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Modeling of Risk of Soil Erosion in Kharkai Watershed using RUSLE and TRMM Data: A Geospatial Approach

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Abstract: ***Soil erosion is one of the most important environmental problems, and it remains a major threat to the land use of mountainous environment. Assessment on soil erosion hazard is essential for soil conservation plans in a mountainous region for sustainable development. RS and GIS technique has been recognized as a powerful and effective tool in detecting land-use change. Its assessment and mapping of erosion prone area are very essential for soil conservation and watershed management. The RUSLE Model has been used for the average annual soil loss of the Kharkai watershed, Jharkhand, India. To achieve the goal of the thesis, the RUSLE factors were calculated.***

Keywords: Soil Erosion, RUSLE, Remote Sensing, GIS

1. Introduction

Soil erosion is a major problem throughout the world (Rauschkalb 1971; Hitzhusen 1993). More than 56% of land degradation is caused by water erosion, raising a global concern on land productivity (Elirehema, 2001). Soil erosion not only reduces soil depth, but also reduces the capacity of soils to hold water due to sealing and depletes plant nutrients in the soil. This reduces soil productivity and causes long term reduction in crop yields (Nanna, 1996), since the necessary plants nutrients are washed away. Apart from reduction in plant nutrients, soil loss also results in siltation and deposition in streams (Sthiannopkao et al., 2007). As the economies of developing countries are based primarily on agricultural production, the primary concern in leveling off the agricultural growth is soil erosion and land degradation. Soil erosion is one form of soil degradation along with soil compaction, low organic matter, loss of soil structure, and poor internal drainage problems. Soil erosion is a naturally occurring process on all land and it becomes a problem when human activity causes it to occur much faster than under natural conditions. Erosion hazard is a major land degradation problem in mountainous environment. Nowadays one of the major problems on global scale is the rapidly increasing demand to the food. This demand is of course totally parallel to the population growth. Even more land is used for agricultural purposes day by day. Cultivation without using specific control techniques, unplanned land use, such as establishing industrial facilities or constructing summer houses on the agriculture land, uncontrolled urban development and also destroying forests are fundamental factors of soil erosion (Biard and Baret, 1997). Soil erosion is fundamental and complex natural process that depends mainly on rainfall erosivity, soil erodibility, land cover and topography, and is strongly modified by human activities such as land clearance, agriculture (ploughing, irrigation, grazing), forestry, construction, surface mining, and urbanization. Soil loss is normally estimated with empirically and physically-based models (Jha & Paudel, 2010). The physically-based models are - Water Erosion Prediction Project (WEPP) (Flanegan & Nearing, 1995), Limburg Soil Erosion model (LISEM) (De Roo, Wesseling, & Ritsema, 1996), European Soil Erosion Model (EUROSEM) (Morgan et al., 1998), and Revised Morgan, Morgan and Finney model (RMMF) (Morgan, 2001).And Empirically based models are - SLEMSA (Soil Loss Equation Model of Southern Africa), and Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978).

2. Objective

The main objective of this study is to estimate the annual average soil loss of Kharkai Watershed...

Sub Objective

- Landuse/Landcover Map.
- Digital Elevation Model.
- Slope Map.
- 3D Visualization of DEM.

3. The Study Area

Kharkai River flows through Adityapur region of Jamshedpur. It arises in Mayurbhanj district, Odhisa, on the north slopes of Darbarmela Parbat and the western slopes of Tungru Pahar, of the Simlipal Massif. It flows past Rairangpur and heads north to about Saraikela and then east, entering the Subarnarekha in north-western Jamshedpur. Its tributaries are the Kardkai, on the left; the Kandria, Nusa and Barhai on the right; and the Karanjia on the left. Approximately nine 10ilometres below the junction with the Karanjia, the Kharkai River forms the boundary between Odisha and Jharkhand State. Its last major tributary is the Sanjai, entering from the left, seventeen kilometers, as the river flows, above its mouth

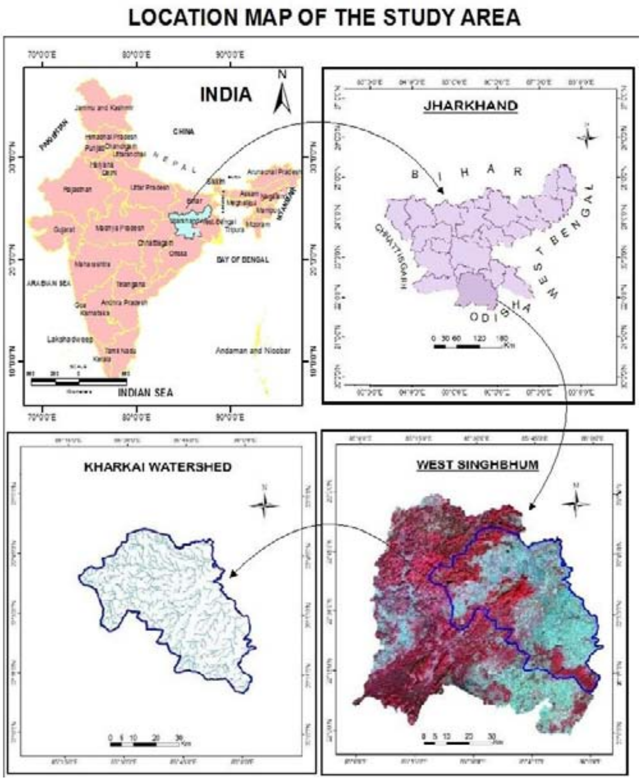

Figure 1: Location Map of the Study Area

(Wikipedia).The longitude of the area is 85˚15'-86˚15' & the latitude is 22˚00'-23˚00'. Kharkai is the tributary of Subarnarekha River. The length of the Kharai River is 136km. The catchment area of the river is 6, 611 sq.km. The Kharkai watershed falls in the West Singhbhum District in the state of Jharkhand. West Singhbhum district is located in the southern portion of the state Jharkhand. The longitude of the area is 84˚45'-86˚15' & the latitude is 21˚45'-23˚00'. It is the largest district of the state. It is bounded by Ranchi in the north, Saraikela in the east, Orissa in south and Simdega in the west. It has an area of 7182 sq. km area. The district comprises two subdivisions (Chakradharpur and Chaibasa) and fifteen development blocks. Besides the district headquarter of Chaibasa the other towns in the district are: Chakradharpur, Chiria, Gua, Jhinkpani, Kharsawan, Kiriburu, Noamundi.The blocks in the district are: Bandgaon, Chakradharpur, Chaibasa, Goilkera, Jagannathpur, Jhinkpani, Khuntpani, Kumardungi, Majhgaon, Manjhari, Manoharpur, Noamundi, Sonua, Tantnagar, Tonto.

