Eurasian J Soil Sci 2019, 8 (4) 321 - 328

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Estimation of soil loss by USLE Model using Remote Sensing and GIS Techniques - A Case study of Coastal Odisha, India

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Article Info

Received : 18.01.2019
Accepted : 25.07.2019

Abstract

Globally, Soil erosion is the major land degradation problem, which impacts seriously on economic and environmental status. Geospatial techniques support and provided quantitative approach to estimate soil erosion in different conditions. In the present study, Revised Universal Soil Loss Equation (RUSLE) integrated with GIS has been used to estimate soil loss in the part of coastal Odisha system. The study area, Ganjam block have undulating topography covering 0-35% slopes. The quantitative soil loss was estimated and classified into different classes and soil erosion map was generated. The soil erosion map is classified into seven classes from very slight (<5 t ha^{-1} yr^{-1}) to extremely severe (>80 t ha^{-1} yr^{-1}). The results indicate that 90.9% (22330 ha) of the study area falls in very low erosion category, which may be due to level topography and regular vegetation cover. The other erosion classes such as moderate, high and very high erosion occurred in the range of 2.12%, 2.23% and 1.49 %, respectively. The high soil erosion risk is spatially situated in the foothills and upper steep slope of the area. The results can certainly aid in implementation of soil management and conservation practices to reduce the soil erosion in the coastal Odisha regions of Eastern India.

Keywords: Soil erosion risk, land use, Remote sensing, GIS, coastal Odisha.

Introduction

Soil erosion is one of the important land degradation problems in agricultural land and consider as critical environmental hazard in modern time, worldwide (Lu et al., 2003; Kim et al., 2005). It is one of the most serious problems as it removes plant essential nutrients from the top soil and increases natural level of sedimentation in rivers and reservoirs which in turn reduce their storage capacity and water availability to plants (Devatha et al., 2015).The coastal systems have different kind of ecological problems due to various anthropogenic and natural interventions and regular prone to different kinds of erosion, sedimentation, floods and cyclones (Vinayaraj et al., 2011; Monalisha and Panda, 2018).

Coastal ecosystems provide livelihood to around 60% of world's population. Overall about 50-70% of population lives in coastline covering only about 4% of earth's land (Poyya Moli and Balachandran, 2008). The coastal agro-ecosystem occupies 19.6 m ha (6.2%) area of land in India (Sehgal et al., 1992). About 14.2% of the total population of India lives in coastal areas. In coastal agro-ecosystem, with the increasing human and animal population, the competition between various land uses has become intensive. Besides, unsuitable land is brought under cultivation and thereby causing physical and chemical degradation on land (Renschler et al., 1999; Srinivasan et al., 2015). Odisha coast line has extended from east to southern, about 445 km (Bandyopadhyay et al., 1984). Besides, there is narrow strip of land of few km in width along the sea

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e-ISSN: 2147-4249 DOI: 10.18393/ejss.598120

coast prone for salt problems (Chaudhary et al., 2008). The soil loss in the deltaic areas of Odisha is estimated to be 10-20 MT/ha/yr. (Singh et al., 1992).

Soil loss is accelerated by anthropogenic or human induced soil degradation (Bai et al., 2008). There are different steps of soil erosion viz. sheet, rill and gully involving detachment, transport, and accumulation of soil particles in catchment area, which deteriorating the soil quality as well as reducing the productivity of potential lands (Tideman, 1996; Fernandez et al., 2003). Among the erosion, sheet erosion is the most serious soil erosion problems in India (Narayana and Babu, 1983). A proper assessment of the erosion problem is greatly dependent on its spatial, economic, environmental and agricultural context (Ganasri and Ramesh, 2016). A better soil loss management will be reducing the land degradation and water quality in contest of siltation and sedimentation to the water body (Karthick et al., 2017). More dependable soil erosion rates are required for land use planning and extension of soil water conservation works in coastal India.

Soil erosion assessment and mapping of soil loss susceptible area will be helpful to select or adoptthe suitable or appropriate soil conservation and ecosystem management techniques in the different scale of the maps (Shi et al., 2004). The mean annual soil loss information per unit land area could be ascertained by employing Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978; van Remortel et al., 2001; Lee and Lee, 2006).

