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Estimation of the Soil Erosion in Cauvery Watershed (Tamil Nadu and Karnataka) using USLE

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Abstract: *Sediments that are brought by the rivers are deposited in the wetlands, particularly in the lagoons, and change gradually the characteristics of the wetland ecosystem. Therefore, the soil erosion through the rivers and the runoff has to be estimated to decide a management action plan. The goal of this research project is to develop a GIS - based soil erosion potential model of the Point Calimere wetland at the apex of Cauvery delta in Tamil Nadu. The basic method of the Universal Soil Loss equation is combined with the computer capabilities of a GIS, specifically the commercial software package ArcGIS 10. The USLE has proved to be very popular and it estimates long term average annual gross soil erosion. This equation multiplies six parameters: rainfall erosivity factor, soil erodibility factor, slope length factor, slope gradient factor, crop cover or crop management factor and conservation practices factor. The GIS is used to store the USLE factors as individual digital layers with interpolation of rainfall data, slope, soil type and land use. These layers has to be multiplied together to create a soil erosion potential map. For this study, rainfall data, soil maps, satellites images for indentify land use and a raster Digital Elevation Model from Landcover were used*
Keywords: *Sediment, Soil erosion, factor, DEMm management*

I. Introduction

A watershed is a surface area drained by a part or the totality of one or several water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. A watershed enables to understand the runoff process in a watershed. Hydrologists face many problems, especially in respect of ungauged catchment where hydrogical data are rarely available. The quantitative analysis of morphometric parameters is found to be of immense utility in a river basin evaluation, watershed priortization of soil and water conservation and natural resources management at watershed level. Morphometric analysis of a watershed provides the quantitative description of the drainage system/ watershed, it is an important aspect of characterization of watersheds. Both intense rainfall and low flow under prolonged wet soil may trigger problems of gully development that may create damage to drainage lines if not protected (Carey, 2006). Stefan et al (1999) have conducted at study on the uncertainty of conceptual rainfall-runoff models caused, by problems in identifying model parameters and structures. Gully growth metamorphoses from morphometric degradation of gullies under the agencies of erosion while soil loss is the accumulated mass wasting of the gullied soil volume at the field rate. Therefore, the biometric scale measurement of gully dimensions as morphometric degradation progresses will quantitatively define gully soil loss volume, which, with its unit weight, will yield the weight of soil loss (Cheng *et al*., 2007). Schumann et al (2000) conducted a study on Geographic Application of a geographic information system for conceptual rainfall–runoff modeling. According to them, Geographic Information Systems (GIS) is a widely used tool for the collection, management, and display—or visualization—of many types of data that describe space. Visualization of spatial data has been the domain of expertise of cartographers and facilitate elaborate recommendations for best rendering of spatial data exist. Pandey et al (2010) conducted a study on developing a local-specific watershed development plan for a small agricultural watershed of Karso, Hazaribagh, India using remote sensing and GIS techniques. In this study, satellite data of Indian Remote Sensing Satellite (IRS-1C), Linear Imaging Self Scanner (LISS-III) along with other datasets, e.g. existing maps and field observation data have been utilized for generating a land use/land cover map and to extract information on morphological parameters (bifurcation ratio, elongation ratio, drainage density, ruggedness number, relief ratio, and circulatory ratio) and other thematic maps which are an essential prerequisites for watershed development.

The USLE main goal consists of the choice of a conservation plan. Making changes in the equation factors is possible to visualize the effect of different scenarios due to different management plans.

USLE calculates the annual average soil erosion and is presented as follows:

A= R.K.L.S.C.P Where, A - Average annual soil loss (t/ha.year); R - Erosive potential rainfall factor of the average annual rainfall as given by "Erosion Index" ($MJ.mm.ha^{-1}.h^{-1}$); K - Soil erodibility factor ($t.ha.MJ^{-1}.mm^{-1}$); L - Slope length factor (m); S - Slope steepness factor (%); C - Cropping - management factor; P - Conservation practices factor (or support conservation practices).

II. Study Area

The study area is located in south India and covers the states: mainly Tamil Nadu, Karnataka and very small parts of Kerala as shown in Fig. 1.. The geographic Coordinates are from 10°17'12.44" N / 79° 52' 42.35 E to 13° 43' 38.07" N / 75° 34' 47.37 E. The projected Coordinates are UTM Zone 43 N/44 N. The watershed has an area of 84559.22 km^2 and with an extent of 2640.85 km.

