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Original Article

Soil Erosion Prioritization Using RUSLE Equation with GIS-based Approach In Ghataprabha Watershed

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Abstract - *Soil erosion modeling technique is a key aspect in soil degradation investigation, specifically in an un-gauged watershed. Soil erosion modeling and prioritization of sub-watershed of Ghataprabha basin, India using Revised Universal Soil Loss Equation coupled with GIS and Remote Sensing technique is the prime objective of this research work. Variables of RUSLE equation were derived and displayed through raster layer in ArcGIS Platform through which thematic map displaying soil erosion rate ranging from 0.0 to 805.65 t/ha/yr is generated. The soil erosion is estimated on a 2×2 kilometer grid cell. The catchment was divided into 34 sub-watersheds, categorized from low to very severe soil erosion zone. 60% of the watershed area was observed in low soil erosion class (0-5 t/ha/yr), 7.5% was under moderate erosion class (5-10 t/ha/yr), and 31.9% watershed area was between High to Very Severe erosion class (10->80t/ha/yr). The classification of watershed components, specifically Land Use Land Cover, Elevation, Curvature, and Slope, by compiling with soil erosion map is displayed in this study. Based on this classification and through the basis of stream orders, the conservative soil measures and conservative soil structures are proposed in a Ghataprabha watershed at the end of this study.*

Keywords — *Erosion modeling · RUSLE · GIS · Basin prioritization · Soil conservation*

I. INTRODUCTION

Plant-Soil-Water resources are nature's gift to mankind. For the last decade, soil erosion has been a severe environmental concern on the planet earth because it seriously threatens farming and the natural surroundings. A recent study delivers, soil erosion has hit the mark of 1.9 billion hectares globally, and currently, it has a growth of 5 to 7 million hectares every year. From the total territory of India, approximately (53%), i.e., 175 Mha, is experiencing the land degradation problem. Almost 5334 Mt soil erosion has been explored annually in India. About 10% get stored at the bottom of the dam, which decreases the dam's storage capacity, whereas 29% of eroded soil reaches the sea(Narayana and Babu 1983). The preventive measures for the decrease of soil erosion are essential due to their adverse effect on agricultural land and turbidity of the river, and it also influenced the threat of flooding and obsolescence of water resource structure at a large percentage(Boardman et al. 1994). Therefore, for implementing and enriching conservative soil programs in a particular river basin. The appraisal of soil catastrophe and testimony of analytical erosion-prone areas in a particular catchment.

The analyst has made significant efforts in erosion modeling work (Nearing et al., 2005; Sanghyun Kim, 2013). The soil erosion modeling work in the watershed has been carried out through numerous empirical equations established on the geomorphologic criteria of the catchment. The Hydrological models like Conceptual, Hybrid, Empirical, Distributed, and Lumped are applied in the watershed for estimating soil erosion potential (Pak et al. 2008; Albaradeyia et al. 2011; Kumar and Mishra 2015; Rodrigues 2016; Tavakoli Targhi et al. 2017). It has always been a challenge for the researcher to carry out watershed management plans; most of the watershed lacks measured soil loss data. Despite this, several soil erosion models have been developed, implemented, and checked with field data successfully in the past at different watersheds. Wide ranges of models are available that can estimate and predict soil erosion at a spatial scale within a watershed. Physical-based models like Revised Morgan, Morgan and Finney model (RMMF), Agriculture Nonpoint Source Pollution (AGNPS) (Sanghyun Kim 2013) are used in the past for predicting soil erosion. Similarly, models which have the root of the empirical equation like Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978; Malleswara Rao et al. 2005), Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997; Abdul Rahaman et al. 2015) are used in the antiquity for predicting soil erosion. The Geospatial technique is used to run this model and is also used to generate input data recommended for this model.

RUSLE is a revised form of the USLE model whose inputs are obtained through software having a platform of Remote Sensing and GIS Environment in the form of a thematic map. RUSLE model has a couple of positive aspects, such as it is more convenient to incorporate and comprehend from the practical point of view, it also works smoothly with GIS software. The model suits the data obtained from the developing nations, which are not too complex to carry out the work. (Miheretu and Yimer 2018) implemented conservative land management planning by carrying out soil erosion modeling at the Gelana sub-watershed, Ethiopia using the RUSLE method. In India, the soil erosion estimation project has been carried out by applying the RUSLE model in the catchment of Central and Eastern India, Western Ghats, and in Mid-Himalaya (Ismail and Ravichandran 2008; Khadse and Vijay 2015; Kalambukattu and Kumar 2017; Pal and Shit 2017; Rajbanshi and Bhattacharya 2020). The up-gradation in the geospatial technique through the availability of a new version of the Remote Sensing and GIS Software and its strong ability to work with a physical model as well as with empirical model had made the researcher use Geospatial technique on a large scale for groundwater potential, rainfall-runoff and soil erosion modeling (Skaugen and Onof 2014; Karamage et al. 2016; Paparrizos and Maris 2017; Vijith and Dodge-Wan 2018; Rane and Jayaraj 2021). A high-level accuracy of real-time data is achieved through Remote Sensing for various components of the watershed like Stream distribution, Soil Type, and Drainage. Additionally, it also identifies the soil erosion hotspot within the watershed, and this information is relevant to be used as input data in the sediment yield and runoff model(Gayen and Saha 2017; Ismanto et al. 2020).

A grid-cell-based erosion model has been used in watersheds (Perović et al., 2013); a process operated through the grid-cell method involves segregating the watershed into a uniform mesh to seize the basin heterogeneity. In this method, a re-sampling process of the catchment into a small grid cell is prepared within the GIS environment as well as the physical aspect of the basin-like type of loam, gradient, and land use land cover are elicited into a small grid cell, which is further used for soil erosion modeling within the catchment. (Wang et al. 2010) had developed a grid-based erosion model in which a grid cell of 500 × 500m is used for soil erosion modeling at the Lushi catchment situated in Central China. The watersheds have been sub-divided into the grids with the size of 200 × 200m, 30 × 30m, 20 × 20m for estimating soil erosion(Fistikoglu and Harmancioglu 2002; Onori and Grauso 2006; Dabral et al. 2008a) it is observed that grids with smaller size had given better result whereas grids with larger size are inadequate for identifying sites for soil conservation measures.

The soil erosion modeling on-grid basis through the RUSLE model has been done in the watershed (Pandey et al. 2007), through which a unique pattern of the soil degradation within the catchment is observed. Further, the grid-cell-based soil erosion model also identifies the individual contribution of the factors causing erosion on a cell-by-cell basis through GIS software. The grid cell-based soil erosion study has been completed in some watersheds of North and East India (Machiwal et al. 2015; Singh and Panda 2017), but very few were focused on Western Ghats (Ganasri and Ramesh 2015). Keeping this view, the research study is carried out with objectives such as i) Soil erosion modeling on the grid-cells basis by integrating the RUSLE model with GIS in the Ghataprabha watershed. ii) Soil erosion prioritization of sub-watersheds in the Ghataprabha basin. iii) Identification of critical erosion prone area along with watershed component for proposing proper planning of conservative soil measures in the Ghataprabha Watershed.

