ESTIMATION OF SOIL EROSION BY GIS & REMOTE SENSING

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Abstract

Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. To estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. In this study use of Geographical Information system and Universal soil loss equation is applied to estimate the annual soil loss for kulhan watershed of Shivnath basin, sub basin of Mahanadi basin, Chhattisgarh. The objective of this study is to evaluate the application of Geographical Information system and Universal soil loss equation to determine soil loss and to predict the amount of soil loss from the Kulhan watershed by using ArcGIS and Universal soil loss equation. ArcGIS software is used to derive land use, land cover and topographical data for the watershed and to carry out geographical data analysis. It is used to store the USLE factors as individual digital layers and multiplied together to create a soil erosion map. The USLE model required annual rainfall data, digital elevation models (DEM), land use classification map, and soil series map for extracting five parameters needed that are rainfall erosivity (R) factor, length-slope (LS) factor, soil erodibility (K) factor, vegetation cover (C) factor and erosion control (P) factor. The rainfall erosivity factor determine from annual rainfall data of study area. The soil survey data is used to develop the soil erodibility factor and Digital Elevation Model of study area is used to generate topographic factor (LS).The values of cover management factor and support practice factor were obtained from land use land cover map. All the thematic maps are analysed in the Raster calculator of spatial analyst tool of Arc map. The soil erosion in each cell is calculated using the universal soil loss equation by carefully determining its various parameters and classifying the watershed into different levels of soil erosion severity. Kulhan watershed is classified according to Indian condition as suggested by singh et al. in to different erosion classes such as (>5) slight, (5-10) moderate, (10-20) high, (20-40) very high, (40 80) severe and (>80) very severe.

Keywords: *ArcGIS, Soil erosion, USLE equation*

1. Introduction

Soil is precious gift of nature to the mankind. Shifting cultivation on the hill slopes, non-adoption of soil conservation techniques and over exploitation of land for crop production due to population stress, leads to enormous soil erosion

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard of modern time in worldwide. It is one of the most serious problems as it removes soil rich nutrients and increases natural level of sedimentation in rivers and reservoirs reducing their storage capacity as well as life and about 5334 m tonne of soil is being detached annually due to various reasons in India. Sheet erosion is the most serious of India's soil erosion problems. Soil erosion has been recognized as a hazard of significant concern, yet the number of studies on this problem is very limited in India. A proper assessment of the erosion problem is greatly dependent on its spatial, economic, environmental and agricultural context. A good soil loss management is therefore, needed to reduce land degradation and low water quality due to siltation and sedimentation.

Soil erosion modelling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Various parametric models such as empirical (statistical), conceptual (semi-empirical) and physical process based (deterministic) models are available to compute soil loss. Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. They are designed for specific set of conditions of particular area.

Universal soil loss equation is most widely used model. The Universal Soil Loss Equation (USLE) was developed by the United States Agricultural Research Service. The Universal Soil Loss Equation (USLE) was designed to predict soil loss from sheet and rill erosion in specific conditions from agriculture fields. USLE estimates soil loss based on the product of erosivity of rainfall (R), erodibility of the soil (K), slope length in metres (L), slope in per cent (S), cover management parameter (C), and support practice parameter (P).

The study area Kulhan watershed is located in Raipur district, Chhattisgarh and Chhattisgarh state is known as the "rice bowl" of India and main crop for study area is rice. In kulhan watershed 75% of area occupies agricultural land. The tillage of agricultural lands, which breaks up soil into finer particles, is one of the primary factors. Due to mechanized agricultural equipment that allows for deep plowing, this severely increases the amount of soil that is available for transport by water erosion. The present study aims to determine spatial distribution of soil loss and to analyze the effect of land use, slope exposition and terrace farming on soil erosion.

Soil erosion hazard mapping was carried out by using GIS base modelling approach in conjunction with satellite remote sensing derived parameters. There have been fewer attempts as such to estimate the total volume of soil loss that is occurring in a given area. Based on the above problem discussed, objectives of the present study are pointed in the following section.

2. METHODOLOGY

Study Area

The study area considered is KULHAN watershed of Kharun river basin, sub basin of Shivnath basin, Chhattisgarh state. The Kulhan watershed located in the right bank of Shivnath river basin (Sub Basin of Mahanadi Basin) Chhattisgarh with a location of 21^{0}34’20” 21^{0}24’0.5”N and 81^{0}38’32.81” 81^{0}55’43.82”E as shown in figure 3-1.Watershed covers four blocks such as Raipur, Abhanpur, Arang & Tandula.The Kulhan watershed comprises about 935Km2 in size consist of various topographic features. The topography is undulating with elevation of 251m to 336m above mean sea level. The study area is characterised by a gentle undulating & flat terrain. Maximum slope in percentage in study area is 10.49%.The total Geographical area of Kulhan watershed is 934 Km2 out of which agriculture occupies 723.33 Km2, which is about 77.44% of total area. 4% area occupies by water bodies, 8% by wasteland, 10% by built up area and 0.014% by tree-clad area. Rice is the main crop of study area. Production of rice is highest in Raipur District considering area. Rice, maize, soybeans are important kharip crops. Among Ravi crops gram, wheat & linseed are the main crops. The average rainfall in the study is 1219 mm. In study area context the classification and distribution of soil is adopted as per the soil orders in US soil taxonomy and there Indian equivalents. Out of 12 orders in US soil taxonomy only four orders are viz. Vertisol, Ultisols; Inceptisols & Alfisol are found in Chhattisgarh. The KULHAN WATERSHED (According to national Bureau of soil survey and land use planning) has a watershed code of 4G3B4. Location map is shown in figure 2-1.

Where

4: River flowing into Bay of Bengal.

G: Code of Mahanadi Basin.

3: Code of Shivnath Catchment.

B: Right bank of Shivnath up to confluence with Amner sub catchment.

Name of watershed: KULHAN.