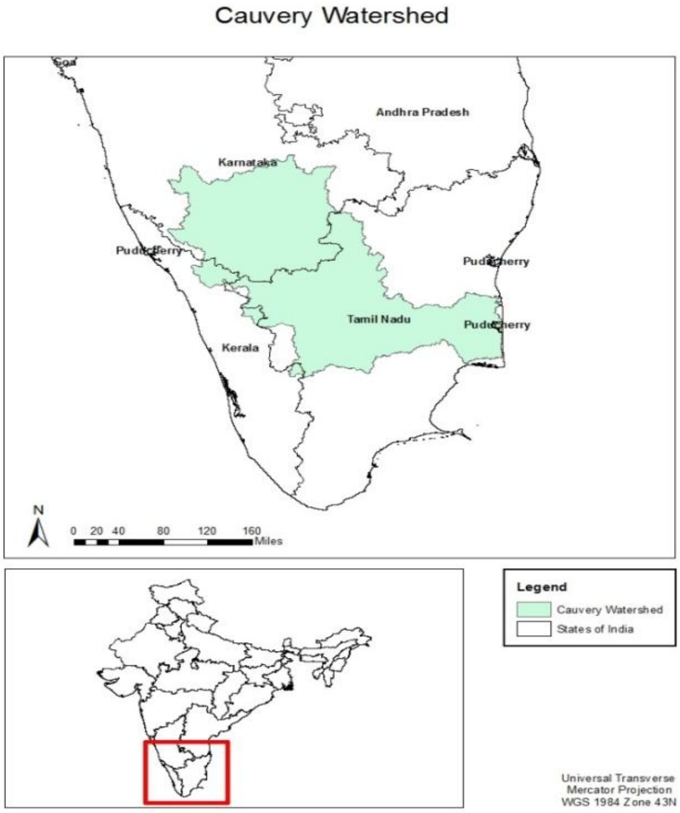


Fig. 1. Study Area

III. Methodology

To carry out the research work, rainfall data, soil, and topographic maps and also satellites images were collected. Joint Research Centre of European Commission at European Digital Archive of Soil Maps were the source of the soil maps. IRS Liss III satellite images were used corresponding to the year 2011. In order to realize the project the methodology was divided in four parts:

1. Literature review about USLE and the interaction of this equation with GIS.
2. Data collection (maps and rainfall data).
3. Digitization of maps and images (contours, drainage lines, land use).
4. Data processing.

For calculating the soil loss using USLE equation, it is necessary that the maps should be in the raster format. This way, all maps generated was converted to raster of cell size of 50m.

Factor R

Wischmeier and Smith (1958) established the EI value, a product of the kinetic energy of the raindrop and the maximum intensity of rainfall over duration of 30 min in a storm. The rainfall mass curve of each single storm is divided into small increments. The intensity of rainfall and their raindrop-kinetic energy are calculated for each increment. Then the maximum intensity of rainfall during a 30 min continuous duration is needed. Multiplied with E, gives the value of EI30. So, the erosivity of rain is calculated by each single storm. For annual rainfall erosivity, the values have to be summed up for the year.

In India, EI30 values are computed using the data of 45 rainfall stations located in different zones, and a simple linear relationship between erosivity index and annual rainfall has been developed (Singh et al., 1981).

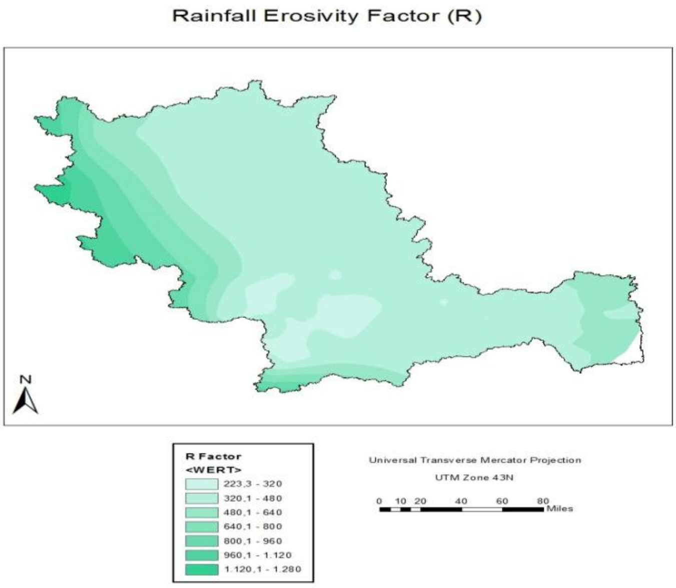


Fig. 2. R Factor

The data for the area are available for 156 rainfall stations. Most of them are located in Tamil Nadu (140 stations) and 16 rainfall stations are distributed in Karnataka (11) and Kerala (5). The rainfall data are only available in very different periods and have the widest range from 1980 to 2008. For every single year in each period, the Annual Erosivity Index was determined. Then, for the whole period the average was calculated for each rainfall station. The area of the watershed was interpolated with the Natural Neighborhood Method and the result is shown in Fig2.

