# Delineation of hot spots by soil loss estimation using GIS modeling approach

*A case of Nayagram Block, Jhargram District, West Bengal, India*

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***Abstract :*** Soil erosion is considered as one of the most significant aspect in soil degradation dynamics. Such geomorphic process naturally continues all over the world with varying level of intensity. Variables such as climate, soil type, topography, vegetation cover and anthropogenic activities greatly influence the process and spatial distribution of soil loss. Often the intensity of soil erosion is triggered by some unplanned anthropogenic interference like, inappropriate agricultural method, over grazing, over exploitation of forest resource etc. to transform it into a serious hazard. Thus monitoring of soil loss is essential not only to reveal the spatial distribution of soil erosion scenario but also to trace the pockets of hotspot having high risk of degradation. Present study was carried out in the Nayagram block of Jhargram district located in the south eastern fringe of Chotanagpur plateau. Soil loss of the area is estimated by using GIS based M-RUSLE which is a modification of revised universal soil loss equation (RUSLE). Different factors, namely the rainfall and runoff (R), soil erodibility (K), slope length and steepness (LS), Cover management (C) and conservation practice (P) factors have been measured by the processing of either geospatial data like satellite images and digital elevation model or conventional data like rainfall data and soil map. By applying M-RUSLE, average annual soil loss of the study area was estimated as 0.060 ton per hectare per annum. The work transmits immense potentiality in estimation of soil loss and forwarding a layout for proper planning to arrest the same.

***IndexTerms* - Soil loss, erosion, RUSLE, M-RUSLE, factor.**

## I. Introduction

Soil erosion is considered as one of the most significant aspects in soil degradation dynamics. It results in both on-site and off-site impacts. Sediment fluxes caused by soil erosion exert its influences badly on soil fertility and channel morphology by exporting the top soil into water bodies and streams (Pimentel et al.1995). The process of soil erosion by water involves detachment, transport and subsequent deposition of soil particle ranging from very fine to very coarse texture (Meyer and Wischmeier 1969). Such process naturally carries on all over the world with different level of intensity under varied geographical condition (Colombo et al. 2005). Variables such as climate, soil type, topography, vegetation cover and anthropogenic activities greatly influence the process and spatial distribution of soil erosion (Lee 2004, Jain and Das 2010). Not only soil resource but also the study of soil loss plays a vital role in sustainable management of various other resources including water, vegetation, agriculture etc. Estimation of soil loss along with the assessment of its influencing variables has become an important agenda in environmental conservation along with economic development planning acknowledging its generic link with biophysical and socioeconomic conditions of the concerned sites.

Indeed it is very difficult to estimate soil erosion precisely as it arises from a complex interaction of various natural as well as anthropogenic process (Singh et al. 2008). Accuracy of the derived results strongly depends on the adopted model for soil loss calculation and reliability of its factors. Contemporarily the models can be grouped into three main groups, i.e. empirical, conceptual and physical (Merrit et al. 2003). The empirical models have greater acceptability among research community as these are more applied as well as dynamic in nature. The Universal Soil Loss Equation (USLE) developed by National Runoff and Soil Loss Data centre under US Department of Agriculture has been considered as pioneer among all empirical approach based study. The USLE was designed to predict the average annual soil loss (Wischmeier and Smith 1978) by the help of pre-existed chart and table based value (Renard 1985) available for selected factors, e.g. runoff (R), soil erodibility (K), slope length and steepness (LS), surface cover and management (C) and support practice (P).

With the advent of Remote Sensing and GIS techniques the modeling of soil erosion has gone a further step ahead. Its wide application includes solving environmental problems like degradation of land by water logging, soil erosion, deforestation, changes in ecological parameters and many more (Jasrotia et al. 2002). The information from digital data has been used in generation of several soil erosion factors by replacing ancient tables and charts. These are more reliable as they provide up to date information on various characteristics of land surface (Deng et al. 2008). By the integration of recent techniques and additional data Revised Universal Soil Loss Equation (RUSLE) was developed from USLE (Renard and Ferreira 1993, Yoder and Lown 1995). It followed the same algebraic operation as the USLE, but the derivation of factors like C, LS and P has been done by following new approach (Karaburun 2010).Since the last 40 years, RUSLE model is widely used as a predictive model for estimating soil erosion (Renard et al. 1997).