II. STUDY AREA

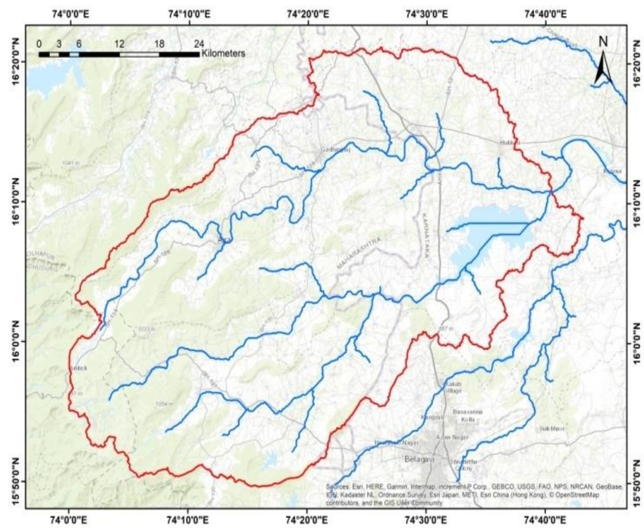

Fig.1 Location of Ghataprabha watershed

The present study is conducted in the Ghataprabha watershed, which is part of an Upper Krishna sub-basin located in southern India (Fig.1). The extend of study area lies between longitudes 74°0'0'' E and 75°50'0'' E and latitudes 15°20'0" N and 16°40'0" N, it includes approximately 2677.20 km² drainage area. Based on the main drain, the watershed gets split into two sub-basins, the north-east part of the basin with 1199.28 km², include Hiranyakeshi as the main tributary, whereas the south-east part of the basin with 1418.42 km² carries Ghataprabha as the main tributary with a major sub-stream as Tambraparni, the confluence point of Hiranyakeshi river with Ghataprabha river is taken as outlet point of the study area. Ghataprabha watershed annually faces a tropical monsoon type of climate, and the precipitation stretches between 6500 mm to 500 mm. Also, maximum rainfall of 40 to 100 days is recorded annually, but most of the rainy days occur between June to September of a calendar year. It is imperative to explore soil degradation in the basin since the tributaries in the basin are un-gauged, and no soil erosion modeling work was found in the basin through the literature review.

III. METHODOLOGY

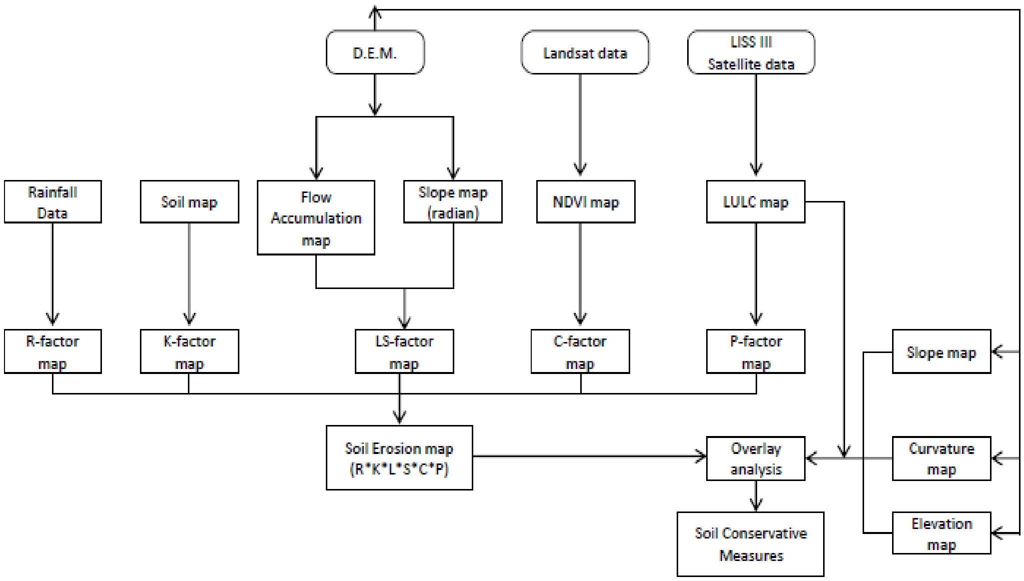

Fig.2 Methodology flow chart

A. Digital Elevation Model of Ghataprabha watershed

The Digital Elevation Model (DEM) of the Ghataprabha watershed is downloaded through the website of the U.S. Geological Survey (earth-explorer.usgs.gov). The DEM shows the range of elevation present in the basin. The range of 610-1048m elevation is displayed (Fig.3) in the DEM of the Ghataprabha watershed. In this study, DEM is used as a base map for generating a thematic map of slope and curvature map of the Ghataprabha watershed. The digital elevation is also used in the process of flow accumulation for the generation of topographic factors.

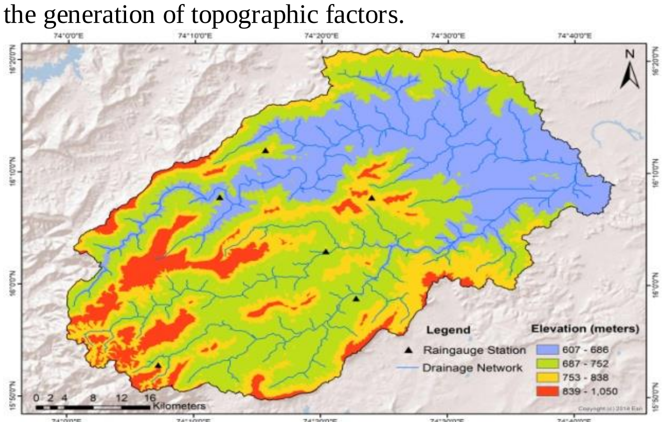

Fig.3 Digital Elevation Model of Ghataprabha watershed

B. Revised Universal Soil Loss Equation model

Flow chart (Fig.2) shows RUSLE was anointed to rate soil erosion at the Ghataprabha watershed. The design of the RUSLE model is emulated by (Renard et al. 1997):

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

Where,

A= computed average annual soil loss (tons/ha/year), R= rainfall-runoff erosivity factor, K= soil erodibility factor, LS= topographic factor, C= cover-management factor, P= conservation practice factor.

C. R- factor of Ghataprabha watershed

The R factor reproduces the sway of numerous precipitation characteristics like intensity and duration over the soil erosion in the catchment. Daily Rainfall data (1990-2014) of six rain gauge stations (Ajara Ramtirth, Ardal, Jambre Umagaon, Kadal, Nadgadwadi, and Tarewadi) collected from Hydrological Department, Nashik, Maharashtra, India, is used as input to generate a thematic map of R-factor. Recorded annual precipitation obtained through the rain gauge station is used to generate an average rainfall map of the basin through the toolbox, namely Inverse Distance Weighted (IDW) available in the ArcGIS platform.