Factor K

Das (2004) describes the K Factor as the rate of susceptibility of soil particles to erosion per unit of rain erosivity factor (R), for a specified soil on a unit plot having a 9% uniform slope and a slope length of 22.13 meters over a continuously clean fallow land with up and down slope farming. The K factor depends on the texture of the soil, but structure, organic matter and permeability also contribute. Soil erodibility factor (K) is a measure of the total effect of a particular combination of soil properties. Some of these properties influence the soil's capacity to infiltrate rain and therefore, help to determine the amount of rate of run off; some influence its capacity to resist detachment by the erosive forces of falling raindrops and flowing water and thereby determine soil content of the run off. The inter-relation of these variables is highly complex. The K factor (

1) is derived from the information about soil type and Hydrological Group. The map of the Soil Classification is shown in Fig3 and the K factor in the Cauvery Watershed is shown in

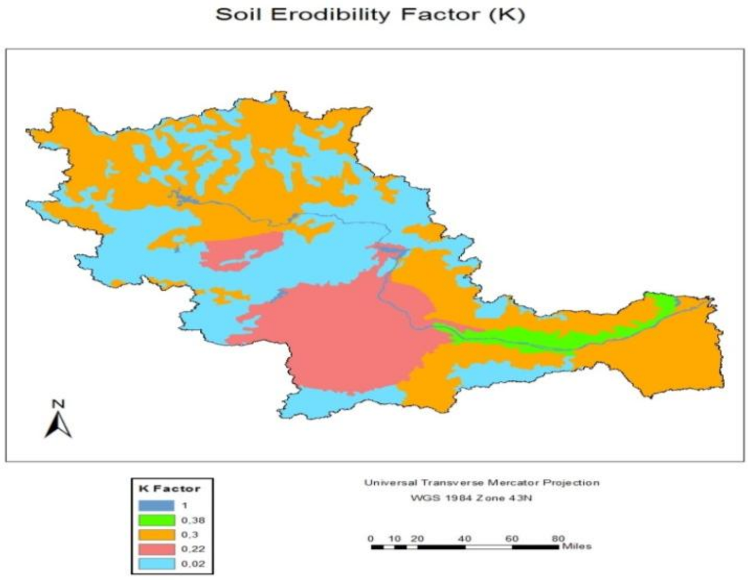


Fig4.

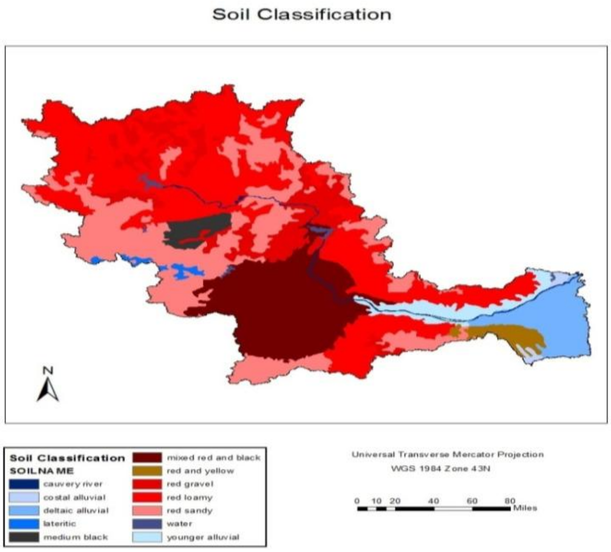


Fig. 3. Soil Loss Classification

Table1: Soil Types and K Value of Cauvery Watershed

Sl. No.	**Soil Name**	**Hydrologic Soil**	**K Value**
1.	Deltaic Alluvial Soil	C	0.3
2.	Red and Yellow soil	C	0.3
3.	Coastal alluvial soil	C	0.3
4.	Younger alluvial soil	C	0.38
5.	Red loamy soil	B	0.3
6.	Red sandy soil	A	0.02
7.	Mixed red and black soil	D	0.22
8.	Red earths	C	0.3
9.	Red gravelly soil	A	0.02
10.	Medium black soils	D	0.22
11.	Lateritic	C	0.3
12.	Water		1

