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SOIL EROSION MAPPING OF WATERSHED IN MIRZAPUR DISTRICT USING RUSLE MODEL IN GIS ENVIRONMENT

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***Abstract*— Soil erosion is one of the serious issues threatening the environment. It is a growing problem especially in areas of agricultural activity where soil erosion not only leads to decreased agricultural productivity but also reduces water availability. This leads to drastic degradation of the agricultural lands. So there is a need to take up conservation and management measures which can be applied to check further soil erosion. Universal Soil Loss Equation (USLE) is the most popular empirically based model used globally for erosion prediction and control. Remote sensing and GIS techniques have become valuable tools for the digitization of the input data and genereation of maps. In the present study, RUSLE model has been adopted to estimate the soil erosion in the Khajuri watershed of Uttar Pradesh, India. This model involves calculation of parameters including runoff-rainfall erosivity factor (R), soil erodability Factor (K), topographic factor (LS), cropping management factor (C), and support practice factor (P). Layer wise thematic maps of each of these factors were generated using GIS platform using various data sources and data preparation methods. The results of the study indicate that the annual average soil loss within the watershed is about t/ha/yr (metric ton per hectare per year).**

***Keywords*: Geo Information systems, RUSLE, Soil erosion, ArcGIS**

I. INTRODUCTION

Balanced ecosystems comprising soil, water and plant environments are essential for the survival and welfare of mankind. However, ecosystems have been disturbed in the past due to over exploitation in many parts of the world, including some parts of India. The resulting imbalance in the ecosystem is revealed through various undesirable effects, such as degradation of soil surfaces, frequent occurrence of intense floods etc. [1] Erosion of soil through various agencies is one such phenomenon. Soil erosion involves detachment and transport of soil particles from top soil layers, degrading soil quality and reducing the productivity of affected lands [2]. In India a total of 1,750, 000 sq.km from a total land area of 3,280,000 sq. km is prone to soil erosion. Thus about 53% of India is prone to erosion.[3] Soil erosion in watershed areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, the rich fertile soil is eroded from the watershed areas [4]. Secondly, there is a reduction in the reservoir capacity as well as degradation of downstream water quality. India, being an agricultural country, faces solemn environmental problems in the reservoirs and decreased fertility causing disastrous economic consequences[5]. Erosion is triggered by a combination of factors such as steep slopes, climate (e.g., long dry periods followed by heavy rainfall), inappropriate land use, and land cover patterns.[6] Moreover, some intrinsic features of the soil can make it more prone to erosion [5]. Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to loss of nutrient rich surface soil, increased runoff from more impermeable subsoil and decreased water availability to plants. Thus, estimation of the critical area for implementation of best management practice is integral to the success of a soil conservation program [5]. The need to quantify the amount of erosion in a spatially distributed form has become essential at the watershed scale and in the implementation of conservation efforts [2]. Often, a quantitative assessment [1] is needed to infer on the extent and magnitude of soil erosion problems so that sound strategies can be developed on a regional basis with the help of management field measurements. Substantial efforts have been made to estimate soil erosion and to develop various erosion models, such as Universal Soil Loss Equation (USLE) [2], Water Erosion Prediction Project Soil Loss Equation (WEPP) [6], Soil and Water Assessment Tool (SWAT) [8] and European Soil Erosion Model (EUROSEM) [9]. The Universal Soil Loss Equation developed by Wischmeier and Smith in 1965 is one of the most widely used models for the estimation of soil loss. Originally, USLE was developed mainly for soil erosion estimation in croplands or gently sloping topography. The USLE, a paper-based model, was computerized and updated by a group of scientists [10] and subsequently called as Revised Universal Soil Loss Equation (RUSLE). The information required for this model are mostly related with the soil type, land use pattern, climate and topography of the area.

With the advent of remote sensing and GIS technologies and their integration with the USLE/RUSLE method led to a more simpler, cost-effective and efficient perception of erosion, and this integrated application was applied by many researchers

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in the whole world[11]. A combination of RS, GIS, and RUSLE is an effective tool to estimate soil loss on a cell-by-cell basis [12]. The prime input required for soil erosion modeling are terrain, slope gradient and slope length which can be generated by processing of DEM in GIS. Multi-temporal remote sensing data (satellite imageries) provide valuable information related to seasonal land use dynamics[11]. Mapping soil erosion using GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations [13]. The combined use of GIS and erosion models have been shown to be an effective approach to estimating the magnitude and spatial distribution of erosion[14]. Many researchers have used RUSLE to predict the magnitude and spatial distribution of soil erosion using GIS software. With this background, the present study is carried out in the Khajuri watershed of Uttar Pradesh, India to estimate the spatial pattern of soil erosion using RUSLE and to find out the most vulnerable land use classes.