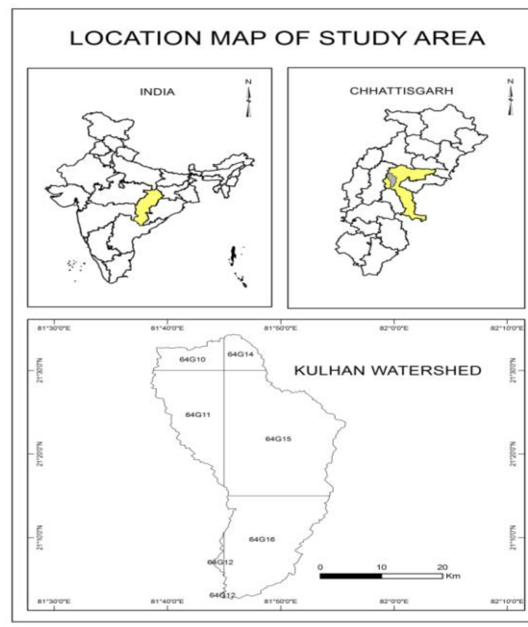

Figure 2.1 Location Map of study area

Data Source & Preparation

Digital Elevation Model (DEM)

For the Study area a 90M resolution DEM is downloaded from Shuttle Radar Topographic mission.

Land use Land cover map

For study area Land use Land cover map is obtained from Chhattisgarh Council of Science & Technology, Raipur, and Chhattisgarh.

Soil Map

Soil map is obtained from Chhattisgarh Council of Science & Technology, Raipur Chhattisgarh. Soil samples are taken at different site locations to know the properties of soil.

Procedural Flow Chart

Detailed procedure adopted in the present study is shown in figure 2-2.

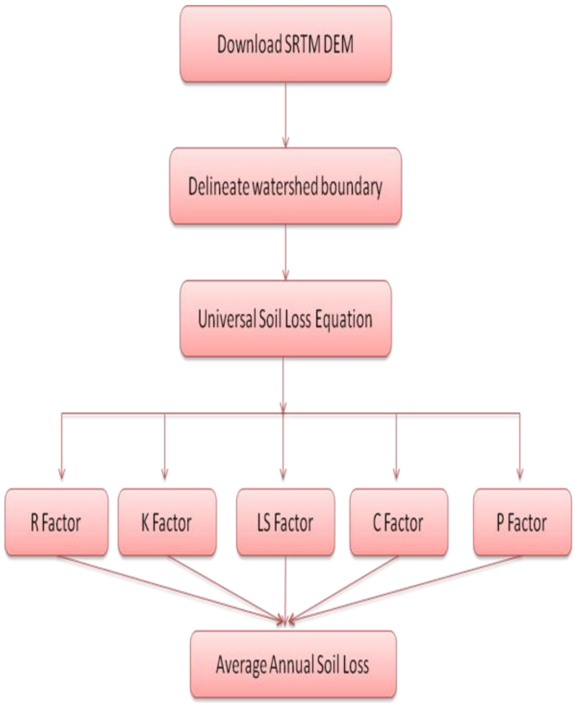

Figure 2-2 Procedural Flow chart.

3. RESULTS & DISCUSSION

General

In this chapter, maps needed for USLE analysis includes R factor, K Factor, LS factor, C factor and P factor are integrated to obtained final soil erosion map.This is accomplished in ArcGIS by using the raster calculator tool. The output file is directed to a temporary folder by default. To generate a permanent output file, the full path of the workspace folder is required along with the desired name of the output file. The results obtained by analyzing the data are presented and discussed in this section.

Generation of maps

Maps generated for the analysis is listed below

- Location Map
- Digital Elevation model
- Watershed Drainage
- Rainfall Factor Map
- Soil Map
- Soil Erodibility factor Map
- Length & Slope Factor Map
- Land use Land cover map
- Cover Management Factor Map
- Support Practice Factor Map
- Soil Erosion Map.
- Soil erosion index map

3.1 Delineation of Watershed Boundary

A specific type of raster data called a digital elevation model (DEM) is used to model the complex terrain of the Kulhan Watershed. The cell size resolution of the DEM is 90 m X 90 m. Each DEM grid cell contains a value corresponding to its actual elevation in the real world. The DEM serves, as the primary input for calculating the Slope Length and Slope Steepness factors (LS-factors). Determination of the flow direction from the DEM is the first step in delineating the watershed boundary. A watershed is delineated by Arc GIS by using a DEM of the area as input.

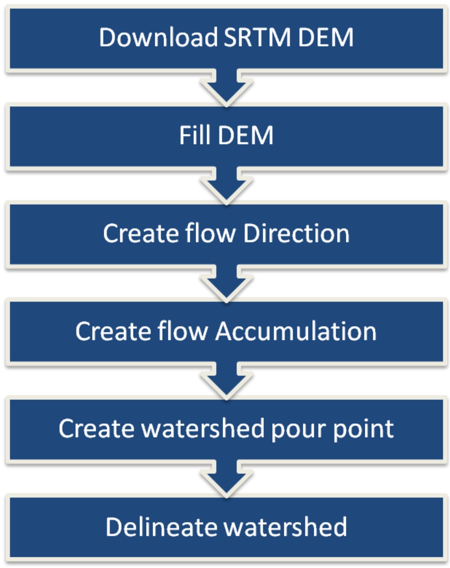

Figure 3-3.Watershed Delineation

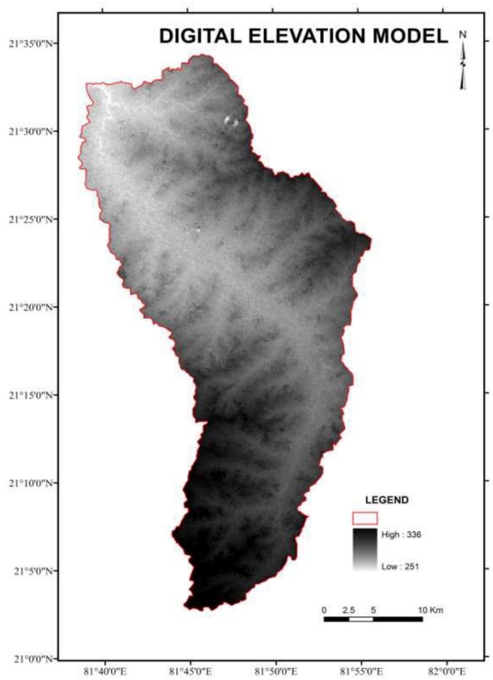

Figure 3-4 Delineated watershed

3.2 Rainfall Erosivity factor (R)

Rainfall erosivity factor, an erosion index for the given storm period in MJ.mm/(ha.hr.year) The rainfall erosivity factor (R factor) represents the erosion potential caused by rainfall.

