



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: III Month of publication: March 2019

DOI: <http://doi.org/10.22214/ijraset.2019.3421>

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Estimation of Water Erosion in Southern Districts of Tamil Nadu using Geo-spatial Technologies

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Abstract: Land degradation can be considered as deterioration of the original quality of land and deterioration or total loss of the production capacity of the soil. Land degradation is caused due to changes in climate and human activities. This study was carried out to map land degradation caused by erosion due to water in Tirunelveli, Thoothukudi and Kanyakumari district using Sentinel-2 optical data. Water erosion is mapped by analyzing the data across Kharif, Rabi and Zaid season between 2017 and 2018. Sentinel-2 optical data has 13 bands with spectral resolution ranging from 0.443 μm to 2.190 μm . The water eroded areas are visually interpreted from the FCC image composed of NIR (8), Red (4) and Green (3) bands with spatial resolution of 10 m. It is estimated that 1563.165 sq.km is degraded due to water erosion. Water erosion areas are more clearly visible in Zaid season when the land conditions are dry. Besides, rainfall, soil, land use land cover and slope data has been used as an input to derive the parameters required for spatial modeling of soil erosion using USLE. Depending on the amount of soil loss they are six categorized into six classes viz. very low erosion ($0 - 5 \text{ t ha}^{-1} \text{ yr}^{-1}$), low erosion ($5 - 10 \text{ t ha}^{-1} \text{ yr}^{-1}$), moderate erosion ($10 - 20 \text{ t ha}^{-1} \text{ yr}^{-1}$), moderately severe erosion ($20 - 40 \text{ t ha}^{-1} \text{ yr}^{-1}$) and severe erosion ($> 40 \text{ t ha}^{-1} \text{ yr}^{-1}$). In the study area soil loss classes ranges from low ($0-5 \text{ t ha}^{-1} \text{ yr}^{-1}$) to severe ($40-873.145 \text{ t ha}^{-1} \text{ yr}^{-1}$). The rate of annual soil loss ranges from 0 t ha^{-1} to $873.145 \text{ t ha}^{-1}$. The visually interpreted water erosion layer is integrated with soil loss map and the accuracy of the erosion layer is found to be 87.3%. High rate of erosion occurred at bare soil and down slope.

Keywords: Water erosion, Rainfall, Slope, Soil, USLE, LULC

I. INTRODUCTION

Land is the most valuable natural resource that forms the foundation of environmental development and ecological sustainability. It is the basis for food, fuel and fibre production and for many other essential goods required to meet critical human and animal needs. Water erosion is the most widespread form of degradation and occurs widely in all agro-climatic zones. The displacement of soil material by water can result in either loss of topsoil or terrain deformation or both. Water erosion is the process of removal of soil particles by flowing water. When a heavy rain drop falls on the surface of the land it causes the soil particles to splash resulting in removal of soil particle by impact of rain drops. When rain water falls on the surface of land with less to no vegetal cover the runoff caused due to water flow results in sheet erosion. When this runoff water accumulates and flows down slope from an elevated land it results in rills and gullies erosion depending up on the gravity of the problem, susceptibility of land and continuity of the process. During visual interpretation, cultivation areas in hilly region and agricultural areas in the lower region are eliminated. The water erosion is mapped for sheet, rill and gully erosion. Sheet erosion is classified into slight, moderate and severe. Rills and gully erosion is classified as very severe. Water erosion is dominant in the semi-arid and dry sub-humid regions. In 2011- 2013, 45.92% of India's total land area was degraded. The major degradation in the country was water erosion with 10.98 % in 2011-2013 based on Desertification and Land degradation Atlas of India ^[1] (2018). Universal Soil Loss Equation (USLE) is a well known paper based model to determine the amount of soil loss occurred in various land use classes over a year (Moore and Wilson 1992; Millward and Mersey 1999). The RUSLE can be adopted for soil loss assessment at well defined area where the adequate information of soil type, soil texture, slope, rainfall and land use are readily available ^[7]V. Prasannakumar et al. (2012), ^[2]Habtamu Sewnet Gelagay et al. (2016), ^[6]Temesgen Gashaw et al. (2017), ^[4]Mengesha Zerihun et al. (2018)). Geographical information system (GIS) has provided a platform in the application of RUSLE to bring about effective and accurate results of the model. Considerable advancements have been made in the application of GIS for preparing and analysing the thematic layers that are used in modelling. ^[5]Narayan Kayet et al. (2018) employed RUSLE model in estimating the amount of soil loss in hill slope and mining areas and the Landsat pan sharpening image and DGPS survey field data were used in the verification of soil erosion results. ^[3]Lulseged Tamene et al. (2017) used the Revised Universal Soil Loss Equation for sediment delivery ratio in a GIS system to assess landscape sensitivity to erosion and to identify hotspots. Remote sensing satellite data provides a rapid, relatively in-expensive means to gather adequate

information on various land features even in inaccessible areas or where the quality of available information that can be obtained is considerably low. It gives the opportunity for repetitive, annual or seasonal multi-spectral examination. Remotely sensed data from satellites were employed subsequently to derive information on the nature, extent, spatial distribution and magnitude of various types of degraded lands by water erosion. Besides, remote sensing data has been used as an input to derive the parameters required for spatial modeling of soil erosion.

II. MATERIALS AND METHODS

A. Study Area

The study area is located in the south eastern part of Tamil Nadu as shown in Fig. 1. Tirunelveli district lies between $08^{\circ}08'N$ and $09^{\circ}23'N$ of latitudes and $77^{\circ}09'E$ and $77^{\circ}54'E$ of longitudes. Thoothukudi district is located in the extreme south-eastern corner of Tamil Nadu State, between $08^{\circ}22'N$ to $09^{\circ}22'N$ Latitudes and $77^{\circ}40'E$ and $78^{\circ}E$ Longitudes. Kanyakumari district lies between $08^{\circ}03'N$ and $08^{\circ}35'N$ of the latitudes and $77^{\circ}15'E$ and $77^{\circ}36'E$ of the longitudes.

