ISH Journal of Hydraulic Engineering
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tish20

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Published online: 07 Jun 2012.

THE INDIAN SOCIETY FOR HYDRAULICS
JOURNAL OF HYDRAULIC ENGINEERING

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by

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ABSTRACT

Erosion is a fundamental and complex natural process that is strongly modified by the activities such as land clearance, agriculture, forestry, construction, surface mining and urbanisation. Inventory on soil loss is vital for effective soil conservation planning of a watershed for sustainable development. An alternative sustainable practice is maintaining a tolerable level of erosion. To control erosion, sound land management practices are to be adopted. Modelling spatial distribution of soil erosion under alternate conservation plan options will help to select the option providing the desired benefits. Mathematical and physical based models with continuous simulation used for estimation of soil erosion requires time series data. The information obtained using remote sensing, Geographic Information System (GIS) techniques help the decision makers to prepare soil erosion map accurately in less time and less cost, which help in estimating, analyzing and solving the complex problem of soil erosion. Using the derived Digital Elevation Model (DEM) from the contour map, Slope and aspect maps have been prepared. In the present study Universal Soil Loss Equation (ULSE) is used for the estimation of soil erosion. The various ULSE factor such as, soil erodibility, slope, aspect, rainfall erosivity index factor map has been generated by linking the attribute data and digital soil map data. The developed GIS based ULSE factors are used in the soil erosion modelling under alternate land use conditions and the results are compared.

KEY WORDS : Watershed, GIS, DEM

INTRODUCTION

Soil erosion is a natural and inevitable process that can be a serious environmental

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Note : Written discussion of this paper will be open until 31st January 2006.

and economic problem when it is accelerated by human activities. Soil erosion is the process by which sediment grains are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil. The consequence of soil erosion occurs both on sites as well as off-site. 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 decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought prone conditions. The net effect is a loss of productivity and results in increased expenditure on fertilizers to maintain yields. Off-site problems resulting from sedimentation down stream, which reduces the capacity of the rivers, enhance the risk of flooding; blocks irrigation canals and reduces the design life of reservoirs.

The factors, which influence the rate of erosion, are rainfall, runoff, soil, slope, plant cover and the presence or absence of conservation measures. Several parametric models have been developed to predict soil erosion at drainage basins, hill slopes and field levels. With a few exceptions, these models are based on soil type, land use, and land cover, climatic and topographic information. Scientific management of soil, water and vegetation resources on watershed basins is, therefore, very important to arrest erosion and rapid siltation in rivers, and lakes. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Traditional sources of investigation are expensive and time consuming. GIS-based universal soil loss equation provides convenient solution for this problem. Further voluminous data gathered with the help of remote sensing techniques are efficiently handled and utilized with the help of GIS. In the present study GIS has been extensively used for the preparation of soil erosion models.

LITERATURE REVIEW

Soil may be deemed as one of the most important resources available as it services the many needs of human living. Brady (1984) justifies this statement by connecting the historical correlation between human settlements within the context of fertile soils such as the river floodplain. Traditional sources of investigation are expensive and time consuming. Several studies have indicated that remote sensing data and Geographic Information Systems (GIS) can be used as a first stage input to identify and map the degraded land Stephen et al., (1981).

It was only recently that an effort to map soil erosion distribution in the North-East of Thailand was made, with the establishment of a manual method by Land Development Department (LDD) (Wichaidit et al., 1992). Several studies showed that the potential utility of GIS as tool for quantitative assessment of soil erosion hazard based on USLE. Saha et al., (1991), Saha and Pande, (1993) and Mangkolsawat et al., (1994) used Landsat TM images for Huai Sua Ten watershed in Thailand. Ogwa et al., (1997) used Landsat TM images for study of erosion of small plateau near North-east of Fatechjang in Pakistan. IRS 1C/1D data has been used by Rinos et al. (1997) to estimate the soil assessment at Bata river basin in India. Universal Soil Loss Equation (USLE) is a statistical model developed modified and updated by Natural Resources Conservation Service (NRCS) scientists Wischemeir and Smith (1978). The USLE was developed by statistical analyses of many plot-years of rainfall, runoff, and sediment loss data from many small plots. The Universal Soil Loss Equation (USLE) model is most accurate for medium-textured soils, slope lengths of less than 400 feet, gradients of 3 to 18% and consistent cropping and management systems that have been represented in erosion plot studies. Bruce Hunter (1990) in a study presented the use of GIS, remote sensing in the USLE based method of estimation of erosion. Burroughs and McDonnell (1998) indicated that empirical models of soil erosion could be useful because data is relatively easy to find and analyze. Models are often limited in ability to analyze sediment transport over large areas. Hudak et al. (2000), identified areas of highest concern for erosion risk in Denton County.