For the determination of R factor, rainfall data is collected for 25 years. After data collection, R factor was determined for every 25 years for all selected rainfall gauge stations using the equations listed below. Then, the average R factor for each rainfall gauge station was inserted into Arc GIS. All the data points were interpolated spatially using Inverse Distance Weighted (IDW) found in the Arc GIS Spatial Analyst tool to IDW.

The erosivity factor R is often determined from rainfall intensity if such data are available. In majority of cases rainfall intensity data are very rare; consequently attempts have been made to determine erosivity from daily rainfall data.In study area R is determined using mean annual rainfall as recommended by Morgan and Davidson (1991).The expression is given below.

$$R = P * 0.5$$

Where, P = mean annual rainfall in mm and R = rainfall erosivity factor in MJ/ha.mm/h.

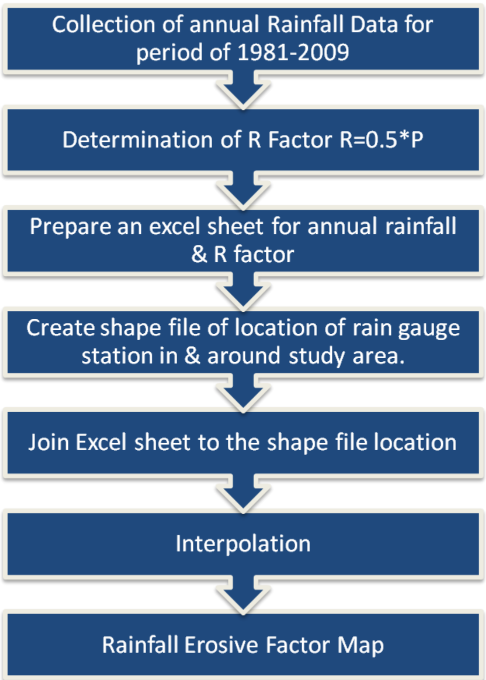

Figure 3-5 R factor flow chart

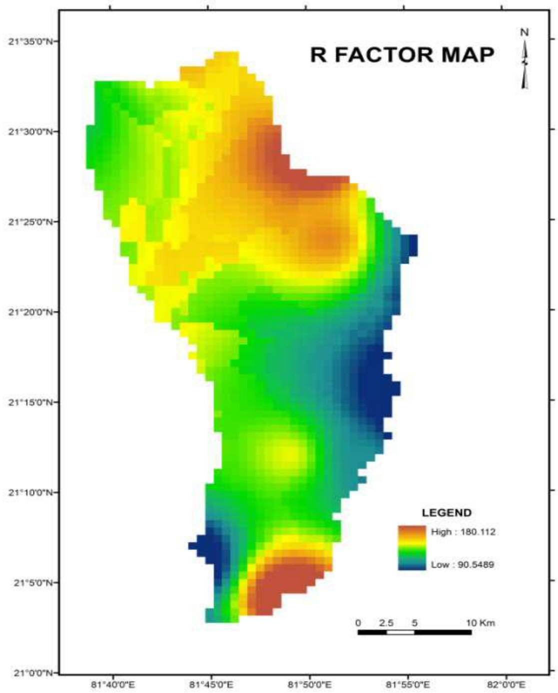

Figure 3-6 Rainfall factor map

3.3 Soil Erodibility Factor

K Factor depends upon organic matter, Soil texture and soil structure. The soil map for study area is obtained from Chhattisgarh council of science and technology, Raipur. . In the study area five major types of soil are found namely clay, clay loam, Gravelly sandy clay loam, sandy clay loam and sandy loam. Soil has moderate K factor value, about 0.33 to 0.14 therefore soil particles are moderately susceptible to detachment and they produce moderate runoff.

Soil samples are collected from different land use and land cover classes of the study area. The first 30 - 45 cm depth of soil was only considered for the calculation and organic matter of soil is determined in the environmental laboratory NIT Raipur by Titration analysis and soil texture is determine from soil, which is obtained from Chhattisgarh Council of Science & Technology, Raipur results are obtained satisfactory.

In this study, Soil erodibility (K) of the study area defined using the relationship between soil texture class and organic matter content proposed by (Stone 2000) shown in table 3-3.The soil erodibility factor is then assigned to different texture classes by adding a new field to the attribute table of soil map.

Table 3-1 organic matter content

Sample	Organic matter content %
Sample 1	0.65
Sample 2	0.75
Sample 3	0.754
Sample 4	0.968
Sample 5	0.438
Sample 6	0.604
Sample 7	0.545
Sample 8	0.658
Sample 9	0.802
Sample 10	0.645

Soil erodibility factor values obtained were shown in table 3-2.

Table 3-2 K factor value

Soil Texture	K Factor
Clay	0.24
Clay Loam	0.33
Gravely sandy clay loam	0.28
Sandy clay loam	0.25
Sandy loam	0.14

Table 3-3 organic matter content (stone 2000)

Soil Texture	Organic matter (< 2%)	Organic matter (> 2%)
Clay	0.22	0.24
Clay loam	0.30	0.33
Fine sand	0.08	0.09
Fine sandy loam	0.18	0.22
Heavy clay	0.17	0.19
Loam	0.30	0.34
Loamy Fine Sand	0.11	0.15
Loamy Sand	0.04	0.05
Gravely Sandy Clay loam	0.28	-
Sand	0.02	0.03
Sandy clay loam	0.20	-
Silt loam	0.38	0.35
Silty clay	0.26	0.27
Silty clay loam	0.32	0.35