Remote sensing and GIS techniques are better tools for assessing erosion at larger scales. For this reason use of these techniques have been widely adopted and used in several studies that show the potential of remote sensing techniques integrated with GIS in soil erosion mapping (Parveen and Kumar, 2012).

Soil erosion is a complex phenomenon governed by a large number of factors such as rainfall erosivity, soil erodibility, slope, land use, and conservation measures. Estimating the soil loss and its spatial distribution are one of the key factors for successful erosion assessment (Bera, 2017). Spatial and quantitative information on soil erosion on a regional scale contributes to conservation planning, erosion control and management of the environment. Identification of erosion prone areas and quantitative estimation of soil loss rates with sufficient accuracy are of extreme importance for designing and implementation (Sharda et al., 2013). Keeping in view of the above aspects, case study was attempted in Ganjam block, part of coastal system to estimate the soil erosion.

Material and Methods

Description of study area

The study area Ganjam block belongs to Ganjam district of Odisha is a part of Indian peninsular subtropics, having tropical climate and sub-humid temperate region, which is located close to the Bay of Bengal coast and lies between 19º 22' 07'' to 19º 32' 24'' N and 84º 58'04" to 85º 10'30" E (Figure 1).

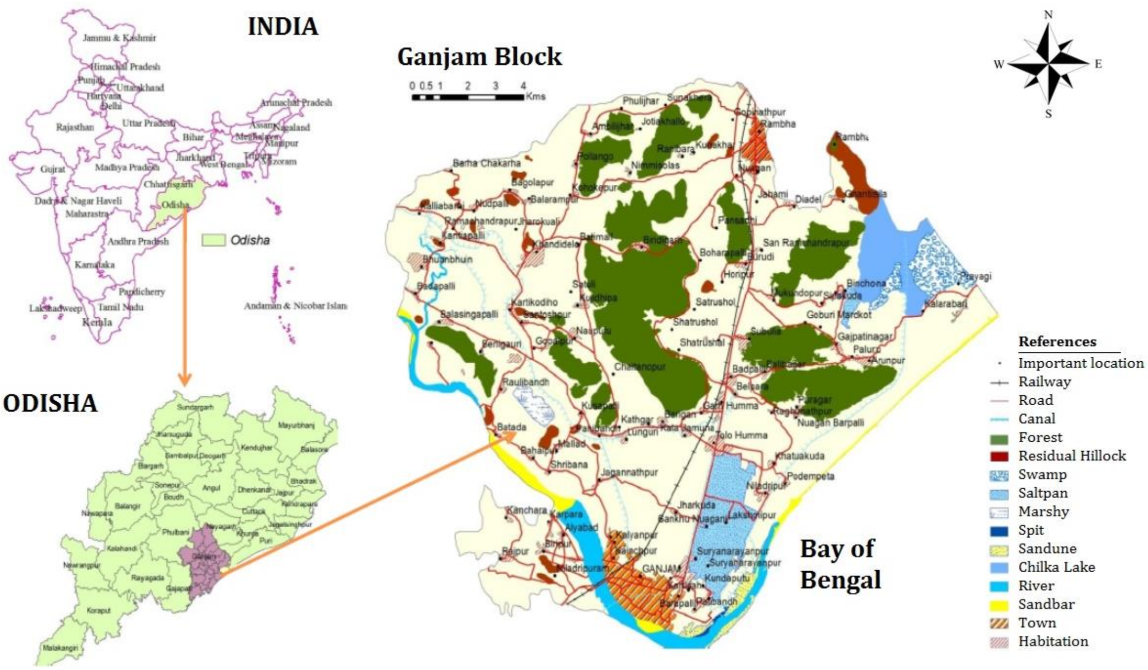

Figure 1. Location map of the study area

The block covers an area of about 246 sq km which is 2.93% of total geographical area of the district. The mean annual rainfall is 1449 mm and more than 60–70% is received during south-west monsoon (June-September). The mean maximum summer temperature is 39 °C and means minimum winter temperature is 11.5 °C. The soil temperature class is "*hyperthermic*" and moisture regime is "*ustic*" which is hot humid plain with LGP of 180–210 days. The soils are formed mainly in the deltaic alluvium of rivers. The major landforms occurred in the study area are denudation hills, lateritic uplands, pediments and inselbergs, lagoon, alluvial plains and swamps. Major soil category consists of lateritic, clayey, coastal saline sands and deltaic alluvium.

