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Assessment of Soil Erosion Using RUSLE and GIS in Upper Manimuktha Subwatershed, Tamilnadu

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Abstract: Soil erosion is being considered as one of the most critical environmental hazards of modern times in the world. Among the predictive equation developed to estimate soil loss, the most used for hilly and plain areas, is the USLE. The USLE, a paper-based model, was computerized and updated subsequently called as RUSLE. The RUSLE factors (R, K, LS, C and P) were computed and presented by raster layer in a GIS environment, then multiplied together to predict soil erosion rates and maps. The R rainfall factor corresponding to rainfall values was calculated using regression equations. LS factor was estimated from the DEM. The C and P factors for various land use/cover with different slopes were collected from literatures on soil loss estimate using RUSLE in India. All the RUSLE factors were multiplied on pixel by pixel basis and in final the spatial distribution of the soil erosion was obtained. Output result was then reclassified into erosion class based on the erosion intensity values as slight, moderate, high, very high, severe and very severe. The predicted average annual soil erosion from the Muktha river sub-watershed 4C1A2e (Upper Manimuktha) is 95.04 ton $ha^{-1}yr^{-1}$. This study can serve as effective deriving strategies for land planning and management in the environmentally sensitive soil eroded areas.
Keywords: RUSLE, R, K, LS, C and P factors, DEM and GIS

I. INTRODUCTION

Soil is a nonrenewable resource and once destroyed it is gone forever. Soil erosion can be defined as the detachment and transportation of soil. Sheet erosion is the most serious of India's soil erosion problems [1]. Soil erosion occurs when soil is removed through the action of wind and water at a greater rate than it is formed. Due to its damage, soil erosion leads to decline in soil fertility, a series of negative impacts to environment that threat to the sustainability and productive capacity of agriculture and the economy of developing and developed countries like India [2,3] and becomes most serious form of land degradation. In India, the latest estimates show that an area of about 120.72Mha (million hectares) is affected by various forms of land degradation, of which 82.57Mha is solely accounted for by water induced soil erosion [4]. [5,6] have estimated that about 5,334 million tons of soil is detached annually in India due to various reasons and out of which about 29% is carried away by river into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the storage capacity. So, it is important to protect soils from erosion for sustain human life. Initially, USLE (Universal Soil Loss Equation) [7] only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. The USLE equation was revised and brought RUSLE (Revised Universal Soil Loss Equation) [8] model which almost same as USLE equation but the RUSLE consists the little more accuracy compared to USLE model. The RUSLE has been widely adopted for soil loss assessment at watershed scale because of its convenience in computation and application [9-12]. RUSLE method with GIS integration provided significantly better results than using traditional methods [13]. Recent studies [14-20] revealed that the combined RULSE, GIS and RS technology is an excellent tool for monitoring, land degradation, land use changes as well as soil and water resources changes over time and great use in the prioritization of watersheds. The aim of this study is to assess the spatial information of soil erosion using RUSLE and GIS. Since, it's an agricultural dependent area so that soil erosion needs to be quantified for controlling and sustaining quality of soil.

II. STUDY AREA

The present investigation area is Muktha river sub-watershed (4CIA2e) in the Manimuktha sub basin of Velar basin (Fig.1). Muktha river originates in the western side of the Eastern Ghats hill range (Kalrayan hills) and join in the Manimuktha dam. It is a part of Sankarapuram and Kallakurichi taluks of Villupuram district in Tamilnadu, India. The study area extends between 78°43'9.22''-78° 59' 21.73" E and 11° 46' 12.80''-11° 53' 42.38'' N with an area of 251.151 km^2. This rural ungauged sub-watershed falls in SOI toposheets 58I/9 and 58I/13. It is a ephemeral river in nature and carry flood water during monsoon rainfall period. Agriculture is the main economical activity of about 80% of the population. The western part of the study area is covered by thick forest vegetation (85.761 km^2) and rest is almost plain terrain (165.390 km^2). The average annual rainfall of the study area is 1175.77mm during 1992-2017. The elevation ranges from 130m to 987m above MSL with a gentle gradient from west to east. The soil types are clay soil, red soil, alluvial soil and red gravelly soil. The soil textures are sand, sandyloam, sandyclay, sandyclayloam, loam, loamysand and clay. The forest cover includes a mosaic of deciduous-open, closed, scrub and tree clad area.