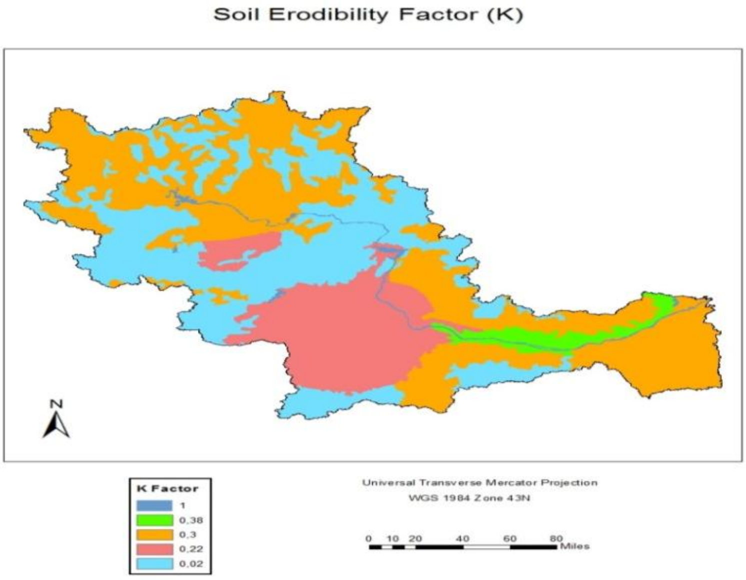


Fig. 4. K Factor

Factor S

The Slope Gradient Factor (S) is the ratio of soil loss from a plot of known slope to soil loss from a unit plot under identical conditions (Das, 2004).

Wischmeier and Smith (1965) expressed following equation to determine the S Factor:

$$S = \frac{0.43 + 0.30\, s + 0.0043\, s^2}{26.613} \quad (2)$$

Where, S is the slope of the field in %.

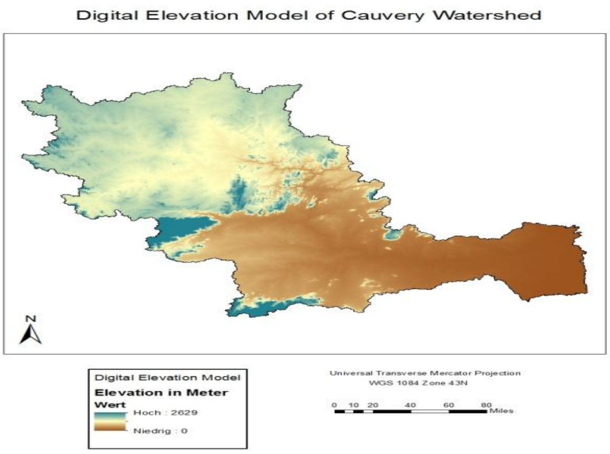


Figure 2: Elevations of the Cauvery Watershed

The slope was derived from the DEM with the Surface Tool “Slope” in ArcGis and with the Raster Calculator the Slope Gradient Factor was calculated. Results for the S Factor are shown in **Error! Reference source not found.**5.’’