Methodology

Data sources

Rainfall erosivity (R) factor

Average rainfall data obtained from IMD last 30 years and processed in ArcGIS software and the R factor was obtained using the equation by Wischmeier and Smith (1978).

$$R = \sum_{i=1}^{12} 1.735 * 10^{\left(1.5\log\left(\frac{pi^2}{p}\right)-0.8188\right)} \tag{1}$$

Where R is the rainfall erosivity, Pi is the monthly amounts of precipitation and p is annual precipitation. Very less variations in R factor ranges from 679 m to 710m.

Soil erodibility factor (K)

Soil information collected from soil resource mapping (SRM) prepared by ICAR- NBSS & LUP, Govt. of India. The soil erodibility factor is the measure of the vulnerability to soil erosion as they are built-in soil properties. The K factor value ranges from 0 to 1, where the value near to 0 indicates least susceptibility to soil erosion and whereas the value closer to 1 indicated that they are very high susceptibility to soil erosion.

Topographic erosivity factor (LS)

The flow accumulation is usually derived from the digital elevation model (DEM) after processing the fill and flow direction in Arc GIS. Cell size is the extentor size of the cells being used in the DEM. The equation for computing the topographic factor (LS) in Arc GIS is computed by the formula recommended by Griffin et al. (1988).

Crop management factor (C)

By using the Landsat 8 data through supervised classification method, raster map of the land use and land cover converted to vector format file and the resultant C factor value was allocated to each of the land use classes are proposed by Hurni (1985).

Conservation supporting practice factor (P)

The conservation practice factor is calculated based on the slope of the area and equivalent P factor values derived based on each slope classes by reclassifying the slope map in ArcGIS.

Soil loss estimation

ArcGIS and ERDAS software were used to produce the desired output for the RUSLE factors such as R-Rainfall erosivity factor, K- Soil erodibility factor, LS- Slope length and steepness factor, C- cover management factor and P- Support practice factor. The USLE is the best empirical soil loss prediction equation, in spite of its limitations. That equation is A = R× K× L× S ×C ×P, where A is average annual soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope steepness factor, C is the cover factor, and P is the conservation supporting-practice factor (Figure 2).

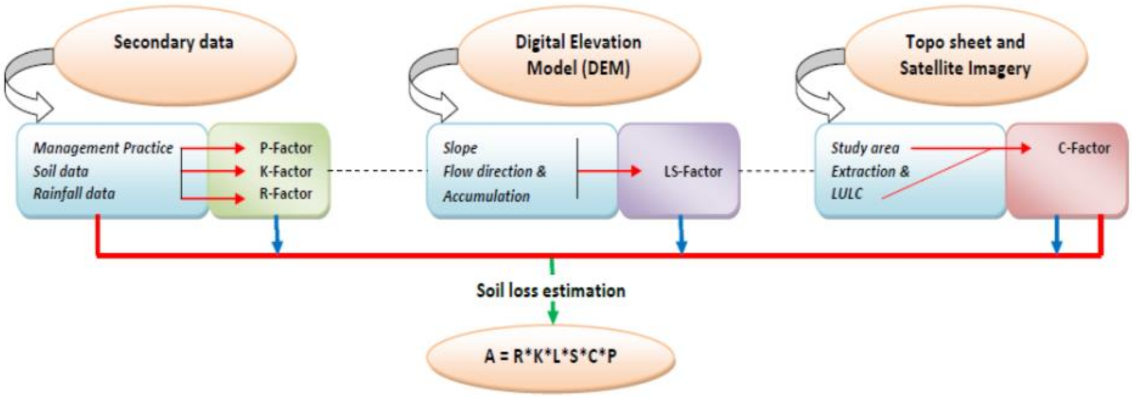

Figure 2. Flow chart of methodology

Results and Discussion

USLE analysis includes R factor, K factor, LS factor, C factor and P factor values which are determined and maps are generated using GIS.