Soil Erosion Modelling in GIS Environment

Most of the models used on soil erosion studies are of the physical based models. It incorporates the laws of conservation of mass and energy is used to predict the spatial distribution of runoff and sediment over the land surface during individual storms. Watershed Erosion Prediction Project model (WEPP) is process based continuous simulation model. This model is applicable to hill slope erosion process and as well as for simulation of hydrological and erosion process on small watersheds. The erosion component of WEPP uses the continuity equation developed by Foster and Mayer (1972). European Soil Erosion Model (EUROSEM) is an event-based model, simulates rill and interrill explicitly (Morgan, 1995). Mangkolsawat et al., (1994) used Landsat TM images for Huai Sua Ten watershed in Thailand. Ogwa et al., (1997) used Landsat TM images for study of erosion of small plateau near North-east of Fatechjang in Pakistan. IRS 1C/1D data has been used by Rinos et al. (1997) to estimate the soil assessment at Bata river basin in India. Atkinson et al. (1988) in their study for City of Dallas, using GIS and Remote Sensing found that the Universal Soil Loss Equation (USLE) model is most accurate for medium-textured soils, slope lengths of less than 400 feet, gradients of 3 to 18%, and consistent cropping and management systems that have been represented in erosion plot studies. Bruce Hunter (1990) in a study compared use of GIS, Remote Sensing and the USLE model with field calculation for estimation of erosion. His methodology incorporated several assumed constant values, such as R, P, and slope length. He found that the USLE model was capable of identifying the same areas of high erosion potential as those identified by a Soil Conservation Service Survey. Most of the erosion studies carried out thorough out the world used only empirical models. Developing of empirical model within GIS is much easier than developing a continuous simulation model. Geographic Information System (GIS) in combination with remote sensing have been found effective in preparing and maintaining database and carrying out analysis related to soil erosion estimation.

