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# Developing soil erosion controlling data layers for MUSLE using RS and GIS: A case study in Raichur district, Karnataka

**Shwetha G and GV Srinivas Reddy**

**Abstract**

The relationship between land attributes and soil erosion process becomes major consideration as resource conservation and development related programmes are being taken up on watershed basis. This study facilitates to obtain such land attributes like soil erodability (K), slope length and steepness (LS), cover management (C) and conservation practice (P) which acts as important input factor to estimate soil loss in selected watershed using MUSLE. The area covers 101.34 km$^2$ between 16º 15'- 16º 30' latitudes and 77º 15'- 77º 30' longitudes. The basic required thematic maps were obtained using Geographical information system tool with processed satellite imagery. The final results of the study gives all the five input factors map (K,LS,C,P) including soil loss map for the watershed. The result revealed that 77.49 t ha$^{-1}$yr$^{-1}$ soil losses occur from Timmapur watershed when calculated using Kirpich time of concentration.

**Keywords:** MUSLE, RS and GIS, watershed, soil loss

## 1. Introduction

Soil erosion is one of the most serious environmental problems in the world today because it threatens agriculture as well as the natural environment. Soil erosion is a natural and land resource problem that occurs on a global scale and can lead to significant economic, environmental, and social impacts. The human impacts on soil erosion can be interpreted from land use changes over long periods and large areas. In India, an area of about 175 M ha out of the total land area of 328 M ha, accounted nearly 53 percent of the total land area is prone to soil erosion (Upadhyay *et al*., 2012) [6]. It is estimated that about 5334 Million tons (16.4 t ha$^{-1}$) of soil is detached annually in India out of which about 29 percent is carried away by river into the sea and 10 percent is deposited in reservoirs resulting in the considerable loss of the storage capacity. Further, it has been assessed that annually about 8.4 Mt of soil nutrients is lost due to soil erosion problem and these are much greater than the quantity used at present in Indian agriculture. Due to this, in terms of annual food grain production, soil erosion accounts for a total productivity loss of about 40 Mt. Low productivity has been recognized as a major result of soil degradation through soil erosion as well as the changes in important climate and ecosystem components. Thus, accurate estimation of soil losses from agro-ecologically diverse areas is extremely important for designing appropriate resource management or soil and water conservation measures (Saleh and Ghobad, 2011) [5].

The factors which influence the rate of erosion are rainfall, runoff, soil, slope, and plant cover, and the presence or absence of conservation measures. Erosion control requires a quantitative and qualitative evaluation of potential soil erosion considering these factors.

To avoid all the problems above listed, the sediment estimation was made easy by the use of remote sensing and GIS Techniques. The advent of remote sensing images from satellite based platforms has provided opportunities for extraction of up-to-date information on land use, soils of a watershed and then used to identify critical soil erosion areas within the watershed and deriving the spatial information on input parameters has become more handy and cost effective. The conventional methods proved to be too costly and time consuming for generating this input data.

## 2. Material and Methodology

### 2.1 Study Area

The study area, Timmapur watershed is located in Raichur district and geographically lies between 16°15' and 16°30' N latitude and 77° 15' and 77° 30' E longitude with an area of

101.34 Sq. km as delineated from Survey of India (SOI) toposheet. Maximum length and average width of watershed are 18.08 km and 5.60 km respectively. Figure 1 shows the location map of the study area.