II. STUDY AREA

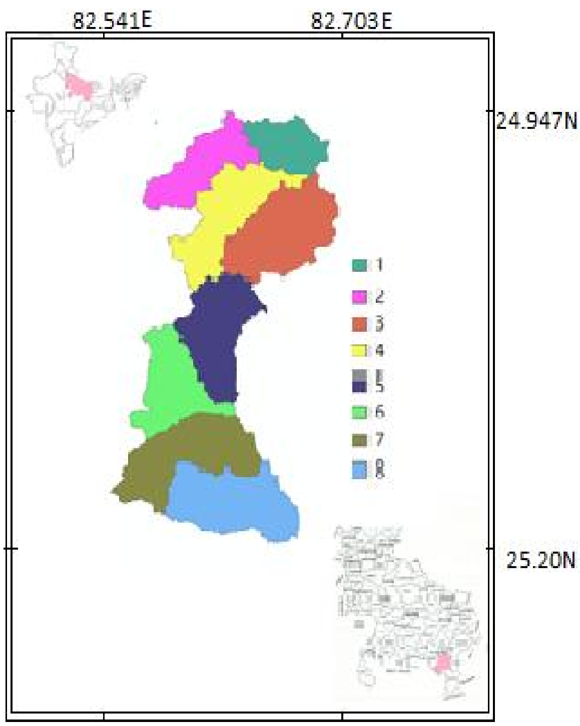

Figure 1. Location map of the study area

The area in the present study is Khajuri watershed. It is located at Barkachha in the south eastern part of Mirzapur District, Uttar Pradesh. The study area has a complex alignment in orientation and distribution, structure, morphology, relief, slope, climate and vegetation. The main river system in the study area is the Ganga system covering around 56% of the district with Khajuri tributary. The drainage pattern is dendritic. Our study river is a tributary of the above mentioned Ganga River.

A. Geology and Soils

Most part of the study area is a rocky terrain with a central plateau region. The study area is almost extremely covered by metamorphic rocks, which includes limestone and sandstone. The topography of the area is generally mountainous and rugged, dissected by distributaries of Khajuri River. There are five major classes of soil found in this area. These are silty clay loam to clay, Clay loam to silty clay, Loam, Loam to clay loam, Sandy loam soil and Gullied land covering about 31.39%, 6.50%, 19.32%, 2.95%, 39.27% and 0.05% of the area respectively (Source; Institute of Agriculture, B.H.U).

B. Vegetation and Land Use

The ecosystem of the area varies as forest-savannah-cropland system along the elevation with dry deciduous forest. The dominant tree species are Shorea robusta, Hardwickia binate, Boswellia serrate, Anogeissus larifolia etc. The land use pattern of the area includes 15% Agricultural land, 14% forest land, 41% rocky terrains, 27% waste land, 3% barren areas and 15 natural water bodies.

C. Climate

Khajuri watershed comes under the sub-humid agro-climatic zone, but is dominated by dry conditions. Average annual temperature varies from 14-45 c. The monsoon is divided into three seasons consisting of a cool-dry season of northerly winds during the months of October-February, a hot-dry season from March-June and hot-wet season during July-October. The rainy season has very high humidity levels of 70-95% and during summers it varies from 31-56%.

III. RUSLE MODEL

The procedure is founded on an empirical soil loss equation that is believed to be applicable wherever numerical values of its factors are available[15].RUSLE is an update of USLE which can be used with the help of a computer program [10].It predicts erosion rates of ungauged watersheds using knowledge of watershed characteristics and local hydro-climatic conditions and presents the spatial heterogeneity of soil erosion with feasibility and better accuracy in larger areas [16].

The RUSLE model has the equation(1) as follows

$$A = R \times K \times LS \times C \times P \quad (1)$$

where, A is the computed average soil loss over a period selected for R, usually on yearly basis (t ha-1 y-1); R is the rainfall-runoff erosivity factor (MJ mm ha-1 h -1 y-1); K is the soil erodability factor (t ha h ha-1 MJ-1 mm-1); LS is the slope length (L) and slope gradient (S) factor (dimensionless); C is the cropping management factor (dimensionless, ranging between 0 and 1); and P is the supporting conservation practice factor (dimensionless, ranging between 0 and 1).

