Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 8 [2] January 2019 : 119-129

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

ORIGINAL ARTICLE **OPEN ACCESS**

Soil Erosion Estimation around Godavari Basin in Andhra Pradesh using Remote Sensing and GIS

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ABSTRACT
Soil erosion is a serious environmental problem in Godavari catchment. Godavari River is predominantly monsoonal since 95% of the total annual load is transported in the rainy season. In the present study, USLE is used to estimate potential soil erosion from Godavari catchment. Rainfall erosivity factor (R) for each sub-watershed was determined using mean annual rainfall from 2002 to 2007. The R factor for Godavari basin ranged between 529.39 and 771.66 MJ mm ha^{-1} h^{-1}. Soil Erodibility factor (K) values for major portion of the soils in the study area ranged from 0.06 to 0.08.Topographic factor (LS) for each sub-basin was estimated. The average LS factor in the Godavari basin was 10448.13.The average Sediment Delivery Ratio (SDR) value for Godavari Basin in Andhra Pradesh was 5.13.Cropping management (C) factor was derived from NDVI map for the year 2007. The C factor in the study area was 0.7.Soil erosion around the Godavari River in Andhra Pradesh was estimated from the year 2002 to 2007. The average soil erosion in the Godavari basin was 4.34 t ha^{-1} year^{-1}.Sediment Yield at Polavaram gauging site was estimated from the year 2002 to 2007 and average sediment yield was 23.22 t ha^{-1} year^{-1}.
Keywords:*Soil erosion,Sediment yield, USLE,Remote Sensing, GIS*

Received 12.08.2018 Revised 22.10.2018 Accepted 16.12.2018

INTRODUCTION

Soil erosion is one of the most critical environmental hazards arising from agricultural intensification, land degradation and possibly due to global climatic change [25]. Cultivation without using specific control techniques, unplanned land use, such as establishing industrial facilities or constructing houses on the agriculture land, uncontrolled urban development and also destroying forests are fundamental factors causing soil erosion. It is quite-intensified and spreading the problem throughout India. Almost 130 M ha of land that is 45% of total geographical area is affected by serious soil erosion through gorgeand gully, shifting cultivation, cultivated waste land, sandy areas, deserts and water logging. About one millimeter of top soil is being lost every year with a total loss of 5,334 million tonnes annually due to soil erosion. The rate of soil loss is 16.4 tonnes per hectare per year [3]. Annual erosion rate due to water is less than 5 Mg ha^{-1} yr^{-1} (2.2 tons acre^{-1}) for dense forest (above 40% canopy), cold desert regions and arid regions of India.

Soil erosion not only decreases land productivity but the eroded soil reaches the productive land, which also loses its productivity posing threat to food security. On the other hand, it also reduces the reservoir capacity by deposition of eroded soil in it. Sediment is getting deposited on river bed and banks causes widening of flood plains during floods. Soil erosion is the most significant contributor of off-site groundwater pollution on a global scale with most of the contaminants originating within an agricultural setting. It is not possible to monitor the effect of each land-use practice in all ecosystems under all weather conditions. Hence, erosion predictions are necessary to rank alternative practices with regard to their likely impact on erosion. Assessment of soil erosion is helpful in planning for soil conservation programmes. Modelling only can provide a quantitative and consistent approach to estimate soil erosion and sediment yield under a wide range of conditions. Models available in the literature for sediment yield estimation can be grouped into two categories: (1) Physically-based models and (2) Empirical models. Physically based models are intended to represent the essential mechanisms controlling erosion process by solving the corresponding mathematical equations. These models are the synthesis of individual components that affect the erosion process and it is argued that they are highly capable to assess both the spatial and temporal variability of the natural erosion processes.

Simple empirical methods such as the Universal Soil Loss Equation (USLE) [13, 23], the Modified Universal Soil Loss Equation (MUSLE) [22], or the Revised Universal Soil Loss Equation (RUSLE) [16] are frequently used for the estimation of surface erosion and sediment yield from catchment areas because of simple structure and ease of application. Erosion Productivity Impact Calculator (EPIC) [21] and Agricultural Non-Point Source Pollution Model (AGNPS) [26] are the examples of commonly used watershed models based on USLE methodology to compute soil erosion.