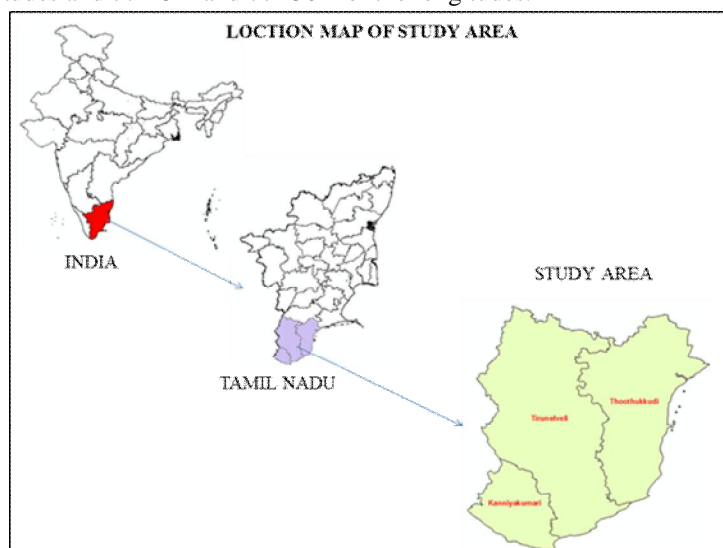


Fig. 1 Location Map of the study area

Depending on the amount of rainfall the study area can be broadly classified into semi-arid agro climatic-zone and heavy rainfall zone. Tirunelveli and Thoothukudi district, in general experiences tropical climate with immensely hot summer, gentle winter and frequent rain showers. The average rainfall during 2017-18 in Tirunelveli is 917.86mm and in Thoothukudi is 699.4mm. Whereas, Kanyakumari is situated in a high rainfall agro-climatic zone, it enjoys a tropical coastal climate. It receives rain under the influence of both southwest and northwest monsoons. The southwest monsoon chiefly contributes to the rainfall in the district. The normal annual rainfall over the district varies from about 826 to 1456 mm.

In Tirunelveli district the soil condition may be grouped into two main varieties namely red loam soil and black soil. This district has fertile soils only in scattered regions. Thoothukudi district is covered with black soils in the western part, red soil in the central part and alluvial Sandy soils in the eastern part. The soils of Kanyakumari district can be classified into Red Soil, Red lateritic soil, Brown soil and Coastal sand. The soils are mostly in-situ in nature, lateritic, earthy and pale reddish in colour. They are derived from laterisation of gneisses. Soil in this district is mostly of loamy variety; however sandy soils are seen in the sea coast and gravelly soils near the mountain ranges. The major soil types present in the study area include montmorillonite, vertisols, kaolinite, Alisols, inceptisols.

B. Satellite Data

Multi-temporal Sentinel-2A data acquired during three different seasons viz. Kharif (June – October), Rabi (November – February), Zaid (March – May) of 2017-2018 were used. Each data for a month is approximately considered for this mapping. The satellite data is then used for visual interpretation, and they are verified with ground truth collection to prepare the land degradation map preparation.

The Sentinel-2A satellite was launched on 2015, as part of the European Copernicus program. Sentinel-2A satellite data consists of an innovative wide-swath, high-resolution, multispectral imager (MSI). It consists of 13 spectral bands. The Sentinel-2 provides images with spatial resolution varying from 10 m to 60 m, and has three bands in the red-edge and two bands in the SWIR region. It is expected to provide extremely useful information for a wide range of land and coastal applications. The band specification of Sentinel – 2 data is shown in Table 3.1. Sentinel 2 data from bands 3, 4 and 8 with the spatial resolution of 10m are considered in this study. The data available for download is in Geo TIFF format. They contain 16 bit data values. The data is layer stacked to produce false colour composite images. Histogram Equalization and rescaling of data is done for better visual interpretation. The thematic layers used in this study for USLE model involves soil data, LULC data, Rainfall data, data regarding the administrative boundary information and slope data. Soil map consisting information on Soil Texture is obtained from Soil survey atlas- soil survey and land use organization in polygon data type with scale of 1:250,000 & 1:50,000. LULC map with information on Land use / Land cover is obtained from NRSC in polygon data format with scale 1:50,000. The administrative boundary map is obtained from Survey of India and IRS in polygon data format. Rainfall intensity map for (2013- 2018) is obtained from Earth science data in gridded format with the resolution of 0.05° x 0.05°. CARTOSAT DEM in gridded format with the resolution of 30m is used in generating slope map, slope angle map and slope length.

III.METHODOLOGY

Sentinel 2A data is prepared for visual interpretation by layer stacking 3, 4 and 8 bands and mosaicing to interpret the study area in single scene. The water erosion is mapped for sheet, rill and gully erosion by identifying the features in False Color Composite (FCC) images. Sheet erosion is classified into slight, moderate and severe. Rills and gully erosion is classified as very severe. The methodology flow chart for estimation of water erosion in study area is given in Fig. 2.