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A. *Rainfall erosivity factor (R)*

Significant erosion is associated to only a few storms. R is the long term annual average of the product of event rainfall, kinetic energy and the maximum rainfall intensity in 30 min in mm per hour [13]. The numerical value used for R in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain event. These requirements were best fullfilled by Rainfall erosivity factor (R) derived by Wishmeier. [7].

B. *Soil erodability factor (K)*

Soil erosion is different from soil erodability. Under same physical conditions different soil erode differently. Net soil erosion is highly affected by soil texture, organic matter content and permeability[17]. The difference in erosion caused by properties of soil is called soil erodibility. Soil erodibility(K) characterizes the vulnerability 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, 72.6ft long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hill slope [8]

C. *Topographic Factor (LS)*

Length and slope are two very important factors affecting the soil erosion. Their effect on soil erosion is accounted for by the LS factor in RUSLE. 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. Slope length (L) is defined as the ratio of soil loss from the field slope length to that from a 72.6 ft. length under otherwise identical conditions. [6]

D. *Cropping management factor (C)*

This factor accounts for combined effects of cover and its management. Soil erosion is highly governed by the type, quality and management of vegetation over it [18] and [19] studied the effects of different vegetation on the soil erosion. The C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot.[7]

E. *Supporting conservation practice factor (P)*

Supporting conservation factor relates to the practices which limit water runoff and decrease the effective soil erosion. The P factor ranges from 0 to 1, where the highest value is allocated to areas with no protection practices.[20] It is the ratio of soil loss with a specific supporting practice to the corresponding loss without any supporting practices.

IV. METHODOLOGY

Creation of database required, through conventional methods is time consuming, tedious and difficult to handle. Remote sensing and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. In present study, different inputs were digitized and thematic maps of different factors were generated in ArcGIS 10.1. 30m resolution ASTER DEM was used to compute LS factor. Also, LANDSAT-8 satellite data was visually inspected to map various land use/land cover types through on-screen digitization. Supervised classification method was used for the land use/land cover mapping. Calculation of different factors is as follows:-

A. *Rainfall erosivity factor (R)*

Collecting data required for computation of original R requires lots of resources. Therefore different approach is needed to be used. Isoerodent maps are contour-maps having lines plotted connecting points of equal soil erodibility. The local values of R factor may be extracted directly from isoerodent maps.[10]; [21] and [22] used similar approach to derive linear relationship between annual rain fall and Rainfall erosivity factor (R). The derived relationship(2) is given below:

$$R = 79 + 0.363Rn \quad (2)$$

Where, Rn is the average annual rainfall in mm.

In preset study, average annual rain fall data provided by the Indian Meteorological Department were used to calculate the R factor.

Fig.2: R factor map

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B. *Soil erodability factor (K)*

Although, according to Renard[9], K values must be found from experimental results in standard conditions. The K values of soil may also be obtained from various tables developed by various scientists. In this study, Soil erodibility (K) of the watershed is defined using the relationship between soil texture class and organic matter content proposed by Schwab et al. (1981) [23].

	Organic matter content (%)	
Texture class	**0.5**	**2**
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy Very fine sand	0.44	0.38
Sandy loam	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay loam	0.28	0.25
Silt clay loam	0.37	0.32
Silty Clay	0.25	0.23
Texture class	0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10

Table I Soil erodibility factor K (by Schwab et al., 1981)[23]

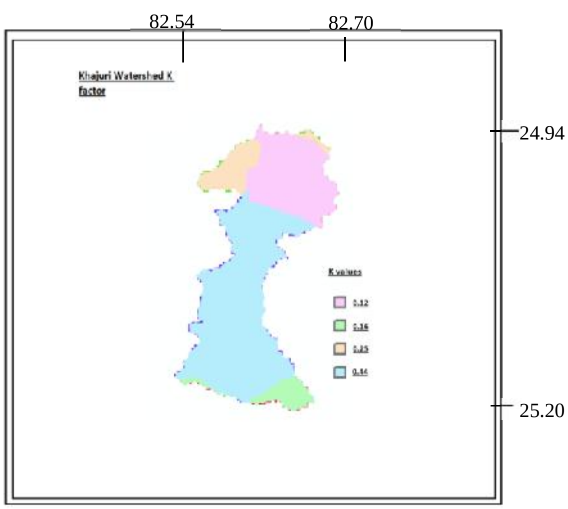

Fig. 3. Soil Erodibility Factor(K)

C. *Topographic Factor (LS)*

There are number of methods available to find out LS. In the present study the two parameters (slope-gradient and slope length) are calculated using DEM. The precision with which it can be estimated depends on the resolution of the digital elevation Model (DEM). Here, in this study 30 m ASTER DEM has been used.