The modified RUSLE model with enhanced C factor has great potential for producing accurate and inexpensive soil erosion scenario in the selected site. This experiential study was carried out in a Community development block under Subarnarekha River Basin locating in south-eastern part of the Chotanagpur plateau. In the present study mandatory input factors have been derived from annual rainfall data, soil map, Digital Elevation Model (DEM), Normalized Difference Vegetation Index (NDVI) respectively. Considering the severity of soil erosion along with its diagnostic propaganda, it is wise to target the areas with high risk or prevailing *hotspots*, rather than spreading them equally across the landscape (Berk 2008).

## II. STUDY AREA

Nayagram, a community development block under the Subarnarekha River Basin located in south western part of Jhargram district, West Bengal, India has been consulted in the present study. It is bounded by $22^{o}\ 44^{/}$ N to $22^{o}\ 74^{/}$ N latitude and $88^{o}\ 08^{/}$ E to $88^{o}\ 13^{/}$ E longitude covering an area of about 501.44$Km^2$.The Subarnarekha basin forming a part of metamorphic terrain of Chota Nagpur Plateau has attracted the attention of eminent earth scientists for past years. But the area under consideration has received mere attention in this regard.

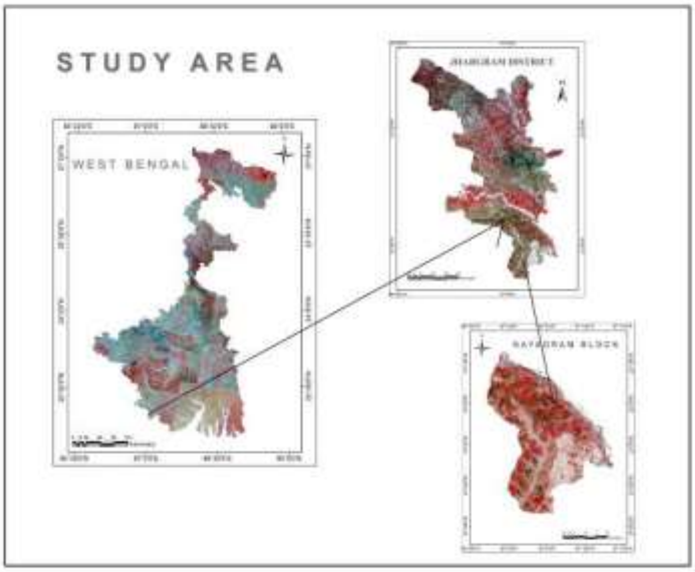


Figure 1 Location of the area

The Study area possesses an undulating topography having highest and lowest elevation of the area from the mean sea level is 110m and 10 m respectively. The drainage of the area is controlled by Subarnarekha river system. It receives about 1615 mm of rainfall of which 90 % is received between May to October. The study area can be divided into 4 soil categories namely, coarse loamy typic ustifluvents, coarse loamy typic haplsfalfs, fine loamy ultic paleustalfs, fine loamy aeric ochraqualfs. Association of forest and greeneries in the area recite its historical connection with Jangal Mahal territory.

## III. METHODOLOGY

### *Data and Software used*

In this study Landsat TM digital data (P/R – 139/45) of 13th February 2010 having resolution 30 m and Cartosat DEM of 2012 has been used and processed under TNT Mips Pro 2013 and ARC GIS 10.1environment..