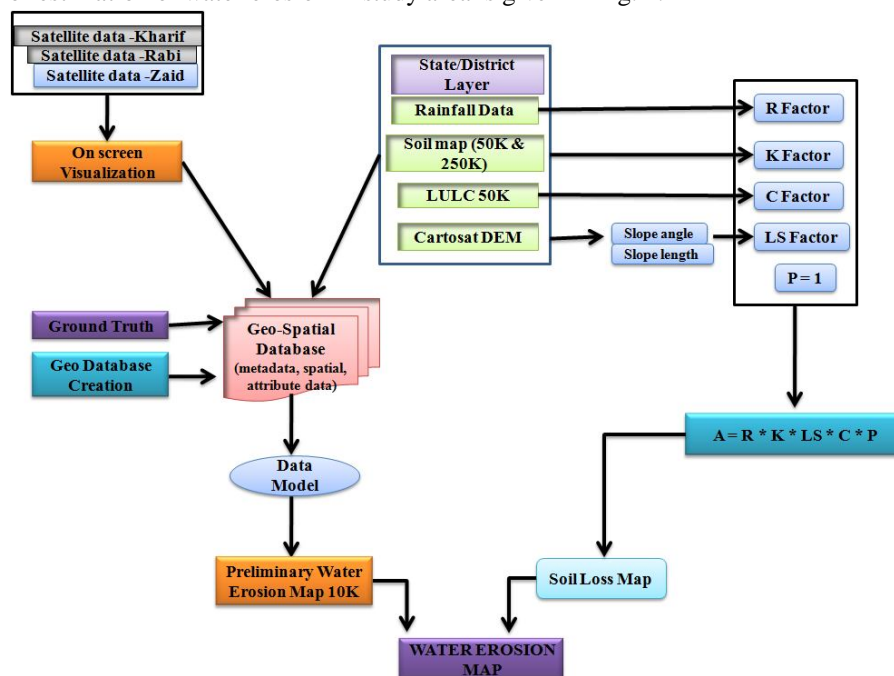


Fig. 2 Methodology flow chart for estimation of water erosion in the study area

A. Water Erosion

- 1) *Sheet Erosion*: During visual interpretation, sheet erosion is identified as slightly brighter patches compared to the surrounding background soil colour. If such places are identified then the slope is checked using the information available from topology layer. The same place checked in all three seasonal images and if there is no vegetal cover in those places for all three seasons then they can be considered as sheet erosion. The areas with good vegetation cover may be eliminated, except for cultivated lands where surface soil is disturbed. In the field, muddiness of water flowing in the streams is checked during rainy season to get an assessment of erosion happening in that land area.
- 2) *Rills*: When the surface runoff goes in the form of a concentric flow, tiny water channels are formed in the field. Rills do not occur at the same place repeatedly. Rills can be identified by checking for brighter patches than the surrounding background

soil colour with medium image texture. They are generally visible in cultivated areas. Rills are generally evident in loamy to clayey soil textures.

- 3) *Gullies*: Gullies are formed as a result of localized surface run-off affecting the unconsolidated material resulting in the formation of perceptible channels causing undulating terrain. If rills are neglected and the erosion continues for a long time, it develops in to gullies. They too are brighter than the surrounding background but have medium to slightly coarse image texture with yellowish tones. They are commonly found in sloping lands, developed as a result of concentrated run-off over fairly long time. They are mostly associated with stream courses, sloping grounds with good rainfall regions and foothill regions. They are directly associated with natural stream network of the area. The erosion starts near the stream and proceeds upwards along the slope.

B. Soil Loss Estimation

The USLE equation is a product of five factors in raster data format. It includes soil erodibility, rainfall erosivity, slope length, slope steepness, cover management and support practice. Each factor varies spatially and temporarily and depends on other input data. Therefore, soil erosion within each pixel was calculated using the Universal Soil Loss Equation (USLE).

The USLE equation is described as:

$$A \equiv R \times K \times LS \times C \times P \text{-----} \quad \text{Eq (1)}$$

where, A is the computed spatial average of soil loss over a period selected for R, usually on yearly basis ($t \cdot ha^{-1} \cdot y^{-1}$); R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$); K is the soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$); LS is the slope length steepness factor (dimensionless); C is the cover management factor (dimensionless, ranging between 0 & 1); P is practices factor (dimensionless, ranging between 0 and 1).

In the present research, annual loss map was generated for the study area consisting of three districts namely Tirunelveli, Thoothukudi and Kanyakumari. The data layers extracted for K, LS, R, C, and P factors of the USLE model were integrated using Equation (1) within the raster calculator option of the ArcGIS spatial analyst in order to quantify, evaluate, and generate the maps of soil erosion risk.

C. Rainfall – Runoff Erosivity Factor (R)

The rainfall-runoff erosivity factor makes use of the annual rainfall data. Rainfall and runoff on the unprotected soil surface results in breakdown and scattering of soil aggregate materials. Runoff on soil increases with decrease in infiltration due to compaction, crusting or freezing. The Rainfall Erosivity factor R can be defined as the product of kinetic energy and the maximum 30 minute intensity and shows the erosivity of rainfall events. Rainfall data of 5 years was obtained and imported into GIS environment to determine the rainfall erosivity factor. The rainfall Erosivity values for the study area that were obtained from the gridded data are used to interpolate the rainfall erosivity surface using the kriging interpolation method in ArcGIS environment to generate a raster map for R- factor. Wischmeier and Smith equation that is modified by Arnoldus was used in the computation,

$$R = \sum_{i=1}^{12} 1.735 \times 10 \left(1.5 \times \log_{10} \left(\frac{P_i^2}{P} \right) - 0.08168 \right)$$

Where, R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$), P_i is the monthly rainfall (mm), P is the annual rainfall (mm).