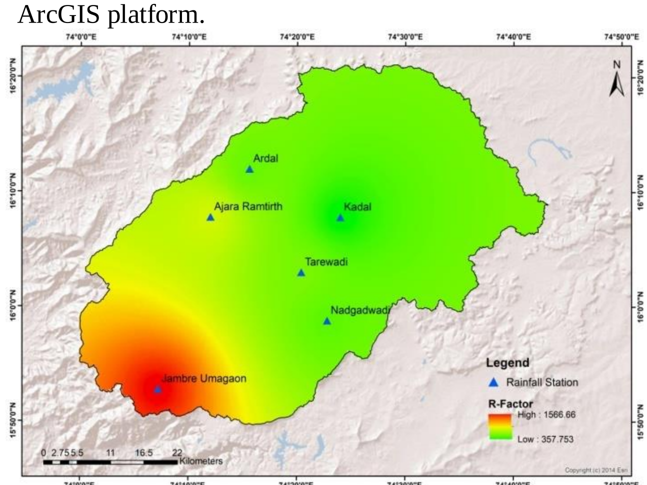

Fig.4 Thematic map of the R factor of Ghataprabha basin

The Rainfall-Runoff erosive factor is calculated based on annual relationship i.e.

$$R_a = 81.5 + 0.380P_a \quad (1)$$

Where,
R_a= Annual Average Erosion Index, P_a= Annual Average Rainfall.
The deviation in the concentration of precipitation is observed within the watershed (Fig.4) since a higher R-value is sighted on the upper side of the catchment, whereas a lower R-value is recognized on the lower side of the catchment area. The R factor ranges between 357-1566 MJ mm $ha^{-1}h^{-1}yr^{-1}$.

D. K- factor of Ghataprabha watershed

Soil erosive factor (K) reveals the outcome of characteristics and properties of soil over the soil erosion within a watershed. Initially, a soil map was collected from the National Bureau of Soil Survey & Land Use Planning, Govt. of India.

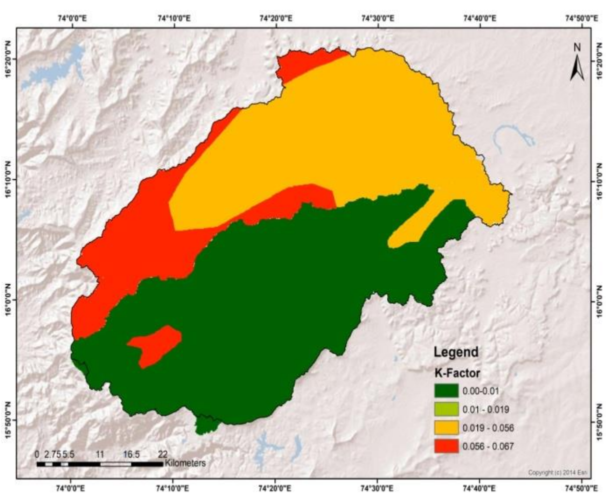

Fig.5 Thematic map of K factor of Ghataprabha basin

By following the Nomo-graph proposed by (Wischmeier et al. 1971), the K-factor for each soil type is calculated from the following regression equation.

$$\mathbf{K}= \frac{2.1\times10^{-4}(12-OM)M^{1.14}+3.25(s-2)+2.5(p-3)}{759.4} \quad (2)$$

Where,
K= soil erosive (tons-yr/MJ-mm), OM= percentage organic matter, p= soil permeability cipher, s = soil design cipher, M= an action of the elementary particle size fraction.
The value of the K-factor (Fig.5) was aligned between 0.01 to 0.067055. According to (Wischmeier et al. 1971), K-value close to 0.01 contributes less to soil erosion, and soil whose K value close to 0.067055 contributes more to soil erosion.

E. LS- factor of Ghataprabha watershed

Topographic erosive factor (LS) is the result of pair of elements, namely, slope steepness and slope length factors. Fundamentally, a hike is observed in stream discharge which increases erosion due to an increase in L & S factor (Ozsoy et al. 2012). Slope length factor (L) is the reaction over soil erosion by slope length.

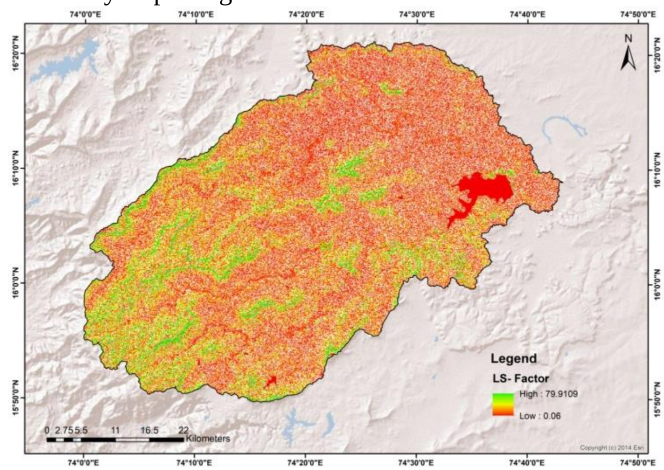

Fig.6 Thematic map of LS factor of Ghataprabha basin

The L-factor is measured through the following equation,

$$L = (\frac{\lambda}{22.13})^m \quad (3)$$

Where,
L= Slop length factor, 22.13= the unit plot length (m), m=a variable inclined length proponent, λ= field slope length. The slope-length exponent m is expressed as,
m=$\frac{\beta}{(1+\beta)}$ where $\beta = (\frac{sin\theta}{0.0896})/[3.0(sin\theta)^{0.8} + 0.56]$

The S-factor is measured through the following equation,

$$S=10.8sin\theta + 0.03 \quad S<9\% \quad (4)$$

$$S=(\frac{sin\theta}{sin5.143})^{0.6} \quad S\geq9\% \quad (5)$$

Where,
S= Slope steepness factor, θ= slope angle in degrees
In ArcGIS Platform software, extension tools like spatial analyst and Hydro toolbox were brought into use to estimate L & S factor. The LS factor ranging between 0.06-79.9109 is shown in (Fig.6). The thick cover of forest in the mountain region was revealed to have the highest LS factor when compared with the land, including the scrub or excluding the scrub in the plateaus of piedmont.

F. C- factor of Ghataprabha watershed

The C-factor is the proportion of soil loss within cropland along with precise cover as well as board to the identical field in bare fallow land.

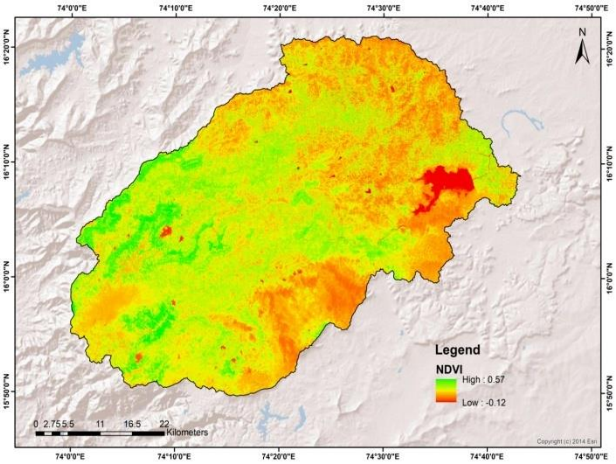

Fig.7 Thematic map of NDVI of Ghataprabha basin

Initially, Land-sat data of the catchment area is downloaded from the USGS Website for the generation of NDVI images.

$$NDVI=(NIR-RED)/(NIR+RED) \tag{6}$$

The component NIR & RED from equation 6 corresponds to the Near Infrared and Red band of the Land-sat data. The range of Normalized difference vegetation index(NDVI) is seen between -1.0 and 1.0; the green vegetation and water bodies are represented by positive and negative values, respectively. In the watershed, NDVI (Fig.7) values bounds between -0.12 to 0.57.