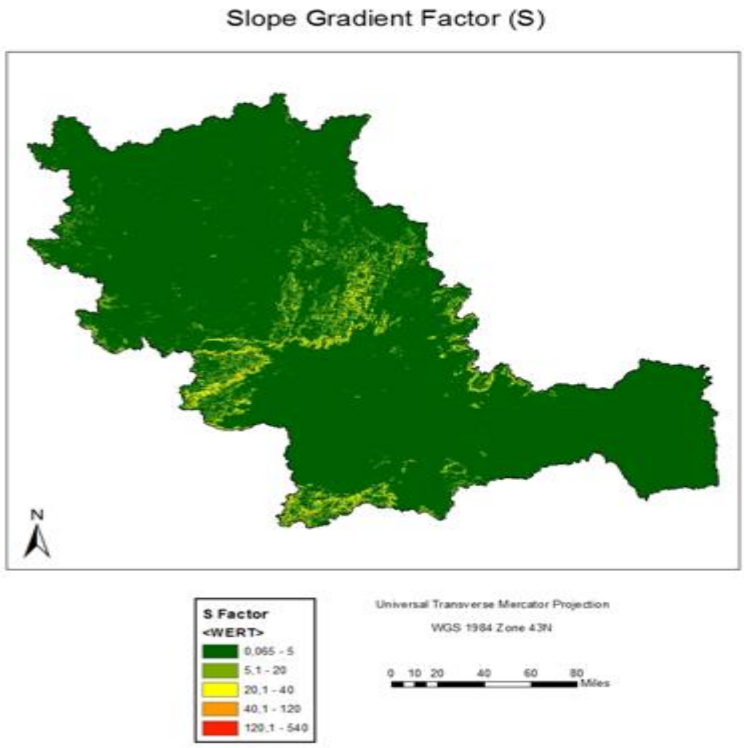


Fig. 5. S Factor

Factor L

The slope length affects the rate of soil erosion, because on larger slope length there will be higher concentration of overland flow, and also a higher velocity of flow which triggers a higher rate of soil erosion (Das, 2004). DEM generated slope length are based on the assumption that each slope plane consists of a homogenous form of slope and vegetation cover, which in practice may not be the case. While deriving topographic factors, GIS techniques tend to predict very long slope lengths on flat to very gentle slopes, which can lead to overestimation of soil loss.

$$L = \left(\frac{L_p}{22.13}\right)^m \quad (3)$$

Where L_p is the actual unbroken slope length in meters and m is the ratio of the soil loss from the field plot length to the soil loss from the unit plot with a slope length of 22.13 meters. Values for m are equal to different slopes, this is shown in
Table2.

Table2: m Value

m Value	Slope in %
0.5	> 5
0.4	3 - 5
0.3	1 - 3
0.2	< 1

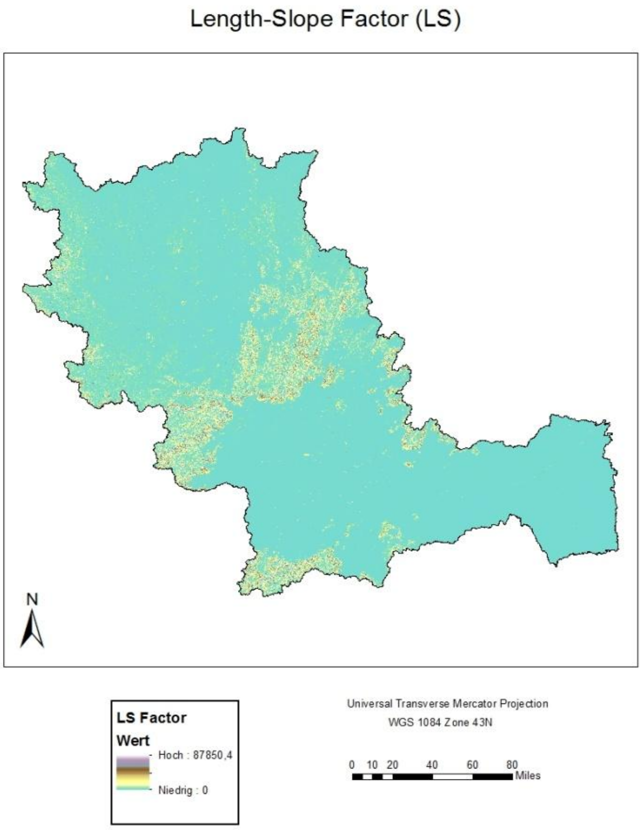
Factors LS

The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith, 1978).

$$LS = \left(\frac{X}{22.1}\right)^m (0.065 + 0.045\ s + 0.0065\ s^2) \quad (4)$$

Where X = slope length (m) and s = slope gradient (%).
The slope gradient in % was already derived in the previous step. For the slope length X, the Flow accumulation was derived from DEM. The m factor (
Table2) was derived from the slope in % with the "Reclassify" Tool.
By substituting X value, LS equation will be:

$$LS = (\text{Flow accumulation} * \text{Cell size} / 22.1)^m * (0.065 + 0.045\ s + 0.0065\ s^2) \quad (5)$$



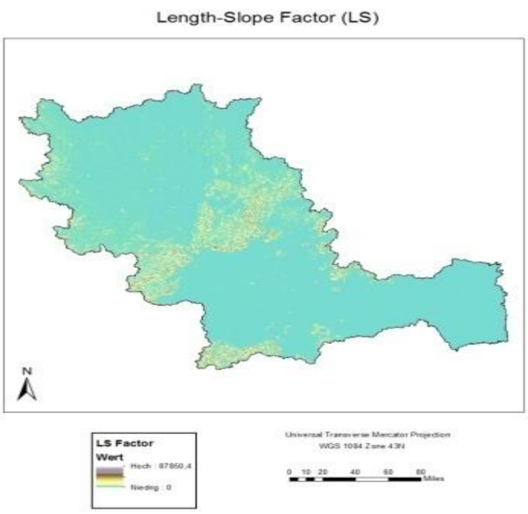


Fig.6. LS Factor

The Result for the LS Factor is shown in Fig. 6.