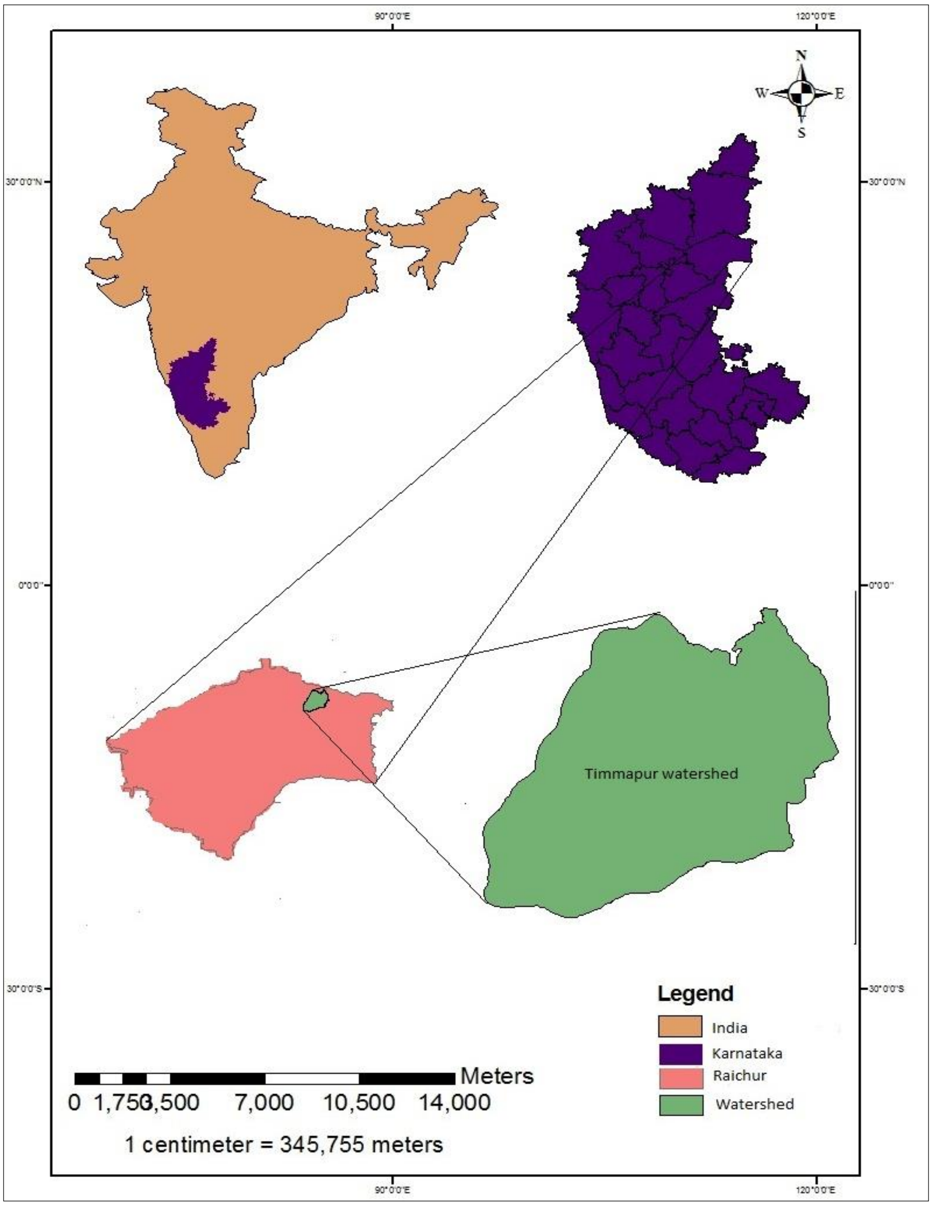


**Fig 1:** Location map of the study area

### 2.2 MUSLE model

$$A = 11.8 \times (Q \times Q_p)^{0.56} \times K \times LS \times C \times P$$

**Where**

A = Annual soil loss (t $km^{-2}$ $yr^{-1}$)
Q = Runoff volume ($mm^3$)
$Q_p$ = Peak discharge in cubic metres per second ($m^3$ $s^{-1}$)
K = Soil erodability factor
L = Slope length factor
S = Slope steepness factor
C = Cover and management factor and
P = Supporting conservation practice factor

**The peak discharge ($Q_P$) was calculated through the equation**

$$Q_p = \frac{(0.208 \times A \times Q)}{(0.5 \times D + 0.6\, t_c)}$$

**Where**

A = Basin size ($km^2$)
Q = Depth of runoff (mm)
D = Duration of storm in hours, assumed as 24 hours, and
$t_c$ = Concentration time in hours calculated through standard formulae

### 2.2.1 Soil Erodability Factor (K) Map

Soil erodibility factor (K) in the MUSLE equation is an empirical measure which expresses the inherent susceptibility of a soil to water erosion as determined by intrinsic soil properties. The K factor is rated on a scale from 0 to 1, with zero indicating soils with the least susceptibility to erosion and one indicates soils which are highly susceptible to soil erosion by water. The factor is defined as the rate of soil loss per rainfall erosion index unit as measured on a standard plot. The soil map of study area was obtained from the KSRSAC, Bangalore with the scale of 1:50000 and this map was brought into GIS environment and soil map was generated having three soil classification fine, loamy and sandy skeletal and K factor map was prepared using spatial analyst tool in Arc GIS.