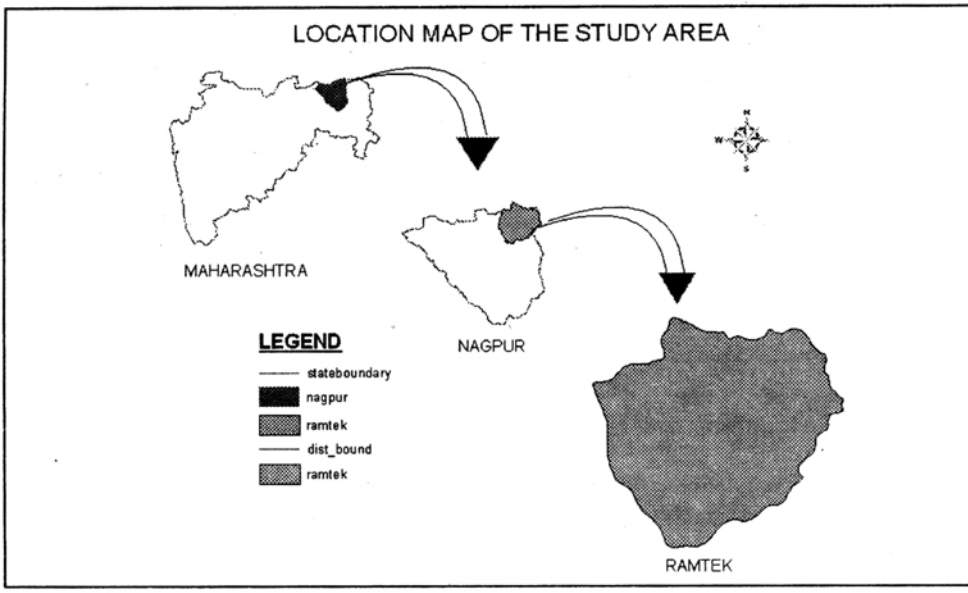

FIG. 1 STUDY AREA

STUDY AREA

The Watershed taken up in the present study is Khindsi watershed located at Ramtek taluka of Nagpur district, Maharashtra. The total basin area is 183sq.km. The Khindsi has a Fan shaped catchment. The Khindsi basin is a sub basin of Wainganga river basin, which is a sub basin of Godavari. The basin length is found to be 21.17 km. The study area lies between 79°15'00" to 79°30'00" East longitude and 21°15'00" to 21°30'00" North latitude covered in topo sheets 55 O/3, 55 O/2, 55 O/6 and 55 O/7. The location map is shown in Fig. 1.

Physiography and Climate

The general elevation ranges from 320m to 470m above the mean sea level and slope is from North-West to South-East for the left half part of the basin and North-East to South-West for the right half part of the basin. Overall climate of the area is characterized by low humidity, medium rainfall and high evaporation rates. The mean annual precipitation is about 900mm.

Data Used

Satellite Imageries

- A Standard False Color Composite (FCC), Geocoded of IRS 1C/1D LISS III data acquired in 22 September 2000, Scale 1:50,000

Analog data

- Topographical Maps: 55 O/3, 55 O/2, 55 O/6 and 55 O/7 of 1: 50,000.

Software's

- Image processing - ERDAS Imagine 8.5
- GIS - ARC/INFO 7.2.1, ArcView 3.2a

GIS DATABASE DEVELOPED FOR THE MODEL GENERATION

Drainage Map

The SOI topo-sheets have been used for the preparation of drainage network map of the study area as shown in Fig. 2. Drainage pattern indicates dendritic with fine tributaries. The drainage has been ordered following the Strahler's stream ordering method. It consists of one to sixth order of stream.

Digital Elevation Model

The contours with an interval of 20mts are digitized from SOI topo-sheet of scale 1:50,000. This is used in generation of TIN and in Digital Elevation Model (DEM) as shown in Fig. 3. Digital Elevation Model is generated by the interpolation technique. Generated DEM was used in the preparation of slope map, slope steepness (LS) factor map.

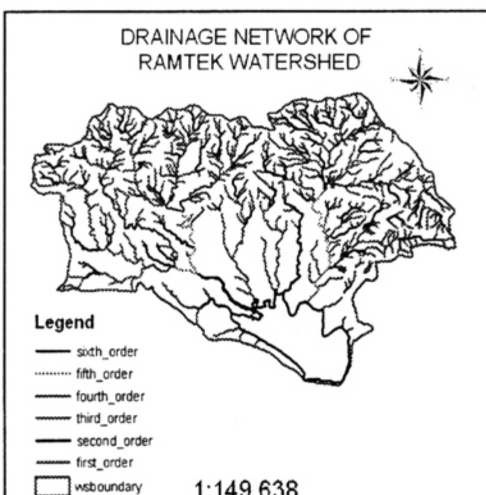

FIG. 2 DRAINAGE MAP

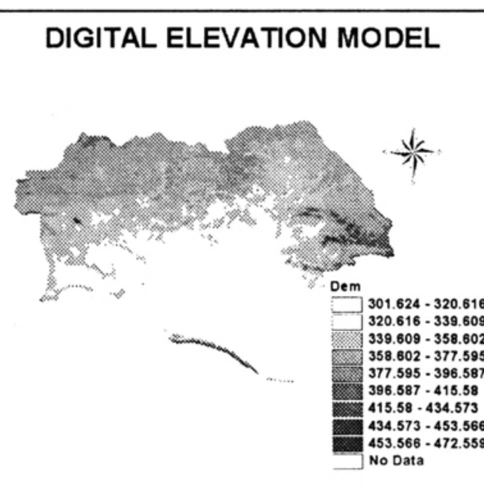

FIG. 3 DIGITAL ELEVATION MAP

Soil Map

The soil map is obtained from National Bureau of Soil Surveys and Land Use Planning (NBBS & LUP) Nagpur. Soils were grouped into six classes depending on soil properties as shown in Fig. 4. The soil erodibility factor (K) has been developed from detailed-reconnaissance soils map (1:50,000) and assigned values according to soil texture.