### *Description of the Model*

The M-RUSLE model with enhanced C factor has been used to produce realistic estimates of average annual soil loss in the selected area (Ferro et al. 1998, Pandey et al. 2007). The M-RUSLE model is expressed with the following equation:

$$\text{M-RUSLE} = [(R/C) \times K \times LS \times P] \qquad (1)$$

Where, A is the amount of annual average soil loss during a specified time period(t ha-1), R is the Rainfall erosivity factor (MJ mm ha-1 yr-1), K represents Soil erodibility factor (t ha-1 per unit of R, LS stands for effects of slope length & steepness, C and P are used to include Crop management and conservation practice dimension. The equation is a modified version of the original formula, ($A = R \times C \times K \times LS \times P$) used in the USLE and RUSLE model. In it the C factor has been transferred to the denominator so that it can transmit its protective strength against soil erosion process (Panagos et al. 2014). The operation was performed in ArcGIS with the help of raster calculator tool to represent soil erosion potential of different grid cell.

## IV. FACTORS OF SOIL EROSION

### *Rainfall erosivity (R)*

Intensity of rainfall directly controls the soil erosion. Rainfall factor is expressed in this study by R factor. Several researchers have attempted to estimate Rainfall erosivity using rainfall data of long time intervals (Morgan 1995). The relationship between rainfall intensity and energy can be identified through different kind of equation. The R-factor is the product of the kinetic energy of a rainfall event having maximum 30 minute intensity (Brown and Foster 1987). In this study, empirical equation (Hurni 1985) was used for the estimation of R-value. So the R can be calculated as:

$$R\ \text{erosivity} = [38.5 + (0.35 \times Pr)] \qquad (2)$$

Where, Pr stands for average annual precipitation of the study area. However like most soil erosion studies, the calculation of rainfall erosivity is limited due to lack of time-series data.

***Soil erosivity (K)***

K-factor represents the inherent erodibility of soil by raindrop and surface flow. It ranges from 0.013 to 0.059 under standard condition (Foster et al. 1981). K value simply increases as the soil content higher amount of silt and sand. Beside texture, organic matter, structure, and permeability also determine the erodibility of a particular soil. In this study K factor has been estimated through experimental equations. According to Wischmeier and Smith, 1978.

$$K\ erosivity = [2.1 \times 10^{-6} \times M^{1.4} \times (12 - Om) + 0.0325 \times (P - 2) + 0.025 \times (S - 3)] \quad (3)$$

Where, M = [{percentage of (silt + very fine sand)} (100 – percentage of clay)]; Om = percentage of organic matter, P = permeability class, and S = structure class. These values can be best estimated from direct field measurements though it has financial restrictions. In this study the value of K was computed from the information provided by soil map prepared by National Bureau of Soil & Land Use Planning (NBSS&LUP). Depending on the inherent characteristics of individual soil type, value of K was assigned following Robert's chart (Robert 2000).

Table 1 Value of K

| Textural Class | Organic Matter Content | | |
|---|---|---|---|
| | Average | >2 % | < 2 % |
| Clay | 0.22 | 0.24 | 0.21 |
| Loam | 0.30 | 0.34 | 0.26 |
| Sand | 0.02 | 0.03 | 0.01 |

Source: Robert, 2000

***Slope length and steepness erosivity (LS)***

LS factor is indeed a combined topographic factor of slope length (L) and slope steepness (S). The slope length factor L is defined as the distance from the origin of runoff source to the point where deposition starts or run off entered into a definite channels. Slope steepness stands for amount of slope which has a linear positive correlation with soil erosion. The interaction of angle and length of slope has an effect on the magnitude of erosion (Edwards 1987). Among many formula available for estimation of the LS factor e.g. Wischmeier and Smith 1978; Moore and Burch 1986, McCool et al. 1987, the Moore and Burch one is selected for the present study as it can be easily derived under GIS environment (Moore and Burch 1986). It is calculated as:

$$LS\ erosivity = [\{(Fm \times Cell\ Size) / 22.13\}^{0.4} \times \{(Ssl \times 0.01745) / 0.0896\}^{1.4} \quad (4)$$

Where, Fm represents flow accumulation and Ssl stands for Sin slope in degree value. Flow accumulation is defined as the accumulated flow to a specific cell from all cells of previous order and sin slope is a derivation of slope raster. Both these are calculated from Digital Elevation Model (DEM).