4. Climate

This watershed is influenced by south west-monsoon. It starts in the month of June and prevails till October. The watershed receives an annual rainfall of 1400 mm. The average annual rainfall of 12 years (2001-2012) is 1397.41-1528.83 mm. Most of the rainfall occurs during the rainy season. July is the rainiest month in the area. The climate is basically tropical with hot summer and mild winters. The winter season remains reasonably cold when minimum temperature is 3°C to 4˚C and the average temperature remains at 16˚C.The winter is generally mild and it extends from October to the end of February. Fogs are uncommon except in deep valleys. Frosts are not of common occurrences except in some remote corners of the forest. During summer the highest temperature is 47.2°C and the lowest is 2.8°C.The mean monthly temperature varies between 40.5˚C–9.00˚C.Annual averages temperatures vary between 32.4°C to 18.0°C.

5. Physiography, Geology and Drainage

This West Singhbhum is dominated by hiily ranges, valleys and plateaus. Hilly and steep sloping areas provide dense forest cover. Of all the geological formations which occur in the district the following three are the most important : (a) granites and gneisses of Archaean age intrusive into the oldest sedimentary rocks, now highly metamorphosed, and known as the Singhbhum granite and gneiss, the Chotanagpur granite-gneiss, and the Chakradharpur and Akarsani granophyric granite-gneiss; (b)the Iron-ore Series which are mostly metamorphosed, ancient sediments with contemporaneous basic igneous rocks and are equivalent to a large part of the Dharwar System of Indian Geology, and (c) the volcanic lava flows of the Dalma hill and its adjoining ranges.

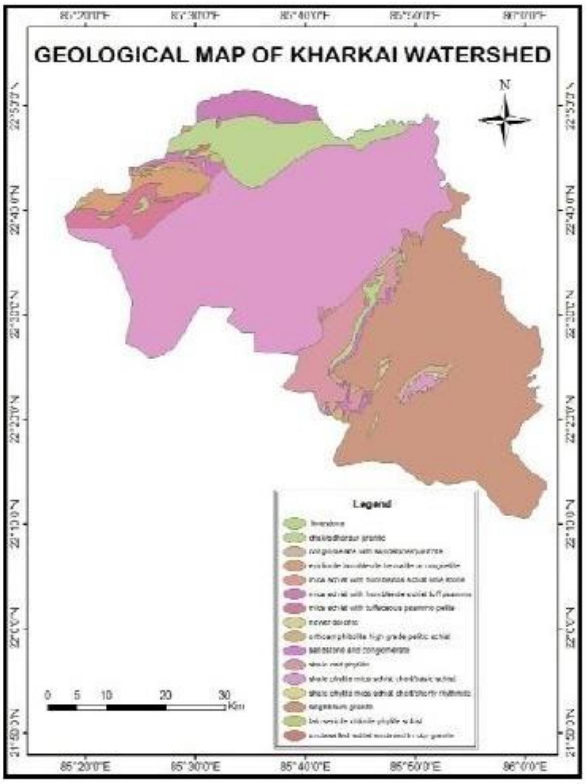

Figure 2: Geological Map of Kharkai Watershed

The Kolhan basin comprises a sequence of sandstone, limestone and shale overlying unconformably a shallow platform shared by the Singbhum Granite basement on the NE, the Jagannathpur lavas on the SE and S and the Iron Ore Group of the eastern arm of the Noamundi Syncline on the west. The Jagannathpur lavas in the south have faulted boundaries with the Kolhans but the Jagannathpur lava and the Iron Ore Formation are believed to underlie the Kolhans. The western boundary of the Kolhan Basin is faulted against the Iron Ore Group (Saha, 1994). North of the Hat Gamaria, the Kolhan shales are intruded by sills of Newer Dolerite (Saha, 1994). The entire Kolhan Basin is thought to be composed of low grade metamorphosed sedimentary rocks. Important ridges are Desbar, Dalma, Chandri Pahar, Raisindri, etc. Important rivers in the area are South Koel, Sanjay Baitarni, Roso, Brahamini, Deo, Koyana, Kharkai etc.

6. Structural Features

The most important structural feature of the geology of the district is a series of great anticlines and synclines which veer round from west-east to north-west-south-east in the northern part of the district. A series of highly metamorphosed rocks form, a great geoanticline which commencing from the east in North Singhbhum extend through Seraikela, turning south-east near Jamshedpur. It thus forms a great curve in the northeastern part of the district which turns southwards near the Mayurbhanj border. Northwest of Kharsawan, a north-westerly branch of the anticline forms an almost closed dome known as the Sonapet anticline. Another remarkable structural feature is a great shear zone which has formed along the overfolded southern limb of the geoanticline as a zone of overthrust. This shear zone follows the same trend as the latter. From west to east trend in the Western part of the district in the north, it takes a decided turn to the south-east along the north-east foot of the hills of the Dhanjori range through Rakha Mines and Badia. It then cuts across the Dhanjori quartzite farther south-east and disappears in the schists towards Singpura. Along this thrust zone the rocks have been highly sheared and even granites have been mylonitised. This zone almost bisects the rocks of Singhbhum and forms a broad arc convex towards the north as it again swings to a west-south-west-east-north-east trend in the Koihan. Its westerly section is marked by the valley of the Sanjai and the railway line. It would thus appear that the Iron-ore Series of sedimentary rocks were folded into well defined anticlines and synclines over-folded towards the south, and formed a great mountain range, extending east to west across North Singhbhum and South Ranchi to North Dhalbhum. South of this main axis of folding, earth movements were less intense and the rocks of Central and South Singhbhum are generally less metamorphosed than those of North Singhbhum.