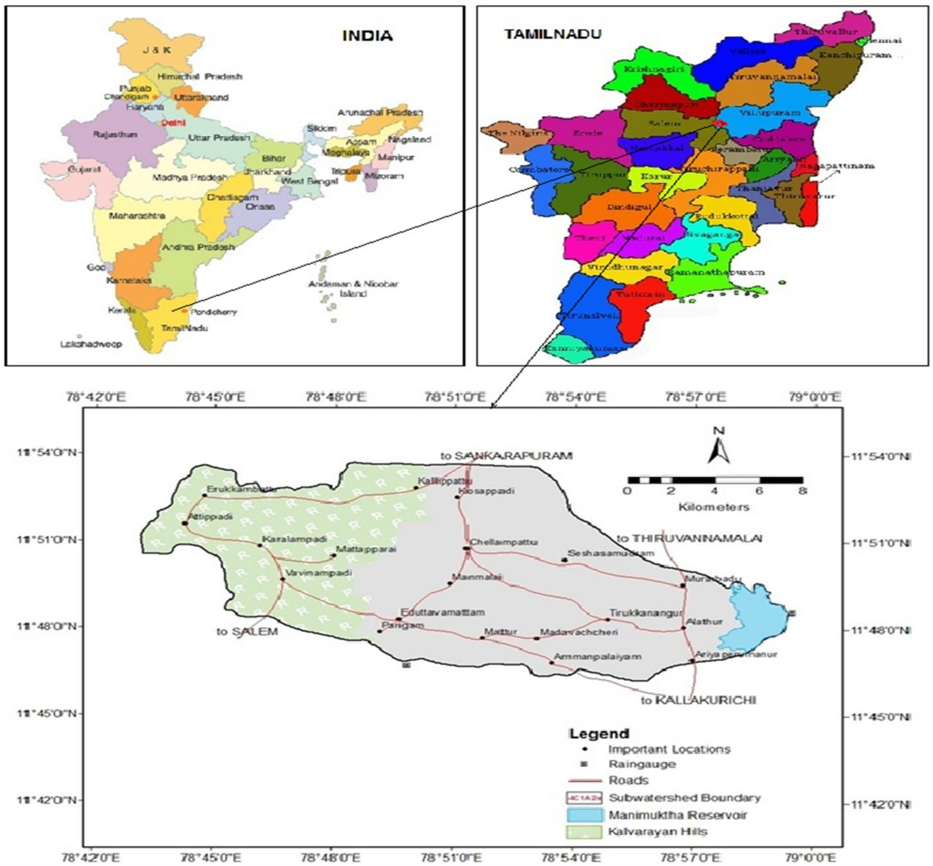

Fig.1 Study area map of the sub-watershed 4C1A2e

III.METHODOLOGY

A. *Watershed Database*

In this study the following data are used

1) Base map of study area (sub-watershed 4CIA2e) from SOI toposheet 58-I/9 and 58I/13 (Source: IRS, Anna University, Chennai).
2) Remote sensing data (IRS 1-C, LISS III) to study the soil type and landuse map (2012) (Source: IRS, Anna University, Chennai)
3) Daily rainfall data of Gomuki dam and Manimuktha dam raingauge stations from 1992 to 2017 (Source: IWS, WRO (PWD),Chennai).

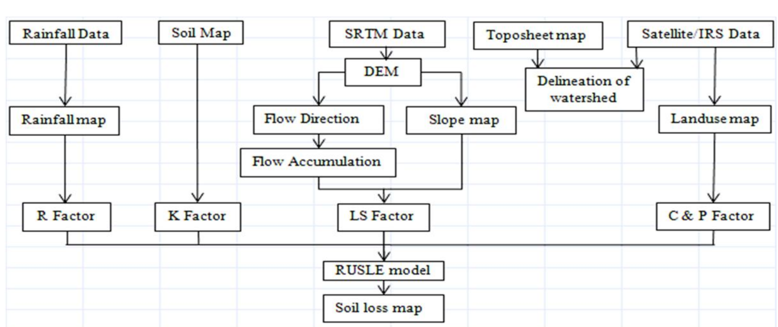

Fig.2 Flow chart showing the methodology of RUSLE model

B. Rusle

The primary method of estimating soil losses from rainfall and runoff is an empirical equation called USLE [7]. A new version of the USLE, called RUSLE has been developed [8], is more detailed than the USLE and it is a computer program. It is composed of 5 factors and can be written as

$$A = R \times K \times LS \times C \times P$$

where A is the average annual soil erosion in ton $ha^{-1}\ yr^{-1}$.R = Rainfall- runoff erosivity factor in MJ mm $ha^{-1}hr^{-1}yr^{-1}$. K = Soil erodibility factor in ton ha $hrha^{-1}MJ^{-1}mm^{-1}$. L = Slope length factor (ratio of soil loss from the field slope length to soil loss from standard 22.1 m slope under identical conditions). S = Slope steepness factor (ratio of soil loss from the field slope to that from the standard slope under identical conditions). C = Cover-management factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow). P = Support practice factor (ratio of soil loss with a support practice-contour tillage, strip-cropping, terracing to soil loss with row tillage parallel to the slope).C, P and LS are dimensionless, different data are used to obtain these factors. The soil erosion varies from places to place, with respect to amount of rainfall, intensity of wind speed, soil texture, and soil permeability, topographical steepness, cropping pattern, geological structures and geomorphologic features. Of these the vegetation and to some extent the soil slope length may be controlled and other climatic and topographic factors are beyond the power of man to control [11,21]. In addition to the biophysical parameters, intensive cultivation, socio-economic pressure, and political components also influence for more land to have accelerated the rate of soil erosion on sloping lands [22].