Although USLE/RUSLE may not replicate the real picture of erosion process as they are based on coefficients computed or calibrated on the basis of observations, it has been extensively applied all over the world mainly due to the simplicity in the model formulation and availability of data set [1, 5]. USLE has been proved to provide good estimate of soil erosion at plot scale. In case of catchment, part of eroded soil is deposited within catchment before it reaches the catchment outlet. Nevertheless, soil erosion computed by USLE can be routed to catchment outlet using the concept of sediment delivery ratio by applying appropriate procedure. Due to the spatial variation in rainfall and catchment heterogeneity, both soil erosion and sediment transport processes are spatially varied. Such variability has promoted the use of data intensive distributed approach for the estimation of catchment erosion and sediment yield by discretizing a catchment into sub-areas, each having approximately homogeneous characteristics and uniform rainfall distribution [26, 2]. However, spatial variability of different watershed characteristics and rainfall can be well represented by utilizing the geo spatial tools like GIS and RS.

Pandey *et al.* [14] combined GIS, Remote Sensing (RS) with Universal Soil Loss Equation (USLE) to identify the critical erosion prone areas of watershed for prioritization purpose. Hence, USLE integrated with geo spatial tools can provide fairly accurate estimation of spatial variability of soil erosion in a river basin.

Godavari River is predominantly monsoonal since 95% of the total annual load is transported in the rainy season. The river basin as a whole is being eroded at a rate higher than that of the world global average. This may be due to the fact that 85% of the basin is covered by intensive human activity. The sediment load, representing physical weathering, is about seven times that of the chemical load. The annual mass transfer of the river is about 10% of that of the Himalayan drainage system. It was noted that very few research studies are available on the estimation of soil erosion in Godavari basin. However, it is not possible to model the entire river basin. Hence, the part of Godavari basin from Manchierial to Polavaram has been selected as the study area for the quantitative assessment of soil erosion

MATERIAL AND METHODS

SOIL EROSION ESTIMATION

The detailed procedure for the estimation of soil erosion is shown in the figure 1. Rainfall erosivity factor (R) is determined using mean annual rainfall. Soil erodibility factor (K)obtained from soils present in the study area. Slope length factor (L) and slope steepness factor (S) has derived from Digital Elevation Model (DEM) map. The cover or cropping management factor is calculated from Normalized Difference Vegetation Index (NDVI) map and Conservation practices factor is assumed as 1. All these factors are substituted in USLE and estimated soil erosion. And also estimated the Sediment Yield (SY) and compared with CWC data at Polavaram gauging site.

Universal Soil Equation

Techniques for the prediction of soil loss have evolved over the years. The most common used equation for soil loss prediction of the catchment is the USLE. The USLE equation computes average annual soil loss (A) which is a product of five different factors that affect soil loss and is given by:

$$A = R.K.LS.C.P \qquad (1)$$

where, A is average annual soil loss in tons per hectare per year, R is rainfall-runoff erosivity factor in MJ mm $ha^{-1}h^{-1}year^{-1}$, K is soil erodibility factor in t ha h ha^{-1} MJ^{-1} mm^{-1}, LS is topographic or slope length/steepness factor, C is cover and cropping management factor, and P is supporting practices (land use) factor. All of the factors are dimensionless, with the exception of R and K.

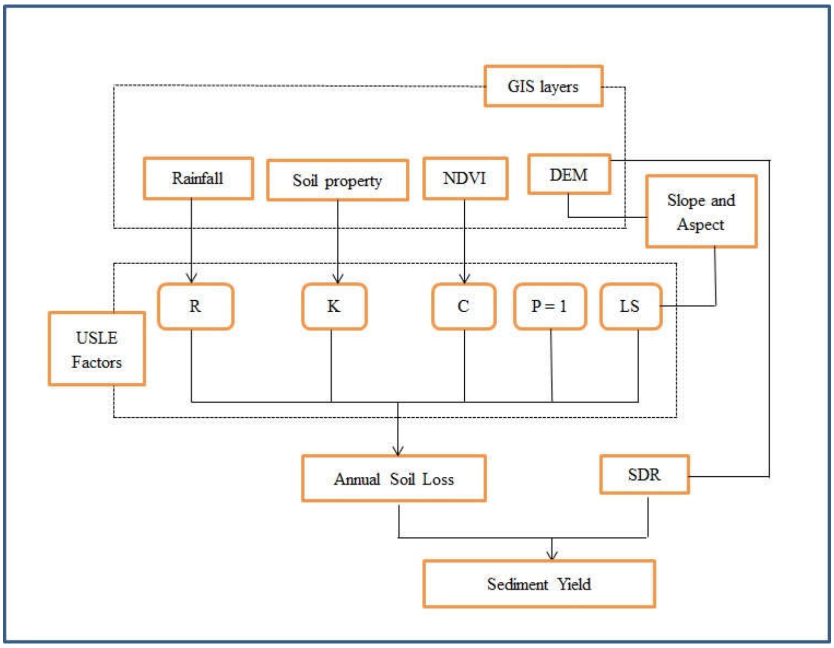

Figure 1. Flowchart of the methodology for soil erosion estimation

Sediment Yield Determination

The ratio of sediment delivered at a given area in the stream system to the gross erosion is the sediment delivery ratio for that drainage area. Thus, the annual sediment yield of a watershed is defined as follows:

$$SY = A \times SDR \qquad (2)$$

Where, A = Total gross erosion computed from USLE, SDR = Sediment delivery ratio.