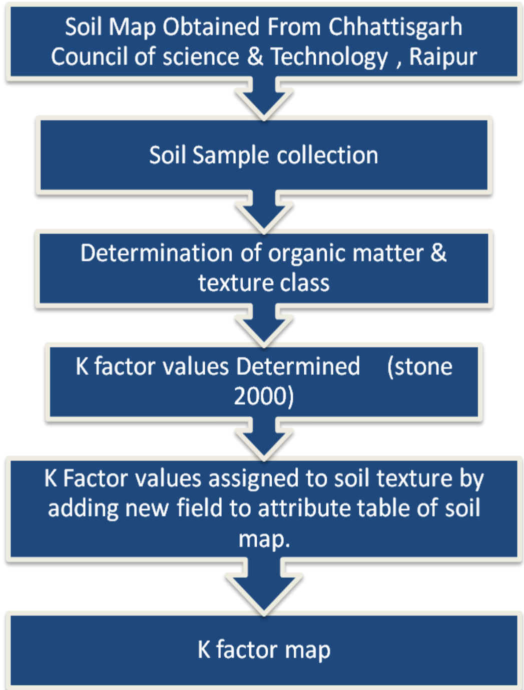

Figure 3-7 Flowchart K factor determination

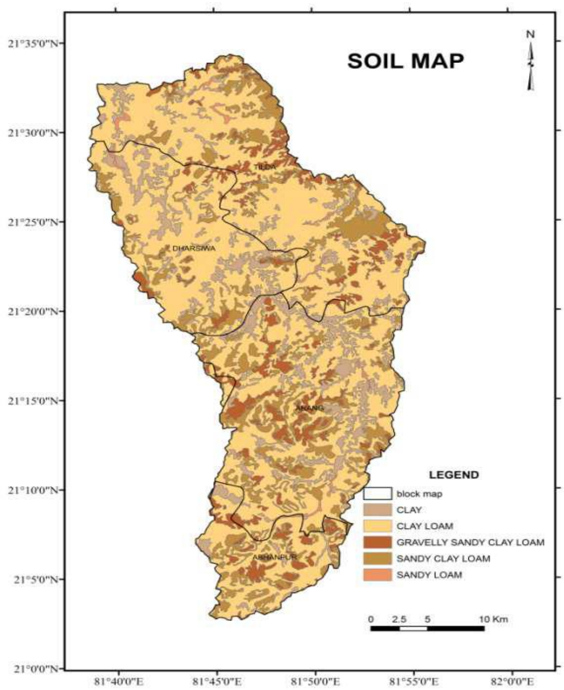

Figure 3-8 Soil map

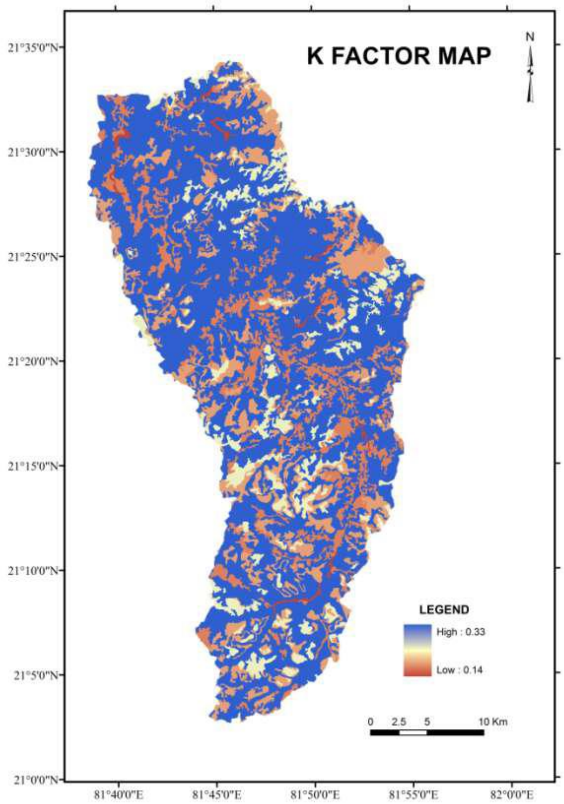

Figure 3-9 K Factor map

3.4 Topographic factor (LS)

Topographic Factor is the combination of Length factor & Steepness factor. The influence of terrain on erosion is represented by Length slope factor, which reflects the fact that erosion increases with slope angle & slope length. DEM is used to calculate LS Factor. Steeper the slope more will be the soil loss. Slope length L is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases to a point where deposition starts or where the flow connects to the river system.

Length Factor according to Desmet and Govers (1996)

$$L = \frac{(\lambda^{\oplus})^{1.4} - \lambda^{1.4}}{Cellsize \; * 22.14^{0.4}}$$

$$\lambda = Flowaccumulation * Cellsize$$

$$\lambda^{\oplus} = \lambda + Cellsize$$

According to Smith and Wischmeier

$$S = \left[\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right]$$

Where s = the percent slope

A procedural diagram of the preparation of LS Factor map in ArcGIS is shown in figure 3-10 and the output LS Factor map is shown in figure 3-11

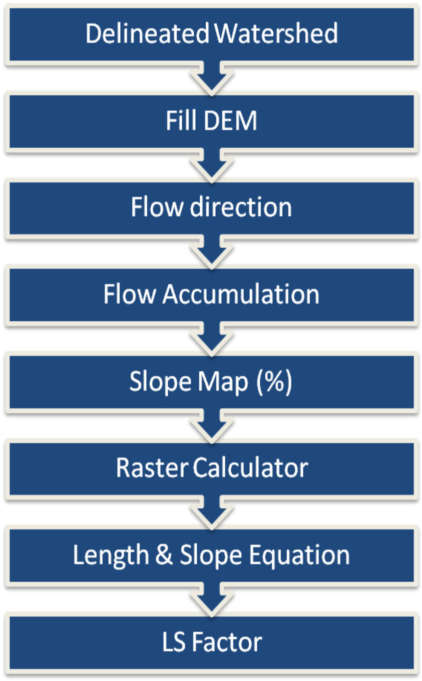

Figure 3-10 Flow chart for LS factor

For Study area maximum slope is observed to be 10.49 %. So this area is considered to be moderate sloping is shown table 3-11. It was observed that the minimum slope is at mainstream channel nearly about 0-0.75%.According slope map it was observed that Slope at the study area is moderate. Analysis of the topographic factor is very important in USLE application, since this parameter characterizes surface runoff speed and, therefore, it is an indicator of soil erosion risk in watersheds.