Rainfall erosivity factor (R)

R factor is calculated based on IMD data over a period of 30 yearsof study area from equation 1 and these values are interpolated spatially through GIS technique and R factor map is generated is shown in Figure 3. The annual average rainfall erosivity factor (*R*) was found to be in the range of 697.48 to 710.16 mt $ha^{-1}cm^{-1}$. Many studies (Jain et al., 2001; Dabral et al., 2008) revealed that the soil erosion rate in the catchment is more sensitive to rainfall. The daily rainfall is a better indicator of variation in the rate of soil erosion and seasonal distribution of sediment yield. While the advantages of using annual rainfall include its ready availability, ease of computation and greater regional consistency of the exponent (Shinde et al., 2010). Therefore, in the present analysis, average annual (obtained by total rainfall divided by the total number of rainy days) rainfall was used for R factor calculation. Similar kinds of R-factor values were also calculated by Tirkey et al. (2013) and Behera (2015).

Soil erodibility factor (K)

The soil-erodibility factor (K) is represented by the susceptibility of the soil for erosion, conveyance of the detached soil and runoff resulted from rainfall. Chance of detachment of soil particles depend upon the structure, infiltration, optimum moisture content, water retentions, presence of cations, texture and composition. Soil erodability (K) of the study area was calculated using the relationship between soil texture class and organic matter content proposed by Schwab et al. (1981); Stone and Hillborn (2000). The soil erodability factor values assigned to different texture classes using GIS technique. Spatial distribution of surface soil K values of study area has shown in Figure 4. From the study (K factor map) it has been found that, in low relief areas like alluvial plains, hills and flood plains region, the K value varies from 0 to 0.36. Soil erodibility at near sea (sandbar) is comparatively high (0.88 to 1.1) because soils texture are course and generally loamy sand to sandy loam in texture and organic matter content was very low, which make more susceptible to erosion. The percentages of organic matter in soil drops erodibility, declines susceptibility of soil detachment, but enhances infiltration rates, hence the runoff by reducing erosion (Behera, 2015; Singh et al., 2002).

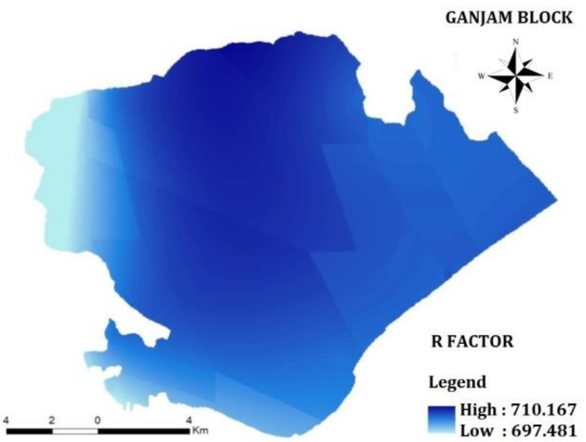

Figure 3. Spatial distribution of Rainfall (R) factor

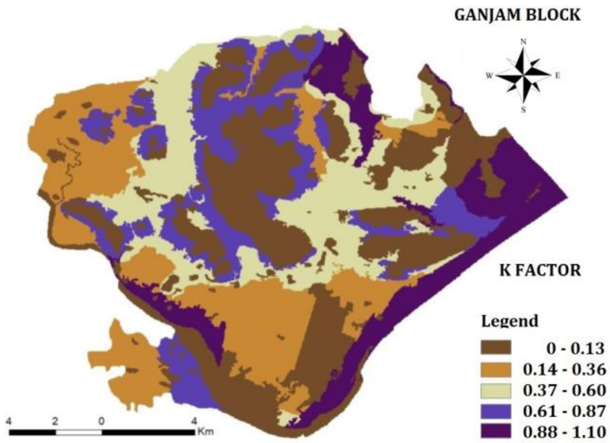

Figure 4. Soil erodibility (K) factor

Topographic factor (LS)

