moderate to rapid class accordingly permeability codes were assigned as 2. Soil erodibility factor for different villages of Kudal Taluka were found in the range of 0.040 to 0.041 t-ha-hr/ha-MJ-mm. Accordingly, K factor map Karli river catchment was prepared as shown in (Fig. 4.6).

Table 4.4 Physico-chemical properties and hydraulic conductivity of soils in Kudal Taluka (Sindhudurg)

Sr. No.	Villages	% Sand	% Silt	% Clay	% OC	OM	HC
1	Naiknagar	40.61	20.88	21.10	1.66	2.9	12.57
2	Pawashi	41.10	20.26	21.02	1.76	3.0	10.89
3	Oros Khurd	37.94	21.98	23.51	3.04	5.2	2.89
4	Aanav	42.48	18.72	20.59	1.98	3.4	8.22
5	Pinguli	40.26	18.74	23.74	1.51	2.6	16.02
6	Shivapur	40.48	20.11	21.99	1.99	3.4	10.11

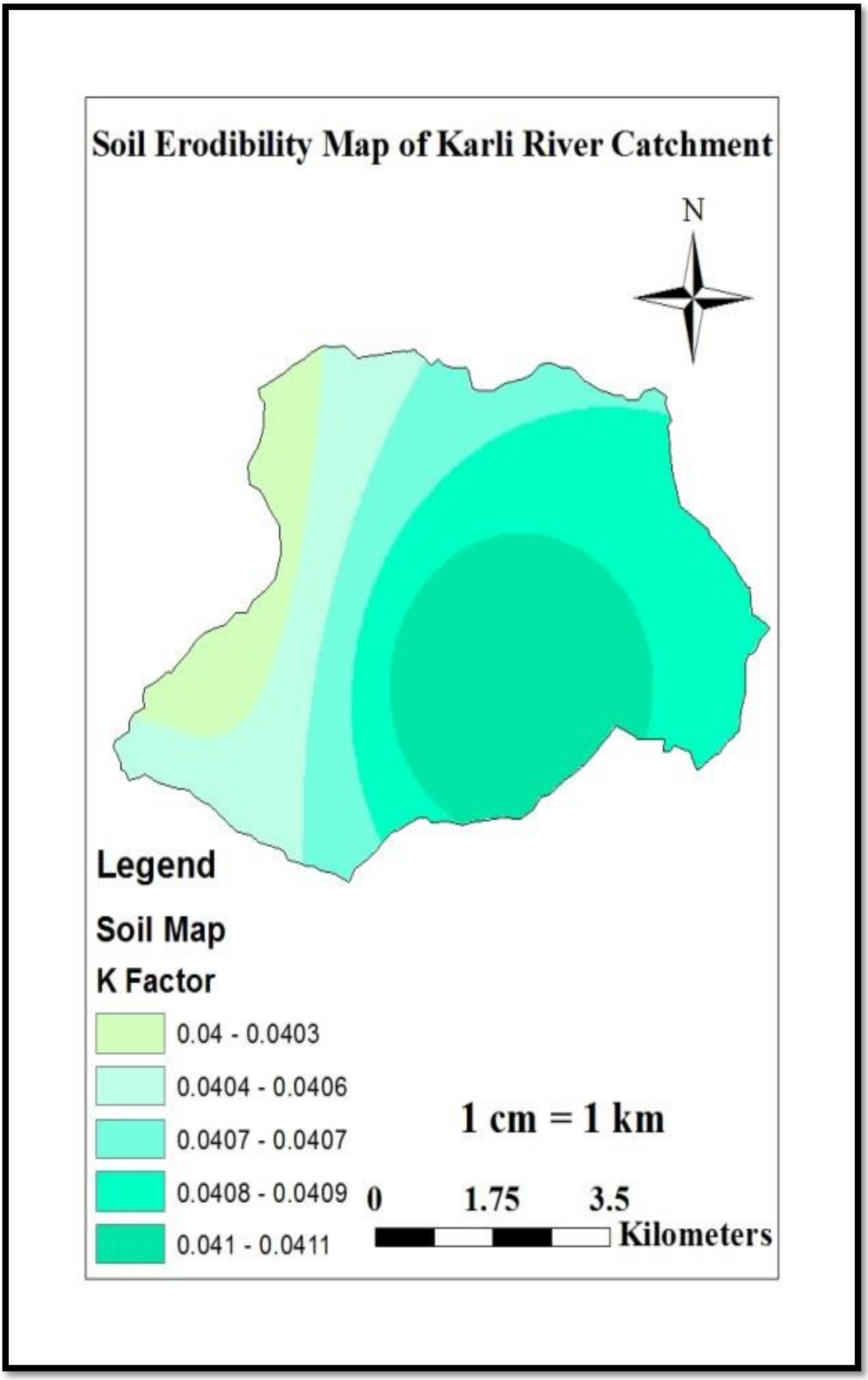


Fig.4.6 Soil erodibility map of Karli River Catchment

4.5.3 Topographic Factor (LS)

The Digital Elevation Model (DEM) for determining the topographic factor (LS) of the study area was prepared using CartoDEM data. A slope map was created from the DEM based on the slope map, slope length (L) and slope gradient (S) maps and finally a layer of LS factor was generated. The values of LS factor for study area was found in the range of 1.81 to 4.53. LS factor map of Karli river catchment were prepared as shown in (Fig.4.7). While deriving topographic factors, GIS techniques tend to predict very long slope lengths on steep to very gentle slopes, which can lead to overestimation of soil loss. The majority portion of Karli River catchment on downstream side having gentle slope length and slopes were also dissected by good stream network. Major portion of Karli River catchment was covered by LS factor ranging between 2 to 3 (48.12%), followed by 3 to 4 (37.61%) and more than 4 (10.56 %). Very small portion of the study area was covered by LS factor 1 to 2 (4.25%) as shown in Table 4.5.

Table 4.5 Spatial coverage of topographic factor

Sr. No.	LS factor range	Area (ha)	Area (%)
1.	1-2	265.44	6.25
2.	2-3	2043.71	48.12
3.	3-4	1512.40	35.61
4.	>4	448.49	10.56