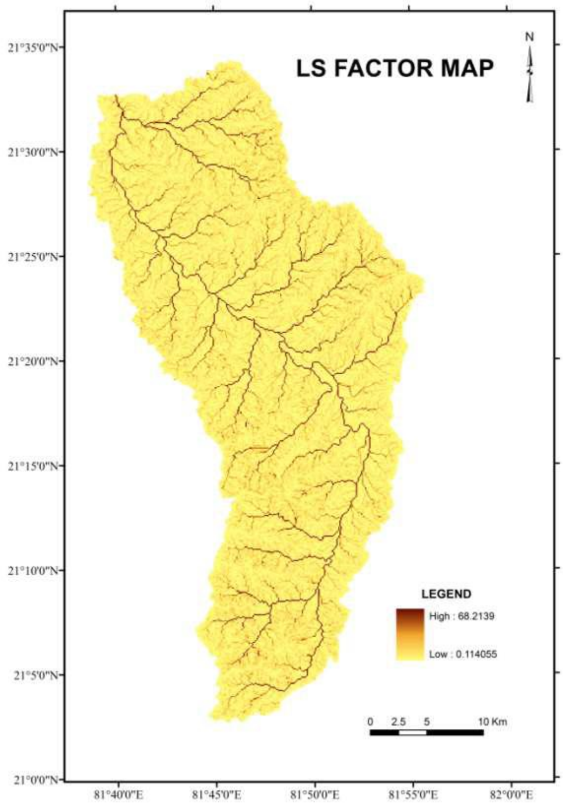

Figure 3-11 LS factor map

3.5 Cover management factor (C)

It is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fellow. It measures the effect of canopy and ground cover on the hydraulics of raindrop impact and amount of runoff. The total Geographical area of Kulhan watershed is 934 Km2 out of which agriculture occupies about 77.44% of total area. 8% by wasteland, 10% by built up area and 0.014% by tree-clad, 4% area occupies by water bodies,Rice is the main crop of study area. Production of rice is highest in Raipur District considering area. Rice maize, soybeans are important kharip crops. Among Ravi crops gram, wheat & linseed are the main crops. The LULC map is shown in figure 3-13 reclassify into five land use classes such as Agricultural Land, Built up, Tree clad Area, waste land and water Bodies. C factor values are assigned to each individual grid of watershed. A polygon shape file of the vegetation was created during a recent resource assessment of the Kulhan watershed.

The C factor values are obtained from different literatures is shown in table 3-4.

Table 3-4 C Factor Value

S No.	Land Cover Classes	C-Factor
1	Agriculture Land	0.34
2	Built Up	0.2
3	Tree clad Area	0.001
4	Waste Land	0.4
5	Water Bodies	0