A general equation for computing watershed delivery ratio is not yet available since they depend on several properties of the watershed-like infiltration, roughness, vegetation cover, hydrograph, or runoff drainage, etc. Since much of the above data are not available for the study area to derive SDR, some of the simple models given by different researchers have been tried to estimate sediment yield at the outlet of the basin, but the one given below by Williams and Berndt's [22] is finally chosen because it gives reasonable results despite using few catchment characteristics.

$$SDR = 0.627 SLP^{0.403} \qquad (3)$$

Where, SLP = % slope of main stream channel

Rainfall Erosivity Factor (R)

R is the long term annual average of the product of event rainfall kinetic energy in MJ ha^{-1} and the maximum rainfall intensity in 30 minutes in mm per hour [24, 15]. The erosivity factor R is often determined from rainfall intensity if such data are available. In majority of cases, rainfall intensity data are very rare; consequently attempts have been made to determine erosivity from daily rainfall data (Jain et al. 2001). In river Godavari catchment, no station has rainfall intensity data. Therefore, R is determined using mean annual rainfall as recommended by Roose [17] cited in Morgan and Davidson [12] and is given below:

$$R = 0.5 \times P \qquad (4)$$

Where, P = Mean annual rainfall (mm), R = Rainfall erosivity factor (MJ mm $ha^{-1}h^{-1}year^{-1}$).

Soil Erodibility factor (K)

The soil erodibility factor (K) represents both susceptibility of soil to erosion and the amount and rate of runoff, as measured under standard plot condition. The soil map has been downloaded from Survey of India (SOI) website having 1:15 million scale and based on this soil map the K factor is prepared. The ranges of soil erodibility factor values used for various soils in the present study. The soils available in the study area are red sandy soils, medium black soils, deltaic alluvial soils, deep black soils and red loamy soils. K values assigned for major portion of soils and it ranges from 0.08 to 0.06.

Slope Length (L) Factor and Slope Steepness (S) Factor

DEM (Digital Elevation Model) is a generic term for digital topographic data, in all its various form. According to U.S Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the terrain at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum. In the figure 2, blue colour indicates highest elevation points and yellow, orange colours indicate medium, lowest elevation points respectively. The value of lowest and highest elevation points ranges from 7 to 1028. Slope and aspect can derive from DEM.

The LS factor accounts for the effect of topography on erosion in RUSLE. The slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion. The effect of topographic factors, namely slope length Land percent slope S, on erosion was derived from slope length factor LS. The equation used to determine this parameter was that recommended by (Morgan and Davidson, 1991) given in follow equation:

$$LS = \frac{\sqrt{L}}{100}(0.76 + 0.53 \times S + 0.076 \times S^2) \qquad (5)$$