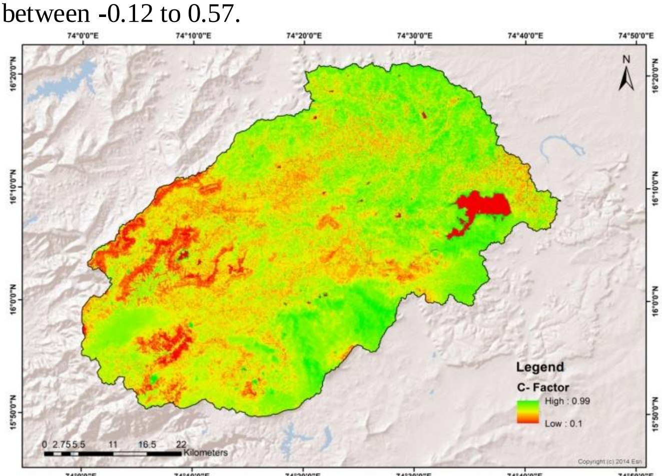

Fig.8 Thematic map of C factor of Ghataprabha basin

Finally, C factor map is generated by taking NDVI raster as an input in the following equation

$$C=0 \quad NDVI \leq 0 \tag{7}$$

$$C=-1.328\,(NDVI)+1 \quad 0 < NDVI \leq 0.75 \tag{8}$$

$$C=0 \quad NDVI \geq 0.75 \tag{9}$$

By running the above equation in the raster calculator of ArcGIS Platform, a C-factor map with values 0.1 to 0.99 was generated (Fig.8). The value of C close to zero is less prone to erosion and vice versa.

G. P- factor of Ghataprabha watershed

P-factor is the RUSLE model reveals the positive outcomes of applying conservative practices in a watershed that cutoff the speed and quantity of runoff, through which the erosion rate in a watershed tends to minimize. The P factor map for a basin is obtained through the inputs acquired from the Land Use Land Cover feature of a particular watershed; therefore, the generation of the LULC map of a Ghataprabha watershed is essential.

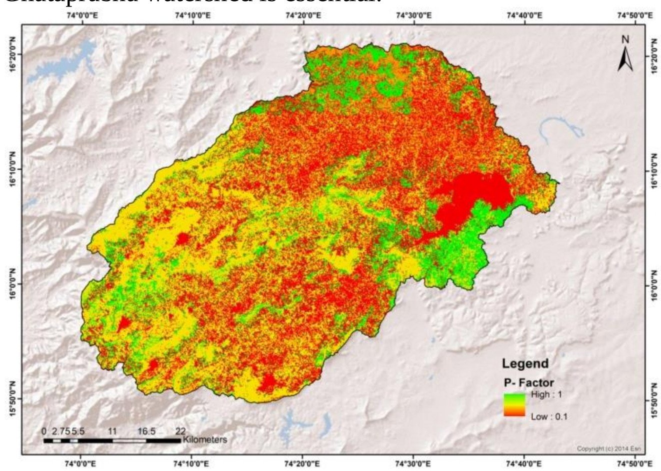

Fig.9 Thematic map of P factor of Ghataprabha basin

The LISS III satellite data of the study area is retrieved from the Bhuvan web portal run by the Government of India's National Remote Sensing Center. The application of ERDAS Imagines 9.0 software is operated to utilize LISS III satellite data to prepare a uniform stacked image of the Ghataprabha watershed corresponding to land use land cover information and classes. This uniform stacked raster image is used in the ArcGIS Platform to develop the support practice (P) factor. In ERDAS Imagine 9.0 Software, Supervised classification with Maximum Likelihood Classifier (MLC) algorithm is used for organizing the watershed into five land use classes a) Agriculture Land b) Waterbody c) Built-up land d) Forest e) Open Land.

After generating the LULC map, the conditional function of the Raster Calculator is applied to generate the 'P' factor map of the Ghataprabha basin (Fig.9). P factor should lie within 0 to 1, pixel reaching the value towards 0 indicates good conservative practices, and the pixel reaching the value towards 1 promotes poor, conservative practices. The range of 0.1 to 1 of P factor value is observed for the Ghataprabha watershed, from which the higher values are concentrated in the south-east direction of lower catchment whereas lower values are scattered in the rest part of the catchment.

IV. RESULTS AND DISCUSSION

A. Estimated annual soil loss

After preparing the thematic map of RUSLE parameters, they were multiplied in a tool box called raster calculator available in GIS Platform software to acquire a soil erosion map of the Ghataprabha watershed.

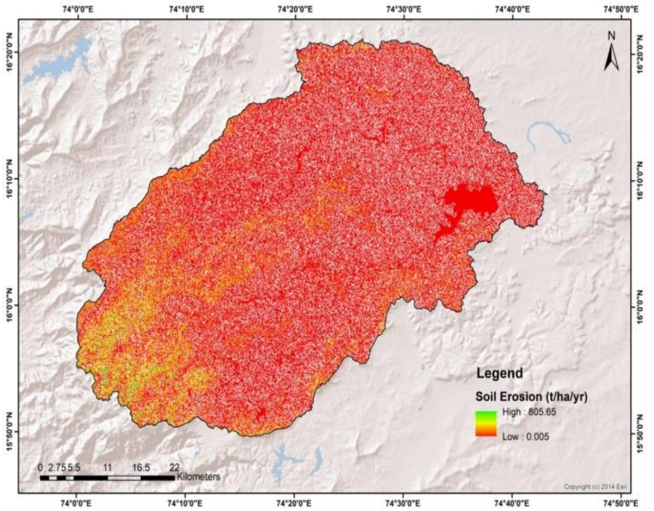

Fig.11 Thematic map of soil erosion of Ghataprabha Basin

The soil erosion in the Ghataprabha watershed was found in the range of (Fig.11) 0.0055 to 805.65 ($t\ ha^{-1}yr^{-1}$). Since the Ghataprabha basin is ungauged, the validation of the estimated soil erosion is done with the soil erosion study engaged in similar terrain with resembling environmental and geological aspects(Pandey et al., 2007; Shinde et al. 2010). Basin estimated mean erosion of 32.4 ($t\ ha^{-1}yr^{-1}$) was very close to the predicted value of 40 (t/ha/yr) of Kaas Plateau (Dahe and Borate 2015) and 47.3 (t/ha/yr) was observed in Nethravathi basin(Ganasri and Ramesh 2015). Apart from both these basins, no more literature review was available on soil erosion study near the Ghataprabha basin. The result of the present work is compared with other soil erosion studies undertaken in watersheds with similar soil formation, terrain, climatic characteristics as well as land use pattern (Dabral et al. 2008b; Kumar and Kushwaha 2013; Swarnkar et al. 2018) where annual average soil erosion was found between 0 to 65 $t\ ha^{-1}yr^{-1}$.

B. Watershed Prioritization

Soil erosion in raster format shown in Fig.12 was modified to a vector file in ArcGIS Platform and merged with the 2 ×2 km grid mesh of watershed to calculate soil erosion in the format of 2 × 2 km grid cell as (Fig.11)**.**

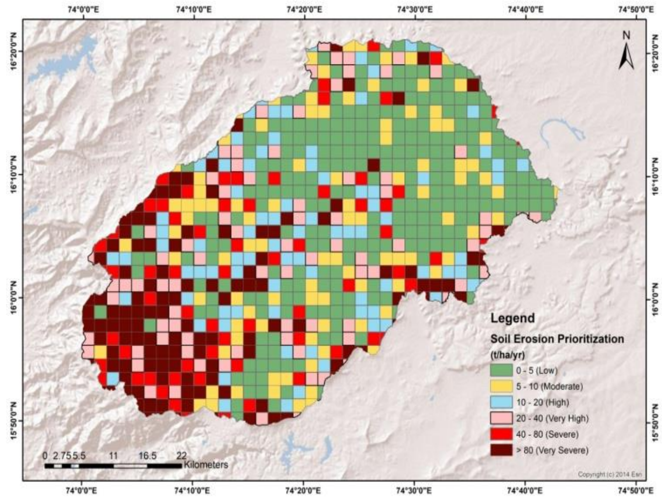

Fig.12 Soil Erosion in the grid pattern of Ghataprabha watershed

The average soil erosion obtained at the Ghataprabha watershed is organized under six erosion classes and put forth in Table.1.