C. R Factor

Rainfall erosivity factor measures the kinetic energy of the rain which is one of the most important quantitative parameters to remove soil particle and expressed in MJ mm $ha^{-1}hr^{-1}yr^{-1}$. The rainfall intensity data for the rural study area was not available. To obtain the factor, [23] suggested that the average of the following regression equations give a reliable value of R factor as

$$R = 0.5\ P \times 1.73$$

$$R = ((9.28\ P - 8838) \times 75/1000)$$

where P is the average annual precipitation in mm. The average annual rainfall data for 25 water years (1992-2017) of two surrounding raingauge stations namely Gomuki dam and Manimuktha dam stations were used to compute the watershed wide rainfall (Table 1). The spatial distribution of R factor (Fig.3) of the study area is constructed using ArcGIS 10.5 spatial analyst tool and the values varied from 460 to 677 MJ mm $ha^{-1}hr^{-1}\ yr^{-1}$.

Table 1 Annual rainfall of surrounding raingauge stations

Water year	Raingauge Station		Water year	Raingauge Station	
	Gomuki Dam	Manimuktha Dam		Gomuki Dam	Manimuktha Dam
1992-93	928.50	857.50	2005-06	2278.00	1690.00
1993-94	1562.80	1062.00	2006-07	997.00	1089.00
1994-95	960.30	777.70	2007-08	1864.00	1285.00
1995-96	796.40	795.50	2008-09	1373.00	1159.00
1996-97	1500.90	1822.10	2009-10	1211.00	1045.00
1997-98	1477.70	1139.50	2010-11	1687.00	1423.00
1998-99	1379.20	659.30	2011-12	1445.00	1033.60
1999-00	1291.50	806.20	2012-13	618.00	353.20
2000-01	1339.00	922.50	2013-14	584.10	684.90
2001-02	1169.30	1007.50	2014-15	1072.40	940.90
2002-03	920.70	749.00	2015-16	1075.10	930.10
2003-04	2295.80	1454.80	2016-17	545.40	558.50
2004-05	1897.00	1087.15	Average	1290.76	1013.32

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D. K Factor

Soil erodibility factor is a measure of soil susceptibility to detachment and transport, by the erosion agents, of the soil particles. It depends on soil properties such as texture, structural stability, organic matter content, clay mineralogy and chemical constituents. The K factor is related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas [24]. In the absence of experimental data, it is possible

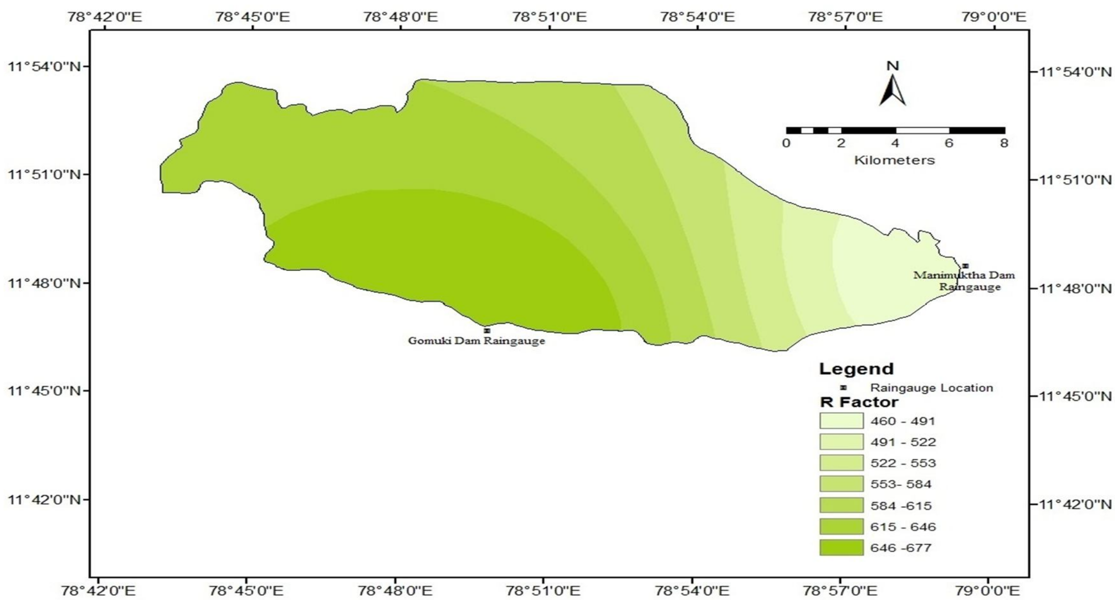

Fig.3 Spatial distribution of R factor of the study area

to use an estimating formula [7] to compute the parameters based on various types of soil in the watershed. The soil erodibility factor is

$K = 2.1 \times 10^{-6} \times M^{1.14} \times (12 - a) + (3.25 \times (b - 2) + 2.5 \times (c - 3))/100$

where M is (% sand+% silt) × (100-% clay), a is the organic matter content. b is the soil structure code in which 1 is very structured or particulate, 2 is fairly structured, 3 is slightly structured, and 4 is solid. c is the permeability code in which 1 is rapid, 2 is moderate to rapid, 3 is moderate, 4 is moderate to slow, 5 is slow, and 6 very slow. The raster format of soil series map (Fig.4) was attributed in the table 2 to generate the K factor map (Fig.5).