***Cover management (C)***

In RUSLE model C factor is considered as the most important factor because it depicts the condition that reduced erosion due to land cover management. It is calculated on the basis of prevailing land use type and can be further broken down into sub-features that include vegetative to bare surface cover range. The study used single factor, vegetative cover based land use classification. Normalized differentiate vegetation index (NDVI) is the most common yet useful index in estimating vegetation properties (Jensen 2009). The spectral reflectance difference between Near Infrared (NIR) and Red band is used to calculate NDVI. For the sake of study NDVI layer was prepared using the LANDSAT TM satellite data. Existing relationship between C factor and NDVI values prompted the modified formula of c value extraction (Karaburun 2010). The C factor can be calculated as:

$$C = [(1.02 - 1.21 \times NDVI) \times 100] \quad (5)$$

***Conservation practice (P)***

P factor is represents by conservation practice or support practice factor which affects the overall soil erosion problem. In RUSLE, P factor is the ratio of soil loss with a precise conservation practice in correspondence with cultivation in different slope (Amsalu and Mengaw 2014). There are various cropping methods that can control the erosion by reducing surface runoff. All these methods are very much associated with the slope of the respective cropping field. The P value 0 represents a very good erosion resistance condition whereas maximum value of 1 suggests complete absence of erosion resistance facility. The study adopts the P value according to the cultivating methods and slope (Shin 1999).

Table 2 Value of P factor

| Slope( % ) | 0 – 5 | 5 – 10 | 10 – 20 | 20 – 30 | 30 – 50 | 50 - 100 |
|---|---|---|---|---|---|---|
| P Factor | 0.11 | 0.12 | 0.14 | 0.22 | 0.31 | 0.43 |

Source: Shin, 1999

## V. RESULT AND DISCUSSION

By the implementation of GIS based M-RUSLE model an annual average soil loss map of Nayagram block was developed having cell size of 30 m for the year 2010. Annual average soil loss of the area was estimated 0.06 ton ha-1 y1. Before going in depth about the map, result of individual factor must be highlighted.

The precipitation data was collected from digital rainfall data archive by accessing the web address world rainfall data. From the link average annual precipitation (AAP) of 17 places in the study area was acquired. AAP map shows annual range of 51 mm rainfall with lowest and highest value of 1573 mm and 1624 mm respectively. Rainfall erosivity (R) factor map was prepared on the basis of AAP raster as there is a strong influence of rainfall distribution presence on R value. Rainfall erosivity was found from 589.05 to 606.9 MJ mm ha-1yr-1 with a mean value of 600.872 MJ mm ha-1yr-1 for the selected site (Figure 2). From the map it was found that R value was highest in the southern part of the block and it was lowest towards northern part.

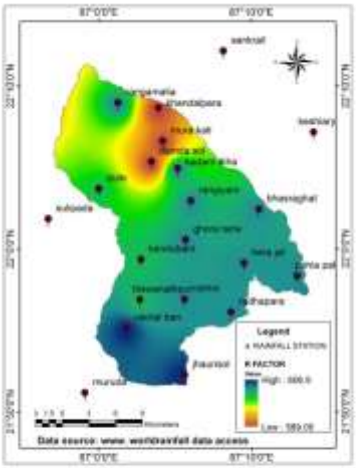


Figure 2, Rainfall erosivity factor

The soil erodibility (K) factor is a quantitative description of the inherent erodibility of a particular soil type. It suggests that when other factor remains unchanged, intensity of soil loss directly relates with K value of particular soil type. The soil erodibility map (Figure 3) of the study area have been prepared having unit t ha-1. The average K factor for the entire site was calculated as 0.221 t ha-1. K value was varied between 0.039 t ha-1 - 0.349 t ha-1. It was found highest in coarse loamy typic haplsfalfs and lowest in fine loamy ultic paleustalfs soil category.