Topographic factor represents the influence of slope length (L) and slope steepness (S) on erosion process. LS factor was calculated by considering the flow accumulation and slope in percentage as an input. From the analysis, it is observed that the value of topographic factor increases in a range of 5 to 50 as the flow accumulation and slope increases. SRTM DEM of 30 m resolution is used to calculate LS factor, steeper the slope more will be the loss. For study area maximum slope is observed to be 0-5%. It's considered as very gently sloping area as from slope classes and LS factor map is generated and shown in Figure 5. It was found that the maximum slope varied in undulated hillock or hills side slope and foothills. According to slope map it was observed that slope at the study area is low. Analysis of the topographic factor is very important in USLE application, since this parameter characterizes surface runoff speed and quantity of sedimentation. Relationship of soil slope on topography established in different condition by Yildirim (2012) and Ozsoy et al. (2012).

Crop management factor (C)

Land use and land cover is a better understanding of the land utilization aspects of cropping pattern, fallow land, forest, wasteland and surface water bodies, which are vital for developmental planning and erosion studies. Survey of India Toposheet and Remote sensing imagery has a potential to generate a thematic layer of land use-land cover of a region. The study area has been classified into three land use classes which were assigned to different land use patterns using the values given in Table 1. Using land use-land cover map, C factor map was prepared and shown in Figure 6. C factor map shows that study area consists of high percentage vegetation cover which will reduce soil erosion (Renard et al., 2011). Soil loss is very sensible to land cover in addition to relief (Chatterjee et al., 2014). In the present study almost 50 % of the area is under forest. C factor is less significant when land use and land cover area comprises maximum percentage of natural vegetation and plantation crops. The value of which ranges from '0' in water bodies to slightly greater than '1' in barren land (Toy et al., 2002).

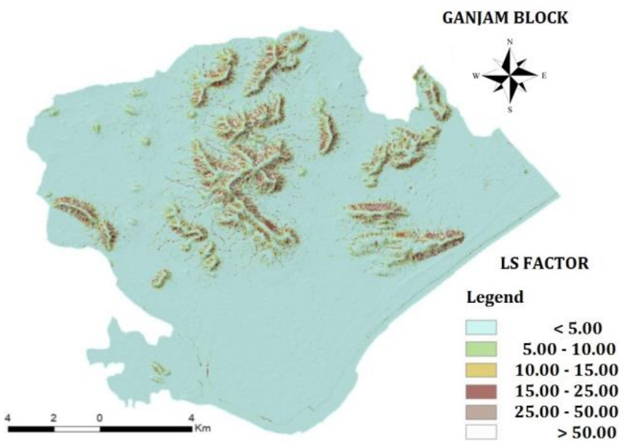

Figure 5. Slope length and steepness factor (LS)

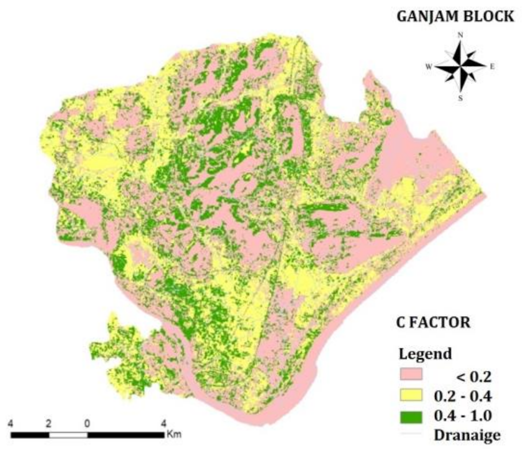

Figure 6. Cover management factor (C)

Table 1. Land use/land cover classes and respective C-factor value

C-Classes	C-factor	Area (ha)	% TGA
Forest	0-0.2	12280	49.9
Fallow land	0.2-0.4	1533	6.24
Agricultural area	0.4-1.0	10748	43.7
Total		24561	100

*TGA-Total Geographical Area

Support practice factor (P)

The support practice factor (P) is the ratio of soil loss in a normal condition to the soil loss due to ploughing in an undulating terrain. P values can be reduced by contouring, vegetative strips, strengthening the soil bunds, diversions, sediment basins and channel of an eroding area. Permanent vegetation like forest and plantation has more P values 0.7 to 1. Plain land open surface have 0.5 to 0.7. The value of P-factor is 1 for the upland and 0.50 for low land with gentle slope and cultivation of paddy and pulses (Figure 7).