D. Soil Erodibility Factor (K)

Soil erodibility factor K represents both susceptibility of soil to erosion and rate of runoff. Erodibility of soil by erosion or running water is related with percentage organic matter, particle size, sodium adsorption ratio and dissolved solids concentration in pore water. Soils with higher amount of organic content and good soil structure have higher resistance to erosion as these soils tend to be more permeable. Organic matter reduces the erodibility as it prevents soil from detachment and it increases infiltration which in turn reduces the runoff. Soil erosion depends on soil texture, soil depth and soil surface structure. Based on soil texture, sandy loam, loam, silty loam, silt are soil which are highly erodible; sandy clayey loam, clayey loam, silty clayey loam, loamy sand and sand are moderately erodible and sandy clay, clay, silty clay are soil are least erodible. The soil erodibility factor (K) is considered to represent the rate of soil loss per unit of rainfall erosion index for a specific soil type. The soil data containing percentage information on sand, silt, Organic carbon, soil permeability and soil structure were obtained. To calculate the soil erodibility, the formula of Wischmeier and Smith was used.

$$K = \frac{2.173 \times \left(2.1 \times M^{1.14} \times (10^{-4}) \times (12 - a) + 3.25 \times (b - 2) + 2.5 \times (c - 3) \right)}{100}$$

Where K is the soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$), M is the particle percentage (% of very fine sand + % of silt \times (100- %clay)), a is the organic matter content (%C \times 1.724), b is the soil structure and c is the soil permeability.

E. Slope Length and Slope Steepness Factor (LS)

The slope factor represents the topographic and the relief factor. The slope length factor L computes the effect of the slope length on erosion and the slope steepness factor S computes the effect of the slope steepness on erosion. When the length of the slope is longer it tends to have longer volume of accumulated runoff with higher velocity and greater depths. This makes it susceptible to more erosion compared to when the length of slope is shorter. Hence longer the slope length, greater is the total soil loss. When the slopes are steeper the runoff flowing downhill will have high velocities and fast flow. The classification of slope is shown in Table I.

TABLE I
CLASSIFICATION OF SLOPE

S.No	Category	Slope (%)
1	Nearly Level	0-1
2	Very Gentle Sloping	1-3
3	Gentle Sloping	3-5
4	Moderate Sloping	5-10
5	Strongly Sloping	10-15
6	Moderate Steep to Steep Sloping	15-30
7	Very Steep Sloping	>35

In order to estimate the impact of slope length and slope steepness in the assessment of soil erosion risk present in the study area, the following categories are considered, **0-5%:** area with very low erosion risk, **5-15%:** area with moderate erosion risk, **15-30%:** area with high erosion risk and **>30%:** area with extremely high erosion risk. Topography factor plays a major role in soil erosion since it dominates the surface run off rate. The combined LS factor was derived from Digital elevation model by means of ArcGIS environment. The computation of LS requires factors such as flow accumulation and slope steepness. The flow accumulation and slope steepness were computed from the CARTOSAT DEM using ArcGIS Spatial analyst extension.

The Equation to calculate LS factor as proposed by Moore and Burch,

$$LS = \frac{(Flow\ accumulation \times Cellsize)^{0.4}}{22.13} \times \frac{(\sin slope)^{1.3}}{0.0896}$$

Where, Flow accumulation denotes the accumulation up slope contributing area for a given cell, LS denotes the combined slope length and slope steepness factor, Cell size indicates the size of the grid cell and Sin slope denotes the slope degree values in sine.

F. Cover Management Factor (C)

The cover management factor is used to reflect the effect of cropping and management practices on erosion rates. It indicates how the conservation plan will impact the average annual soil loss. The main effects of cover management are rainfall interception and reduction in velocity of runoff. The impact of raindrop and runoff is taken care by the vegetation cover rather than by the soil. Different type of land use class has different C factor as shown in Table II. The values are adopted from the agricultural handbook.

TABLE II
DIFFERENT CLASS NAME AND THEIR CORRESPONDING C-FACTOR

S.No	Class Name	C-Factor
1	Agriculture Area	0.63
2	Built-up Area	0.09
3	Forest	0.03
4	Waste Lands	0.5
5	Water bodies	0
6	Others	0.001

G. Conservation Practice Factor (P)

The P-factor indicates the impact of support practices in the average annual erosion rate. As with other factors, the P-factor differentiates between cropland and range land or permanent pasture. In this study, the soil erosion on non-agricultural areas is the main scope; it is considered that there were no conservation practices in non-agricultural areas. Normally the conservation practice factor ranges from 0-1. The highest value 1 is assigned to areas with no conservation practice, in this study.

IV. RESULTS AND DISCUSSION

Water erosion management on soil will continue to be the principal determinant of the soil organic matter (SOM) content and susceptibility to erosion for the next few decades, but the changes in vegetation cover caused by stress might affect the land which ultimately results in deterioration. Hence, there is a need to understand the importance of rainfall in water erosion.

Rainfall can erode soil by the force of raindrops, surface and subsurface runoff, and river flooding. The breaking apart and splashing of soil particles due to raindrops is only the first stage of the process, being followed by the washing away of soil particles and further erosion caused by flowing water. However, without surface runoff, the amount of soil erosion caused by rainfall is relatively small. Once the soil particles have been dislodged they become susceptible to runoff. In general, when the intensity of rainfall is high the quantity of soil available for runoff is also high. In the case of light rain for a long duration, most of the soil dislodgement takes place in the underwater environment and the soil particles are mostly fine. A critical factor that determines soil erosion by rainfall is the permeability of the soil, which indirectly influences the total amount of soil loss and the pattern of erosion on slopes. One unfortunate by-product of runoff is the corresponding transport of agricultural chemicals and the leaching of these chemicals into the groundwater.

A. Rainfall Distribution for the Study Period

Rainfall distribution for the period of study is observed to determine the pattern of vegetation growth along with rainfall. Fig. 3(a) & (b) show the comparison of rainfall during the period of study (May 2017 – April 2018) with the annual mean rainfall for semi-arid zone and heavy rainfall zone respectively. Fig. 3(a) shows only one peak (November) indicating that the semi-arid zone receives maximum rainfall in November and the minimum rainfall is recorded in the month of January. Whereas Fig. 3(b) shows two peaks (September and November) indicating that heavy rainfall zone receives maximum rainfall during the month of September and November. The minimum rainfall is recorded in the month of January. In the study are the maximum rainfall occurs at hilly regions in Kanyakumari and Tirunelveli districts and the least rainfall occurs in the low lands of Thoothukudi district.