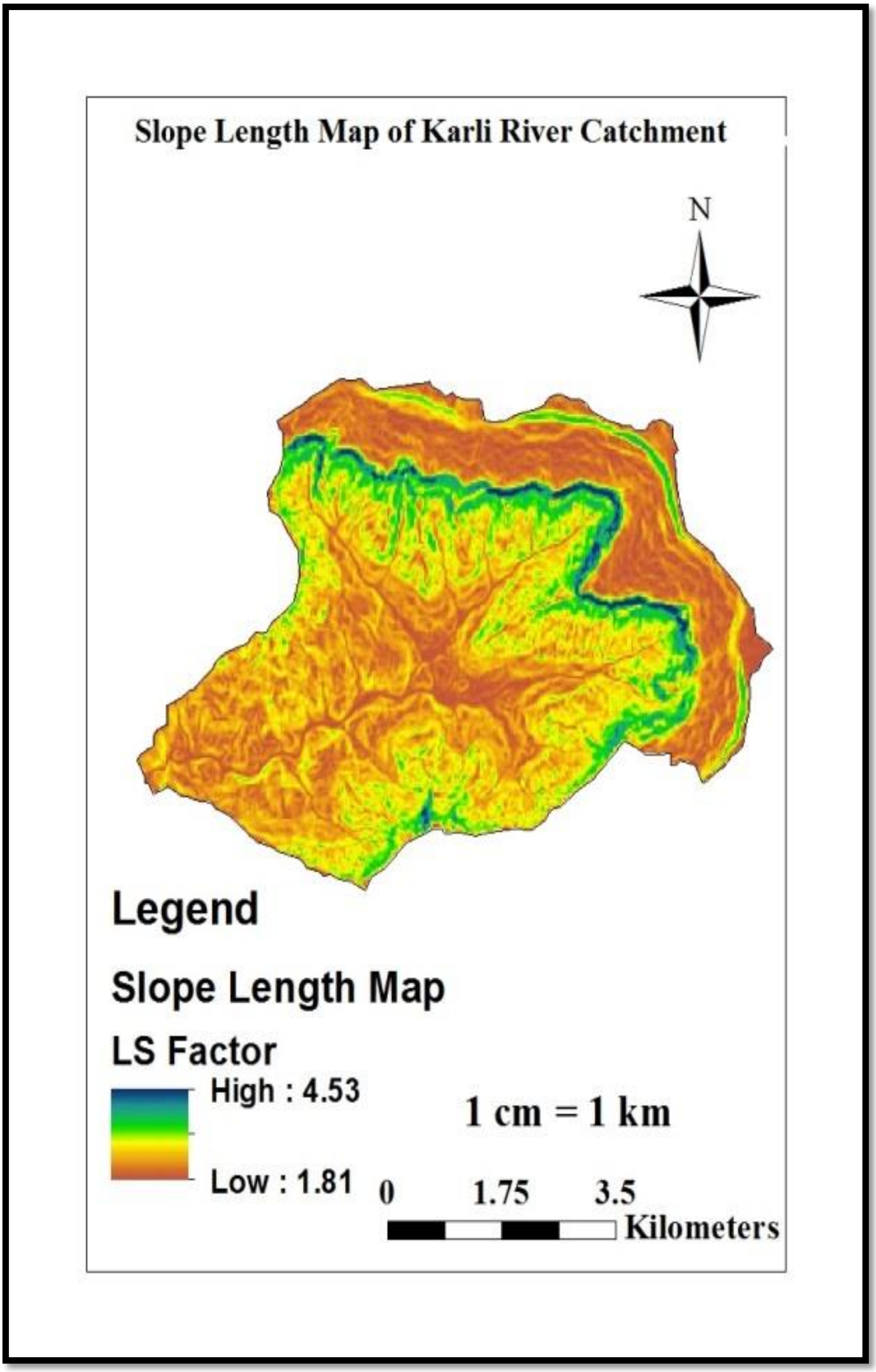


Fig.4.7 Slope length (LS) map of Karli river catchment

4.5.4 Crop Management Factor (C)

Remote Sensing and Geographical Information System techniques have a potential to generate a thematic layer of land use land cover of a region. Information on land use permits a better understanding of the land utilization aspects of cropping pattern, forest, permanent pastures, open shrub and urban area which were vital for development planning and erosion studies. Classification was carried out for five land use classes: forest, agricultural land, water body, barren land and urban area. Land use/land cover map of Karli river catchment was generated using LANDSAT imageries using supervised classification. Crop management factor (C) values for Karli River catchment ranged from 0.024 to 0.12. C factor for different land cover class were shown in Table 4.6. C factor map of Karli river catchment was prepared as shown in (Fig 4.8).

Table 4.7 Crop Management Factor for different Land use/Land cover classification

Sr. No.	Land use/Land cover	Area (ha)	C Value
1.	Water bodies	34.26	0
2.	Build up	152.62	0.024
3.	Agricultural	865.64	0.12
4.	Barren	650.58	0.034
5.	Forest	2544.02	0.04
	Total	**4247.12**	

4.5.5 Conservation Practice Factor (P)

The value of P factor was considered as 1 for of Karli river catchment as it was untreated. With P value as 1, P map as shown in Fig.4.9 was prepared and used in USLE for calculating soil loss.