Factors C and P

The C factor is described as the ratio of soil loss from a cropped land under specific condition to soil loss from clean tilled fallow on identical soil and slope under the same rainfall conditions (Dabral et al. 2008).
Using the “Image Classification” toolbar, eight land-use classes were defined from the satellite image with the help of the training sample manager and supervised Classification. The landuse map is shown in Fig.7. The values for C Factor are shown in
Table. The land use classes were reclassified with the “Reclassify” Tool to get the C Value (Fig. 8).

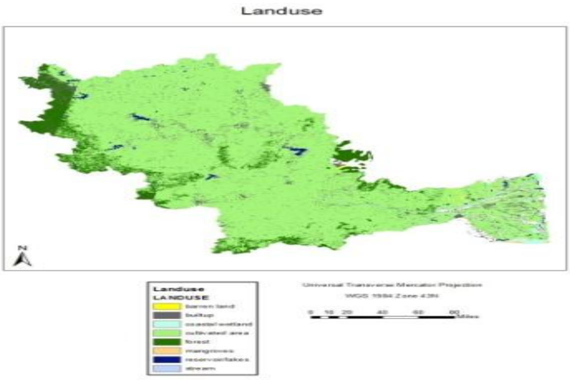


Figure 7. Land use

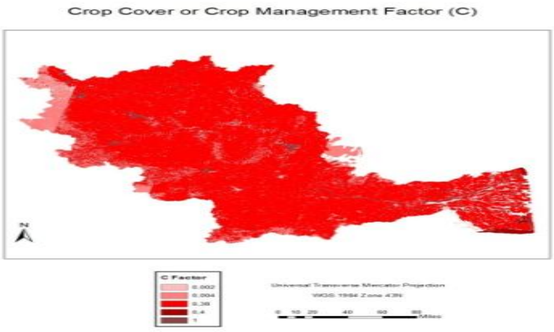


Fig. 8. C Factor

Supporting Conservation Practice Factor (P)

The P factor is the ratio of soil loss from a plot with a specific conservation practice to the corresponding loss from a plot with up and down cultivation under identical conditions (Das, 2004). The land use was already derived in the previous step by the “Image Classification” Toolbar. Values for P Factor were taken from the literature (Priya et al, 1998) and are shown in

Table3. The land use was reclassified with the “Reclassify” Tool to convert the land use in P Values (Fig. 9).

Table 3. Values for C and P Factor

Land use	C Factor	P Factor
Built-up	0.002	1
Forest	0.004	1
Reservoir/Lakes	1	1
Stream	1	1
Mangroves	0.4	1
Costal wetlands	0.4	1
Cultivated area	0.38	0.39
Barren land	1	1

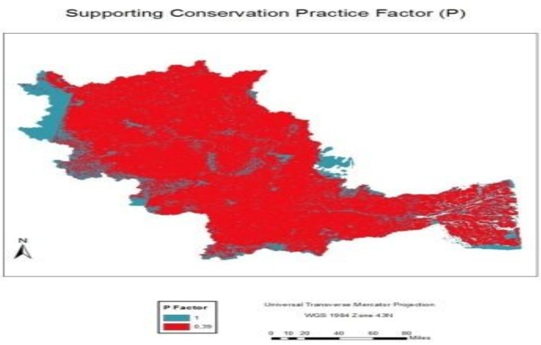


Fig. 9. P Factor

USLE Map for Erosion Potential

Finally, with all the maps of the cited factors, the soil loss map was generated. To obtain the soil loss map, the factor S and L were aggregated, using the raster calculator, using the equation: $LS = 0{,}00984.L^{0,63}.S^{1,18}$; where: LS = Slope and length factor; L = Slope Length (m); S = Slope steepness (%).

Two maps were obtained: one with the qualitative soil loss, and a second one with the quantitative soil loss. For the first map, all the raster maps of different factors raster were reclassified using the reclassify tool of spatial analyst toolbar. With these results, the weighted overlay was carried out with the equal percentage of influence for all maps. For the second, all map factors were overlaid using weighted sum and it was possible to quantify the soil loss for the study area.