Table 2 Values of K Factor (Source:IRS,Chennai)

Series	Sand %	Silt %	Clay %	a (in %)	b	c	M	K
Alagappapuram	60.20	15.20	24.60	0.44	4.00	4.00	5685.16	0.55
Ammapalayam	70.00	8.00	22.00	0.24	4.00	4.00	6084.00	0.60
Ayyalur	87.10	8.00	4.90	0.32	3.00	1.00	9044.01	0.78
Endal	95.95	1.95	2.10	0.18	1.00	1.00	9584.41	0.78
Kiliyur	44.00	26.40	29.60	0.93	4.00	4.00	4956.16	0.47
Kombaikkadu	24.40	29.60	46.00	0.78	4.00	4.00	2916.00	0.30
Kombuthuki	54.50	25.00	20.50	0.79	4.00	2.00	6320.25	0.55
Koralampatti	52.00	22.00	26.00	0.41	4.00	4.00	5476.00	0.53
Kuruvakkadu	47.00	18.00	35.00	1.11	4.00	5.00	4225.00	0.43
Mangalathupatti	74.00	8.00	18.00	0.36	1.00	2.00	6724.00	0.51
Maramangalam	82.20	1.10	16.70	0.09	1.00	2.00	6938.89	0.54
Meyyur	51.02	25.17	23.81	0.75	4.00	4.00	5804.92	0.55
Nagalur	68.90	7.00	24.10	0.02	4.00	4.00	5760.81	0.58
Ooty	33.30	24.70	42.00	0.99	4.00	5.00	3364.00	0.36

Palaviduthi	47.10	25.70	27.20	0.29	1.00	2.00	5299.84	0.38
Perapperi	78.75	9.78	11.47	0.60	1.00	2.00	7837.56	0.60
Periyanaickenpalaiyam	47.20	11.90	40.90	0.63	4.00	5.00	3492.81	0.38
Pilamedu	81.00	0.90	18.10	0.62	4.00	4.00	6707.61	0.64
Puduvadavalli	52.40	22.20	25.40	0.65	4.00	4.00	5565.16	0.53
Salem	78.70	5.35	15.95	0.10	1.00	2.00	7064.40	0.55
Settuppalapatti	52.00	24.80	23.20	0.69	4.00	4.00	5898.24	0.56
Vanavasi	44.74	15.26	40.00	0.00	4.00	5.00	3600.00	0.40
Velimadurai	11.00	22.00	67.00	0.86	4.00	5.00	1089.00	0.18
Vetavalam	65.12	15.68	19.20	0.64	4.00	4.00	6528.64	0.62
Villukam	46.72	18.28	35.00	0.31	4.00	5.00	4225.00	0.45
Yercaud	48.38	13.28	38.34	1.52	4	5	3801.95	0.38
Water body	0	0	0	0	0	0	0	0.00

E. LS Factor

It is a topographic factor or slope length gradient factor. The effects of topography and hydrology on soil loss are characterized by the combined L (slope length) and S (slope steepness) factors usually referred as LS factor. Wishmeir and Smith [7] examined that soil loss per unit area increases with increase in slope length and slope steepness. The LS factor was calculated from the equation [7] is,

$$LS = \left(\frac{\lambda}{22.13}\right)^{0.4} \times (0.065 + 0.046S + 0.065S^2)$$

where λ is the length of slope in m and S in the slope steepness in percentage. To calculate the λ values, flow accumulation was derived from the SRTM DEM resolution of 90m x 90m pixel after conducting Fill, Flow direction and Flow accumulation in ArcGIS10.5 Hydro tool.

λ = Flow accumulation x Cell value.

The spatial distribution of slope map and the corresponding LS factor map are shown in Fig. 6 and 7. The LS factor for the study area ranges between 0.000 and 6.562.