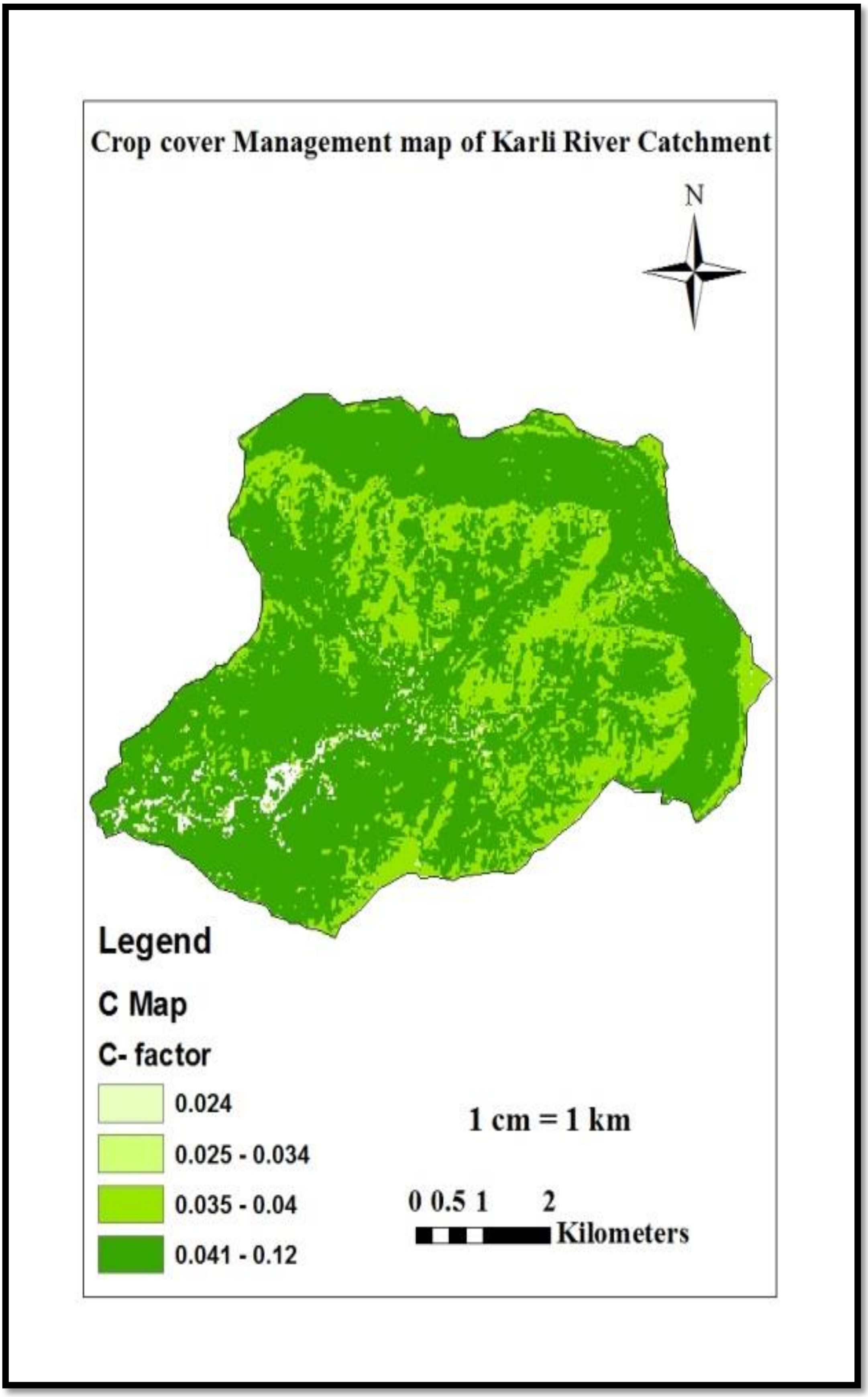


Fig.4.8 Crop cover management map of Karli river catchment

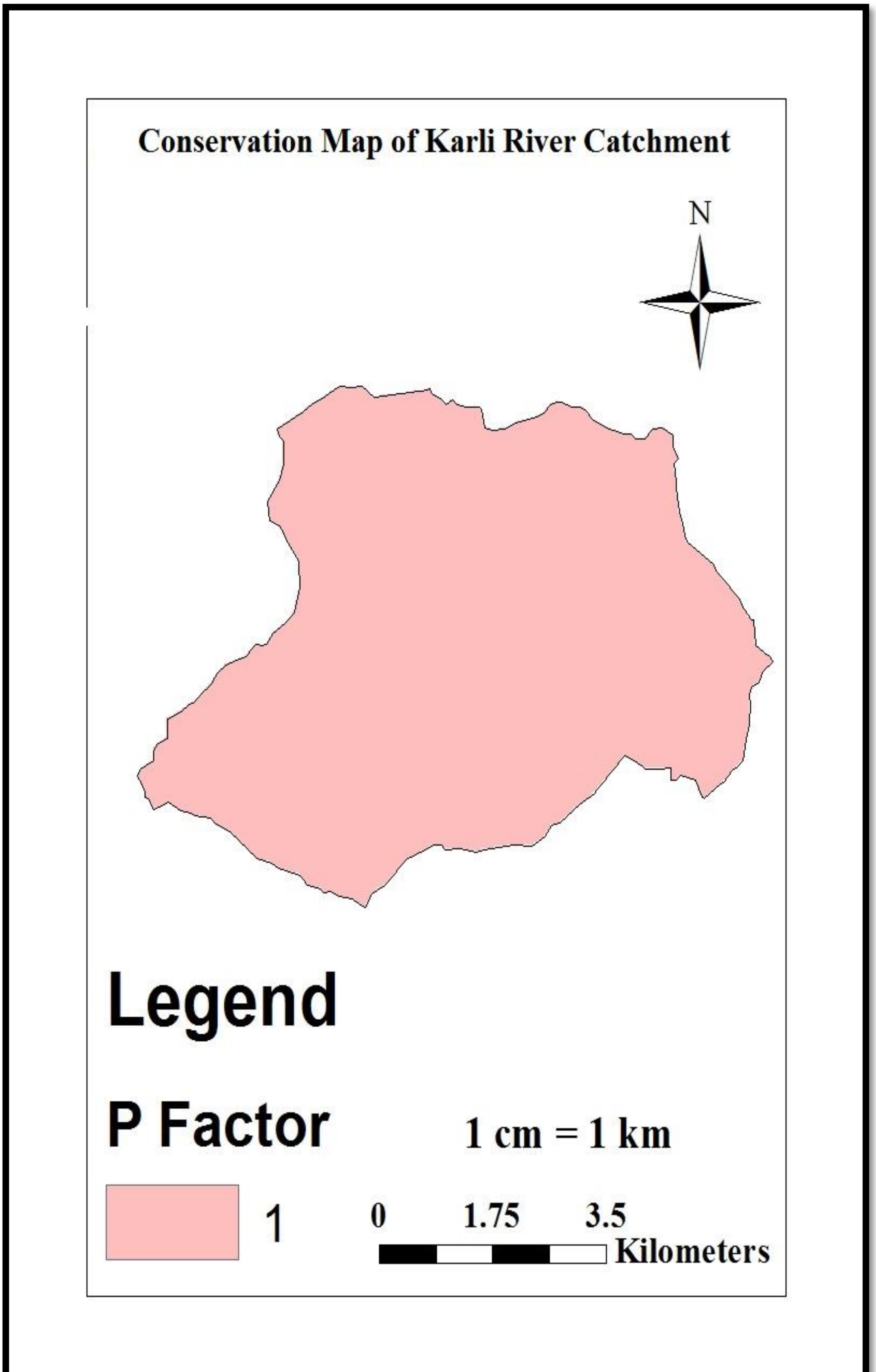


Fig.4.9 Conservation Practice factor map of Karli river catchment

4.6 Average Annual Soil Loss using USLE

The annual soil loss for the Karli river catchment was calculated by annual average R (based on annual average rainfall data of 1990-2013) and K, LS, C and P factors. The soil erosion rates (t/ha/yr) were estimated for Karli river catchment. All the layers viz. R, K, LS, C and P were generated in GIS and were overlaid to obtain the product, which gave annual soil loss of the Karli river catchment. Average annual soil loss from study area was 42.66 t/ha/yr. Area under different classes of soil erosion in India was shown in Table 4.7.

Table 4.7 Area under different classes of soil erosion in India

Class	Soil loss (t/ha/yr)
Slight	<5
Moderate	5-10
Moderately severe	10-20
Severe	20-40
Very severe	40-80
Extremely severe	>80

(Singh *et al.*, 1992)

Area under slight erosion class was found to be 88.91 ha, moderate erosion class was 692.22 ha, moderately severe erosion class was 436.17 ha, severe erosion class was 1076.82 ha, very severe erosion class was 1010.25 ha and under extremely severe erosion class the area was 942.75 ha. Highest per cent of area before recommendation of soil and water conservation measures was found under the severe soil erosion class of (25.35 %), followed by very severe (23.78 %), extremely severe (22.19 %), moderately severe (11.21 %), moderate (16.29 %) and slight (2.09 %) .

It showed that more than 71 per cent of area comes under severe to extremely severe erosion class which was cause of concern. Average annual soil loss from study area was 42.66 t/ha/yr as shown in Table 4.8 and in (Fig. 4.10). These prove the need of soil and water conservation measures in the watershed for the sustainable management of natural resources.

Table 4.8 Area under different classes of soil erosion before conservation measures for Karli river catchment

Soil erosion class	Soil loss (t/ha/yr)	Area (ha)	Per cent area
Slight	0-5	88.91	2.09
Moderate	5-10	692.22	16.29
Moderately severe	10-20	436.17	11.21
Severe	20-40	1076.82	25.35
Very severe	40-80	1010.25	23.78
Extremely severe	>80	942.75	22.19