7. Topography

The Digital Elevation Model (DEM) shows the topography of the area. The area represents an undulating topography with an average height of 350m. The maximum height of the area is 806m & the minimum height is about 102m. The 3D view of the digital terrain model (DTM) show the undulating surface of the study area. The north-east and southern regions are comparatively densely forested with many tropical trees.

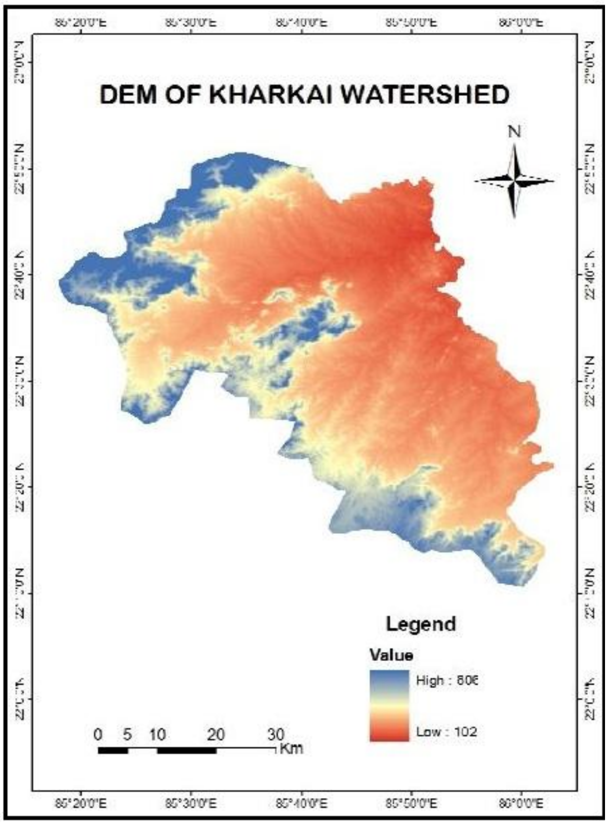

Figure 3: DEM of Kharkai Watershed

8. Agriculture & Land Use

The area reveals variation in land use pattern. All the hilly ranges are under forest cover and only in patches cultivation observed. Chaibasa plain area is mostly under agricultural use. Main sources of irrigation are canals and
Reservoirs. Most of the land is vacant.

9. Soil

The area is covered with various types of soil. In this area fine soil, loamy soil, fine loamy soil, coarse loamy soil & gravely loamy soil are observed. Soil map has been used From State Agricultural Management & Extension Training Institute (SAMETI), Jharkhand.

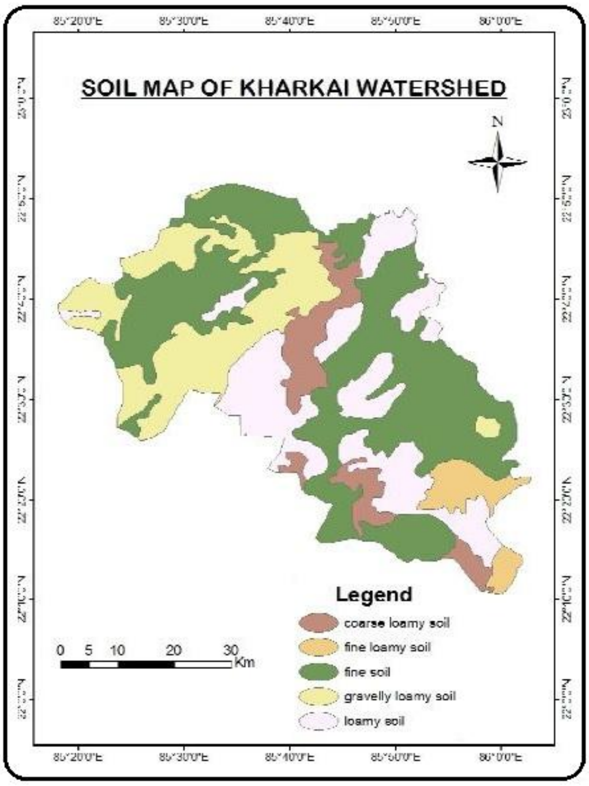

Figure 4: Soil Map of Kharkai Watershed

10. Materials & Methodology

1) Data Used

The various types of data used in this study are:

- Landsat 8 Satellite Imagery.
- Cartosat Data for Elevation Map.
- TRMM Data for Rainfall.
- Soil Map.

2) Landsat 8 Satellite Imagery

Landsat 8 satellite imagery at spatial resolution of 30 m acquired on 11th November 2013 has been used in this study, georeferenced with WGS_1984_UTM_Zone_45. Landsat 8 is an American Earth observation satellite launched on February 11, 2013. It is the eighth satellite in the Landsat program; the seventh to reach orbit successfully. Originally called the Landsat Data Continuity Mission (LDCM), it is collaboration between NASA and the United States Geological Survey (USGS). With Landsat 5 retiring in early 2013, leaving Landsat 7 as the only on-orbit Landsat program satellite, Landsat 8 will ensure the continued acquisition and availability of Landsat data utilizing a two-sensor payload, the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). Respectively, these town instruments will collect image data for nine shortwave bands and two long wave thermal bands. The satellite has been developed with a 5.25 years mission design life but has enough fuel on board to provide for upwards of ten years of operations. Landsat 8 data includes additional bands, the combinations used to create RGB composites differ from Landsat 7 and Landsat 5. For instance, bands 4, 3, 2 are used to create a color infrared (CIR) image using Landsat 7 or Landsat 5. To create a CIR composite using Landsat 8 data, bands 5, 4, 3 are used.