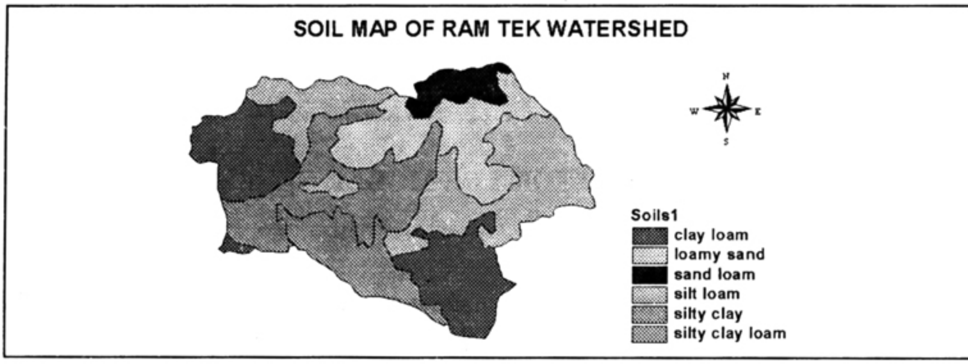

FIG. 4 SOIL MAP

Land Use/Land Cover Map

A land use/land cover map has been prepared using the digital data of an IRS-1D LISS III image. Land use and land cover is a highly dynamic phenomenon and hence this data is extremely useful for estimation of soil erosion. Multi-spectral supervised classification using ERDAS software has been used to prepare a land use / land cover map. The conservation practice factor (P) map and crop management factor map have been generated from the land use and land cover map which is shown in Fig. 5.

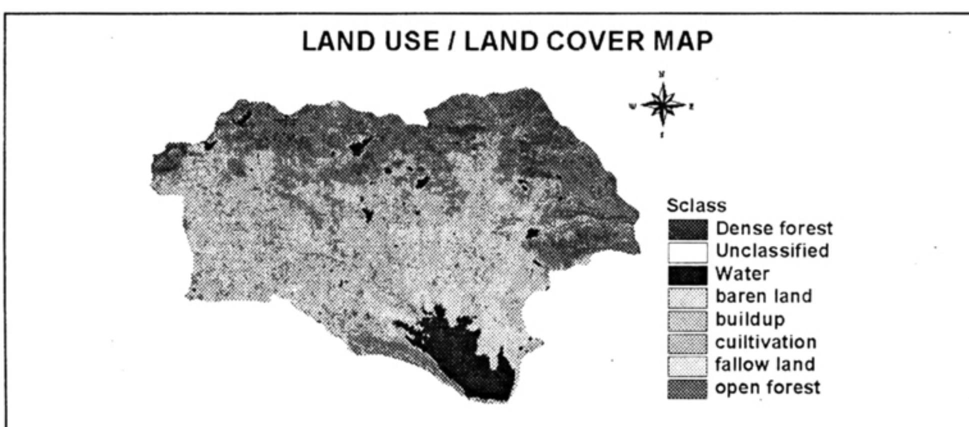

FIG. 5 LAND USE / LAND COVER MAP

METHODOLOGY

The Universal Soil Loss Equation (USLE) is an empirically based model on soil erosion rates. This equation is the best available method, which is used most widely for estimating soil losses as average annual mass per unit area as a function of the major factors affecting sheet erosion.

The Universal Soil Loss Equation is:

$$A = R*K*L*S*C*P \tag{1}$$

A = average annual soil loss in tons /acre /year,
R = rainfall and runoff erosivity index, **K** = soil erodibility factor, **L** = slope length factor,
S = slope steepness factor, **C** = cover and management factor,
P = conservation or support practice factor.