Estimated Gross Soil Erosion (A)

The estimated gross soil erosion was calculated by integrating all the factors as shown in equation 6.

“r_factor” * “k_factor” * “ls_factor” * “c_factor” * “p_factor” (6)

The result for the estimated gross soil erosion in t/(ha/year) is shown in Fig.10.

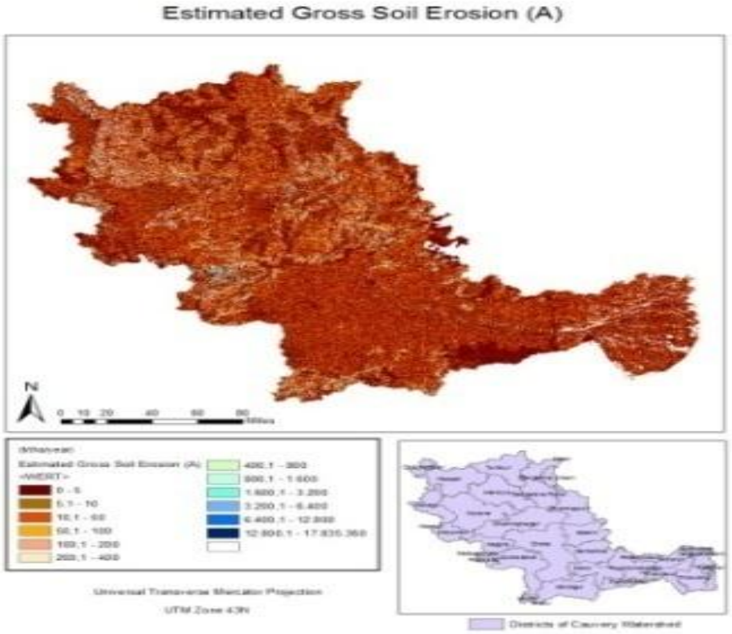


Fig. 10. Estimated Gross Soil Erosion (A)

IV. Results And Discussion

DEM

The Cauvery Watershed is divided into two big areas: A plain area in Tamil Nadu with lowest elevation of 0 m in the Delta and the mountainous area in Karnataka and the Tamil Nadu districts like Nilgiris, Palakkad, north part of Erode, Dharmapuri, Idukki and small parts in Dindigul and Namakkal with maximum elevation of 2829 m. The highest elevations exist at the western border between the plain area and the mountainous area and also a small area in the south of the watershed.

R Factor

The R Factor is a linear function depending on the amount of rainfall in the area. A high rainfall rate influences a high rainfall erosivity and vice versa. A middle high rainfall rate exists in the delta, which is usually influenced by the north-east Winds. A very high rainfall rate exists in the west of the watershed, especially in the districts Chikmagalur, Kodagu and Wayanad, which is near the west coast of India and a part of the Kerala state. These very high rainfall rates on the west coast of India are usually influenced by the summer monsoon. Therefore, the rainfall erosivity index has high values in these areas. Dry conditions are found in the south/middle of the watershed, in the districts Coimbatore and Erode, typically a continental climate, as the mountains act as a barrier and therefore the rainfall erosivity index have lowest values.

K Factor

The K Factor depends on the soil classification. In the watershed eleven different soil types are available. The largest portion is covered by red loamy soil, red sandy soil and mixed black and red soil. The delta region is mostly covered by deltaic alluvial soil. The K Factor for the soil ranges from 0.02 to 0.38.

LS Factor

The slope parameter has a high influence on the LS factor. The highest slope occurs at the confluence regions of plain and the mountainous area, in the middle of the watershed (Districts: Nilgiris, Palakka, north of Erode, south east of Chamrajnagar, Dharmapuri, Bangalore Rural), and in the small scattered areas in the districts of Salem, Coimbatore, Namakkal, Idukki, Dindigul and Kodago. The values for LS vary between 0 and 87850, where the lower values for LS are more distributed in the delta region.

C and P Factor

The land use influences the values of the C and P Factor. The watershed is covered with a lot of small and big lakes/ reservoirs, which are widely distributed in the watershed. Forest is mostly located at the edge of the watershed. The most dominant land use is the cultivated area. Values for C reach from 0.002 to 1. The value 0.38 is the most dominant value for cultivated area. Values for P are 0.39 and 1, where 0.39 is the most distributed value.