Table 1: OLI Spectral Bands:

Spectral Band	Wavelength	Resolution
Band1- Coastal / Aerosol	0.433 - 0.453 µm	30
Band 2 – Blue	0.450 - 0.515 µm	30
Band 3 – Green	0.525 - 0.600 µm	30
Band 4 – Red	0.630 - 0.680 µm	30
Band 5 - Near Infrared	0.845 - 0.885 µm	30
Band6 – Short Wavelength Infrared	1.560 - 1.660 µm	30
Band 7 – Short Wavelength Infrared	2.100 - 2.300 µm	30
Band 8 – Panchromatic	0.500 - 0.680 µm	30
Band 9 – Cirrus	1.360 - 1.390 µm	30

3) TRMM Data

In this study, a continuous rainfall record was adopted from TRMM rainfall data. Here, the average monthly rainfall image of 12 years have been used from 2001-2012. The 3B43 Version 7 dataset has been used. TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) and was primarily designed to study and monitor tropical rainfall. This data is acquired globally, and is free of charge. It can be retrieved either as graphic illustrations/ or as contour maps for any area worldwide and to any selected time interval.3B43 TRMM Data: The 3B43 dataset merges the daily 3B42 dataset with the GPCC rain gauge analysis. The resulting 3B43 rain rates are monthly averages gridded over 0.25 x 0.25 degree lat/long boxes. The 3B43 retrieval algorithm used for this product is based on the technique by Huffman et al. [1995, 1997] and Huffman [1997].The TRMM 3B43 data used are freely available from the NASA database. This dataset is the result of the combination of precipitation datasets (Microwave Imager TMI, Precipitation Radar PR, Visible and Infrared Scanner VIRS with the Special Sensor Microwave Imager.

4) Soil Map

In this study the soil map has been used from State Agricultural Management & Extension Training Institute (SAMETI), Jharkhand. The soils in this area are-Coarse Loamy, Fine Loamy, Fine Soil, Gravelly Loamy Soil, Loamy Soil.

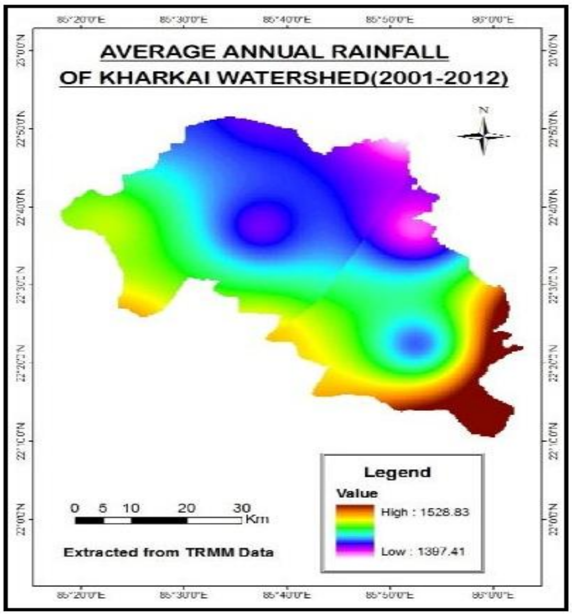

Figure 5: Average Annual Rainfall of Kharkai Watershed (2001-2012)

11. Software Used

In this thesis several types of software have been used. The software's are-Arc GIS 9.3, Envi 4.7, Erdas Imagine 9.0, Ms Excel, Ms Word.

12. Methodology

The RUSLE (Revised Universal Soil Loss Equation) model was implemented in geographic information system (GIS) for predicting the soil loss. Several erosion models are available to predict the soil loss and to assess the soil erosion risk. The Universal Soil Loss Equation (USLE), an empirical model (Wischmeier and Smith 1978) or RUSLE model (Renard *et al* 1997) are widely used to predict potential soil water erosion. Apart from rainfall and runoff, the rate of soil erosion from an area is also strongly dependent on its soil, vegetation and topographi characteristics. In real situations, these characteristics are found to vary greatly within the various subareas of a watershed. A watershed therefore needs to be discretized into smaller homogeneous units before making computations for soil loss. It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands (Millward and Mersey, 1999; Boggs et al., 2001; Mati and Veihe, 2001; Angima et al., 2003).The USLE is an empirical equation that was developed to predict soil erosion rates from agricultural fields in the United States of America (Wischmeier & Smith, 1978). It has, however, been used widely all over the world either in the original or modified form (Mellerowicz, Ress, Chow and Ghanem,, 1994), because of its simplicity and limited data requirement. Simple models have limited data requirements and thus can be practical for large watersheds in developing countries, where data may be lacking (Millward & Mersey, 1999; Kinnell, 2001; Fistikoglu & Harmancioglu, 2002; Renschler & Harbor, 2002). RUSLE uses the same empirical principles as USLE, but includes numerous improvements in computation of various factors. It predicts longtime average annual soil loss as a product of rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), vegetation cover (C) and conservation practices (P) factors. Among these factors, topographic factor is most sensitive in prediction of the soil loss (Risse *et al* 1993). The product of slope length (L) and slope steepness (S) factor represents the topographic factor (LS). The Revised Universal Soil Loss Equation (RUSLE), which is greatly accepted and has wide use is simple and easy to parameterize and required less data and time to run than other models. The RUSLE was applied in GIS software to determine the average annual soil loss and its distribution in the study area. The RUSLE predicts soil loss for a given site as a product of six major factors whose values at a particular location can be expressed numerically. The RUSLE is suitable for predicting long-term average of soil losses. The soil erosion is calculated as follows:

$$A = R*K*LS*C*P$$

Where, A is Average Annual Soil Loss (ton/hec/year)
R is Rainfall Erosivity Factor
K is Soil Erodibility Factor
L is Slope Length Factor
S is Slope Steepness Factor
C is crop management factor
P is conservation supporting practices factor

13. Rainfall Erosivity Factor (R)

R factor is the principal function of USLE, which is mainly responsible for the amount of soil loss. Rainfall erosivity is a term that is used to describe the potential for soil to wash off disturbed, de-vegetated areas and into surface waters during storms. It is an index of rainfall erosivity which is the potential ability of the rain to cause erosion. R is a measure of erosivity of rainfall which is the product of storm kinetic energy and maximum 30 minute intensity EI30. When other factors are constant storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30 minute intensity (I-30) (Arnoldus, 1978) .