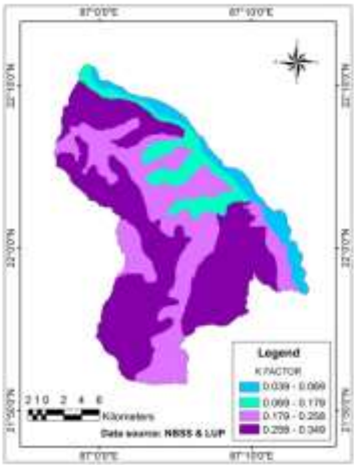


Figure 3 Soil erodibility factor

The Slope length and steepness (LS) factor was developed using flow accumulation and downhill slope. Flow accumulation was derived from flow direction raster. For the preparation of flow direction and flow accumulation ArcGIS hydrology toolset of spatial analysis extension was used. For quality output of flow direction, the Fill Sink feature was applied to DEM.

The map of LS factor (Figure 4) was found in accordance with the complex topography of the selected area. It was observed that the minimum value of LS is 0 and the maximum value is 113.393. The high values were found associated with drainage network of the area. As the area is a planation surface, the topography is not so rugged which brings Slope length and steepness of the river channel under LS consideration.

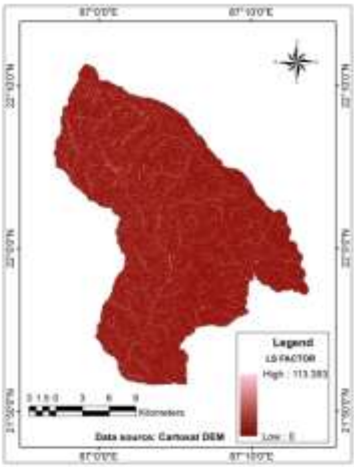


Figure 4 Slope length and steepness factor

Land cover management (C) factor reveals the effect of vegetative cover on soil erosion. The NDVI map of the study area was prepared for the generation of C factor. The value of NDVI for the study area was found between – 0.353 to 0.408. Final C factor map (Figure 5) was developed using NDVI raster. The high C value suggests reduced erosion due to dense vegetation cover, whereas low C value indicates barren, permanent fallow and uncultivated fallow surface which are more prone to soil loss due to minimum vegetative coverage. C value of the area was varied from 52.312 to 144.815 with a mean value of 87.571.

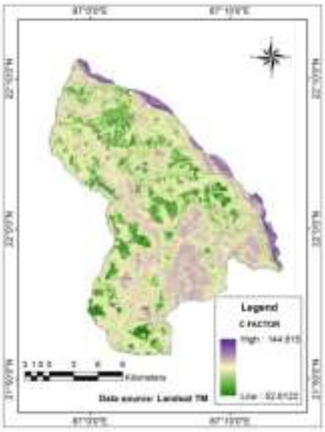


Figure 5 Land cover management factor

The conservation or support practice (P) factor was used in RUSLE model to represent anthropogenic management practices such as contouring, terracing and strip cropping which help in reduction of soil erosion. P value is equal to 1 when the worst or high slope cultivation is practiced. It is less than 1 when the adopted conservation practice reduces soil erosion due to plowing in low slope. Highest and lowest P values (Figure 6) in the present area were found 0.109 and 0.430 respectively.

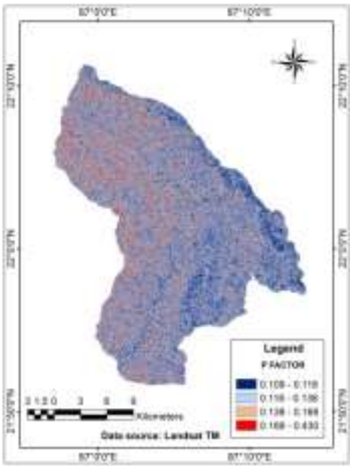


Figure 6 Support practice factor

With the help of M-RUSLE the spatial pattern of soil erosion potentiality of the selected area has been depicted. From the average annual soil loss map, lowest of 0 and highest of 38.909 ton per ha per year was estimated. In order to better representation the annual soil loss raster was classified into 5 zone ranging from very low to very high. High values were associated with steep rugged surface, whereas low values were abundant in low elevate flat surface. During integration of the parameter, though all the factors were given equal weight, yet M-RUSLE output highly depends on LS factor next to C factor.