Where, L = slope length in feet and S= percent slope

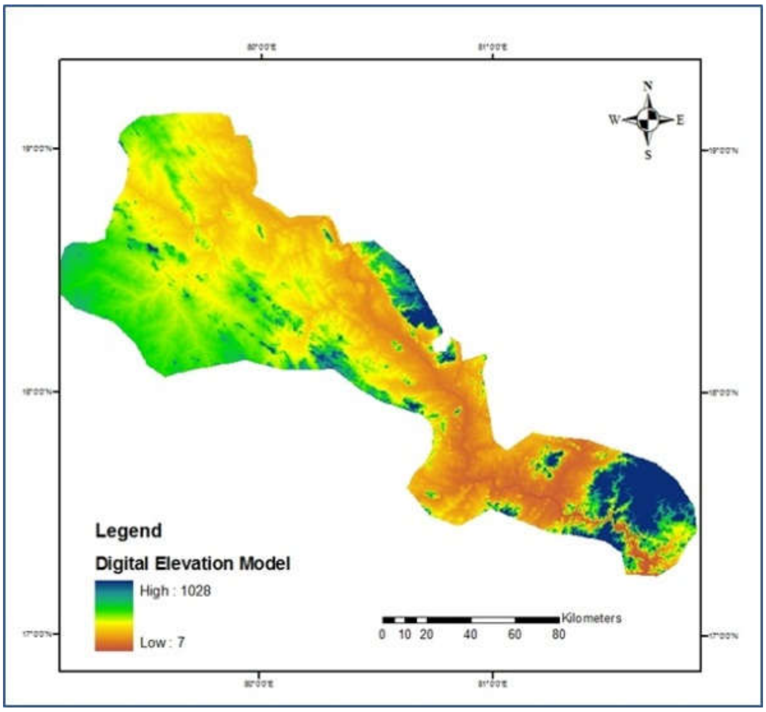

Figure 2. Digital elevation Model of Godavari River Basin

Cover (C) or cropping management factor

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is an index of plant “greenness” or photosynthetic activity, and is one of the most commonly used vegetation indices. Vegetation indices are based on the observation that different surfaces reflect different types of light differently.

The Normalized Difference Vegetation Index (NDVI), one of the vegetation indices, measures the amount of green vegetation. The spectral reflectance difference between Near Infrared (NIR) and red is used to calculate NDVI. The formula can be expressed as [9];

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \qquad (6)$$

The NDVI has been used widely in remote sensing studies since its development [10]. NDVI values range from -1.0 to 1.0, where higher values are for green vegetation and low values for other common surface materials. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values [11, 13, 18, 19]. 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 [4]. The C factor values vary between 0 and 1 based on types of land cover

C-factor Estimation

Land use/land cover in the study area during 1992–2007 has not much changed. NDVI is positively correlated with the amount of green biomass therefore it can be used to give an indication for differences in green vegetation coverage. NDVI values are scaled to approximate C values using the following formula, developed by European Soil Bureau:

$$C = e^{-\alpha(NDVI/\beta - NDVI)} \quad (7)$$

Where α, β are the parameters that determine the shape of the NDVI-C curve. A α-value of 2 and a β-value of 1 have been assumed.

Support practice factor /conservation practices (P) factor

Support practice factor indicates the rate of soil loss according to the various cultivated lands on the earth. There are contour, cropping and terrace as its methods and it is important factor that can control the erosion. It reflects the impact of support practices in the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up-and-down slope. As there is only a very small area has conservation practices in the study area, P factor values are assumed as 1 for the basin.

RESULTS AND DISCUSSION

Estimation of average annual soil loss

Average annual soil loss is estimated based on 6-year average rainfall erosivity factor and K, LS, C, P factors.

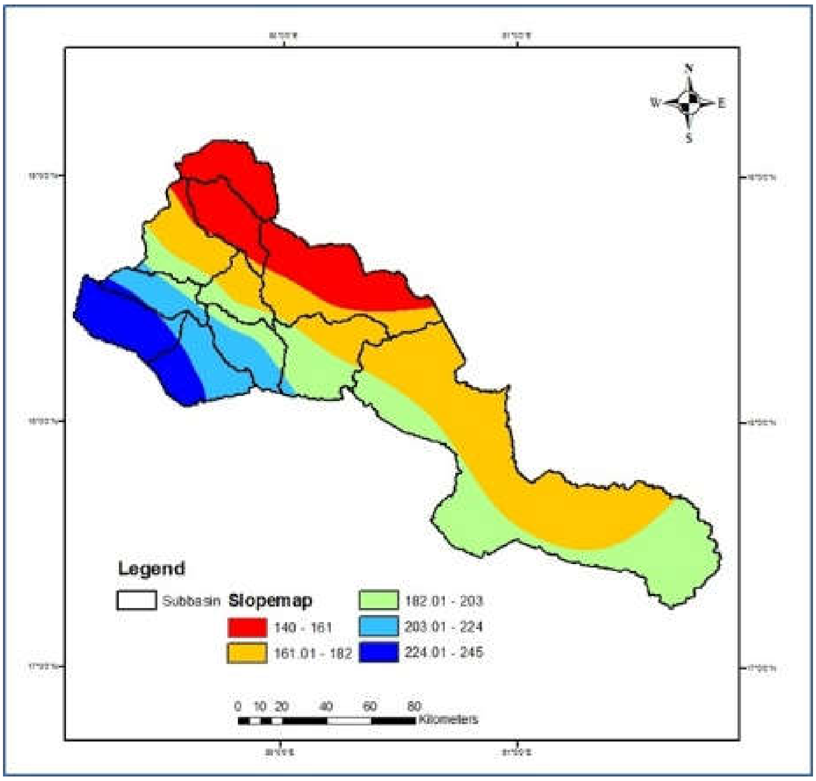

Figure 3. Slope map of Godavari Basin

The slope map of the Godavari basin is shown in the Figure 3. The slope values are ranges between 140 to 245%. In this Figure, red colour and blue colour represents lowest slope and highest slope respectively.