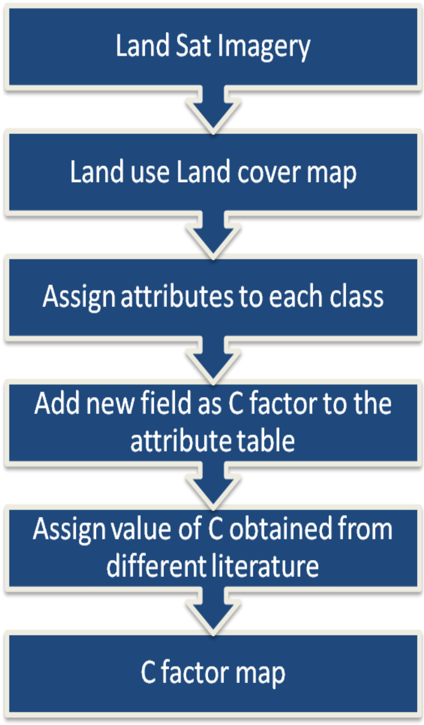

Figure 3-12 Flow chart for C Factor

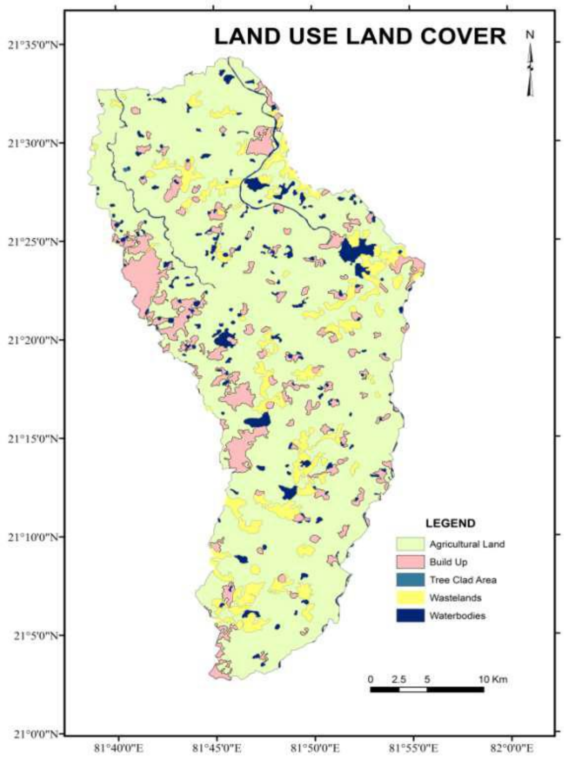

Figure 3-13 LULC map

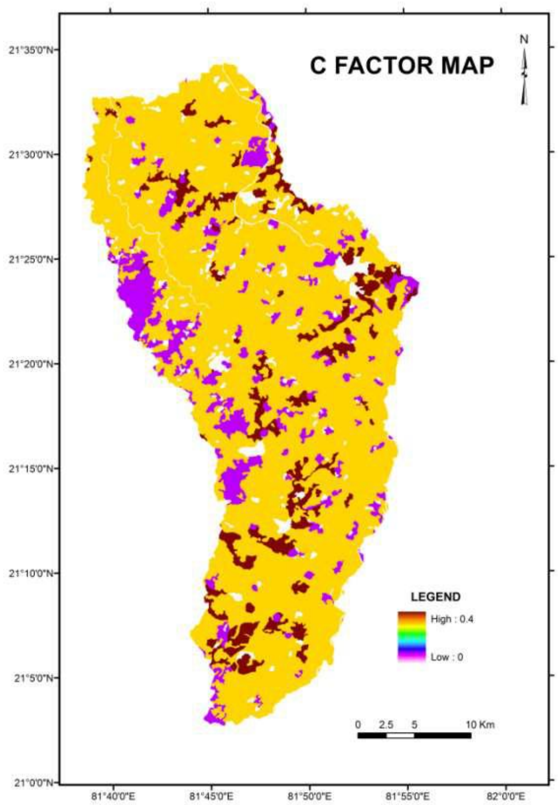

Figure 3-14 C Factor map

3.6 Support practice factor (P)

It is the ratio of soil loss with specific support practice to the corresponding loss with up and slope tillage.

The P value for the study area ranging from 0.1 to 1.P factor map is obtained from LULC map. Support practice factor values are obtained from different literatures and assign to land cover classes. The adopted value of P for different land use is shown in table 3-5.

Table 3-5 P Factor value

S No.	Land Class	P Factor
1	Agriculture Land	0.4
2	Built Up	1
3	Tree clad Area	0.1
4	Waste Land	1
5	Water Bodies	0.5

A procedural diagram of the preparation of P Factor map in Arc GIS is explained figure 3-15 and the output P factor map is shown in figure 3-16.

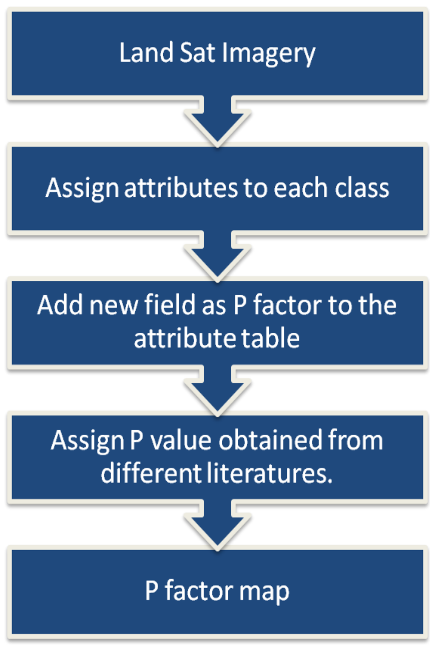

Figure 3-15 Flow chart for P factor

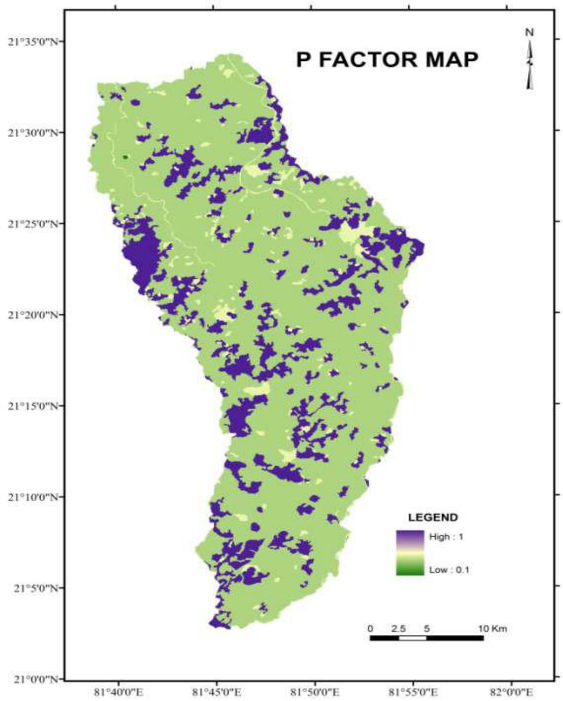

Figure 3-16 P Factor map

4. USLE model result

The average annual soil erosion potential (A) is computed by multiplying the developed raster files from each USLE analysis (A = R K L S C P). All the raster maps R factor map, K factor map, C factor map, LS factor map and P factor map are multiplied in raster calculator tool in ArcGIS is shown in figure 4-19 and the output map is shown in figure 4-20. The average annual R factor values vary from 90.54 to 180.112 MJ. mm ha-1 h-1 with a mean value of 135.326 MJ.mm ha-1 h-1. The K value in the study area varies from 0.14 to 0.33. DEM of the study area has altitude from 251 m to 336m. The combined spatial distribution of LS factor is derived using the DEM of the study area. LS factor values in the study area vary from 0.11 to 68.215 and the C value in the study area varies from 0 to 0.4. Support practice factor P value is observed between 0.1 to 1.

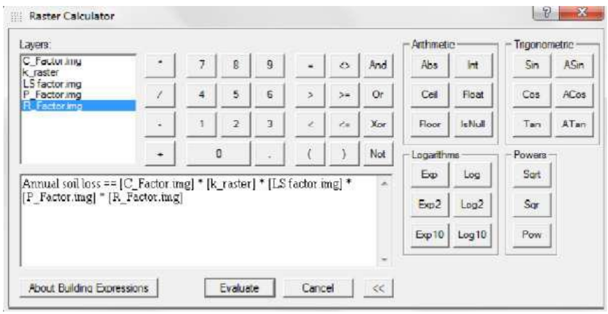

Figure 4-17 Raster calculator

The final USLE map displays the average annual soil erosion potential (A) of the Kulhan Watershed is shown in figure 4-18. The highest computed estimate of soil erosion potential is 556 t/ha/year. The mean annual soil loss for the entire watershed area is 0.1783 t/ha/yr; it was observed that the maximum soil loss is occurred on the area of mainstream. Because of high Length & steepness factor value (68.16) as well as slope value ranges from (0-10.49%).Most of the area is covered by agricultural land, less erosion occurred. Total soil loss is calculated to be 16556 t/yr is moved from the watershed. Total area of watershed is 93400ha. So mean annual soil loss for watershed is 0.1786 t/ha/yr. The soil loss is estimated by determination soil loss for each individual grid cell.