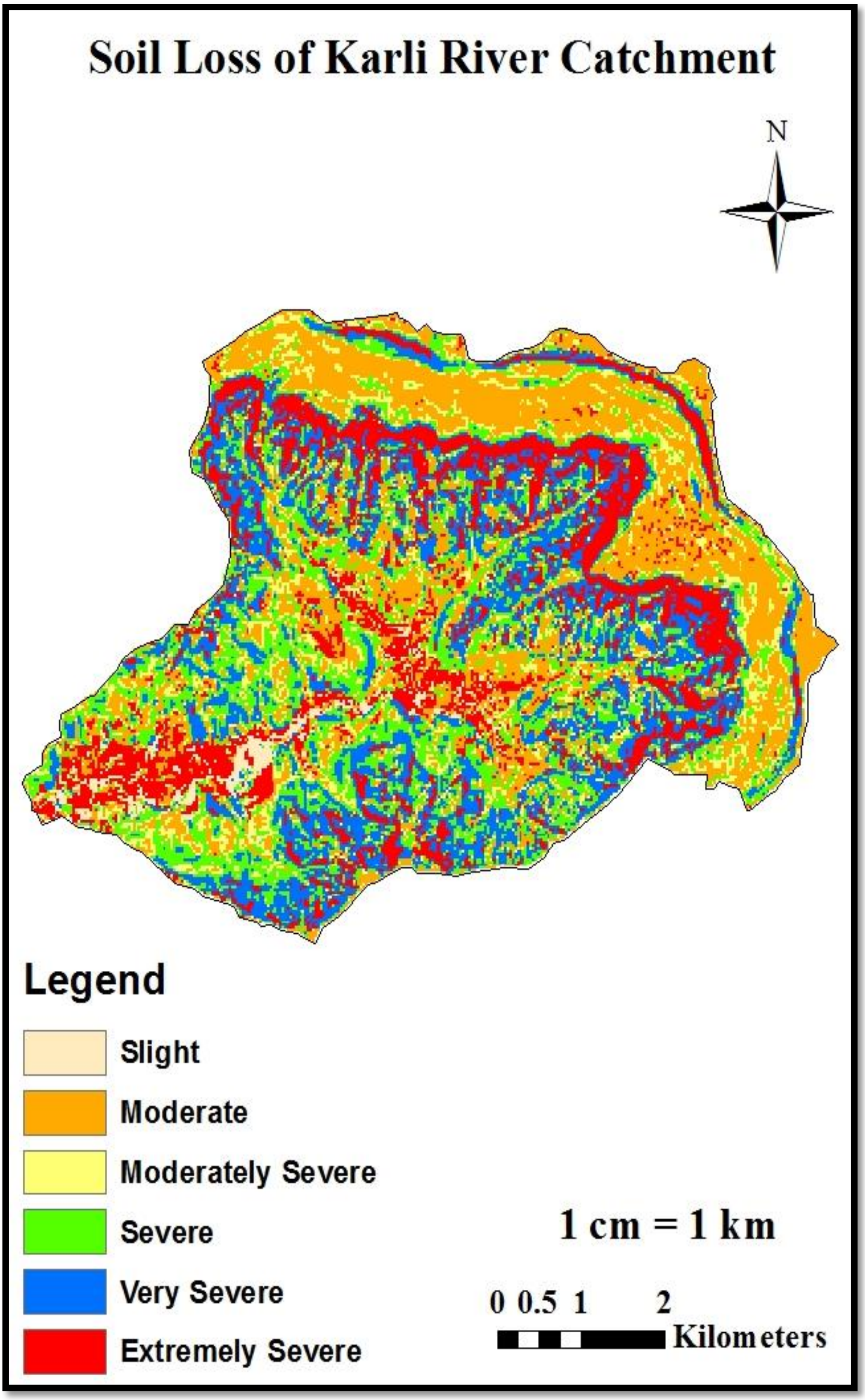


Fig.4.10 Soil Loss map of Karli River Catchment

4.7 Comparative Performance of WEPP and USLE model

The Comparative Performance of Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE) model were based on the soil loss, sediment yield, different input file, Data required and preprocessing of data, Time Consumption and mode of operation, and various outcomes.

4.7.1 According to soil loss

1. The predicted soil loss by using Water Erosion Prediction Project (WEPP) model was 51.67 t/ha/yr.
2. The predicted soil loss by using Universal Soil Loss Equation (USLE) model was 42.66 t/ha/yr.
3. The Water Erosion Prediction Project (WEPP) model predicted 9.01 t/ha/yr more soil loss than the Universal Soil Loss Equation (USLE) model.

4.7.2 According to sediment yield

1. The predicted sediment yield by using Water Erosion Prediction Project (WEPP) model was 17.92 t/ha/yr.
2. The predicted sediment yield by Water Resources Department, Hydrology Project observed data was 8.12 t/ha/yr.
3. The Water Erosion Prediction Project (WEPP) model predicted 9.80 t/ha/yr more sediment yield than the government observed data.

4.7.3 According to different Input files

1. The Water Erosion Prediction Project (WEPP) model required only four input file such as Slope, Climate, Soil and Management input file.
2. The Universal Soil Loss Equation (USLE) model required five input file such as Rainfall erosivity, Soil erodibility, Slope length, Crop management, and Conservation practice factors are overlaid with each other.
3. The Water Erosion Prediction Project (WEPP) model required less input file than the Universal Soil Loss Equation (USLE) model.

4.7.4 According to data required and pre-processing of data

1. The Water Erosion Prediction Project (WEPP) model required Digital Elevation Model (DEM), Rainfall data, detailed Soil Data and preprocessed Land Use/Land Cover (LULC) data.
2. The Universal Soil Loss Equation (USLE) model required preprocessed Digital Elevation Model (DEM), preprocessed Rainfall erosivity factor,

preprocessed Soil erodibility factor, and preprocessed Land Use/Land Cover (LULC) factor with all crop data of study area.

3. The Water Erosion Prediction Project (WEPP) model required less data with only LU/LC preprocessed file but in the Universal Soil Loss Equation (USLE) model required crop data and all files are should be preprocessed.