Estimation of yearly soil loss

Among the all five different factors, rainfall data are available on yearly basis for the period of 2002–2007. Therefore, R factor is computed for each of the years for the above period following the procedure described in the Sect. 2.4. Using yearly R factor and keeping the remaining factors as constant, yearly soil loss (t/ha/year) is calculated. The entire catchment delineated into 11 sub-watershed. The R factor value from 2002 to 2007 with respect to sub-watershed is shown in the Table 1.

Table 1. Rainfall erosivity factor value from 2002 to 2007

	R-Value					
Sub-basin	2002	2003	2004	2005	2006	2007
1	676.26	459.43	332.61	622.98	722.65	584.75
2	627.5	392.6	479.8	609.1	776.7	504.3
3	720.02	384.38	464.1	522.26	662.05	436.67
4	511.25	349.25	381	628.1	665.9	470.25
5	489.93	408.1	414.75	568.15	596.42	382.96
6	571.71	353.82	372.39	411.55	597.3	457.21
7	625.3	438.86	352.86	572.05	568.42	518.62
8	538.08	378.12	367.38	434.25	633.49	403.57
9	571.38	356.83	331.97	555.98	521.21	476.15
10	683.05	453.9	415.82	685.42	801.32	579.77
11	702.88	511.78	435.96	735.73	708.41	664.3
Avg.	726.61	540.84	529.39	695.88	771.66	623.80

The R factor distribution in study area during the year 2002 is shown in the Figure 4. It is shows that R factor value ranges from 489 to 754 MJ mm ha^{-1} h^{-1}. In the Figure green colour shows the lowest and red colour shows the highest R factor. Figure 5 shows the R factor distribution during the year 2003. According to this, the R factor ranges between 348.36 - 512.50MJ mm ha^{-1} h^{-1}. Light yellow colour and blue colour shows the lowest and highest R factor. The R factor distribution during the year 2004 is shown in the figure 6. It presents the lowest R value is 321.87 and highest value is 480.03 MJ mm ha^{-1} h^{-1}.