Table 4-6 Erosion Risk Class

S No.	Priority Class	Soil Loss (ton/ha/yr)	Class
1	P6	< 5	Slight
2	P5	5 – 10	Moderate
3	P4	10 – 20	High
4	P3	20 – 40	Very High
5	P2	40 – 80	Severe
6	P1	> 80	Very Sever

Soil erosion map is reclassify according to erosion risk classes suggested by Singh et.al (1992) for Indian conditions explained in table 4-7.The output map of soil erosion index is shown in figure 4-19.

Table 4-7 Soil Loss classification acc. to area.

SNo	Area(ha)	Class
1	78433.12	Slight
2	8232.81	Moderate
3	41.37	High
4	1438.63	Very High
5	731.44	Severe
6	425.78	Very Severe
Total	93400.01ha	

According to erosion risk classes it is observed that only 78433.12ha area is under slight class where as only 425.78 ha area is under very severe class as explained in table 4-7.

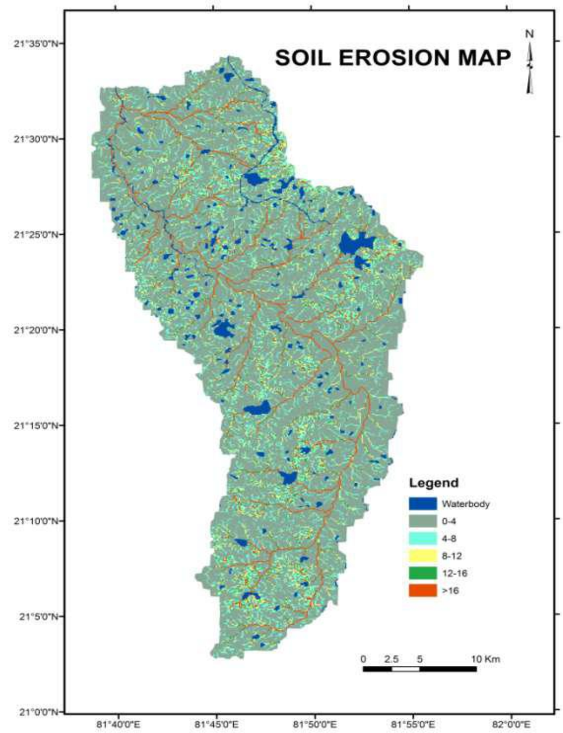

Figure 4-18 Soil Erosion Map

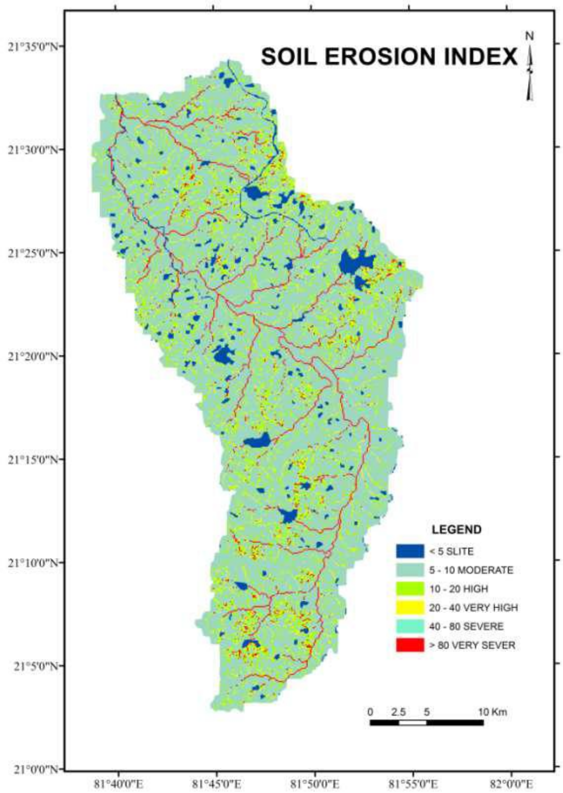

Figure 4-19 Soil erosion index

5. CONCLUSION

In the GIS environment, the USLE is applied to predict annual soil erosion loss & erosion risk over the Kulhan watershed by generating R, K, LS, C, P factor map and this map is integrate in raster calculator tool.

It is observed that the soil erosion for KULHAN watershed is very less because 78% of total area is covered by agricultural land. In this area the erosion class is moderate and as this is the first study on this area so no previous data is available for cross check. Modelling soil erosion is complicated because soil loss varies spatially and temporally depending on many factors and their interactions. The study proves that soil erosion model in combination with GIS is an efficient tool for determining the spatial distribution of soil erosion. The USLE is a good method to estimate soil erosion risk for different scenarios because it is simple, fast and economic to use. Following are the conclusions drawn from the study.

- The average annual soil loss for the study area is 0.1783t/ha/yr.
- As the slope of the study area is gentle undulating and is about 10.49%. Most of the area (78%) is occupied by agricultural land. Therefore, the erosion for this area is very less and does not require any kind of support practice management.
- Generated soil loss map is also able to indicate high erosion risk area; it is useful to soil conservationist and decision makers.
- It was found that 83.97 % of total area is under slight erosion risk class and only 0.45% of total area is under very severe class. This class is observed near the banks of mainstream line.
- USLE with application of GIS is efficient and useful way to handle large volume of data needed for watershed soil loss studies and provides a permanent storage and retrieval system for erosion information.

6. REFERENCES

- Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss," in Agricultural Handbook 703, USDA-ARS.
- Predicting Soil erosion by water," Agricultural Hand book, USDA-ARS, p. 703.
- A. De Roo, "Soil erosion assessment using GIS." Geographical information systems in hydrology,," Dordrecht; Boston, Kluwer Academic Publishers, 1996, pp. 339-356.