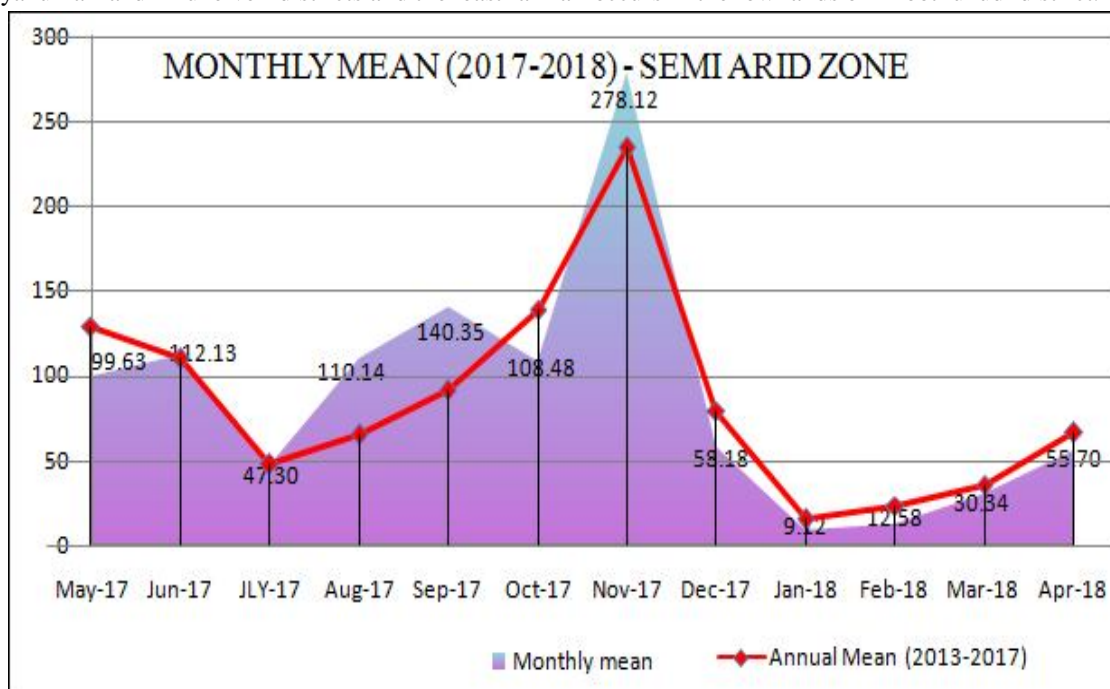


Fig. 3 (a) Graph showing the comparison of monthly mean rainfall during study period with annual mean rainfall between 2013 and 2017 for semi- arid zone

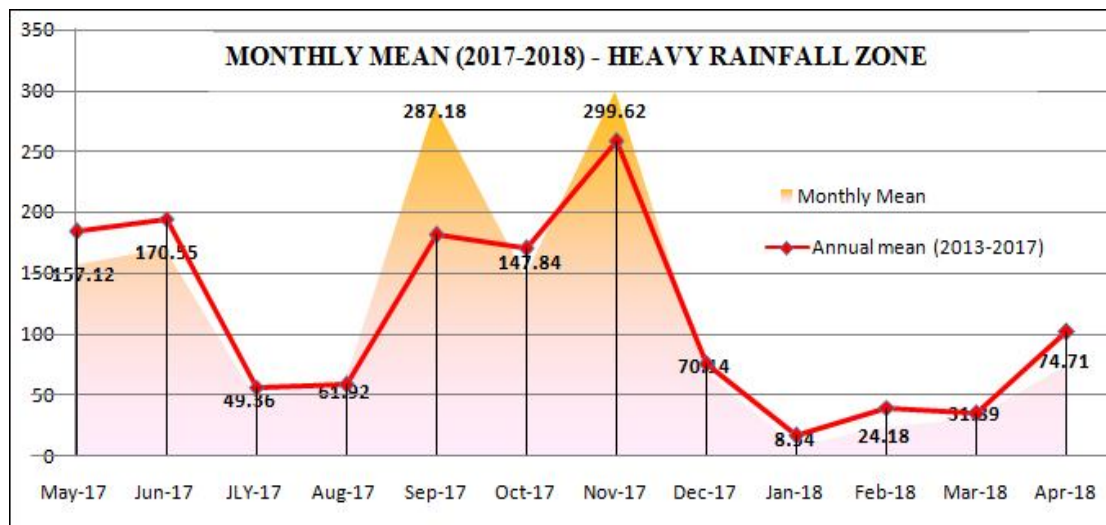


Fig. 3 (b) Graph showing the comparison of monthly mean rainfall during study period with annual mean rainfall between 2013 and 2017 for heavy rainfall zone

B. Water Erosion Mapping

- 1) **Sheet Erosion:** It is the detachment of soil particles by raindrop impact and their removal down slope by water flowing overland as a sheet. The removal of uniform layer of fine particles is from the entire surface of an area, results in an extensive loss of rich topsoil. Sheet erosion can be commonly found on recently ploughed fields or on other sites having poorly consolidated soil material with scant vegetative cover. When the rains splash the soil particles get knocked into the air by raindrop impact. A hundred tons of particles per acre may be dislodged during a single rainstorm where the loose particles are moved down slope, commonly by sheet. Soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Satellite image showing the water erosion taking place in different parts of study area is given in Fig. 4.