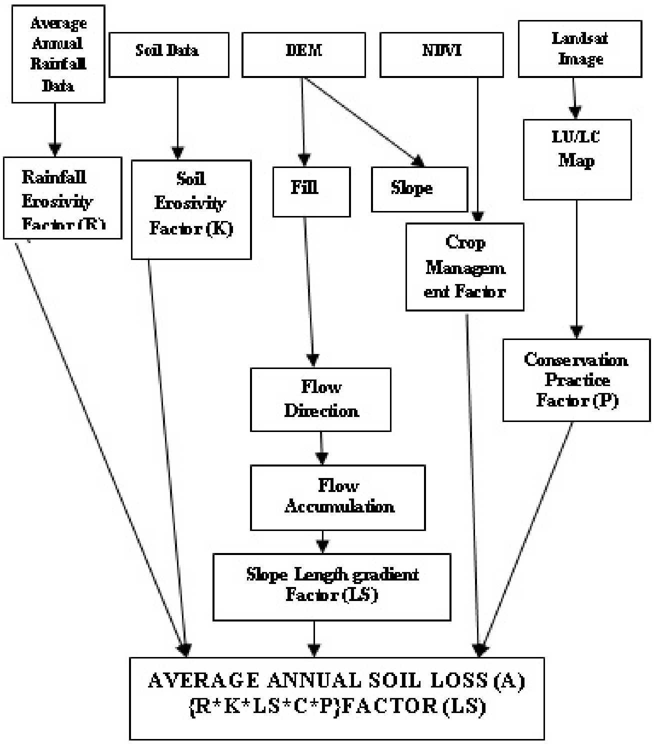

Figure 6: Flowchart of the Methodology

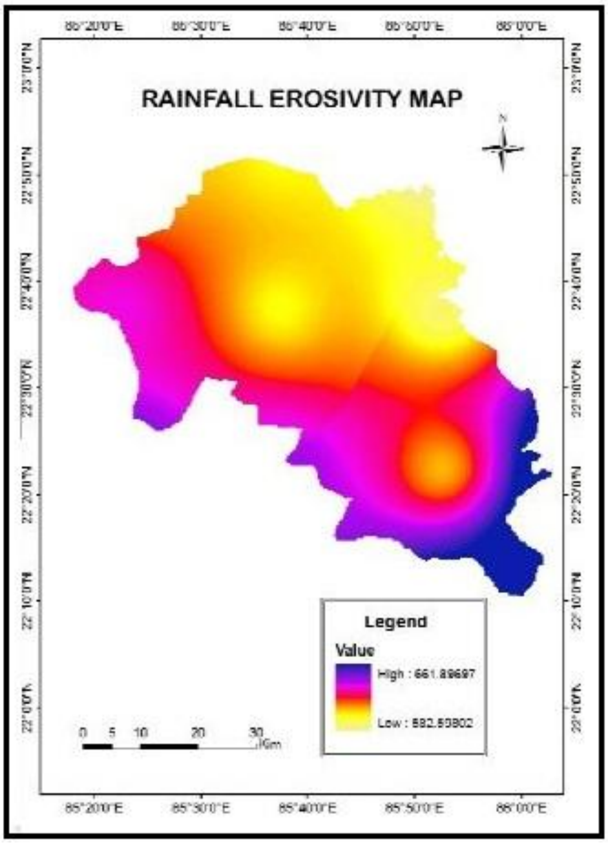

Figure 7: Rainfall Erosivity Factor map.

Most of the time rainfall intensity and storm kinetic energy data are not available at national Meteorological Stations. By the absence of rainfall intensity and storm kinetic energy data for this study area, average annual rainfall data have been used to estimate the R factor (Arnoldus, 1978). It can be assumed that if there is no rain, contribution of other factors of USLE will result in a much less amount of soil loss, which perhaps can be attributed to erosion because of wind. This factor is may be the most important factor in the USLE compared to the other input parameters (Jebari, 2009). The kinetic energy of the rain can be considered as the potential rainfall energy available to be transformed into erosion. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994).Here average annual rainfall data of 12 years (2001-2012) have been used to calculate R factor. The R factor was determined using the formula,

$R = 79+0.363Xa$ (Choudhury and Nayak, 2003)
Where, R= Rainfall Erosivity,
Xa = The average annual rainfall in mm over the study area.

14. Soil Erodibility Factor (K):

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. The soil erosivity factor, relates to the rate at which different soils erode. However, it is different than the actual soil loss because it depends upon other factors, such as rainfall, slope, crop cover, etc. Higher values of soil erodibility indicate its higher susceptibility to erosion. Soil erodibility factor represents both susceptibility of soil to erosion and the rate of run-off. The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall (Wischmeier and Smith, 1978).The soil erodibility factor, *K*, is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Soil texture is the principle component affecting *K*, but soil structure, organic matter and profile permeability also contribute. K factor is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter content and nature of clay minerals, of which soil texture is an important factor that influences erodibility. In this study, soil textural triangle is used to determine the soil textural class from the percentages of sand, silt, and clay in the soil.

In this study soil erodibility was estimated by using the K values from different sources.

Table: K Values for Different Soil used in Different Studies.

Soil Type	*K Values*	*Reference*
Loamy Soil	0.310	K. C. Krishna Bahadur (2008)
Fine Loamy Soil	0.232	K. C. Krishna Bahadur (2008)
Coarse Loamy Soil	0.256	K. C. Krishna Bahadur (2008)
Gravelly Loamy Soil	0.450	K. C. Krishna Bahadur (2008)
Fine Soil	0.12	U.S. customary