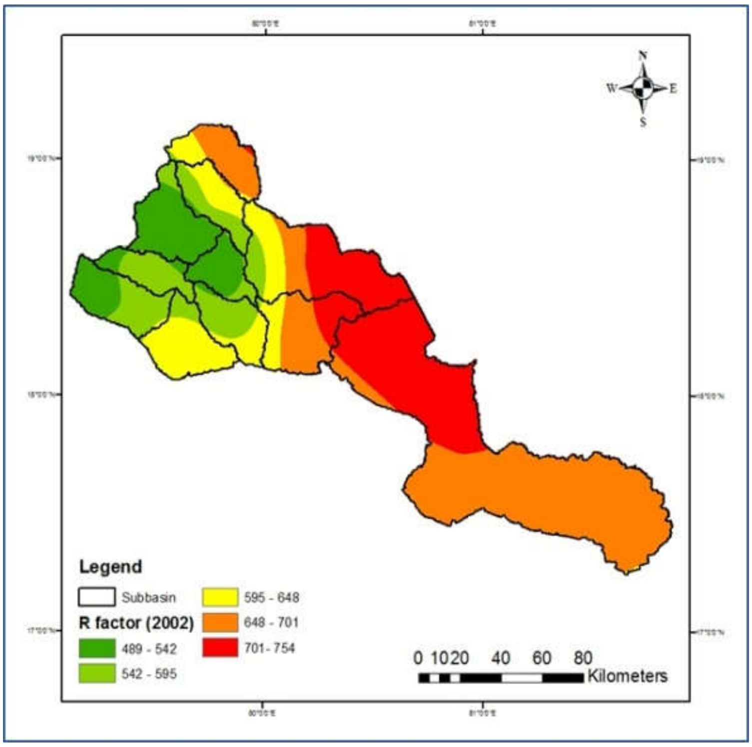

Figure 4. Distribution of R factor during the year 2002

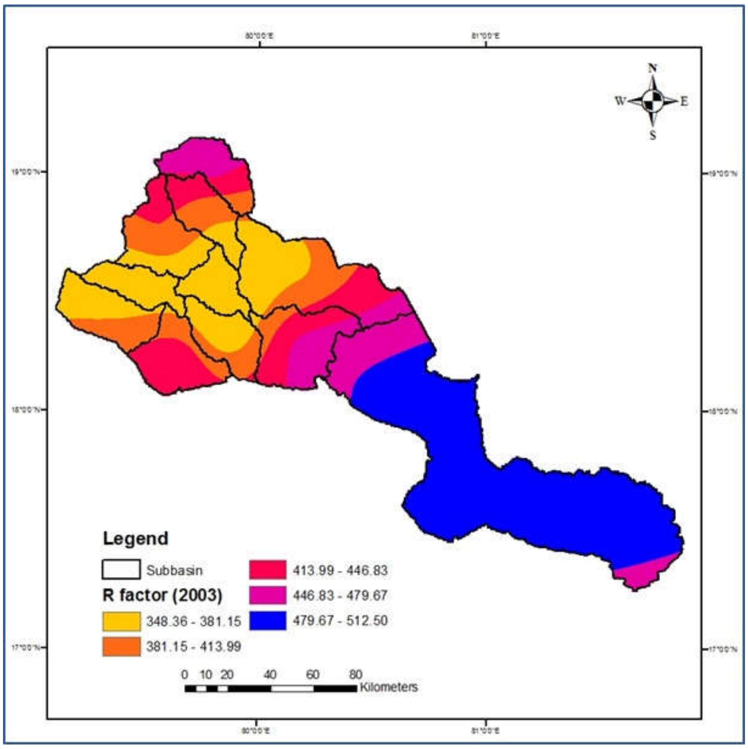

Figure 5. Distribution of R factor during the year 2003

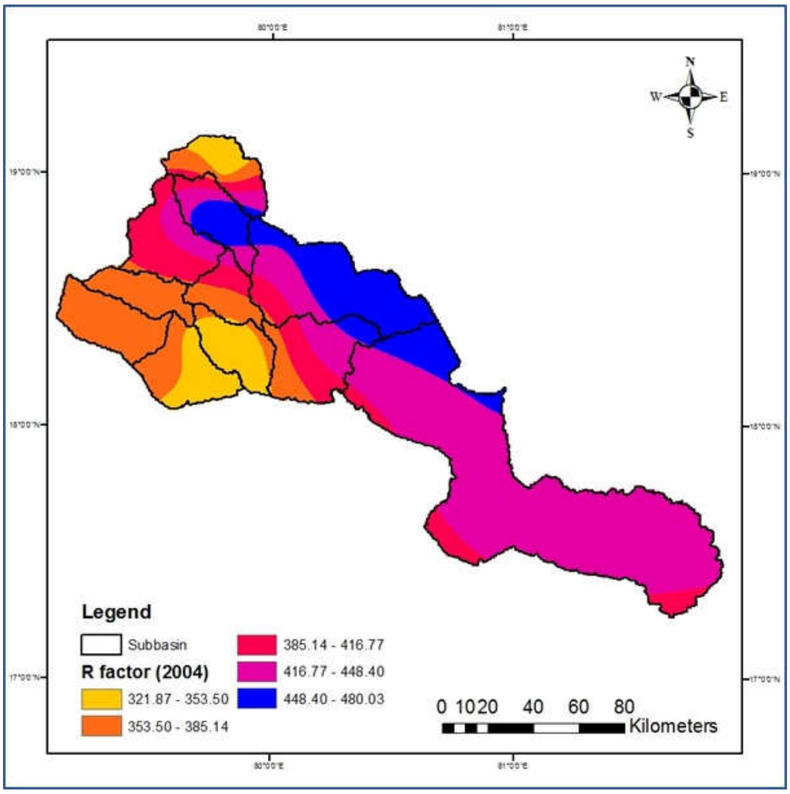

Figure 6. Distribution of R factor during the year 2004

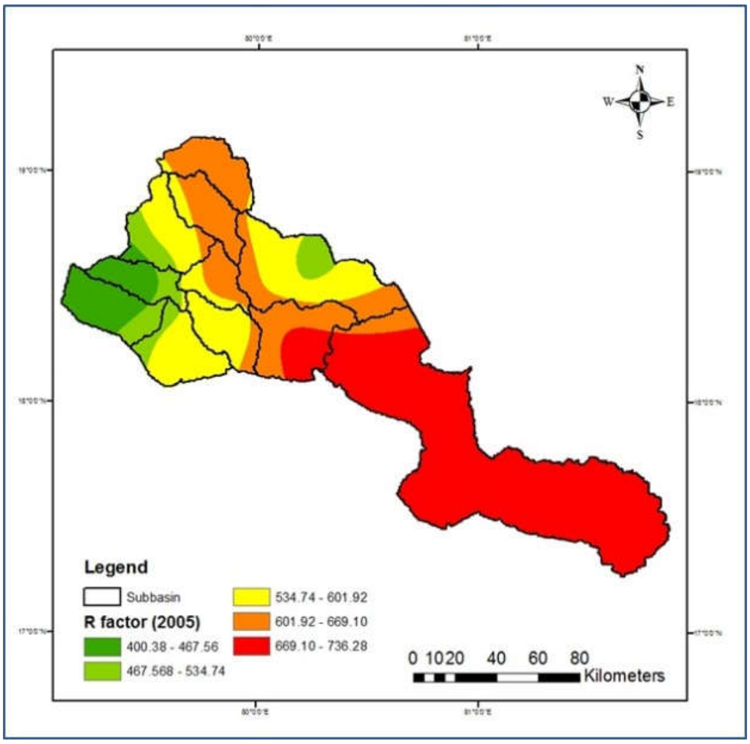

Figure 7. Distribution of R factor during the year 2005

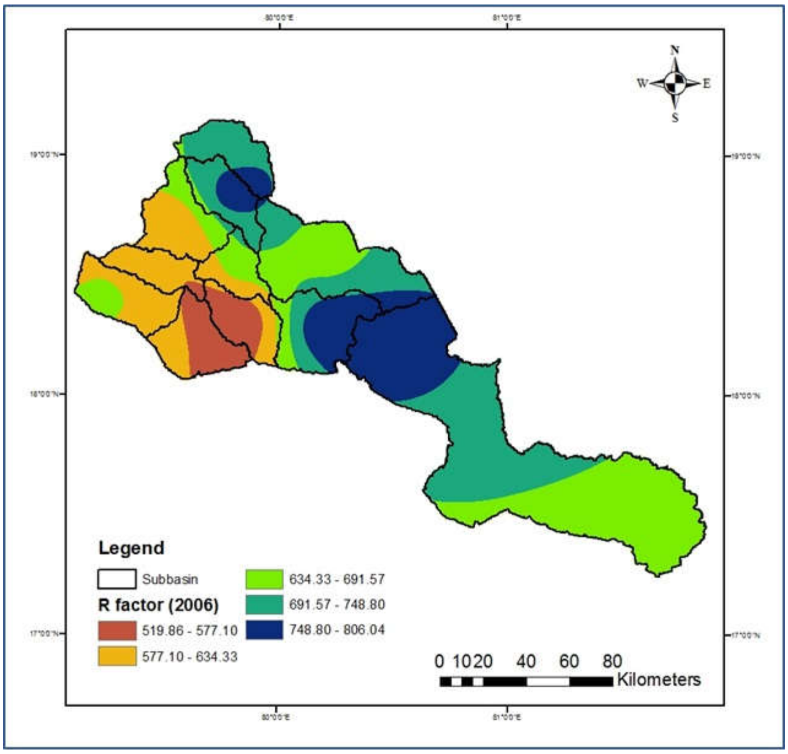

Figure 8. Distribution of R factor during the year 2006

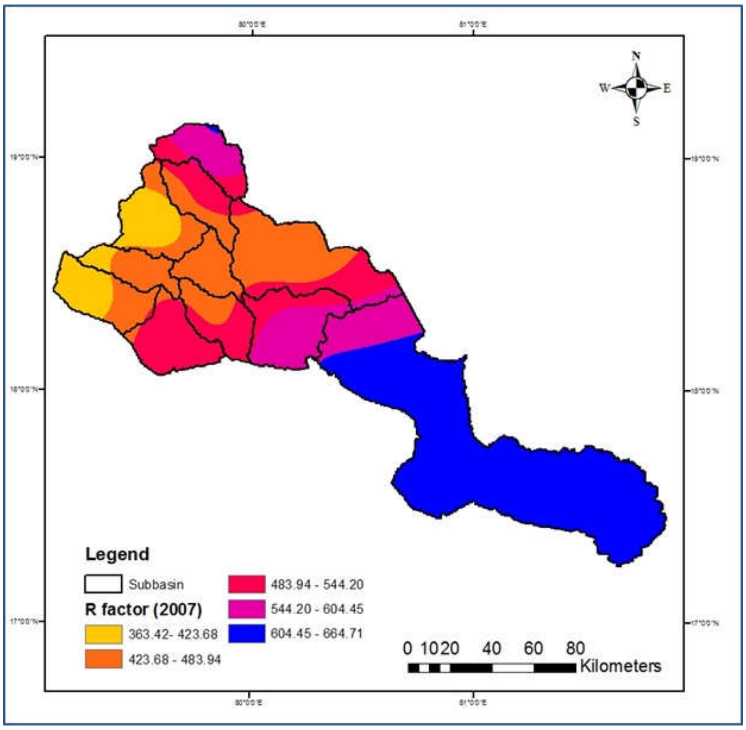

Figure 9. Distribution of R factor during year 2007

The R factor distribution during the year 2005 is shown in the Figure 7. It is noticed that the R value ranges from 400.38- 736.28 MJ mm ha^{-1} h^{-1}. In this Figure, green colour and red colour indicates lowest and highest values respectively. Figure 8 shows the R factor distribution during the year 2006. In this Figure, blue colour indicates the highest R factor. The R factor values ranges from 519.86-806.04 MJ mm ha^{-1} h^{-1}. The R factor during the year 2007 ranges from 363.42- 664.71 MJ mm ha^{-1} $h^{-1}$is shown in the Figure 9. The yellow colour in this Figure indicates lowest R factor and blue colour indicates highest R factor.

Table 2. Soil erosion and sediment yield in Godavari Basin from 2002-2007

Year	Soil Erosion (t ha^{-1} $year^{-1}$)	Sediment Yield (t ha^{-1} $year^{-1}$)
2002	3.58	18.77
2003	4.29	22.32
2004	2.97	15.57
2005	5.2	27.19
2006	5.99	31.42