Table 1 Soil Erosion Prioritization of Ghataprabha Watershed (Singh et al. 1992)

Class	Soil Erosion (t $ha^{-1}yr^{-1}$)	Area in (K.M.) ^{2}	% Area
Low	0-5	1607.34	60.03
Moderate	5-10	202.68	7.57
High	10-20	209.19	7.81
Very High	20-40	185.48	6.92
Severe	40-80	165.97	6.19
Very Severe	>80	295.38	11.03

C. Watershed Prioritization of sub-watersheds of Ghataprabha Watershed

Prioritization of sub-watershed involves dividing the sub-watershed into different severity zone. This method will help to implement conservative practices with respect to different severity zone areas present in the sub-watershed. In this study, with the help of Arc-Hydro tool from ArcGIS software, the Ghataprabha basin was divided into 34 sub-catchment; shown in Fig.13, later on with the help of overlay tool in ArcGIS platform; soil erosion in the form of 2 × 2 km grid cell is overlaid by Ghataprabha sub-watershed to prioritize the sub-watershed into different soil erosion severity zone. (Table 2) represents estimated soil erosion within the sub-watershed of the Ghataprabha basin.

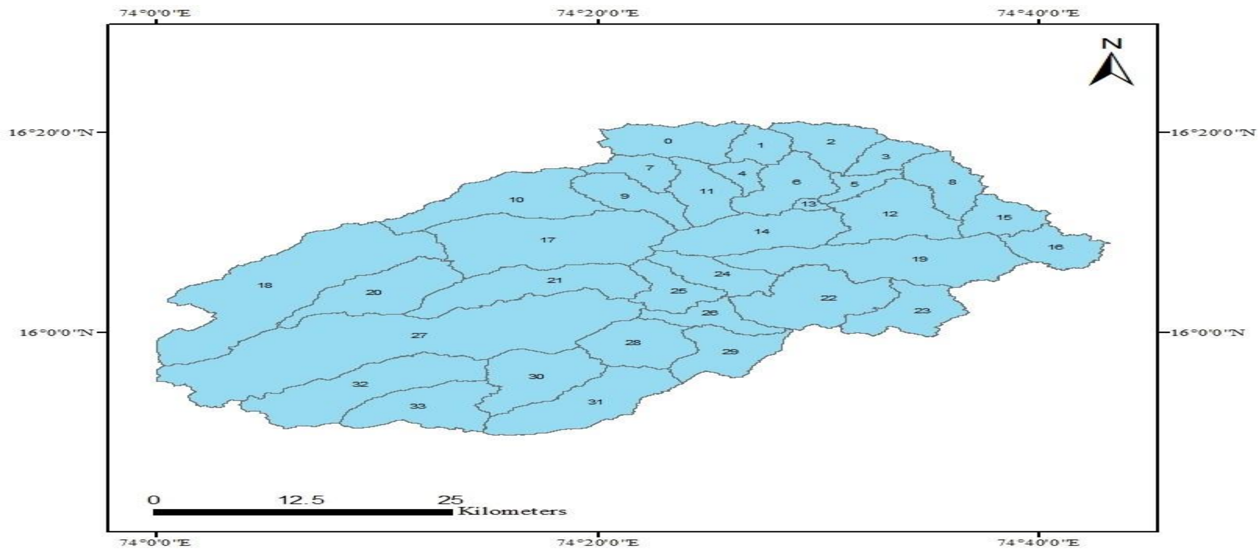

Fig.13 Sub-watersheds of Ghataprabha

Table.2 Sub-watershed wise soil erosion prioritization of Ghataprabha Basin [modified (Samanta et al. 2016)]

		Soil Erosion (t $ha^{-1}yr^{-1}$)											
Watershed No	Total Area (km²)	Low (0-5)		Moderate (5-10)		High (10-20)		Very High (20-40)		Severe (40-80)		Very Severe (> 80)	
		(km²)	%	(km²)	%	(km²)	%	(km²)	%	(km²)	%	(km²)	%
WS_0	63.7	39.2	61.5	5.7	8.9	6.4	10	5.1	8	3.3	5.1	4	6.2
WS_1	26.8	19.5	72.7	2.4	8.9	2.1	7.8	1.3	4.8	0.7	2.6	0.8	2.9
WS_2	48.7	36.7	75.3	4.5	9.2	3.2	6.5	2.1	4.3	1.4	2.8	0.8	1.6
WS_3	26.4	20.8	78.7	2.1	7.9	1.7	6.4	0.8	3	0.5	1.8	0.5	1.8
WS_4	16.1	12.9	80.1	1.4	8.6	0.9	5.5	0.3	1.8	0.2	1.2	0.4	2.4
WS_5	19	16.8	88.4	1.4	7.3	0.5	2.6	0.2	1	0.1	0.5	0	0
WS_6	55.7	45.9	82.4	4.5	8	2.6	4.6	1.3	2.3	0.7	1.2	0.7	1.2
WS_7	29.3	21.2	72.3	2.8	9.5	2.3	7.8	1.3	4.4	1	3.4	0.7	2.3
WS_8	47.6	40	84	3.3	6.9	2.3	4.8	1.1	2.3	0.7	1.4	0.2	0.4
WS_9	46.8	39.4	84.1	3.6	7.6	1.8	3.8	1	2.1	0.7	1.4	0.3	0.6
WS_10	103.5	70.6	68.2	8.8	8.5	7.6	7.3	6.2	5.9	4.4	4.2	5.9	5.7
WS_11	47.8	40.4	84.5	3.1	6.4	2.1	4.3	1.1	2.3	0.8	1.6	0.3	0.6
WS_12	83.3	73.2	87.8	5.6	6.7	2.9	3.4	1.1	1.3	0.4	0.4	0.1	0.1
WS_13	4.8	4.6	95.8	0.1	2	0.1	2	0	0	0	0	0	0
WS_14	88.4	62.7	70.9	7.6	8.5	5.3	5.9	4.1	4.6	5	5.6	3.7	4.1
WS_15	37.3	30.4	81.5	3.1	8.3	2.3	6.1	1	2.6	0.4	1	0.1	0.2
WS_16	43.4	33.1	76.2	4	9.2	3.1	7.1	2	4.6	0.9	2	0.3	0.6
WS_17	169.5	111.7	65.8	15.7	9.2	13.7	8	11.5	6.7	9.3	5.4	7.6	4.4
WS_18	233.9	91.8	39.2	12.8	5.4	25	10.6	22	9.4	24.2	10.3	58.1	24.8
WS_19	145.4	115.7	79.5	9.1	6.2	7	4.8	5.3	3.6	5.3	3.6	3	2
WS_20	83.3	35.1	42.1	4.7	5.6	9.3	11.1	8.1	9.7	7.8	9.3	18.3	21.9
WS_21	95.2	43.5	45.6	8.4	8.8	12.1	12.7	9.8	10.2	8.4	8.8	13	13.6
WS_22	100.7	57.3	56.9	9.7	9.6	8.8	8.7	7.9	7.8	8.7	8.6	8.3	8.2
WS_23	59	27.8	47.1	5.3	8.9	6.8	11.5	5.3	8.9	7.5	12.7	6.3	10.6
WS_24	43.9	29.1	66.2	4.4	10	3.3	7.5	2.9	6.6	2.3	5.2	1.9	4.3
WS_25	39.7	24.3	61.2	3.8	9.5	3.3	8.3	3.4	8.5	3	7.5	1.9	4.7
WS_26	33.6	20.2	60.1	3	8.9	3	8.9	2.9	8.6	2.7	8	1.8	5.3
WS_27	343.6	151.8	44.1	22.5	6.5	26.8	7.7	33.1	9.6	28.3	8.2	81.1	23.6