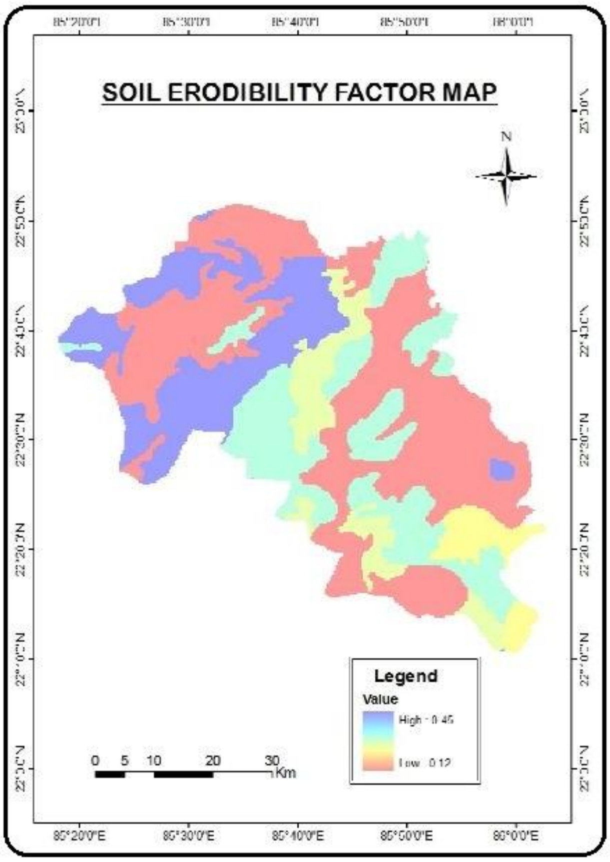

Figure 8: Soil Erodibility Factor map.

15. Slope Length/Gradient Factor (LS)

The slope length/gradient factor, *LS*, describes the combined effect of slope length and slope gradient on soil loss. Slope gradient and slope length are normally combined into one single factor in the RUSLE. The steeper and longer the slope of a field, the higher the risk for erosion. Steep sloping area had higher steepness factor (S) and lowest slope length (L) factor. The highest slope length (L) factor value was observed where overland flow tends to accumulate in the area of concave topography and the lowest in area of convex topography such as ridge, where flow diverges (Hoyos 2005). However, area with higher slope had high LS values. It is the ratio of soil loss per unit area. The influence of topography on erosion is complex. The local slope gradient (S sub-factor) influences flow velocity and thus the rate of erosion. Slope length (L sub-factor) describes the distance between the origin and termination of inter-rill processes (Wischmeier and Smith, 1978; Renard, Foster, Weesies, McCool and Yoder, 1997). Some researchers have argued that upslope drainage area is a better parameter when describing the influence of slope length on erosion, not slope length (Desmet & Govers, 1996a; Moore, Turner, Wilson, Jenson and Band, 1993; Mitas & Mitasova, 1996).

Basically the LS factor can be estimated through field measurement or from a Digital Elevation Model (DEM). Of Digital Elevation Model into GIS, the slope gradient (S) and the slope length (L) may be determined accurately and combined to form a single factor known as the topographic factor LS. With the incorporation The LS factor grid was estimated with the following equation proposed by (Moore and Burch, 1986a and b; Engel, 2005):

LS = ([Flow Accumulation] * [cell size] / 22.13)0.4 * (sin slope /0.0896)1.3

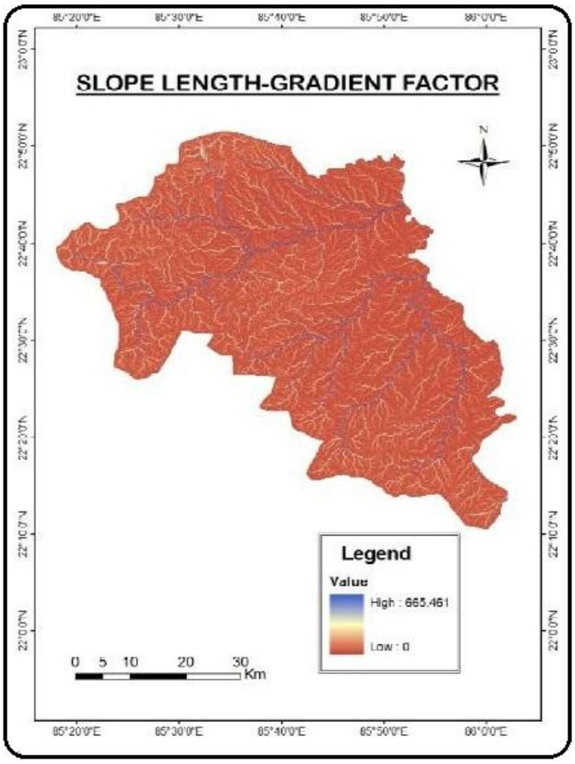

Figure 9: Slope Length-Gradient Factor.

16. Crop Management Factor (C)

Cover factors. In the tropics most farming practices are seasonal, this also affects crop cover in a year, and in some periods there is no crop cover where the land may be bare or weedy. The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The cover management factor (C-values) reflects the effect of cropping and management practices on the soil erosion rate (Renard, Foster, Weesies,

McCool, and Yoder, 1997). It is used to determine the relative effectiveness of soil and crop management systems in preventing soil loss. The C- value is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. Soil loss is very sensitive to vegetation cover with slope steepness and length factor (Renard and Ferreira 1993; Benkobi et al., 1994; Biesemans et al., 2000). Vegetation cover protects the soil by dissipating the raindrop energy before reaching soil surface. The value of C depends on vegetation type, stage of growth and cover percentage (Gitas et al., 2009). The C factor values vary between 0 and 1 based on types of land covers. Since NDVI values have correlation with C factor (De Jong, 1994; Tweddales et al., 2000; De Jong et al., 1999; De Jong and Riezebos, 1997). Here, the C factor was determined using the formula,