### 2.2.2 Slope-Length (L) and Slope Steepness (S) Map

L factor, which is the function of slope length along with the S factor (slope steepness), represents the topographical factor commonly expressed as LS factor. Many researchers have used these two L and S factors as the combined LS factor. Slope length(L), defined as the distance from the point of origin of overland flow to either the point where the slope decreases to the extent that deposition begins or the point where runoff enters well defined channels (Wischmeier and Smith 1978) [9]. The slope steepness factor (S) relates to the effect of the slope gradient on erosion in comparison to the standard plot steepness of > 10%. The effect of slope steepness is greater on soil loss compared to slope length. For this study, the combined LS factor was computed by means of ArcGIS spatial analyst extension in which DEM, Slope, flow direction and flow accumulation maps were used. The flow accumulation, which denotes the accumulated upslope contributing area for a given cell, was calculated by summing the cell area of all upslope cells draining into it. Computation was done from DEM using the watershed delineation tool available in hydrological modelling extension in arc view spatial analyst. The combined LS factor for the watershed was calculated and its spatial distributions in the watershed were presented. The following equation was used in map calculator tool for obtaining LS factor map.

$$LS = \text{Power}(\text{flow accumulation} \times \text{Cell Size}/22.1,\ 0.4) \times \text{Power}(\sin(\text{slope}) \times 0.01745/0.09, 0.4) \times 1.4$$

Where flow accumulation denotes the accumulated upslope contributing are for a given cell, LS is combined slope length and slope steepness factor, cell size is size of grid cell (for this study 90 m) and sin slope = slope degree value in sin.

### 2.2.3 Cover Management Factor (C) Map

Cover Management Factor (C) factors that can be used to control soil loss at a specific site. The Cover Management Factor (C) represents the effect of vegetation and management on the soil erosion rates (McDool *et al*., 1989) [1]. It is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous bare fallow. The amount of protective coverage of a crop for the surface of the soil influences the soil erosion rate. C value is equal to 1 when the land has continuous bare fallow and have no coverage. C value is lower when there is more coverage of a crop for the soil surface resulting in less soil erosion.

A good estimation of the cover factor which only accounts for the vegetation cover can be derived rapidly from satellite imagery. The effect of vegetation cover as a control on soil erosion is well established. Vegetation is regarded as the second most critical factor after topography used to derive the NDVI by computing the ratio (Band 2 - Band 3)/(Band 2 + Band 3). The NDVI is highly correlated with the amount of green biomass, and can therefore be applied successfully to provide information relating to the green vegetation variability. Studies by Van der Knijff (2000) [7] and van Leeuwen (2003) [8] provide a more refined and reasonable estimation of the C-factor using the NDVI. The NDVI map of study area was generated in Arcgis and the following equation was used to derive the C-factor using NDVI in this study.

$$C = \exp\left[\alpha \frac{NDVI}{(\beta - NDVI)}\right]$$

Where $\alpha$ and $\beta$ parameters determine the shape of the NDVI curve. Values of $\alpha = 2$ and $\beta = 1$ were proved to be suitable to get reasonable results.

### 2.2.4 Support Practice Factor (P) Map

The conservation practice P factor is an important consideration of the MUSLE model. The support practice factor is defined as the ratio between soil loss with a specific support practice and the corresponding loss with upslope and downslope tillage. Renard *et al*. (1997) [3] explain that support practice essentially affects soil erosion through altering the flow pattern, gradients, or direction of surface runoff and by reducing the amount and rate of runoff. Different P values were assigned according to the local slope and cultivation methods. Regarding the rural roads, only objects lying across the slope direction were mapped, considering only these as the roads having a protective character to erosion.