- A. K, Soil mechanics & foundation engineering, New Delhi: Standard publisher Distributor.
- A. M. R. -GonZales, " Soil erosion calculation using remote sensing and gis in río grande de arecibo watershed, puerto rico".
- ArcGIS 9.3 desktop help.
- B. B, K. K.L. and Rajkumar, "Characteristics and erosion risks ratingof soils of Patiala-Ki –Rao –Watershed in the lower Shiwalic of Punjab," Indian Journal of soil conservation, vol. 30(1), 2002.
- Babu. R, Narrain. P. Bhushan. L.S.,Abrrol. I.P. Singh G, "Soil erosion rates in India.," J Soil and water cons,, 1992. .
- D. Khosrowpanah, "Developing a gis-based soil erosion potential model of the ugum watershed".
- D. Morgan R P C and Davidson, "Soil Erosion and conservation,Longman Group,U.K.".
- D. Narayana and R. Babu, "Closure to "Estimation of Soil Erosion in India", J. Irrig. Drain Eng., vol. 111(4), p. 408–410, december 1983.
- F. Troch, "1 Soil And Water Conservation, Productivity And Environmental rotection. Third edition, Prentice Hall, Englewood Cliffs, N.J., USA".
- Gopalrao. R. Krishna, N. R. Venkatachalam., P. Suri. J. K. Adinarayana J., "A rule based soil erosion model for hilly catchment," CATENA, vol. 37, pp. (309 - 318).
- H. M. Markus Neteler, Open source GIS: A Grass GIS Approach.
- H. S. Kim, "Soil erosion modeling using rusle and gis," South Korea.
- J. Blaszczynski, A Manual of GIS Procedures, Center Denver,Colorado 80225: Physical Scientist Division of Applied Resource sciences BLM service center.
- J. Blaszczynski, Watershed Soil Erosion, Runoff and Sediment Yield Prediction Using Geographic Information Systems: A Manual of GIS Procedures., U.S. Department of the Interior Bureau of Land Management.
- J. Blaszczynski, Watershed Soil Erosion, Runoff and Sediment Yield Prediction Using Geographic Information Systems: A Manual of GIS Procedures., Colorado : U.S. Department of the Interior Bureau of Land Management.
- K. K. R. Bhushan B., "Characteristics and erosion risks rating of soil of patiala," IJSC, vol. 30(1), (2002).
- M. A. Mohamed, "Application of Remote Sensing and GIS on soil erosion assessment at Bata River Basin,," ACRS, 1997.
- M. K.Jain, S. K. Mishra and R. Shah, "Estimation of sediment yeild and areas vulnerable to soil erosion and deposition in a Hymalaya watershed using GIS.," Social Section Hymalaya bio geo Database I.
- Menintim. M. a. Huygen. A. Sharma, "Modeling spatial sediment delivery in an arid region using thematic mapper data and GIS.", Transactions of the ASAE, vol. 39(2), pp. 551-557, 1996.
- N. I. o. Hydrabad, "Estimation of soil Erosion & sediment yield using GIS," CSAR, no. 35, 96/97.
- Narain. P., Khybri. M.L, Tomar. H.P.S. and S. N.S, "Estimation of Runoff ,soil loss & USLE parameter for Doon valley," Indian Journal of Soil Conservation, vol. 22(3), 1994.
- Panda. R. K. Raghuwanshi. N. S. Singh. R. Tripathi M. P., "Hydrological modelling of a small watershed using generated rainfall in the soil and water assesment tool model,Hydrological process," vol. 18(10), (2004) .
- R. Morgan, "A simple approach to soil loss prediction: a revised Morgan–Morgan–Finney model," Catena, Vols. 44, , p. 305–322, 2001.
- R. Singh., S. Aggarwal, U. Turdukulov and V. Hariprasad, "Prioritization of Beta river basin using GIS & remote sensing," Indian Journal of Soil Conservation, vol. 30 (3), pp. 200-205, 2002.
- R.C. Morgan, "A simple approach to soil loss prediction: a revised Morgan - Morgan - Finney model," CATENA 44, pp. 305-322.
- Renard. K.G, Yorder. D.C., Lighttle. D.T. and D. S.M., "Handbook for USLE".
- Renard. K.G., Foster. G.R. and Y. D.C., "Predicting soil erosion by water:

A guide to conservation planning with reviced universal soil loss equation," USDA Agricultural Handbook 703.

- Rose C. An Introduction to the Environmental Physics of Soil, Water, and Watersheds, 2004.
- S. ghosh and S. K. Guchhait, "Soil loss Estimation through USLE & mmf methods in the lateric tracts of easterm plateau fringe of raj mahal traps," Ethiopian Journal of Environmental Studies and Management EJESM, vol. 5, no. 4, 2012.
- S. K. Mishra. B. S. Manoj K. Jain, "Estimation of sediment yield and areas," Special section: himalayan bio-geo databases–I.
- S. R, "Soil and consevation engineering," Standard publishing Distributors, New Delhi, 2000.
- Siti. Yasmin, Yaakubb.. Nor. Liyaana. Mohammad. Khan, TamtzeHueyd, Ab. Latif Ibrahima, "Application of geographic information system in soil erosion prediction," Aiming smart space sensing.
- Soil survey manual.
- U. B. P. Sreenivasulu Vemu, "Sediment yield estimation and prioritization of watershed using remote sensing and gis," International Archives of the photogrammetry,Remote sensing and spatial information sciences., Vols. XXXIX-B8, 2012.
- U. Tim, "Emerging technologies for hydrologic and water quality modeling," Transactions of the ASAE, vol. 39(2), pp. 465-476., 1996.
- W. A, "Soil erodibilty factor".
- W. a. D. S. Wischmeier, "Predicting rainfall erosion losses.," Washington DC, USDA, 1978, p. 78.
- Shreshta. R.P, E.Apisit and Somachai B.,"Soil erosion assessment and its policy implications-," GIS development .net> AARS >ACRS, 1996.
- Hydrology of chhattisgarh, Raipur, 2008.