WS_28	63.9	45.9	71.8	6.1	9.5	4.2	6.5	3.5	5.4	2.3	3.5	1.9	2.9
WS_29	58.3	32.8	56.2	5.4	9.2	6.7	11.4	4.7	8	3.3	5.6	5.4	9.2
WS_30	79.4	51.8	65.2	9.2	11.5	7	8.8	5.2	6.5	3.7	4.6	2.5	3.1
WS_31	96.1	49.8	51.8	7.3	7.5	10.5	10.9	8.5	8.8	6.9	7.1	13.1	13.6
WS_32	118.9	43.4	36.5	6.8	5.7	7.3	6.1	12.9	10.8	12.6	10.5	35.9	30.1
WS_33	77.2	35.4	45.8	5.6	7.2	6.6	8.5	7.6	9.8	7.5	9.7	14.5	18.7
Total	2630.2	1578.8	59.8	203.8	7.7	208.6	7.9	184.6	7.0	165	6.2	293.4	11.1

From (Table 2) it is observed that the greatest magnitude of very severe soil erosion zone was observed in WS_32 sub-watershed, it is followed by sub-watershed no.WS_18, WS_27 and WS_20. The undermost magnitude of very severe soil erosion zone was observed in WS_5 sub-watershed, and it is followed by sub-watershed no.WS_13, WS_12 and WS_15. The highest magnitude of severe soil erosion zone was observed in WS_23 sub-watershed; it is followed by sub-watershed no.WS_32, WS_18 and WS_33. Zero magnitudes of very severe soil erosion zone were observed in the WS_13 sub-watershed, and further lowest magnitude was followed by sub-watershed no.WS_12, WS_5 and WS_15. The highest magnitude of very high soil erosion zone was observed in WS_32 sub-watershed, it is followed by sub-watershed no.WS_21, WS_33 and WS_20. The lowest magnitude of severe soil erosion zone was observed in WS_13 sub-watershed, and it is followed by sub-watershed no.WS_5, WS_12 and WS_4. The highest magnitude of high soil erosion zone was observed in WS_21 sub-watershed; it is followed by sub-watershed no.WS_23, WS_29 and WS_20. The lowest magnitude of very severe soil erosion zone was observed in the WS_13 sub-watershed, and it is followed by sub-watershed no.WS_5, WS_12 and WS_9. Most of the sub-watershed having the highest magnitude and lowest magnitude of very severe to high soil erosion zone is observed at upper and lower catchment area respectively.

D. Soil Erosion category on land use type, slope, and curvature

a) Soil Erosion category on land use type

With the help of overlay tools present in ArcGIS Platform, the overlay analysis is carried out between the soil erosion composed in 2 × 2 km grid-cell and LULC map in vector format of Ghataprabha watershed (Ref Fig.14).

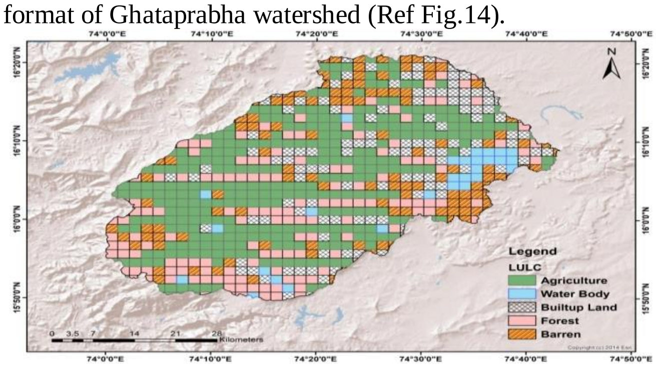

Fig.14 Classification of Land Use Land Cover in Ghataprabha watershed

The response of soil erosion to different LULC categories of the watershed is presented in (Table 3).

Table.3 Classification of land use type based on erosion category (Percentage of area) [modified (Shit et al. 2015)]

Land Use Type	Soil Erosion Category (%)						Total
	Low (0-5)	Moderate (5-10)	High (10-20)	Very High (20-40)	Severe (40-80)	Very Severe (> 80)	
Water Body	3.32	0.22	0.13	0.09	0.06	0.03	3.85
Agriculture	15.73	6.64	5.42	4.2	3.66	6.64	42.29
Built Up Land	9.22	2.57	1.49	1.35	1.35	0.67	16.65
Forest	5.56	2.17	2.17	2.44	2.03	5.69	20.06
Barren Land	3.25	1.62	2.17	3.25	1.89	3.79	15.97
Total	37.08	13.22	22.79	11.33	8.9	16.82	100

The analysis illustrates that the Forest and Built Up land contributes 39.11% and 33.44% respectively of total soil loss, but Forest contributes to the high and above soil erosion category in a large percentage compared to the Built-up land. Waterbody (3.85%) and Crop Land (4.6%) contribute less towards overall erosion in the basin. The open land delivers (17.26%) soil erosion in the overall basin. The analysis carried out of soil erosion category on land use type will be helpful to carry out conservative soil measures in the study area.

b) Soil Erosion category on the slope

The slope map in a uniform grid pattern (Fig.3) displays the entire watershed to be grouped into five slope categories based on geometric intervals. The upper catchment of the study area displays the highest-ranking slope whereas, the slope <3 dominates the lower catchment area. Slope with medium rank was traced in the western and central part of the catchment area. With the support of the overlay toolbox available in ArcGIS Platform, the overlay analysis is carried out between the soil erosion composed in 2 × 2 km grid cell and spatial distribution of slope map of Ghataprabha watershed (Ref Fig.15).

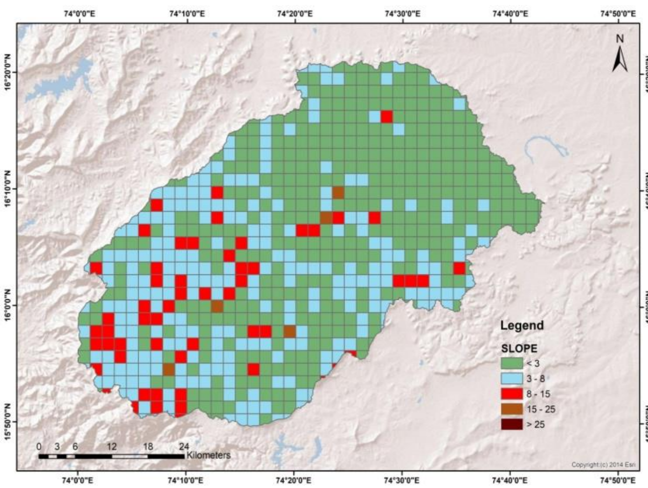

Fig.15 Spatial distribution of Slope in Ghataprabha watershed

The responses of soil erosion to different slope categories of the watershed are presented in (Table 4).