As in most agricultural lands in taluk, agricultural practices in the study area consist of upslope and down slope tillage without any conservation support practices, such as contouring or terracing. In this study, remotely sensed data have been used to estimate the P factor distribution based on LULC classification results (Millward and Mersey 1999), assuming that the same land covers have the same P factor values. An LULC map of the study area which lies in two toposheets E43×03 and E43×07 derived from the IRS ID Resourcesat-1 LISS III full frame satellite images acquired on 8 February, 2012 with a spatial resolution of 24 m, was used as the base map for determining the P factors. After obtaining the LULC map of the study area, the P factors for the land classes were entered as attributes and P factor map of the watershed was generated using the reclassification method in the GIS.

Peak discharge obtained using kirpich time of concentration, runoff volume along with four potential and actual soil erosion-controlling data layers K, LS, C and P were integrated as in MUSLE within the raster calculator option of the Arc GIS Spatial Analyst. This led to the creation of soil loss map giving the annual soil loss in tonnes per hectare per year.

## 3. Results

The study area constitutes different land use/ land cover about 67.8% of the area is occupied by *Rabi* crop land, 8.05% of the area occupied by *Kharif* crop land, 20.14% of area by double crop land, 1.47% of area by Barren land and remaining 2.54% of the area is occupied by others such as, water body, settlement. In general, among the different land cover types the crop land plays the major role for the direct surface runoff and soil loss.

The theoretical calculation of the soil loss is accomplished by estimating various catchment parameters such as area, land use patterns, runoff, peak rate of runoff, MUSLE factors (K, LS, C, and P) of the study area as explained in methodology. Prasanta and Akhouri (2014) [2] utilized GIS and remote sensing for generation of MUSLE factors which was found to be more accurate compared to conventional methods. The calculated data and factors that were considered in the present study summarized and applied in MUSLE model for estimating annual soil loss. The result revealed that 77.49 t $ha^{-1}$ $yr^{-1}$ and 59.66 t $ha^{-1}$ $yr^{-1}$ soil loss occurs from Timmapur watershed when calculated using Kirpich and Williams' time of concentration respectively. Sadeghi (2004) [4] assessed the efficiency of the model for sediment yield prediction. Based on the derived values, four potential and actual soil erosion-controlling data layers K, LS, C and P were integrated within the raster calculator option of the Arc GIS Spatial Analyst tool along with the runoff obtained using kirpich time of concentration. This led to the creation of soil loss map giving the annual soil loss rate per hectare per year and the range in map was found to be 6.92 to 148.08 t $ha^{-1}$ $yr^{-1}$

The four factor layers (K, LS, C and P) were generated in the GIS spatial analyst tools. The maps of all the four layers K, LS, C and P are presented in Fig 2 and Fig 3, respectively. Annual soil loss is estimated from the product of factors (Q, $Q_p$, K, LS, C and P) which represents geo-environmental scenario of the study area in spatial analyst extension of Arc GIS software. The values of soil loss obtained through the MUSLE model are presented in Table 2 and the soil loss map obtained by integrating soil erosion-controlling data layers is presented in Fig 4.