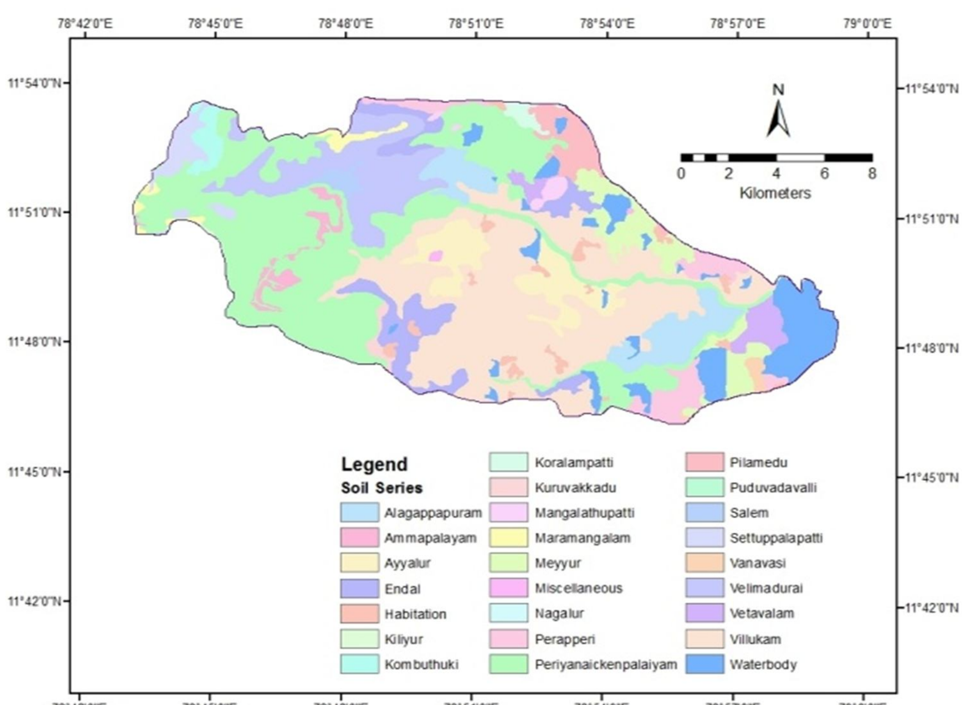

Fig.4 Soil series map of the study area

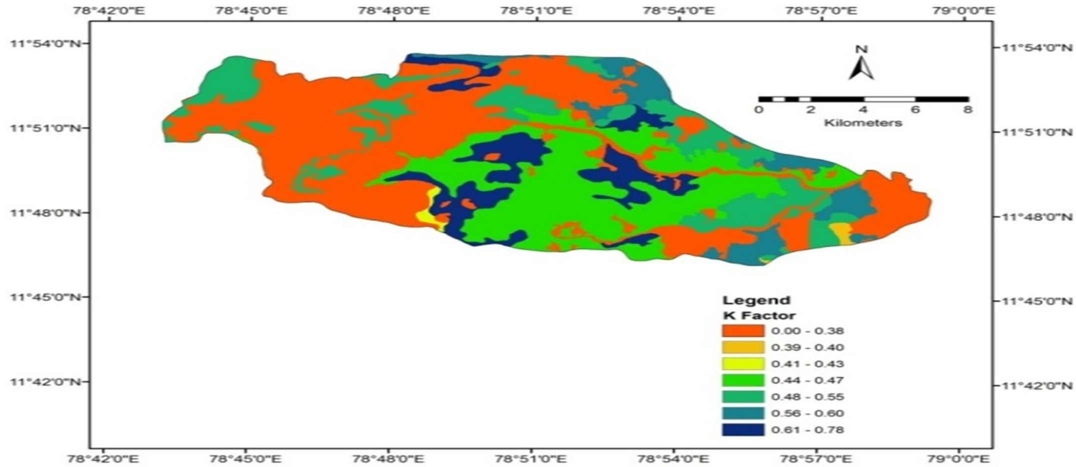

Fig.5 K factor map of the study area

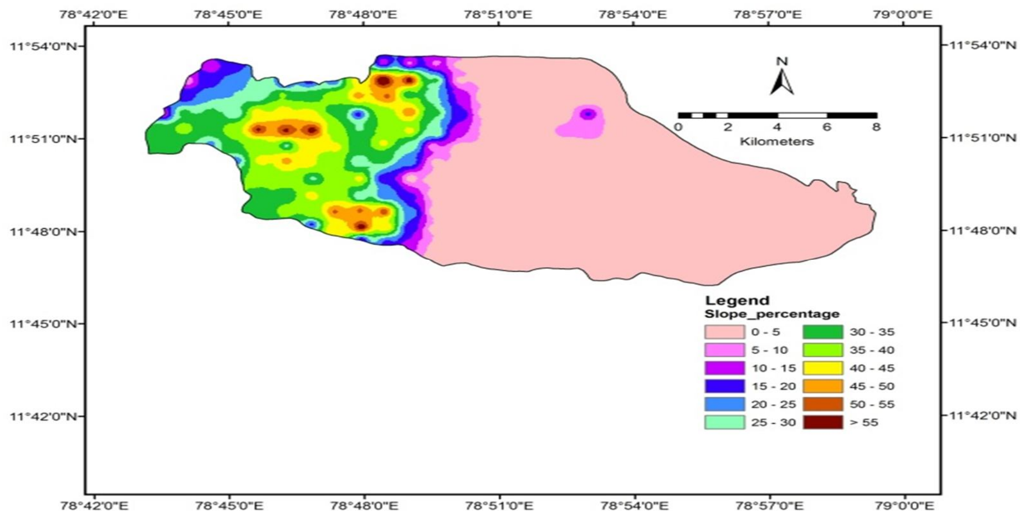

Fig.6 Slope map of the study area

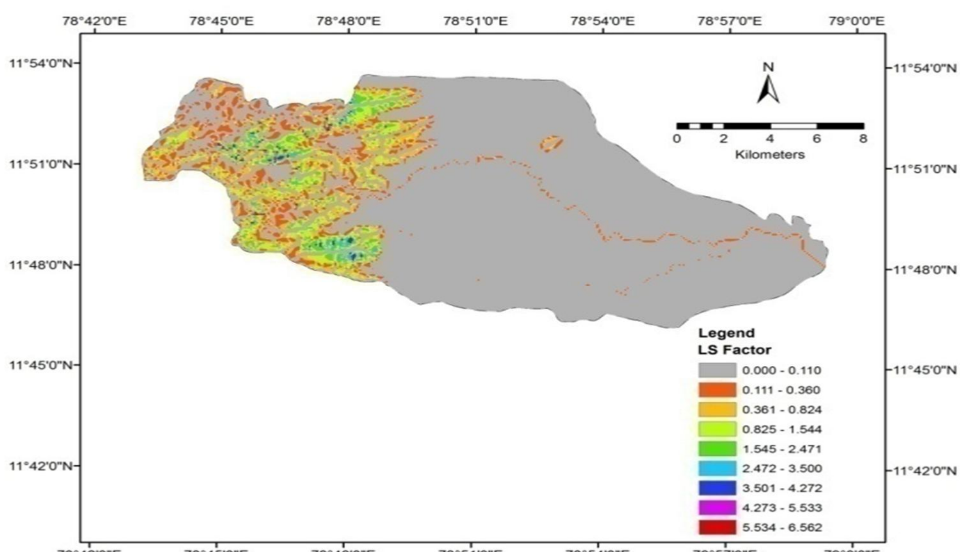

Fig.7 LS factor map of the study area

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F. C Factor

The crop management factor is the ratio between a bare soil and a vegetated soil. It expresses the role of the plants used of their management techniques on the response of the soil to the water. It includes the effects of cover, crop sequence, productivity level, tillage practices, residue management, and length of growing season [7,24].The C factor ranges from 0 to 1, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow, while lower C means a very strong cover effect resulting in no erosion [25].The leaves of scrub protect the soil from rain drop impact and reduce the volume of overland flow running down the slope [26,27]. Actual loss from the irrigated field is usually much less than the amount of soil loss from a field kept continuously in fallow condition [17]. C-factors are not available for most of Indian crops. Therefore, based on literature review, table 3 gives the crop management factor with respect to different land use coverage (Fig.8). Fig.9 shows the spatial distribution of C factor and the results indicate the effect of cropping and management practices on soil erosion rates in agricultural lands.

Table 3 Values of C Factor (Source: from Literature Review)

Land Use/Cover	C Factor
Agricultural Land Plantation	0.39
Agricultural Land Crop Land	0.28
Agricultural Land Fallow	0.60
Built Up Land Rural	0.10
Forest Deciduous	0.04
Forest Scrub	0.14
Forest Tree Clad area	0.30
Wastelands Salt affected	1.00
Wastelands Scrub	0.70
Wastelands without Scrub	0.18
Wastelands water logged	1.00
Water bodies Tanks/River	0.00