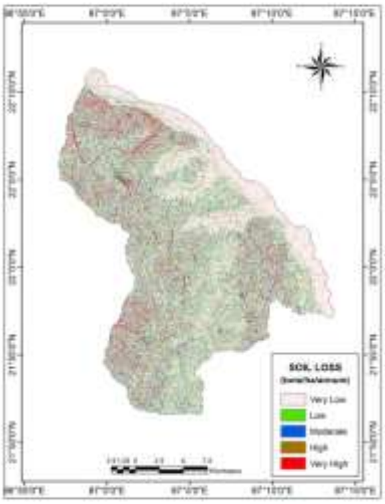

Figure 7 Average annual soil loss map

Due to low moisture content in the elevated area severe soil loss was experienced. Loss of organic matter from agricultural field due to unscientific practice of agriculture was sorted as another concerning fact regarding soil loss. The zone with very high average annual soil loss was identified as the areas with high risk or prevailing *hotspots*. Spatial extension of such zone was found 31.533 $Km^2$ which was calculated as 6.29 % (Figure 8) of total study area. Identification of such degraded spot helps in future management for such a precious natural resource.

Table 3 Classified soil erosion status

| Erosion Class | Numeric Range (ton /ha /year) | Erosion Class | Area in ($Km^2$) | Area in (%) |
|---|---|---|---|---|
| 1 | 0 - 0.050 | Very Low | 327.461 | 65.306 |
| 2 | 0.050 - 0.100 | Low | 61.279 | 12.219 |
| 3 | 0.100 - 0.200 | Moderate | 58.876 | 11.741 |
| 4 | 0.200 – 0.300 | High | 22.290 | 4.446 |
| 5 | 0.300 – 38.90 | Extreme | 31.533 | 6.288 |
| Total | | | 501.439 | 100 |

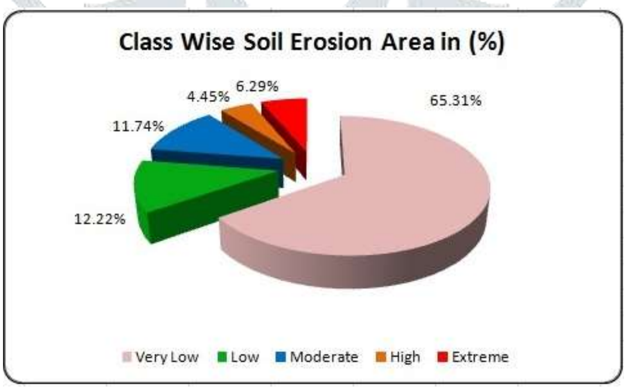


Figure 8 Spatial distribution of soil loss zone

## VI. CONCLUSION

As the selected area is under the influence of high rainfall, coarse textured soil, moderate to high slope and high drainage density, potentiality to average annual soil loss is explored very high. The exploration was done in GIS environment following M-RUSLE model in which responsible factors and their assignment to the model was adjusted depending on the regional environment and field experience. Due to topographic variation rill and gullies are actively participated in transporting the loosen surface downward. The load of eroded material is dumped to areas having low slope. This promotes excessive sedimentation in drainage outlet resulting into lowering of water storage. Hence flood is also very common in this type of morphological condition. Not only flood but also many direct impact of soil erosion was also observed in the selected site, i.e. poor agricultural productivity, forest degradation etc.

Soil, the crucial resource of our environment is depleting first from the various pockets of the study area. Identification of those pockets by GIS based modeling approach a new dimension for planning of management policy. Government intervention along with people awareness is essential for managing this high risk pockets. Adoption of root practice for soil conservation, i.e. plantation, placing mat of grass, adoption of proper farming method will be also helpful in this regard. Nevertheless the study put forward a new approach for the potential estimation of average annual soil loss.

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