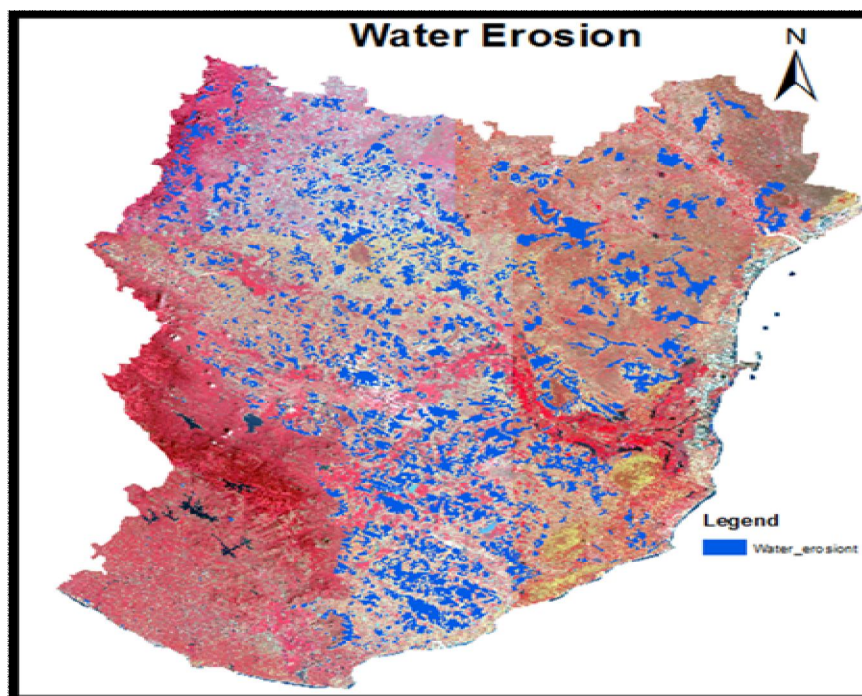


Fig. 4 Water erosion in study area

From the Fig. 4 it can be noted that the places having high to moderate rainfall are more prone to erosion. The places having Sandy loam, sandy loam clay soils are observed to have more erosion areas compared to clay textured soil. The places with minimal

vegetation cover are also prone to erosion. Runoff from agricultural land is greatest during rainfall months when the soils are typically saturated, and vegetative cover is minimal. The rills and gullies are found along the down slope area.

The preliminary water erosion layer identified by visual interpretation is further improved by comparing the results with the soil loss risk map. Each class of water erosion is identified and they are further classified according to the amount of soil loss obtained for that area. The places having less than $5 \text{ t ha}^{-1} \text{ y}^{-1}$ is considered as negligible. The soil losses of $10 \text{ t ha}^{-1} \text{ y}^{-1}$ and above are considered as eroded area. According to this assumption the preliminary water erosion layer is further improved to obtain the revised water erosion layer. The water erosion classification in terms of severity is tabulated depicting the percentage of area coverage of each class Table III. The percentage wise area distribution of severity of water erosion is graphically represented in Fig. 5

TABLE III

WATER EROSION CLASSIFICATION IN STUDY AREA AND THE PERCENTAGE OF AREA AFFECTED

Degradation Class	Area (ha)	Area (%)
Water Erosion – Sheet - Slight	42409.59	27.928
Water Erosion – Sheet - Moderate	65976.78	42.407
Water Erosion – Sheet – Severe	35053.95	22.424
Water Erosion – Rills	10953.56	7.07
Water Erosion - Gullies	1922.24	1.23

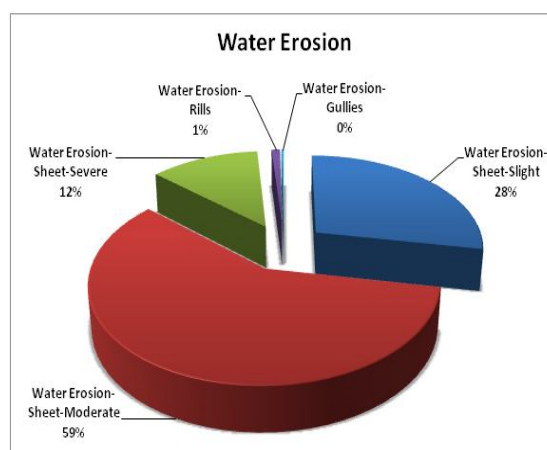


Fig. 5 Percentage break-up of study area based on severity of water erosion

C. Soil Loss Risk Map

The data layers obtained for K , LS , R , C , and P factors of the USLE model were integrated using equation mentioned in the study within the raster calculator option of the ArcGIS spatial analyst in order to quantify, evaluate, and generate the maps of soil erosion risk and severity.

- 1) **Rainfall Erosivity Factor (R):** The long-term mean annual rainfall varies between 537.079 and 2149.69 mm at the study area. The rainfall distribution has been influenced by topographic characteristics of the study area. The highland areas like Kanyakumari and part of Tirunelveli receive relatively high rainfall compared to the lower plain area. Considering topographic variation, the R factor was determined from average long-term rainfall data interpolated from five years. The R factor value ranges between 665.203 and 202.54 $\text{MJmmh}^{-1} \text{ ha}^{-1} \text{ yr}^{-1}$. Approximately 61 % of rainfall erosivity factor R ranges between 900 and 1550 $\text{MJmmh}^{-1} \text{ ha}^{-1} \text{ yr}^{-1}$. On the other hand, the erosion potential of rainfall is low in the central plain and the upper part of the study area.
- 2) **Soil Erodibility Factor (K):** The K factor reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion. Soils that are more permeable with higher level of organic matter and good soil structure have higher resistance to erosion. Soils that have high clay content have greater resistance resulting in lower K values. Coarse textures soils like sandy soils also have low runoff even though these soils are easily detachable and also have low K values. Medium textures soils like silty loam soils are moderately susceptible to erosion and they produce moderate runoff hence they have moderate K values. Soils having high silt content have low infiltration and also prone to soil crust formation which tends to seal the surface and produce high rates of runoff. They are the most erodible of all soils. If the value of K more nearer to 0

then they are less susceptible to erosion. The k value ranges from 0 to 0.163. In the study area around 30 % of the soil is of clay, 24 % sandy clay loam, 19% sandy clay, 16% sandy loam, 4% clay loam, 3% loamy sand and 2 % sand.