4.7.5 According to time consumption and mode of operation

1. The Water Erosion Prediction Project (WEPP) model required less data and less input which taken the less time to run the model.
2. The Water Erosion Prediction Project (WEPP) model was ease to understand and operate.
3. The Universal Soil Loss Equation (USLE) model was very time consuming model, it take the more time to collect and preprocessing the data.
4. The Universal Soil Loss Equation (USLE) model was also ease to understand and but not ease to operate or preprocess and for data collection.
5. The Water Erosion Prediction Project (WEPP) model required less time and easy to operate and understand than the Universal Soil Loss Equation (USLE) model.

4.7.6 According to different various outcomes

1. The Water Erosion Prediction Project (WEPP) model mainly calculates the soil loss, Sediment yield, Runoff, and Sediment delivery ratio.
2. The Universal Soil Loss Equation (USLE) model only computes the soil loss.
3. The Water Erosion Prediction Project (WEPP) model has more number of outcomes than the Universal Soil Loss Equation (USLE) model.

Along with the prediction of the soil loss by using WEPP model and its comparison with USLE model the sediment yield predicted by WEPP and observed data by Government department was also considered and for the purpose, According to the observed data, the average annual sediment yield was 8.12 t/ha/yr whereas the predicted sediment yield from the WEPP model was 17.92 t/ha/yr. which is 54.68 % more predicted than the observed data. The sedimentation also 15.71 % and 34.68% of predicted soil loss by WEPP and for the observed sediment yield and predicted sediment yield respectively. The similar statement is made and that is the sediment yield is 30 to 60% of soil erosion loss (Fernandez *et al*., 2003; Vemu *et al*., 2012; Richarde *et al*., 2014).

V. SUMMARY AND CONCLUSIONS

Soil erosion is a complex phenomenon as it is governed by various natural processes, and it, in turn, results in decreasing in soil fertility and reduction in crop yield. In recent decades, models have been built (empirical, conceptual, or physically based) in order to represent and to quantify the processes of detachment, transport, and deposition of eroded soil, with the aim of implementing assessment tools for educational, planning and legislative purposes.

The Universal Soil Loss Equation (USLE) is an erosion model designed to compute long term average annual soil loss on a field scale (A) as the product of six major factors: rainfall erosivity factor (R), soil erodibility factor (K), slope length factor (L), steepness factor (S), cover and management practices factor (C) and conservation practices factor (P). Process based models incorporated in a continuous soil-plant simulation model, such as the current Water Erosion Prediction Project (WEPP) model, are, in principle, applicable to even finer temporal scales, since such models simulate erosion using time-steps of seconds. This temporal resolution is large enough to simulate the variations in soil conditions, plant development and Surface cover that may affect erosion rates are updated between each event.

The Remote Sensing and Geographical Information System techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. Therefore, present study was undertaken to access the soil erosion. The present research work was conducted at Karli river catchment, Taluka- Kudal, District – Sindhudurg, Maharashtra. Study area is located between the longitude 73.92^0 to 74.01^0 E and latitudes 16.04^0 to 16.10^0 N on the western coast of India in the southern part of Maharashtra state. The total geographical area of study location is 4247.12 ha. The area under study receives average annual rainfall of about 3,287 mm.

The average annual soil loss and soil erosion rates (t/ha/yr) were estimated for Karli river catchment by GeoWEPP model. Soil, climate, management and slope files were generated in GeoWEPP and were used as input in the WEPP model, which gave average annual soil loss and soil erosion rates of the study area. The WEPP model computed soil loss for 7 channels and 18 hill slopes of Karli river catchment. The GeoWEPP model run for Karli river catchment with contributing total area to outlet was 3978.75 ha. The Average Annual total hill slopes and channels soil loss was

42.89 t/ha/yr and 8.78 t/ha/yr respectively. The WEPP model also calculate the sediment yield of Karli river catchment was 17.92 t/ha/yr. The Water Erosion Prediction Project (WEPP) model predicted the 9.01 t/ha/yr more soil loss than the Universal Soil Loss Equation (USLE) model. It also overestimates the sediment yield than the government data by 9.80 t/ha/yr.

Universal Soil Loss Equation (USLE) was used for estimation of soil loss from the watershed. The parameters of these models were determined by using Remote Sensing data and Geographical Information System tools. R factor values were calculated using relationship between the daily rainfall and erosivity index of Wakawali region by developing regression equation. The average annual erosivity obtained for Dukanwadi station was 6635.65 MJ-mm/ha-hr-yr. Soil erodibility factor values were estimated using sand (%), silt (%), clay (%), organic matter content (%), structural code and permeability code of each village. Weighted soil erodibility factor for Karli river catchment was ranging between 0.040 to 0.041 t-ha-hr/ha-MJ-mm.