2007	4.59	24.04
Average	4.34	23.22

Table 3.Comparison of Modeled and Observed sediment yield at Polavaram

Year	Predicted Sediment Yield from Model	Observed Sediment Yield from CWC
2002	18.77	19.56
2003	22.32	24.32
2004	15.57	14.21
2005	27.19	39.29
2006	31.42	35.16
2007	24.04	25.23
Average	23.22	26.3

The average annual R factor values vary from 529 to772 MJ mm ha^{-1} h^{-1}. The K value in the study area varies from 0.6 to 0.8. The combined spatial distribution of LS factor is derived using the DEM of the study area and showed in Figure 2. Spatial distribution of C factor is derived for the year 2007.It is found that C value in the study area is 0.698, which is calculated using the equation 7. The K factor value for this study area is 0.08. P factor value is assumed as 1. The soil erosion and sediment yield in Godavari Basin is shown in the Table 2. The average soil loss and sediment yield estimated around the Godavari River are 4.34 and 23.22 t ha^{-1} $year^{-1}$ respectively. Comparison of modeled and observed sediment yield at Polavaram gauging site is shown in the Table 3. The average modeled and observed sediment yields are 23.22 and 26.3 t ha^{-1} $year^{-1}$ respectively.

CONCLUSION

RS & GIS is very useful tool compared to traditional methods because it can divide the land surface into many cells, which permits analysis to be performed on both large regions as well as small areas. The USLE model is a statistically-based soil erosion model that is