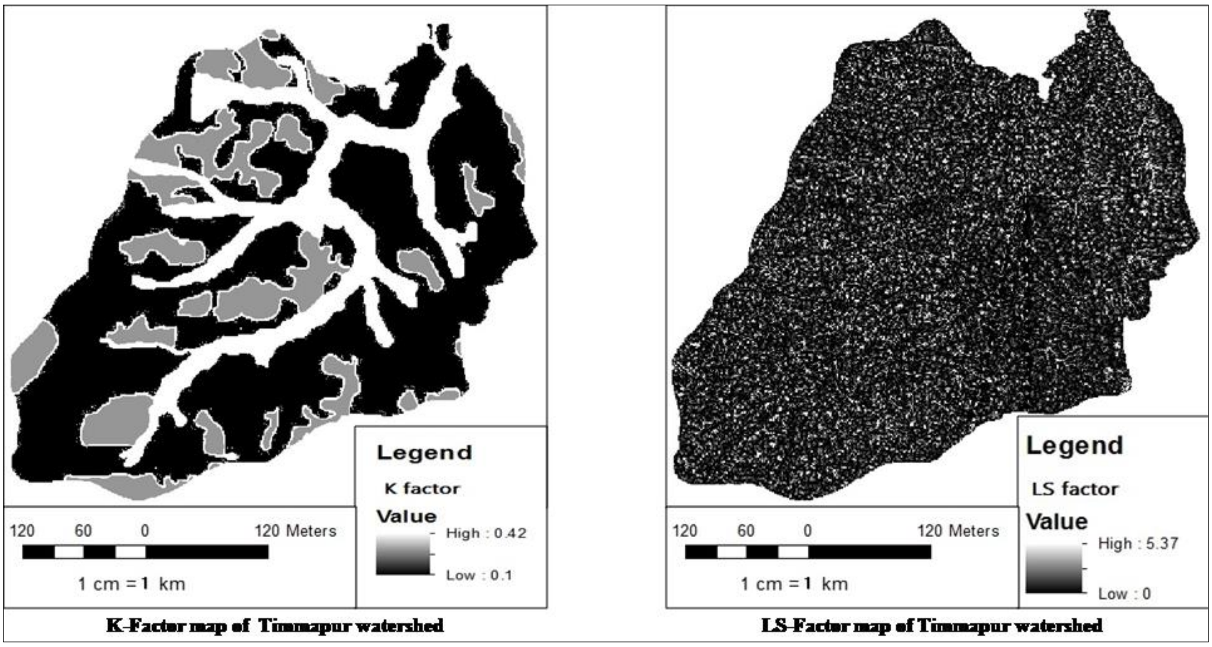


**Fig 2:** K factor and LS factor map

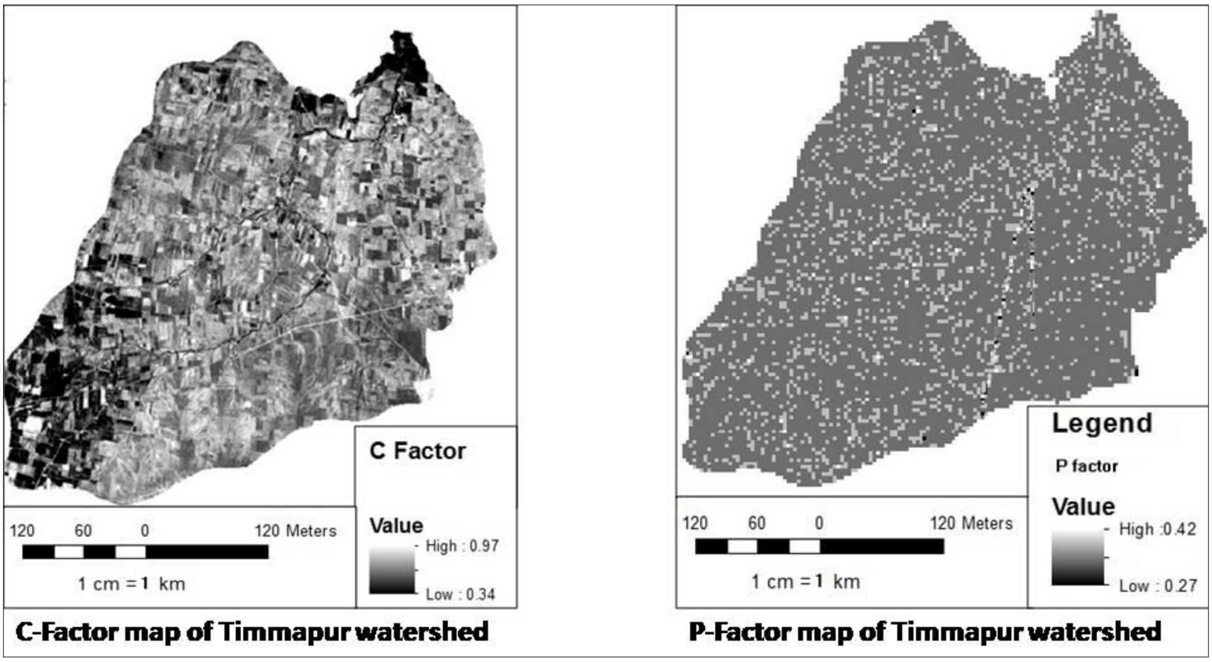


**Fig 3:** C factor and P factor map

**Table 2:** Estimated average soil loss using MUSLE model

| MUSLE factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| K | L.S | C | P | Time of concentration(min) | | Peak