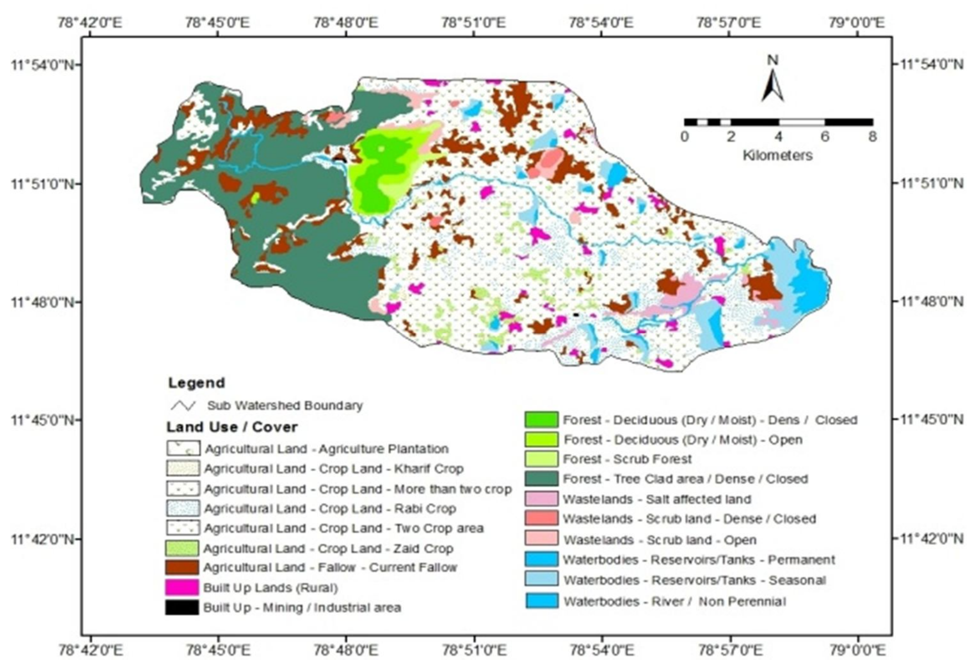

Fig.8 Land use and Land cover map of the study area in 2012

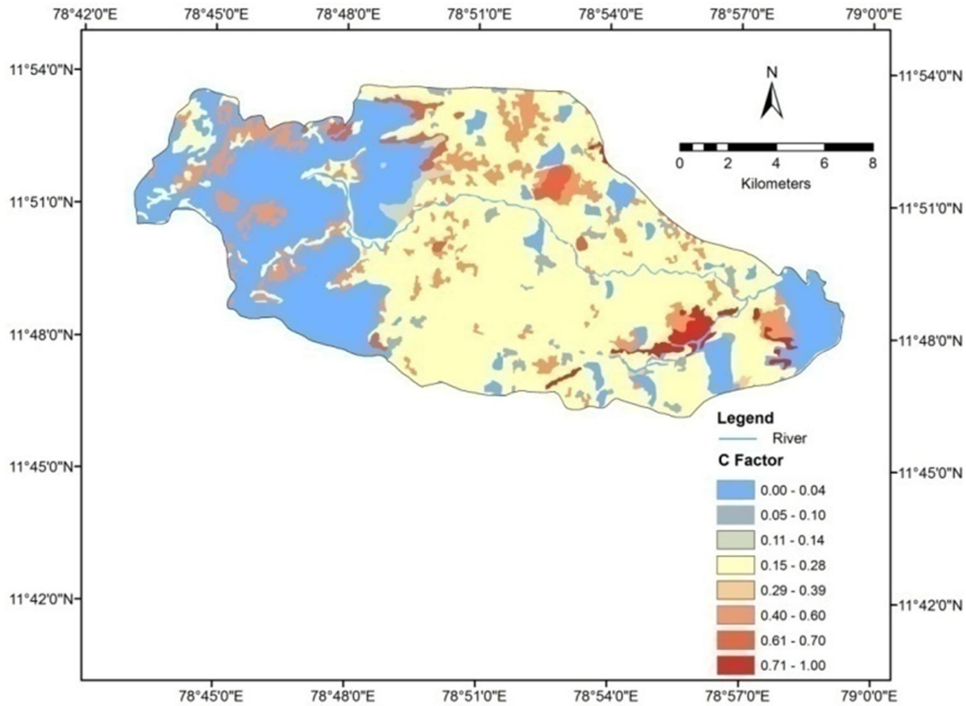

Fig.9 C factor map of the study area

G. P Factor

The land management or conservation practices effect depends on the changes induced on manifold factors, such as flow speed, surface roughness, infiltration rate etc. The result of these practices is not easy to quantity. So the supporting practice factor P is necessary to find opportune adoptions by means of coefficients. The value of P factor is normally determined by the method of cultivation and slope of the terrain [22]. In the present study area, the main conservation method is the use of bunds around the agricultural fields. P factor is roughly determined from the table 4 that is based on interpolation [7]. After assigning the P factor values, the output map named as P factor map (Fig.10)

Table 4 Values of P Factor (Source:from Literature Review)

Land Use/Cover	Slope %	P Factor
Agricultural Land	0-5	0.10
	5-10	0.12
	10-15	0.14
	15-30	0.19
	>30	0.25
Built Up Land	--	0.00
Fallow Land	--	1.00
Forest Categories	--	0.80
Wastelands	--	1.00
Water bodies	--	0.00