- 3) **Slope Length and Steepness Factor (LS):** Length and steepness of a slope affects the amount of soil loss. Erosion increases with slope steepness. The computation of LS requires factors such as flow accumulation and slope steepness. The flow accumulation and slope steepness were computed from the DEM using ArcGIS Spatial analyst plus and arc hydro extension. The LS factor value in the study area varies from 0 to 25. Majority of the study area has LS value less than 5 and some specific areas only showing values higher than 10.
- 4) **Cover Management Factor (C):** The C factor represents the effect of plants, crop sequence and other soil cover surface on soil erosion. The C factor is dimensionless with values between 0 and 1. Six representative landcover classes were identified for the study area. Finally, land-cover classes were used to calculate the mean C factor values by averaging each record for a particular land use.
- 5) **Conservation Practice Factor (P):** In this study the soil erosion was applied on non-agricultural areas, it is considered that there was no conservation practices in non-agricultural areas. The conservation practice factor Ranges from 0-1. The highest value 1 is assigned to areas with no conservation practice, in this study
- 6) **Soil Loss Risk Map:** The soil loss risk map of the study area developed from USLE model using ArcGIS is given in Fig. 6. There are six categories of soil loss risk in the study area ranging from low ($0-5 \text{ t ha}^{-1} \text{ yr}^{-1}$) to extreme ($40-873.145 \text{ t ha}^{-1} \text{ yr}^{-1}$). The rate of annual soil loss ranges from 20 t ha^{-1} to $873.145 \text{ t ha}^{-1}$. The highest erosion rates are found at the hilly parts of the study site. This situation was severe in mountainous lands where farming is common. The estimated soil loss was relatively much lower on plain sites compared to the hill slope lands. Most parts of the study area lie within the low-severity class that contributes only 44.88 % of the total annual loss estimated. 8% of the study area is classified as high and very high soil loss risk zones. The pie-chart showing the different severity classes of soil erosion risk in the study area is given in Fig. 7. Various categories of soil erosion prevailing in the study area and the percentage of areas affected by each category are described clearly in Table IV.

TABLE IV
EROSION CATEGORY IN STUDY AREA AND THE PERCENTAGE AREA AFFECTED BY EACH CATEGORY

Erosion Categories	(t / ha yr)	Area (ha)	Area (%)
Very Slight	< 5	574488.8371	44.88421687
Slight	5-10	227983.7558	17.81213433
Moderate	10-15	146675.1068	11.45957393
Moderate Severe	15-20	90096.66334	7.03915884
Severe	20-40	137176.8331	10.71748366
Very Severe	> 40	103513.8841	8.08743238

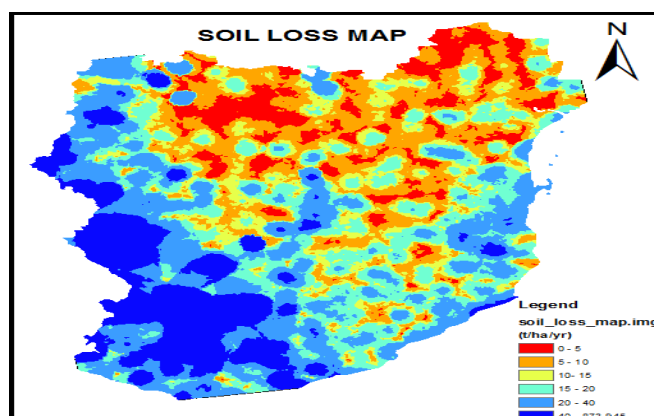


Fig. 6 Soil loss risk map of study area

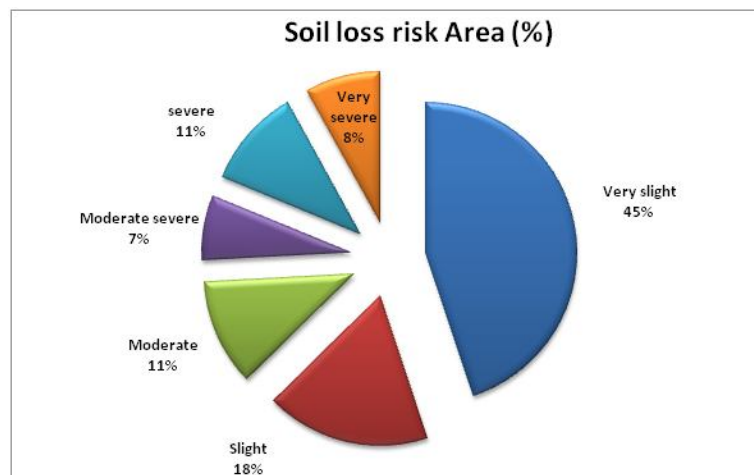


Fig. 7 Percentage break-up of study area based on severity of soil erosion

The preliminary water erosion layer generated from visual interpretation of satellite data is cross checked with the soil loss map generated using the Revised USLE model. The sheet erosion of slight and moderate category are considered as very low erosion with the annual soil loss $0 - 5 \text{ t ha}^{-1} \text{ yr}^{-1}$. The erosion due to severe sheet erosion is considered as low erosion with annual soil loss $5 - 10 \text{ t ha}^{-1} \text{ yr}^{-1}$. Rills and gully erosion areas falls under the moderate to severe erosion with annual soil loss $> 10 \text{ t ha}^{-1} \text{ yr}^{-1}$. It also includes the younger gullies formed in the down slope region which with time can develop into a mature gully. Water erosion classes in soil loss map and their corresponding region in False Color Composite is shown in Fig. 8 and Fig. 9.