Table.4 Classification of slope based on erosion category (Percentage of area) [modified (Shit et al. 2015)]

Slope (degree)	Soil Erosion Category (%)						Total
	Low (0-5)	Moderate (5-10)	High (10-20)	Very High (20-40)	Severe (40-80)	Very Severe (> 80)	
< 3	41.54	4.59	3.86	2.73	1.66	1.28	55.66
3-8	15.76	2.60	3.31	3.48	3.53	6.28	34.96
8-15	2.07	0.27	0.50	0.57	0.84	2.96	7.21
15-25	0.16	0.02	0.04	0.06	0.08	0.33	0.69
>25	0.002	0.0003	0	0.0003	0.001	0.004	0.007
Total	59.5	7.48	7.71	6.84	6.1	10.85	100

The analysis represents slope <3% contributes 55.66%, and slope 3-8° contributes 34.96% of affected erosion vicinity. The low erosion category is predominately marked in the zone having a slope of less than 3%. The percentage area between high to very severe soil erosion category was found more in the slope 3-8°. The contribution of soil erosion through the slope 8-15°, 15-25° & >25° is less since a large area of the basin comes under less than a slope of 8°. The soil erosion category grouped into different slopes is the essential component of the soil conservation method.

c) Soil Erosion category on elevation

The spatial distribution of the elevation map displays the classification of the entire study area into five elevation categories based on geometric intervals. In this study area, the upper catchment showed an elevation range between 788-1000 meters, whereas; the elevation between 610-678 meters is observed in the lower catchment area. The elevation between 679-787 meters is spotted in the central portion of the basin. With the help of the overlay toolbox present in the ArcGIS platform, the overlay analysis is carried out between the soil erosion composed in 2 × 2 km grid cell and spatial distribution of elevation map of Ghataprabha watershed (Ref Fig.16).

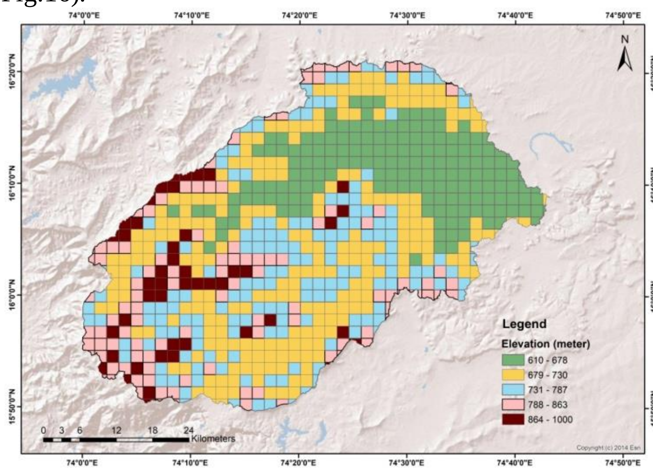

Fig.16 Spatial distribution of Elevation map in Ghataprabha watershed

The responses of soil erosion to different elevation categories of the watershed are presented in Table 5.

Table.5 Classification of Elevation based on erosion category (Percentage of area) [modified (Shit et al. 2015)]

Elevation Zone (m)	Soil Erosion Category (%)						Total
	Low (0-5)	Moderate (5-10)	High (10-20)	Very High (20-40)	Severe (40-80)	Very Severe (> 80)	
610-678	20.80	1.81	1.15	0.61	0.30	0.11	24.78
678-730	20.48	3.10	3.07	2.63	2.03	1.86	33.17
730-787	11.36	1.77	2.14	2.03	1.86	3.10	22.26
787-863	4.42	0.58	0.93	1.10	1.27	3.69	11.99
863-1048	2.08	0.18	0.38	0.45	0.62	2.10	5.81
Total	59.1	7.4	7.6	6.8	6.1	10.8	100

From table 5, approximately 33% of soil erosion area was marked down between the elevation zone of 678 and 730 m. It is followed by 24% between 610 and 678m. The percentage area between very high, high, very severe, and severe soil erosion category was observed more in the elevation ranging between 678-730 to 730-787 meters. The study of soil erosion with respect to different elevation zone in a catchment is considered to be an important aspect during the planning of installation of soil conservation structures in the catchment.

d) Soil Erosion category on the curvature

The spatial distribution of the curvature map displays the distribution of the entire study area into three curvature categories based on geometric intervals, namely Concave, Plane, and Convex. The curvature demonstrates the morphology of the topography. A curvature greater than 0.05 represents, the surface is upward convex at that cell, and a value less than -0.05 shows that the surface is upward concave at that cell. A value between -0.05 to 0.05 indicates a flat surface. In this study area, the concave and convex curvature is observed in the upper catchment area whereas, the Plane surface is observed in the lower catchment area. With the help of the overlay toolbox present in the Esri ArcGIS platform, the overlay analysis is carried out between the soil erosion composed in 2 × 2 km grid cell and spatial distribution of curvature map of Ghataprabha watershed (Ref Fig.17).

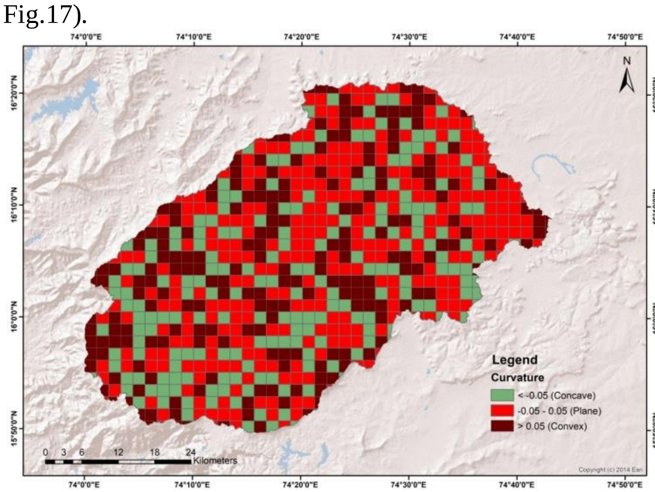

Fig.17 Spatial distribution of curvature map in Ghataprabha watershed

The soil erosion grouped in different curvature classes of the watershed is presented in Table 6.

Table.6 Classification of curvature based on erosion category (Percentage of area)

Curvature	Soil Erosion Category (%)						Total
	Low (0-5)	Moderate (5-10)	High (10-20)	Very High (20-40)	Severe (40-80)	Very Severe (> 80)	
Concave <-0.05	15.37	1.95	2.16	2.06	1.88	4.05	27.47
Plane -0.05-0.05	30.42	3.6	3.4	2.82	2.26	3.36	45.86
Convex >0.05	14.21	2.17	2.28	2.11	2.10	3.67	26.54
Total	60	7.7	7.8	6.9	6.2	11.1	100

Approximately 45% of soil erosion was recorded on the flat surface, whereas 27% & 26% was recorded on concave and convex surface respectively. Since the area acquired by the flat curvature is near 50%, it has contributed more to the soil erosion as compared to the convex and concave curvature.