easy to parameterize and thus requires less data and time to run. Integrating the model with GIS can help land managers identify problem areas and adopt best management practices. Rainfall erosivity factor (R) for each sub-watershed was determined using mean annual rainfall from 2002 to 2007. The R factor for Godavari basin ranged between 529.39 and 771.66 MJ mm ha^{-1} h^{-1}. Soil Erodibility factor (K) values for major portion of the soils in the study area ranged from 0.06 to 0.08. Topographic factor (LS) for each sub-basin was estimated. The average LS factor in the Godavari basin was 10448.13. Sediment Delivery Ratio (SDR) for each sub-watershed was calculated. The average SDR value for Godavari Basin in Andhra Pradesh was 5.13. Cropping management (C) factor was derived from NDVI map for the year 2007. The C factor in the study area was 0.7. Soil erosion around the Godavari River in Andhra Pradesh was estimated from the year 2002 to 2007. The average soil erosion in the Godavari basin was 4.34 t ha^{-1} $year^{-1}$. Sediment Yield at Polavaram gauging site was estimated from the year 2002 to 2007 and average sediment yield was 23.22 t ha^{-1} $year^{-1}$.

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CITATION OF THIS ARTICLE

K. Srinivasa Rao, Kiran Yarrakula, A. Mani and R Jayaprakash. Soil Erosion Estimation around Godavari Basin in Andhra Pradesh using Remote Sensing and GIS. Bull. Env. Pharmacol. Life Sci., Vol 8 [2] January 2019: 119-129