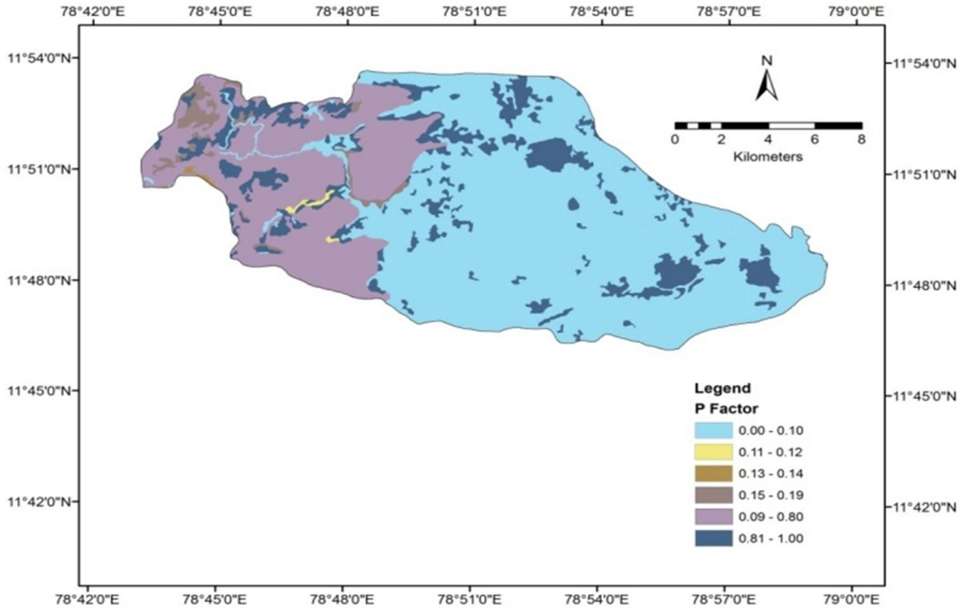

Fig.10 P factor map of the study area

IV. RESULTS AND DISCUSSION

All the factors required for soil erosion estimation as given in the equation were calculated using ArcGIS 10.5 software and stored as thematic maps in raster format. By simultaneous overlay operation on these five layers of RUSLE using PC ARC/INFO GIS in grid environment and the soil loss in each grid was obtained by multiplying the values of each raster datasets by ArcMap / Spatial Analyst / Raster Calculator. The resultant map showing the intensity of soil erosion by water in each grid is obtained (Fig.11). The RUSLE map was then reclassified into 6 categories of estimated erosion of soil loss as suggested by previous research [24] as slight (0-5 ton $ha^{-1}yr^{-1}$), moderate (5-10 ton $ha^{-1}yr^{-1}$), high (10-20 ton $ha^{-1}yr^{-1}$), very high (20-40 ton $ha^{-1}yr^{-1}$), severe (40-80 ton $ha^{-1}yr^{-1}$) and very severe (>80 ton $ha^{-1}yr^{-1}$) and the prone areas are noted in table 5. The predicted average annual soil erosion from the sub-watershed is 95.04 ton $ha^{-1}yr^{-1}$. It is evident that very severe (9.28%), severe (4.63%), very high (5.30%) and high (6.12%) soil erosion hazard areas are found at the higher slopes in the hilly terrain (in reserved forest area, open scrub forest, degraded plantation and in steep slopes) due to deforestation and agricultural activities are practiced. Moderate soil erosion hazard areas (4.50%) occurred in the reserved forest and also the plateau portion of the study area. Slight soil erosion hazard areas (70.17%) are found to the foot hills and plain regions of the study area.

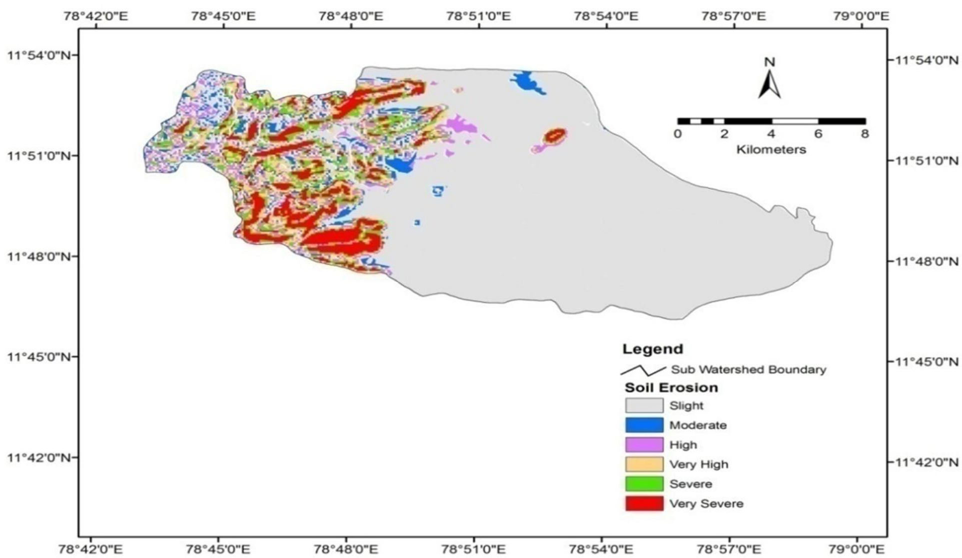

Fig.11 Spatial distribution of annual Soil Erosion by RUSLE model

Table 5 Intensity of soil erosion prone area in the study area

Soil loss potential	Degree	Area in Km^2	% of area
0-5 $ton.ha^{-1}.yr^{-1}$	Slight	176.230	70.17
5-10 $ton.ha^{-1}.yr^{-1}$	Moderate	11.306	4.50
10-20 $ton.ha^{-1}.yr^{-1}$	High	15.364	6.12
20-40 $ton.ha^{-1}.yr^{-1}$	Very high	13.310	5.30
40-80 $ton.ha^{-1}.yr^{-1}$	Severe	11.640	4.63
More than 80 $ton.ha^{-1}.yr^{-1}$	Very severe	23.301	9.28

V. CONCLUSION

The soil loss due to water erosion for the study area is computed using RUSLE integrated with RS and GIS. The soil erosion risk is extremely higher on the steep slopes and adjoining foot hills. Even though most of the areas are coming under slight soil erosion class, they are prone to soil erosion due to cultivation activities. Due to deforestation, unscientific/improper land management by local people, high rate of soil erosion is aggravated in hilly areas. The combination of RULSE and GIS can be useful for decision making to establish appropriate strategies of soil and water conservation.

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