The formula(3) used for calculation of LS factor is the further modified version of the method suggested by Mitasova & Mitas[23]

$$LS = (((\text{Flow accumulation}) * (\text{resolution}) / 22.1)^m) * (0.065 + 0.045 * \text{Slope} + 0.0065 \text{Slope}^2) \quad (3)$$

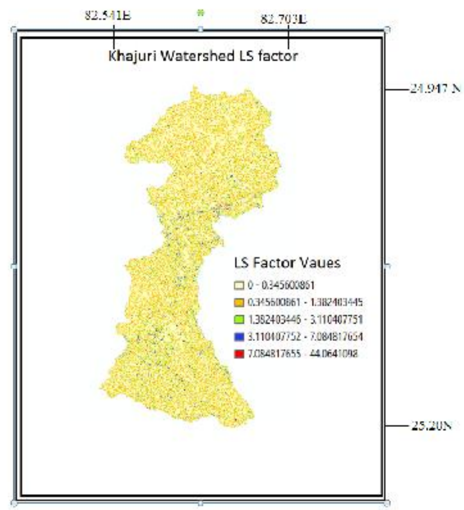

Fig. 4. *Topographic Factor (LS)*

D. *Cropping management factor (C)*

(Loh) pointed towards the use of various Vegetation Indexes(VIs) for estimation of C factor. The most widely used indicator of vegetation growth is the Normalized Difference Vegetation Index, which for Landsat-TM is given by the following equation(4):

$$NDVI = (NIR - red) / (NIR + red) \quad (4)$$

Where, *NIR*: the reflection of the near infrared 1portion of the electromagnetic spectrum and *IR*: the reflection in the visible spectrum. NDVI values range from -1.0 to 1.0. NDVI threshold between a full and a partial vegetation cover allows one to scale NDVI between hare soil and 100%(Carlson and Ripley). In the present study LANDSAT-8 data of 30m resolution was used to generate NDVI map and then the value of C-factor was calculated in Raster calculator using the relation(5) as follows:

$$C = e^{(-a((NDVI)/(b-NDVI)))} (5)$$

Where 'a' and 'b' are unit less parameters and there values were taken as 2 and 1[25].

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E. Supporting conservation practice factor (P)

The study area no major conservation practices are followed except that the agricultural plots under cultivation are bounded. Hence, on the basis of value suggested by Parveen and Kumar [21], agricultural lands were assigned P factor of 0.28 and other land uses were assigned P factor of 1.

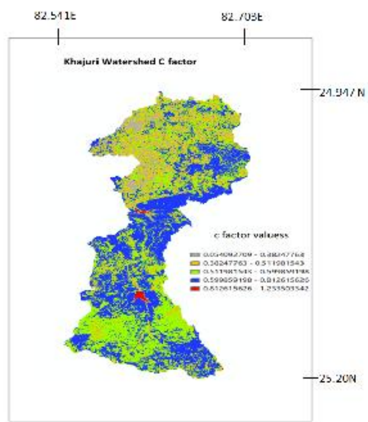

Fig.5. Cropping management factor (C)

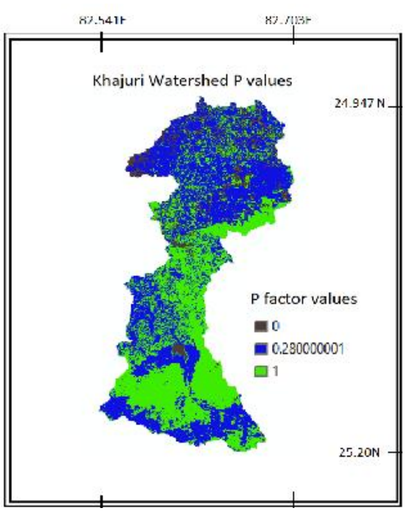

Fig.6. Supporting conservation practice factor (P)