C factor = 1.02 – 1.21 * NDVI

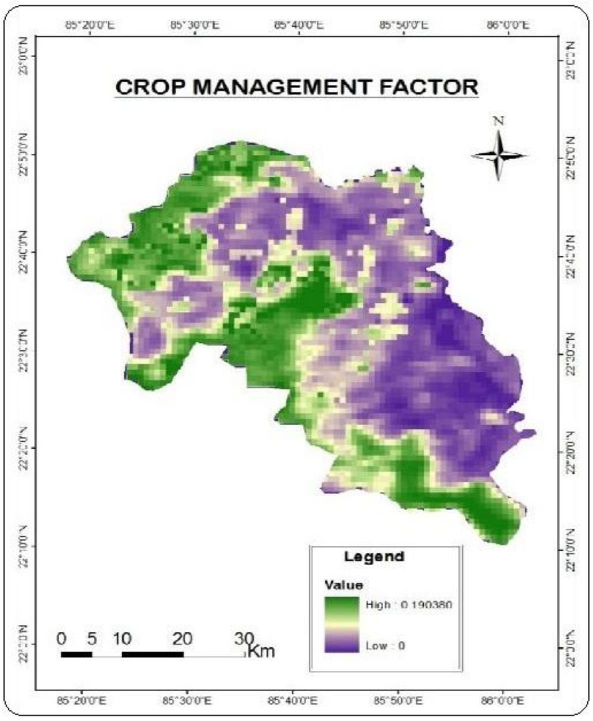

Figure 10: Crop Management Factor

17. Conservation Practice Factor (P)

The P factor is a management soil erosion control. It helps protect the top soil from erosion. It is intentional initiatives of the farmers to control erosion. This factor defines the ratio between soil loss from a field with the given conservation practice to that where no conservation is practiced. When there are no conservation measures the value of P is 1.0 (Morgan, 1986). The conservation practices factor (p-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P-value ranges from 0 to 1 depending on the soil management activities employed in the specific plot of land. Usually the P factor is determined from experimental data like satellite images, aerial photos, and some field observations. Those data help to recognize the erosion control measures applied on the catchment area. For the P value the Supervised Classification has been done in Erdas Imagine 9.0. The classified features are-

- Dense Forest.
- Open Forest.
- Water body.
- Agricultural Land.
- Settlement.
- Fallow Land.
- Barren Land.

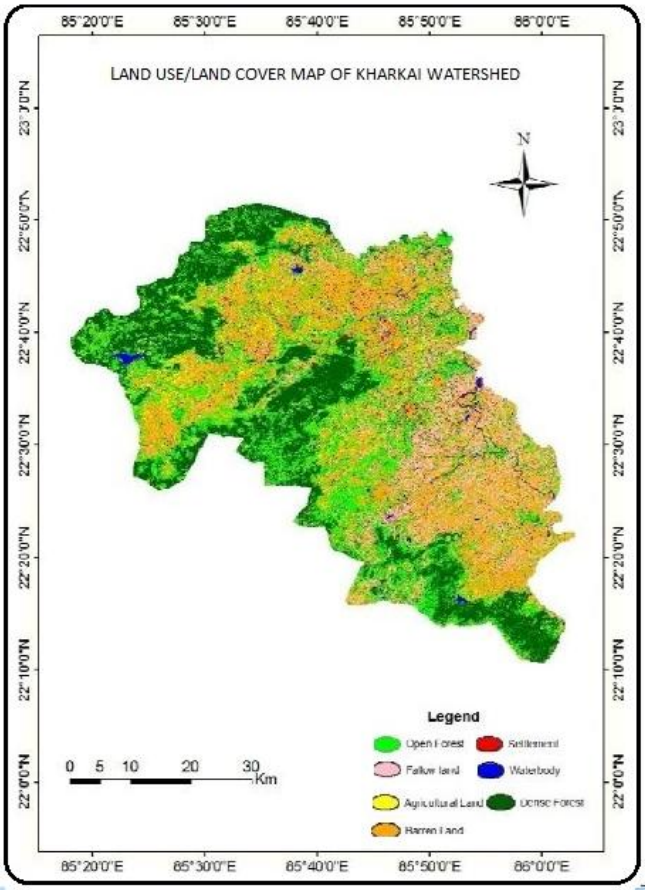

Figure 11: Land use/Land cover Map of Kharkai Watershed

The value of P is obtained from the Table

Landuse/ Landcover type	P-values	Reference
Dense Forest	1	Suresh Kumar and SPS Kushwaha
Open Forest	1	Suresh Kumar and SPS Kushwaha
Waterbody	0	V. Prasannakumar et al. (2011)
Agricultural Land	0.92	Soil & Water Conservation Society 2003
Settlement	0	V. Prasannakumar et al. (2011)
Fallow Land	0.5	Suhas s. Potdar (2003)
Barren Land	1	USDA-NRCS; HDI, 1987; Wischmeier and Smith, 1978

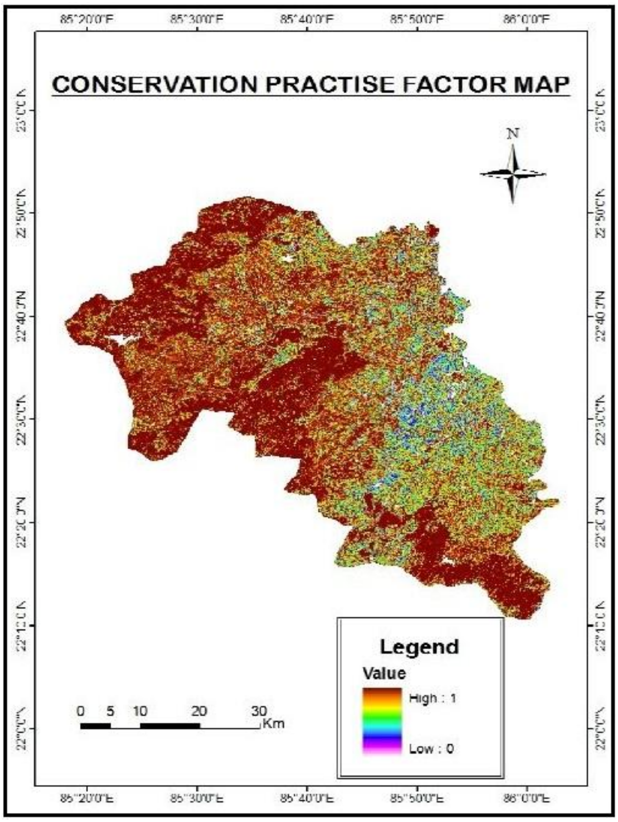

Figure 12: Conservation Practice Factor

18. Result & Discussions

- **Rainfall Erosivity Factor:**

Average annual rainfall map has been prepared from the TRMM Data to get the rainfall distribution map of the entire watershed. The average annual rainfall in the study area varied between 1397.41 mm to 1528.83 mm. The rainfall & runoff erosivity factor map was generated in Arc-GIS from average annual rainfall map. The value of the erosivity varies according to the rainfall distribution. The erosivity factor varied from 582.59802 – 661.89697 MJ ha/mm/hr/yr.