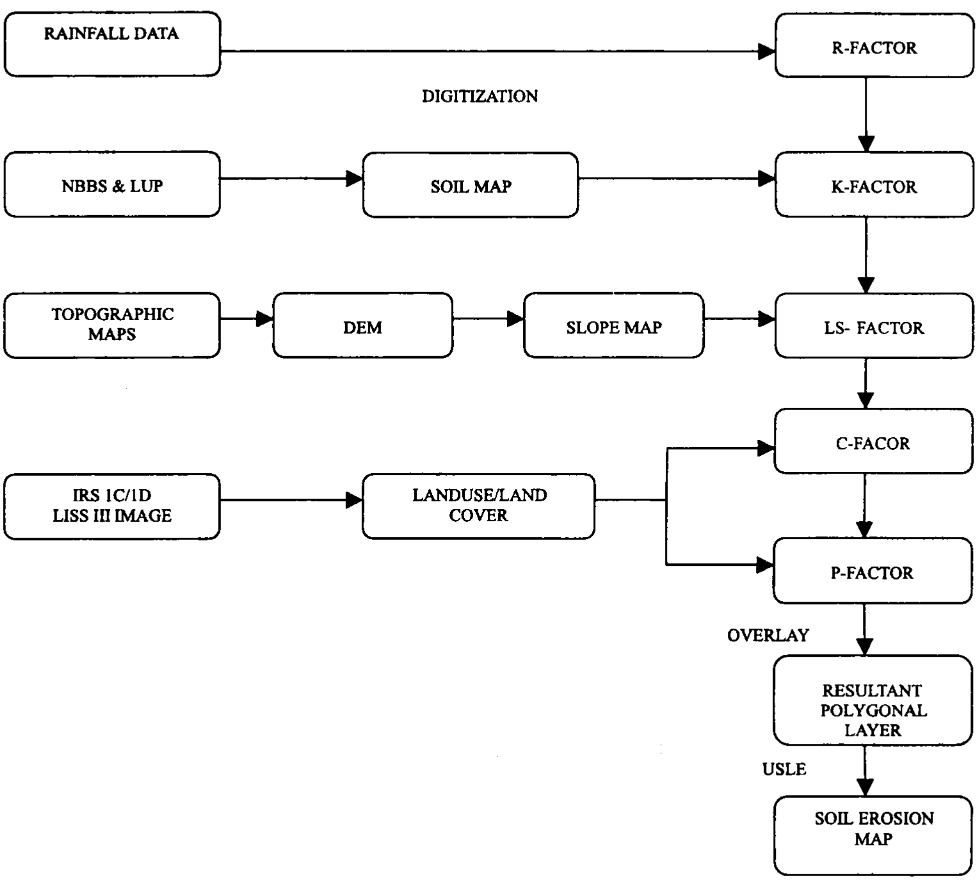

FIG. 6 SCHEMATIC FLOW CHART FOR PREPARATION OF SOIL EROSION MAP

EVALUATING THE FACTORS OF USLE

R-Rainfall and Runoff Factor

Soil loss is related to rainfall through the detachment power of raindrops striking the soil surface and the entrainment of the detached soil particles by run-off water down slope. The R-values for each station were computed using the following equation and input in the GIS as a discrete point file with location and R-value have been obtained from using the following equation

$$\mathbf{R = -8.12+0.562*Y} \qquad (2)$$

Where, Y= Annual rainfall.

K-Soil Erodibility Factor

Soil erodibility is a measure of the susceptibility of a given soil to erosion by rainfall and runoff. The K factor map have been prepared from the soil map, which is obtained from the previous studies done at Geo-Science Division, IIRS, Dehradun, using the values given in Table 1.

TABLE-1
K- VALUES FOR DIFFERENT SOIL TEXTURES

Textural Class	Organic Matter Content (%)		
	0.5	2.0	4.0
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Silty clay	0.25	0.23	0.19

LS- Topographic Factor

The topographic factors L and S are used to adjust the erosion rated based upon the length and steepness of the slope. For convenience L and S are frequently lumped into a single term. The LS factor map have been created from the slope and aspect map derived from the DEM. Contour data were extracted from existing topography maps (4 sheets at scale 1:50000) through scanning and manual digitization.

For slope < 21 %,

$$LS = (L/72.6)*(65.41*Sin (S) + 4.56*Sin (S) +0.065) \quad (3)$$

For slope > 21 %,

$$LS = (L/22.1)\ 0.7*(6.432*Sin (S)\ 0.79*Cos S)) \quad (4)$$

Where,

LS = Slope length and slope steepness factor
L = Slope length (m),
S = Slope steepness (radians).

C - Croping-Mangement Factor

The cover and management factor, C, is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land. The USLE have been developed for use on agricultural fields. It is adapted to use in non-agricultural conditions by appropriate selection of the C factor. Relating the land use conditions to some agricultural situation often does this. The crop and cropping practice effects the soil erosion in many ways by their various features, such as kind of crop, quality of cover, root growth, water use by growing plants etc. C-factor map have been prepared from Landuse/landcover map and ground truth.