E. Soil erosion management strategies

a) Soil conservative measures

The aim of soil conservation measures is to cut down erosion rate and to utilize agricultural land within its capability, and get a sustained yield of crop per hectare from an agricultural land point of view. The slope and land use land cover are considered prime aspects during the planning of soil erosion management strategies in the Ghataprabha basin, and the obligatory soil conservative measures are supposed to be adopted given in Table 7.

Table.7 Soil conservative measures in Ghataprabha basin.

LULC	Slope (%)	Soil Conservation Measures
Agriculture	< 10	Contour Farming, Graded bunding
	10-15	Graded Treanches
	16-33	Inward Sloping Bench Terraces
Forest	<10	Raising Utility Trees
	>10	Afforestation
Open Land	<10	Contour Trenching
	>10	Stone Walls, Raising grassland

b) Site for soil conservation structure

The soil and water conservation programs are being carried out by the central as well as by the state government under central sponsored foreign aided programs such as “Soil conservation in the catchment of river valley project (RVP)” and Operation Research Projects on Integrated Watershed Management (ICAR) in several watersheds in India. No such programs were implemented in the Ghataprabha basin for soil conservation practices. Based on ground truth information, it is found that streams from first 1st order to 5th order (Table No.8) along with conservative soil structures such as Nala bund, Minor Irrigation Tank, and Kolhapur Type Weir (Table No.9) are already present in the basin. An attempt is made to propose a location for the installation of modern soil conservative structures such as Gully Plugs and Check Dam (Table No 10) in the Ghataprabha watershed with respect to the stream order and existing soil conservative structures presented in the Ghataprabha watershed.

The Gully Plug is installed on 1st order and 2nd order streams. Since the 1st order stream flows into and “feed” larger streams but does not normally have any water was flowing into them. It is easy to construct a temporary gully plug structure with the help of construction material readily available on the installation site, such as loose stone, woven

wire, and boulders with the help of semi-skilled laborers.
The check dams are installed on 2nd and 3rd order streams. They operate more effectively on gentle slopes. The gentle slopes allow stream flow stabilization and deposition of sediment particles in the check dam. The stability of water in the check dam promotes flora around the site of the check dam. Check dams in streams along steep slopes are less effective in catching sediment. Suggested timber check dam to be constructed on 2nd order stream flow and concrete check dam are to be constructed on 3rd order streamflow. The existing structure and proposed structure are shown in Fig.18. (Farhan et al. 2013) had observed, after construction of conservative soil structures, soil loss was decreased by 50% in the Kufranja watershed of Northern Jordan. Similar results are expected after the installation of Gully Plugs and Check Dam in Ghataprabha Watershed.

Table.8 Stream order in Ghataprabha watershed

Sr.No	Stream order	No of Streams
1	5th order	1
2	4th order	62
3	3rdorder	83
4	2nd order	89
5	1st order	240

Table.9 Soil/Water Conservation existing structures in the Ghataprabha watershed

Sr.No	Type of Structure	Number of structures
1	Nala bund	44
2	Minor Irrigation Tank	19
3	Kolhapur Type Weir	49

Table.10 Soil Conservation proposed structures in the Ghataprabha watershed

Sr.No	Type of Structure	Preferred slope	Preferred stream	Number of structures
1	Gully Plugs	>10%	1st and 2nd order	20
2	Check Dam	0-8%	2nd and 3rd order	16

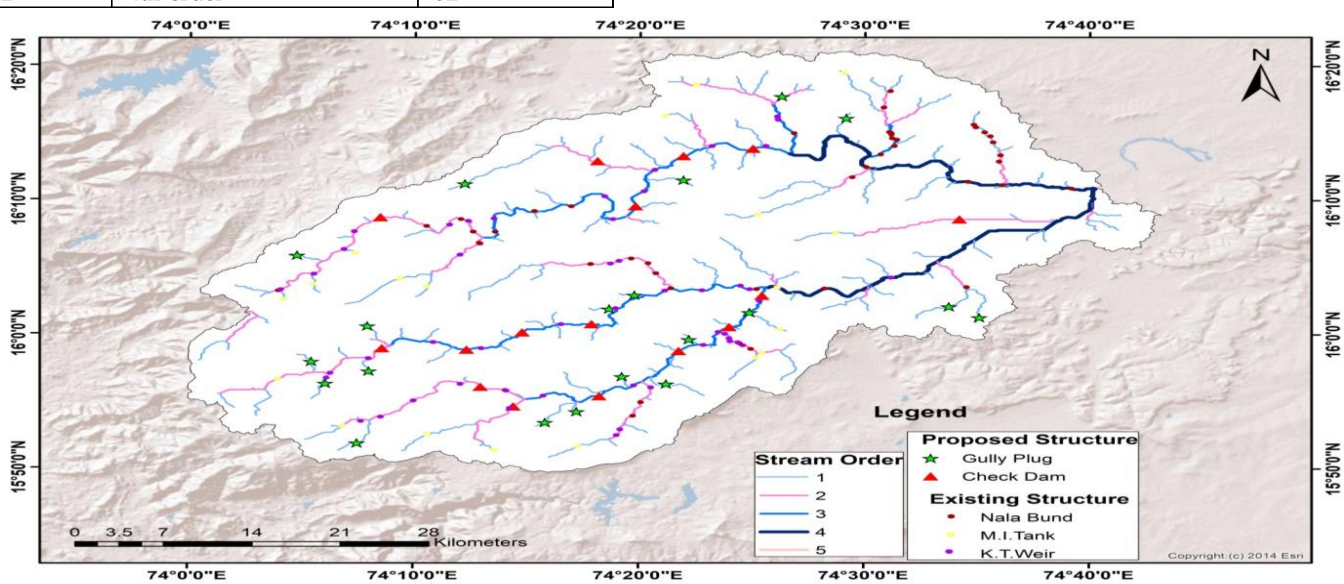

Fig.18 Existing and proposed soil conservation structure in Ghataprabha Watershed

VI. CONCLUSIONS

Quantitative inspection of soil erosion modeling based on a 2 × 2 km grid cell was made using the RUSLE to discover the critical erosion-prone area in the Ghataprabha watershed. The parameters of the RUSLE equation are generated in ArcGIS Software. Also, LULC of the Ghataprabha watershed, which is used as a base map for P-factor in the RUSLE model, is generated in Erdas software. The mean annual soil erosion 32.4 (t/ha/yr) estimated for the Ghataprabha watershed matches well with the soil erosion modeling studies done in the neighboring watersheds present in the Western Ghats. Also, using overlay analysis, 34 sub-watersheds of the Ghataprabha basin are prioritized into six different soil erosion severity zones. About 30% of the watershed area comes under the High to Very Severe soil erosion zone. The reference of the contribution of soil erosion through different types of LULC, Slope, and Elevation was used for proper planning of soil conservation measures in the basin. In the Ghataprabha watershed, conservative soil structures are proposed, such as Gully Plug and Check Dam, which will prevent the soil from getting transferred from lower-order streams to higher-order streams in the watershed. Lastly, it is highlighted that the GIS and Remote sensing techniques incorporated with RUSLE are encouraging and affordable tools for predicting mean annual soil erosion primarily in the un-gauged catchment of Western Ghats and in other parts of India.

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