- **Soil Erodibility Factor:**

Soil erodibility is a quantitative estimation of erodibility of particular soil type and the main factor affecting the capability of the soil to erode is its soil texture. However the other factors affecting K factor are soil structure, permeability and the organic matter content. The soil erodibility factor values show that the erodibility of soil is dependent on soils particle diameter and soils with high concentration of clay are least susceptible to soil erosion, while soils with high silt concentration are highly susceptible for soil erosion than that of soils rich in clay and texture. Soil erodibility factor map was prepared from soil map of the study area based on different soil textures. Higher values of soil erodibility indicate its higher susceptibility to erosion; lower values of soil erodibility indicate its lower susceptibility to erosion.

- **Slope Length-Gradient (Ls):**

The slope/topographical factor depend on both the length & gradient of slope. The topographic factors slope gradient and slope length significantly influence soil erosion. It has been observed that soil loss increases more rapidly with slope steepness than it does with slope length. Slope and flow accumulation map was prepared from Cartosat DEM in Arc GIS. Then the LS map was prepared in Arc GIS. The LS factor values range from 0 -665.461.From the analysis of all factors we can say that LS factors seem to have a significant effect on the soil loss in that area. This is because the areas mostly affected by erosion within the study area coincided with the areas where LS factor is the highest contributing area.

- **Crop Management Factor:**

Using the NDVI image of the study area C factor map was generated. The C factor values in the study area varied between 0 to 0.190380.

- **Conservation Practice Factor:**

The erosion management practice, P value, is also one factor that governs the soil erosion rate. The P-value ranges from 0-1 depending on the soil management activities employed in the specific plot of land. For the P value the Supervised Classification has been done from the Landsat 8 image & each feature was assigned their values. Using the values the P factor map was generated. The P factor values in the study area varied between 0-1. When there are no conservation measures the value of P is 1.0 (Morgan, 1986). Higher the P value, higher the soil erosion.

- **Average Annual Soil Loss:**

After completing data input procedure and preparation of R, K, C, P, and LS maps as data layers, they were multiplied in GIS environment to draw up the erosion risk map showing the spatial distribution of soil loss in the study area. Average soil loss was calculated as the product of each pixel value multiplied by pixel area. Rainfall erosivity, Soil erodibility, Slope Length, Slope Steepness, Crop Management Factor, Conservation Practise Factors was calculated. The RUSLE calculated the average annual soil loss. After estimating the different RUSLE factors (R, K, LS C and P), the total soil loss (A) was estimated by multiplying all the factors. Fig.13 shows annual erosion map of study area, helpful in identification of areas vulnerable to soil erosion. 48.46177% of the study area is affected by 0-2 ton/hec/year soil loss, 0.869245% area is affected by 2.1-10 ton/hec/year soil loss, 7.141883 % area is affected by 10.1-25 ton/hec/year soil loss, 11.1724% area is affected by 25.1-50 ton/hec/year soil loss, 13.7573 % area is affected by 50.1-100 ton/hec/year soil loss, 15.86527% area is affected by 100.1-500 ton/hec/year soil loss, 2.732105% area is affected by >500 ton/hec/year soil loss. In the study area, the hilly area has more erosion risk due to its soil erodibility. These areas need special soil conservation measures to check soil degradation depending upon the soil site characteristics and land utilization type.

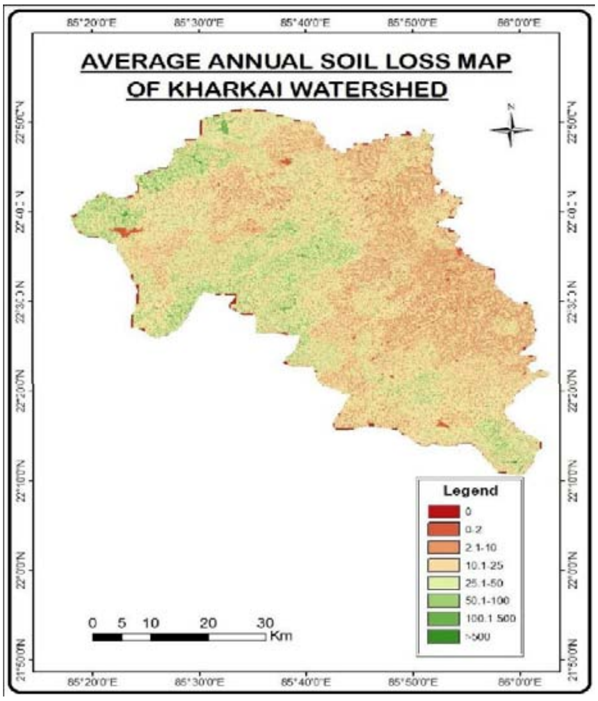

Figure 13: Average Annual Soil Loss

19. Conclusion

This study attempts to evaluate soil losses and map the area susceptible to the soil erosion in Kharkai watershed by means of satellite images and GIS tools. The result shows that the 48.46177% of the study area is affected by 0-2 ton/hec/year soil loss, 0.869245% area is affected by 2.1-10 ton/hec/year soil loss, 7.141883 % area is affected by 10.1-25 ton/hec/year soil loss, 11.1724% area is affected by 25.1-50 ton/hec/year soil loss, 13.7573 % area is affected by 50.1-100 ton/hec/year soil loss, 15.86527% area is affected by 100.1-500 ton/hec/year soil loss, 2.732105% area is affected by >500 ton/hec/year soil loss.

The study demonstrates that the RUSLE together with satellite remote sensing and geographical information systems are useful tools to estimate soil loss over areas. RUSLE is often used to estimate average annual soil loss from an area. Creation of database through conventional methods is time consuming, tedious and is difficult to handle. Therefore various thematic layers representing different factors of RUSLE were generated and overlaid in GIS framework to compute the spatially distributed average annual soil erosion map for the Kharkai watershed.

On the whole, this study has demonstrated conclusively that Remote Sensing and GIS are useful tools for modeling soil erosion.

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