A Factor

The major part of the plains of the watershed has a soil erosion below 100 t/(ha/year). The soil loss is below 5 t/(ha/year) in the pudukottai district. Whereas, the soil loss in the mountainous area range from values under 5 t/(ha/year) till 3200 t/(ha/year), and in some scattered areas the values higher than 400 t/(ha/year), with extreme values more than 12800 t/(ha/year).Areas with values above 400 t/(ha/year) to 3200 t/(ha/year) are mostly situated in the districts of Hassan, Kodagu, Chikmagalur, south of Bangalore Rural, north/ west and south of Mysore, Chamrajnagar, north west and south parts of Salem, Nilgiris, Idukku, small east areas of Namakkal, east and south of Coimbatore and south of Dindigul. Areas with more than 3200 t/(ha/year) are very less. Values more than 12800 t/(ha/year) are the extreme values and are located in the district of Nilgiris and in some parts of the watershed nearer to the borders of the districts Chamrajnagar and Dharmapuri. The R Factor does not have a big influence in soil loss, because when a high R Factor occurs, then the soil loss does not show high values. The soil loss does not follow the parallel contours of the R Factor. The C Factor has a visible influence in the A Factor. Smaller C Factors, 0.002 (built up) and 0.004 (forest), causes visible smaller soil erosion values. However, the value of 0.38 (cultivated area) can cause both higher and smaller soil erosion values. Therefore, the C Value of 0.38 is more influenced by the LS Factor. The P Factor value of 1 (all the other and use) causes smaller values for the A Factor. Very obviously when a high soil loss rate occurs, the LS factor is also high (see Fig.6. LS Factor), especially it is visible in the districts of Nilgiris, Palakkad, north of Erode, south east of Chamrajnagar, Dharmapuri, Salem, Coimbatore, Namakkal, Idukki, Dindigul, Bangalore Rural and Kodago. Even in the conjunction with the smallest K value, in the middle part of the watershed, there occurs high LS values and high soil erosion values. Therefore, the LS factor has the biggest influence on the soil erosion. The soil loss reflects very well the K Factor of 0.02 (red gravelly soil and red sandy soil) and 0.3 (here: red loamy). These soil types seem to have an influence on the soil loss, because they cause visible marks in the map. In the mountainous area, there are visible differences between the soil erosion, where the K Factor with 0.02 and the K Factor with 0.3 occur. Soil erosion values in the mountainous area are higher, where the K Factor with 0.3 is situated, than areas with the K Factor of 0.02. In the plain area, where the K Factor of 0.02 occurs, there are less soil erosion values, except in the small mountain area in the south (Idukki and Dindigul), where also high LS values occur. Red loamy soil seem to have no influence in the delta region and also the other soil types with the K Factor of 0.3 (Deltaic Alluvial Soil, Red and Yellow soil, coastal alluvial soil, Lateritic) and even for the highest K Factor 0.38 (Younger Alluvial Soil), which are located in the delta, do not cause higher soil loss values. Reason could be the combined influence of the LS Factor, which has the higher values also in the mountainous region and not in the delta region.

V. Conclusion

A quantitative assessment of average annual soil loss on watershed basis was made using the well-known USLE with a view to know the spatial distribution in the study watershed. The use of GIS and satellite data enabled the determination of the spatial distribution of the USLE parameters. The highest soil erosion occurs in the watershed in the mountain area and reaches mostly from under 5 t/(ha/year) until 3200 t/(ha/year), with extreme values in very small areas with more than 3200 t/(ha/year). The plain area has a lesser soil erosion until 100 t/(ha/year). The soil Erosion shows a high correlation with the LS Factor. The LS Factor is the parameter with the highest influence on soil erosion. Moreover, red loamy soil (K Factor of 0.3) causes high soil erosion in the mountainous area, but not in the plains. The reason could be in combination with the LS Factor, which has higher values in the mountainous area. The smallest K Factor of 0.02 causes usually less soil erosion, but when there are high LS values, the influence of LS Factor is higher and causes high soil erosion. The R Factor has no big influence on the A Factor. The smaller C Values 0.002 (built up) and 0.004 (forest) cause less soil erosion. The C value of 0.39 (cultivated area) is more influenced by the LS values and other factors and can cause high and small erosion. The P value for cultivated area is also more influenced by other factors. The districts with the highest soil erosion (more than 400 t/(ha/year) are Nilgiris, Kodagu, north/east and west of Mysore, north of

Chimrajnagar, Chikmagalur, Hassan, south part of Bangalore Rural, Salem, Erode, Idukki and Dindigul of Cauvery watershed.

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