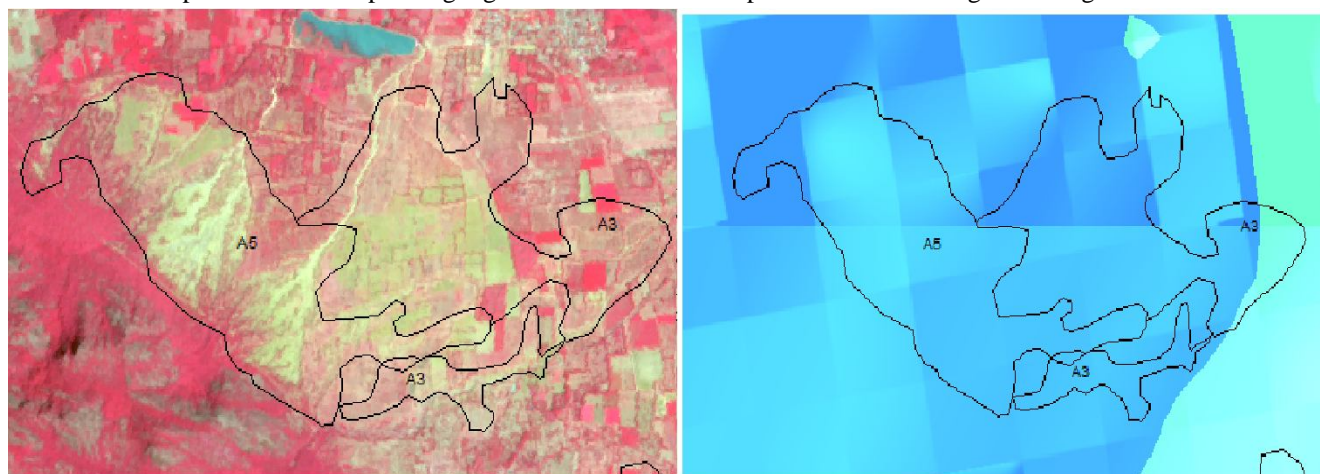


Fig. 8 Water erosion classes in soil loss map and their corresponding region False Color Composite (FCC) for Gully erosion

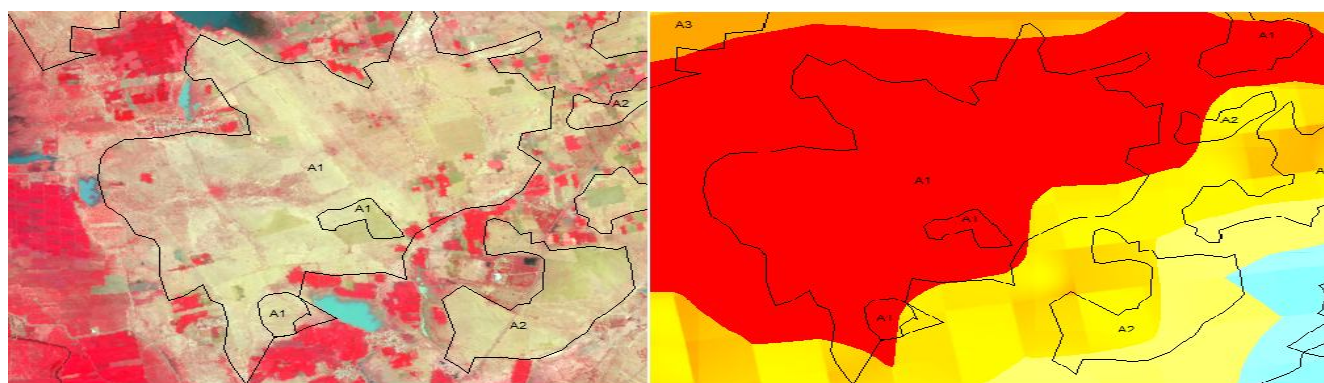


Fig. 9 Water erosion classes in soil loss map and their corresponding region False Color Composite (FCC) for Sheet erosion

It can be seen from the images above that the region marked as gully through visual interpretation is similarly indicated as severe erosion region in soil loss map and the region marked as sheet erosion through visual interpretation is similarly considered as very low erosion region in soil loss map. By comparing the output of the results obtained the water erosion layer is modified and final results are thus obtained with 87.3 % accuracy.

V. CONCLUSIONS

A conventional method of identifying erosional risk zones involves enormous computational works and requires large amount of time. In such cases the Revised USLE model is a very effective technique in assessing annual soil loss. In order to spatially visualize the erosion prone areas and predict the amount of soil loss in a region, the Revised USLE model could be integrated in GIS platform along with high resolution satellite data. This allows us to visualize and assess the soil erosion region, identify the risk zones and prepare appropriate measures in landuse management practices. In this study, it has been revealed that the risk of soil erosion is higher on the sloping lands. Soil erosion from these sloping lands, especially foothills area, accounts for a large portion of the total soil loss. Remote sensing satellite images proves to be advantageous in continuous monitoring of soil loss, runoff and landuse changes are also needed to achieve the sustainable development of the region.

VI. ACKNOWLEDGMENT

With deep sense and obligation I wish to thank my guide Dr. S. RAMA SUBRAMONIAM, Senior Scientist, RRSC-S, NRSC/ISRO, Bengaluru for his encouragement, constructive criticism and intellectual stimulation during my research work. I would like to thank Dr. K. GANESHA RAJ, General Manager, RRSC- South, NRSC / ISRO, Bengaluru for giving me an opportunity to work in an esteemed organization. I would like to thank my guide Dr. S. SURESH BABU, Head of the Department, Department of Civil Engineering, Adhiyamaan College of Engineering (Autonomous), Hosur who gave me moral support throughout the project tenure. I express my sincere gratitude to all scientists of RRSC-S for their expert guidance, valuable suggestions, continued help and constant encouragement.

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