This C-factor value for different land use/land cover is given in Table 2.

TABLE-2
C-FACTOR VALUES FOR DIFFERENT LAND USE/LAND COVER

Land use / Land cover	C-Values
Open forest	0.005
Dense forest	0.003
Built up land	0.200
Cultivation	0.800
Fallow land	0.003
Barren land	0.800
Water	1.000

P-The Consevation Practice Factor

The ratio of soil loss for a given conservative practice to the soil loss obtained from up and down the slope farming. Accounts for the effects of cover above the ground, ground cover, root mass, incorporated residue, surface roughness, and soil moisture on soil erosion. Conservation Practices of mainly contouring, strip cropping (alternate crops on a given slope established on the contour) and terracing, in which contouring appears to be the most effective factor. As a rule of thumb, contouring reduces to one-half the soil loss caused by up-and-down hill farming, strip cropping to one-half that of contouring, and terracing to one-half that of strip cropping. This conservation practice factor was not accounted in this study area as shifting cultivation commonly conservation practices that did not contribute significantly to erosion protection. In this study area the P factor is assumed to be one (1) here.

PREPARATION OF SOIL EROSION MAP

All the factor maps of R, K, LS, C and P were integrated to generate a composite map of soil erosion map. The LS factor map has been generated from the slope and aspect map derived from the DEM. The K-factor map have been generated from detailed-reconnaissance soil map and assigned values according to the soil texture. The R-factor value is obtained from the Eq. (4) (obtained value is 1788.02). The cropping management and conservation practice factor map have been generated from the landuse and landcover. In this study area p-factor is taken as 1.0 here. Maps covering the parameter (R, K, LS, C and P) were overlay to generate a composite map of soil erosion based on the advance GIS functionality. The map calculator can be used to estimate USLE soil erosion for every grid cell in the area of interest using map calculator. From this to found annual average soil loss 14.82 ton/ha/year. Shown in Fig. 7. The flow chart of the spatial overlay showing spatial data and associated attribute data is illustrated in Fig. 6.

RESULTS AND DISCUSSIONS

The estimation of soil erosion obtained from the USLE model shows an average annual soil loss of the watershed. The rainfall and run off factor is obtained from Eq. (1), based on the average annual rainfall values is 1788.07. From the soil survey average K factor is found to be 0.283. The L and S factors are combined into a single topographic factor, LS. The average LS factor obtained from Eq. (4) is 6.037. The C factor for different classes like forest, open forest dense forest, built up land cultivation land, fallow land and barren land is found to be 0.245. At present there are no conservation practices in the watershed, therefore the P factor for these conditions is 1.0. The USLE factors and the corresponding calculations of erosion are as follows

Rain fall and runoff index	R	=	1788.07
Conservative practice factor	P	=	1.0
Soil erodibility index	K	=	0.283
Slope steepness factor	LS	=	6.037
Cropping management factor	C	=	0.245

Average annual soil loss A= 14.82 ton/ha/year

The Average annual soil in a given period is found to be 14.82 ton/ha/year. The soil erosion map has been shown in Fig. 7. The land use has shown a major impact over the erosion rates. Agricultural fields having moderate slope are more prone to erosion than other land use types.

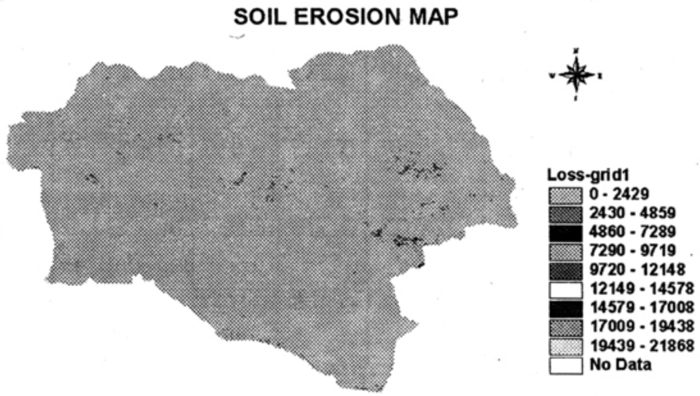

FIG. 7 SOIL EROSION MAP

SOIL EROSION MODELLING WITH RESPECT TO ALTERNATE LAND USE

By evaluating the factors of the soil loss equation, the soil loss from a field under a given set of conditions can be determined. The soil erosion modeling can be done by changing the parameters of rainfall index factors, crop management factor and soil erodibility factor. This is presented in different soil erosion maps and corresponding calculation are given below in the Table 3 and corresponding sample maps are shown in Figs. 8 and 9.