Potential annual soil erosion estimation

The average annual soil erosion potential has been computed by multiplying the developed raster data from each factor of USLE analysis. The final soil erosion map displays the average annual soil loss potential of the coastal Odisha is shown in Figure 8. The GIS analysis has been carried out for RUSLE to estimate annual soil loss on a pixel-by-pixel basis and the spatial distribution of the soil erosion in the study area. The potential soil loss in the study area has been categorized into seven types viz., very slight, slight, moderate, moderate severe, severe, very severe and extremely severe erosion based on the rate of erosion (t/ha/year), i.e., More erosion corresponds to very high erosion and least rate of erosion correspond to low erosion (Table 2). It is observed that few parts of the study area have higher values of soil loss, which may be due to the steep slope and poor vegetation. It is observed that most part of the study area around 93.03% comes under low erosion category due to low slope variability. Negligible soil loss areas (5-10 t/ha/yr) have been recorded under forest and low land area. Soil erosion rate was predicted moderately high (10-15 t/ha/yr) for upland agriculture, which needs proper soil conservation measures to reduce the erosion. The high rate (20-80 t/ha/yr) of soil erosion was found in hills side slopes, foothills, barren and fallow land and sand bar of along the coastal basin (Behera, 2015; Mishra and Das, 2017).

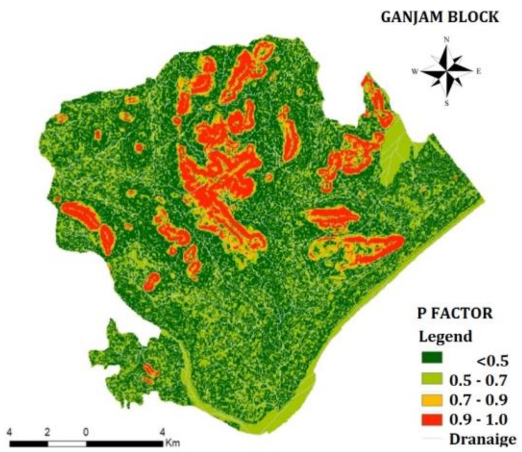

Figure 7. Conservation practices factor (P)

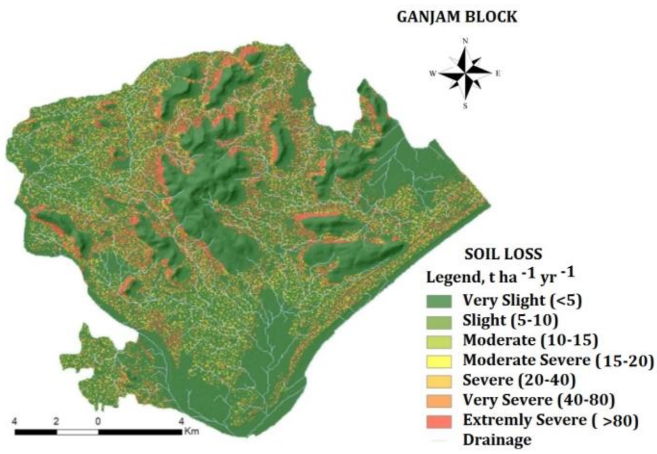

Figure 8. Soil erosion map

Table 2. Soil loss classifications according to the erosion risk classes

Erosion classes	Area (ha)	% TGA
Very low	22330	90.91
Low	721	2.93
Moderate	522	2.12
High	548	2.23
Very high	440	1.79
Total	24561	100

Conclusion

The soil erosion has been estimated and spatially distributed in the part of coastal Odisha using RUSLE and GIS technique and the soil loss map is classified into seven different erosion risk classes. According to that 23051 ha (93.03%) land has low erosion risk and 522 ha (2.12%) are moderate and 988 ha (3.72%) are high erosion risk category in Ganjam block based on variable climatic, soil and topographical condition. The average annual soil loss map is very useful to adopt soil conservation measures and protective method of agriculture practices for sustainable natural resource management.

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