RUSLE is used for estimating average annual soil erosion loss based on sample plot data. What we require is to map the spatial distribution of soil erosion risk; for which we use remote sensing and GIS. We used RUSLE equation to calculate the annual average soil loss rate in ton/ha/year. For prediction of annual average soil loss rate, the R, K, LS, C and P factors were multiplied with the aid of the raster calculator function tool of ArcGIS. Thematic maps of the parameters and the estimated potential soil erosion were determined. Utilizing this information precisely by focusing on management interventions along with giving priority to sectors with severe erosion along River Khajuri Watershed, resulted in this particular conclusion. The pixel level soil loss value was estimated and categorized into five classes. Fig. 7.

V. Results and Discussion

In general, RUSLE is used for estimating average annual soil erosion loss based on sample plot data. The use of remote sensing and GIS allows us to map the spatial distribution of soil erosion risk. The RUSLE equation was used to calculate the annual average soil loss rate in ton/ha/year. In order to predict the annual average soil loss rate, the R, K, LS, C and P factors were multiplied using the raster calculator function tool of ArcGIS .Thematic maps of the parameters and the estimated potential soil erosion were determined. With this information, management interventions can be precisely focused and priority given to areas with severe erosion along River Khajuri Catchment. The estimated pixel level soil loss value was grouped into Five classes. The results shown in Table 2 and Fig. 8. show that about 76 % of the study area is classified as low potential erosion risk(0–10t/ha/yr). About 11 %of the study area is under the high to very high erosion risk (20 t/ha/yr). The spatial pattern of soil erosion classes indicates that the areas with high erosion risk are mainly located in the foot hills.

Erosion	%Area
Very Low(0-10)	72.24776725
Low(10-20)	5.83649631
Moderate(20-40)	6.60165429
High(40-60)	2.115803426
Very high (60 and above)	13.19827872

Table II Results of the analysis

Further, the erosion map was compared with current LULC map. It was found that most of the plantation tracts and fallow lands on the sloping foot hills require immediate attention of soil conservation practices. As of today, barren lands have suffered very high soil loss whereas soil erosion is lower in the dense forests as well as agricultural fields

The methods and results described in this article are valuable for understanding the relationship between soil erosion risk and LULC classes and are useful for managing and planning land use that will avoid land degradation. It is evident that the steepest slopes show high risk of soil erosion, and is therefore recommended that further study be

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undertaken to establish the suitable soil and water conservation measures required to be implemented in these areas as well as the whole watershed.

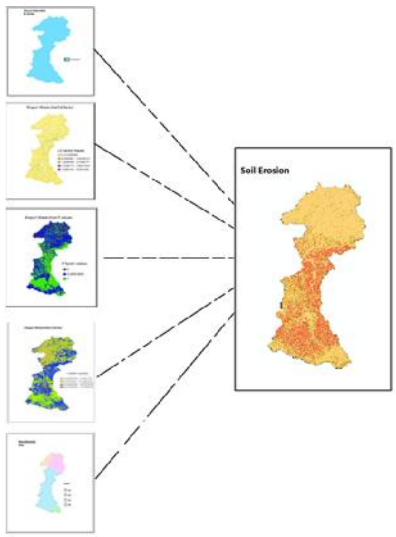

Fig. 7. Accumalation of all factor to generate erosion map of the region

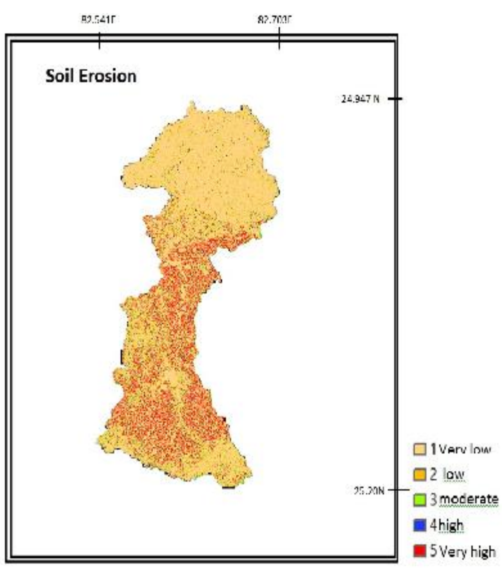

Fig. 8. Final map showing variation of erosion in the region.

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