TABLE-3
SOIL EROSION ESTIMATION WITH RESPECT TO ALTERNATE LAND USE PLANNING

Description	Average grid values of R, K, LS, C and P factors					Average annual soil loss (ton/ha/year)
	R	K	LS	C	P	
Annual rainfall	1788.07	0.283	6.037	0.245	1.0	14.820
Maximum Annual rainfall	2606.30	0.283	6.037	0.245	1.0	25.770
Open forest as dense forest	1788.07	0.283	6.037	0.244	1.0	14.800

Description	Average grid values of R, K, LS, C and P factors					Average annual soil loss (ton/ha/year)
	R	K	LS	C	P	
Dense forest as open forest	1788.07	0.283	6.037	0.245	1.0	14.816
Fallow land as a cultivation land	1788.07	0.283	6.037	0.252	1.0	14.855
Cultivation land as a fallow land	1788.07	0.283	6.037	0.096	1.0	5.910
Organic matter content increase up to 4%	1788.07	0.323	6.037	0.245	1.0	7.400
Organic matter content is 0.5%	1788.07	0.286	6.037	0.245	1.0	17.980

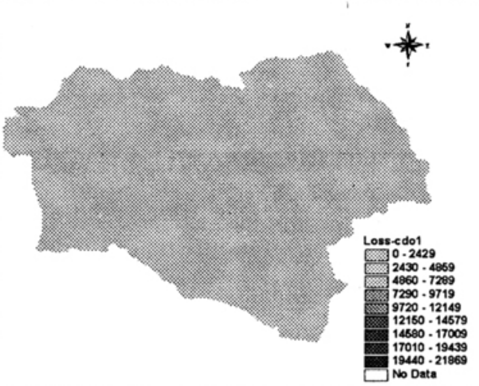

FIG. 8 SOIL EROSION MAP (DENSE FOREST IS CONSIDER AS A OPEN FOREST)

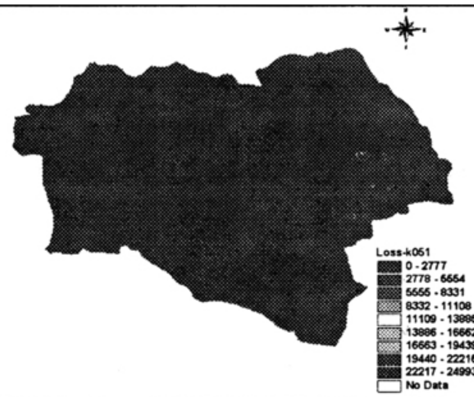

FIG. 9 SOIL EROSION MAP (ORGANIC CONTENT 4%)

CONCLUSIONS

The present study for the soil erosion estimation is well suited for agricultural and forest land soil erosion modelling. Developed USLE model can be used in predicting possible impacts of alternative land use / land cover changes.

- The model can be used for identifying critical sub watersheds for developing best watershed management practices.
- The USLE model is well suited for the estimation of soil erosion; it requires a several dimensionless coefficient in order to estimate the soil erosion. Therefore it would be beneficiable for the estimation of soil erosion in Khindsy watershed.

- It has been found that there is no significant change in total soil loss when open forest is taken as dense forest or vice-versa, but considerable amount of increase in the volume of erosion has been found when organic content in the soil is decreased. When maximum annual rainfall is considered the quantity of soil erosion is maximum.
- The USLE model calculation applied to the resultant polygon layer gives the good result for average annual soil loss over long period of time.
- Developed USLE model can be used in predicting possible impacts of alternative land use / land cover changes.

ACKNOWLEDGMENTS

This work is a part of on-going TAPTEC research project "Preparation of action Plan for Watershed Management Using GIS, funded by All India Council for Technical Education (AICTE), New Delhi.

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