The value of LS factor for Karli river catchment was found in the range of 1.81 to 4.53. The crop management factor associated with erosion losses is site specific. Detailed information on land use land cover was obtained by LANDSAT imageries and field survey. Crop management factor (C) values of Karli river catchment were ranging from 0.024 to 0.12. Considering support conservation practice factor value as 1, soil loss was estimated for Karli river catchment and its micro watersheds using USLE.

The soil loss of Karli river catchment was determined by using WEPP and USLE model. It was found that the predicted soil loss from the WEPP model was 51.67 t/ha/yr. Also, the predicted result of soil loss from the USLE model was found to be 42.66 t/ha/yr.

Along with the prediction of the soil loss by using WEPP model and its comparison with USLE model the sediment yield predicted by WEPP and observed data by Government department was also considered and for the purpose, The sediment data of Dukanwadi station from 2001-2010 was collected from Hydrology Project, Water Resource Department, Government of Maharashtra (India). According to the observed data, the average annual sediment yield was 8.12 t/ha/yr whereas the predicted sediment yield from the WEPP model was 17.92 t/ha/yr. which is 120 % more predicted than the observed data. The sedimentation also 15.71 % and 34.68% of predicted soil loss by WEPP and for the observed sediment yield and predicted sediment yield respectively. The similar statement is made and that is the sediment yield is 30 to 60% of soil erosion loss (Fernandez *et al*., 2003; Vemu *et al*., 2012; Richarde *et al*., 2014). According to comparative performance of Water Erosion Prediction Project (WEPP) model overestimates the soil loss value and sediment yield value than the Universal Soil Loss Equation (USLE) model and Government data respectively. WEPP model was best suitable model for Karli river catchment due to its less input files, less time consumption, ease to operate and understand, and less data requirement with minimum pre-processed data.

CONCLUSIONS:

The salient conclusions drawn from the present study are as follows:

1. Estimated soil loss and sediment yield from Karli river catchment using Water Erosion Prediction Project (WEPP) model was 51.67 t/ha/yr and 17.92 t/ha/yr respectively.
2. Estimated soil loss from Karli river catchment using Universal Soil Loss Equation (USLE) model was 42.66 t/ha/yr.
3. According to comparative performance Water Erosion Prediction Project (WEPP) model overestimates 9.01 t/ha/yr soil loss value and 9.80 t/ha/yr sediment yield value than the Universal Soil Loss Equation (USLE) model and Government data respectively.
4. WEPP model was suitable model for Karli river catchment due to its less input files, less time consumption, ease to operate and understand, and less data requirement with minimum pre-processed data.

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VII. APPENDICES

APPENDIX I

1. Average annual rainfall (mm) for Dukanwadi Station

Year	Annual Rainfall (mm)	Year	Annual Rainfall (mm)
1990	3808.38	2002	3187.24
1991	3999.01	2003	2281.48
1992	2717.22	2004	3006.20
1993	3851.25	2005	3240.80
1994	3912.99	2006	4025.14
1995	3503.62	2007	3369.71
1996	3262.62	2008	2987.57
1997	3831.72	2009	3111.82
1998	3621.26	2010	2869.25
1999	3195.96	2011	4389.70
2000	4105.39	2012	3707.30
2001	2927.28	2013	4815.77

APPENDIX II

2. Textural, Structural and Permeability classes and codes of soils of Kudal Taluka

.	Villages	Tehsil	Textural class	Structure class	Structure code	Permeability class	Perm
	Naiknagar	Kudal	Sandy clay loam	Moderate	3	Moderate to rapid	
	Pawashi		Sandy clay loam	Moderate	3	Moderate to rapid	
	Oros Khurd		Sandy clay loam	Moderate	3	Moderate to rapid	
	Aanav		Sandy clay loam	Moderate	3	Moderate to rapid	
	Pinguli		Sandy clay loam	Moderate	3	Moderate to rapid	
	Shivapur		Sandy clay loam	Moderate	3	Moderate to rapid	

APPENIDIX III

3. Crop management factor of Karli river catchment

$$Weighted\ C = \frac{C_1 A_1 + C_2 A_2 + C_3 A_3}{A_1 + A_2 + A_3}$$

$$Weighted\ C = \frac{0.15 * 462.77 + 0.10 * 392.31 + 0.28 * 10.56}{462.77 + 392.31 + 10.56}$$

$$Weighted\ C = 0.12$$

LU/LC class	Area(ha)	C value	Weighted C value
Rice, Nagli, Varali, Pulses	462.77	0.15	0.12
Horticultural crops	392.31	0.1	
Oil seeds	10.56	0.28	