discharge ($m^3s^{-1}$) | | Soil loss (t $ha^{-1}yr^{-1}$) | |
| | | | | Kirpich | Williams | Kirpich | Williams | Kirpich | Williams |
| 0.26 | 2.69 | 0.65 | 0.34 | 382.56 | 623.39 | 1.58 | 0.99 | 77.49 | 59.66 |

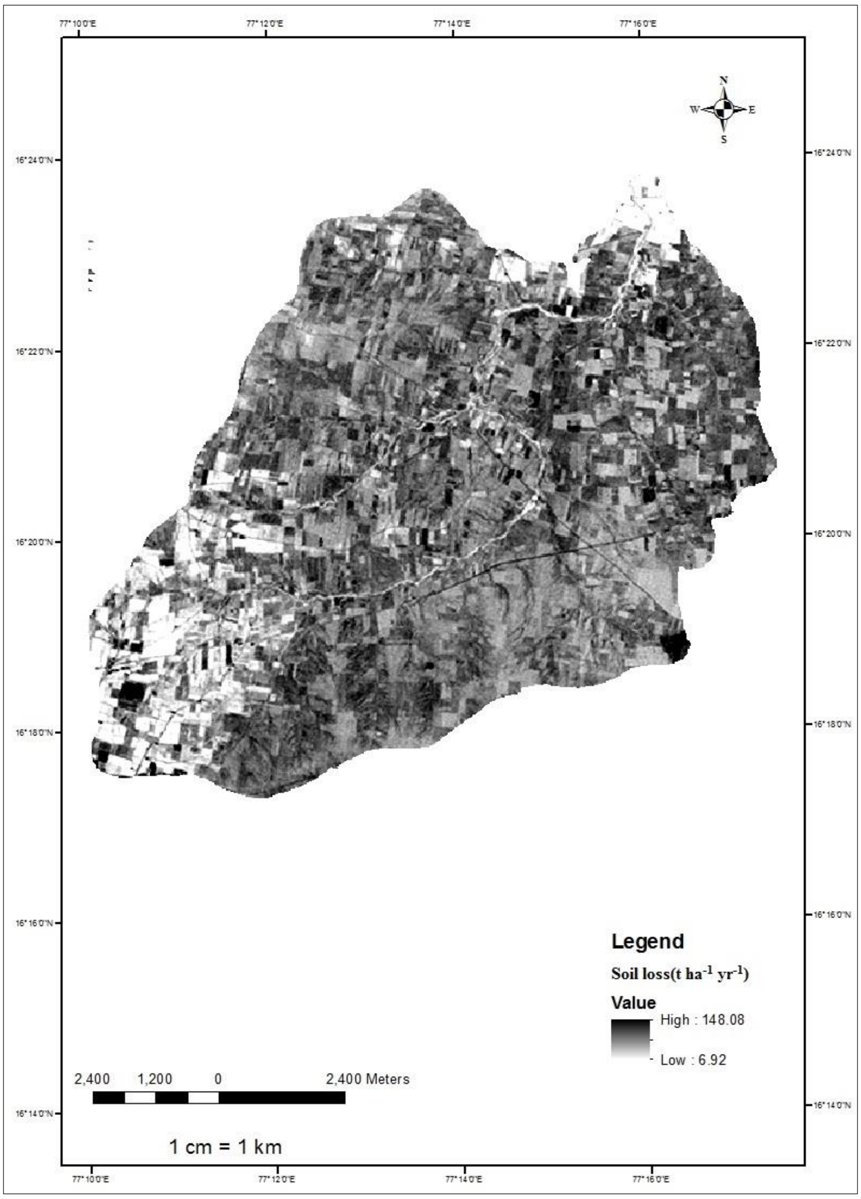


**Fig 4:** Soil loss map

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