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Technical Paper

Assessment of Soil Loss using Revised Universal Soil Loss Equation (RUSLE): A Remote Sensing and GIS Approach

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Abstract

A comprehensive methodology that combines Revised Universal Soil Loss Equation (RUSLE), Remote Sensing data and Geographic Information System (GIS) techniques was used to determine the soil loss vulnerability of an agriculture mountainous watershed in Maharashtra, India. The spatial variation in rate of annual soil loss was obtained by integrating raster derived parameter in GIS environment. The thematic layers such as TRMM [Tropical Rainfall Measuring Mission] derived rainfall erosivity (R), soil erodibility (K), GDEM based slope length and steepness (LS), land cover management (C) and factors of conservation practices (P) were calculated to identify their effects on average annual soil loss. The highest potential of estimated soil loss was 688.397 t/ha/yr. The mean annual soil loss is 1.26 t/ha/yr and highest soil loss occurs on the main watercourse, since high slope length and steepness. The spatial soil loss maps prepared with RUSLE method using remote sensing and GIS can be helpful as a lead idea in arising plans for land use development and administration in the ecologically sensitive hilly areas.

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1 INTRODUCTION

Soil weathering and linked deprivation of land resources are extremely important spatio-temporal phenomena in numerous nations (Fistikoglu and Harmancioglu, 2002; Hoyos, 2005; Pandey *et al.*, 2009). Soil erosion, usually related with agrarian practices in arid and semi-arid regions, results into deterioration in soil productiveness, carries on a sequence of undesirable influences of environmental difficulties and has developed a danger to workable agronomic manufacture and aquatic eminence in the area. It has been assessed that in India around 5334 million tons of surface soil is being removed yearly owing to numerous activities (Narayan and Babu, 1983; Pandey *et al.*, 2007). In current years, as share of environment and land deprivation evaluation procedure for sustainable farming and progress, soil loss is increasingly being documented as a threat which is more thoughtful in highland zones (Millward and Mersey, 1999; Angima *et al.*, 2003; Jasrotia and Singh, 2006; Dabral *et al.*, 2008; Thomas *et al.*, 2017). The assessment of soil loss by the new technique such as remote sensing and GIS can be helpful for sustainable resources management in watersheds (Thomas *et al.*, 2017).

The remote sensing mainly is used for the area where the human accessibility less for assessment of resources management. It will be very handy technique for the study of soil erosion, groundwater recharge, groundwater potential and rainfall-runoff modeling in large area (Kadam *et. al.*, 2018; Mundalik *et al.*, 2018; Thomas *et al.*, 2017; Singhai *et al.*, 2017). The remote sensing data such digital elevation model (DEM) is freely available for study of slope characteristic that mainly affects the soil loss of the region and can be effectively used to allow quick as well as comprehensive

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evaluation of loss risks (Patil *et al*., 2014; Gelagay and Minale, 2016). The satellite image used mainly for study of cropping pattern or land use land cover (LULC) that helps to identify the soil loss potential of area and it is successfully used by the many researcher in prediction of soil erosion studies (Gaubi *et al.* 2017; Vijith *et al.* 2017). The satellite image used mainly for study of cropping pattern or land use land cover (LULC) study that helps to identify the loss potentials of the area and it is successfully used by the many researcher in prediction of soil loss (Gaubi *et al.*, 2017; Vijith *et al.*, 2017). The satellite image is also used for erodibility study by considering different remote sensing output such as slope, aspect study by many researchers for study of soil loss, land suitability assessment study and soil water conservation study (Ganasri and Ramesh, 2016; Markose and Jayappa, 2016; Thomas *et al*., 2017). The remote sensing data along advanced GIS technique can be effectively used for spatial and measurable evidence on soil loss at sub-watershed level to contributes suggestively to the scheduling and forecasting for soil protection, loss management, and organization of the watershed atmosphere (Bagyaraj *et al.*, 2011; Rawat *et al*., 2014; Lazzari *et al.*, 2015; Dorici *et al*., 2016).

The outcomes of assessment of soil loss study at sub-watersheds level were carried out on an testing basis in numerous tropical areas using different calculation methods (Ganasri and Ramesh, 2016; Markose and Jayappa, 2016; Thomas *et al*., 2017). Though, soil attrition managing plans in the Western Ghats are controlled by lack of such data, since authentic quantities of soil loss from agriculture area and hilly sections are rare in the country. The present study includes the semi urbanized as well as good agricultural practicing area of Western India and it is also having tourist place for Singhgad fort. The gathering of people for religious reasons for week time in an area has caused in numerous conservational problems. Most of the study area is hill and semi-arid having high rainfall runoff ratio covered with sparse forest, the area has under gone changes in the forest/land use and roots ecological deprivation. Subsequently majority of travellers or trekkers favors the traditional forest routes, sparse forests facing degradation and devastation. Therefore, this study was carried out with an aim to evaluate the yearly soil loss rate and to map potentials of soil losses in a hilly sub-watershed of river Shivganga using RUSLE and remote sensing and GIS method. TRMM [Tropical Rainfall Measuring Mission] and gauge data was combined to estimate the soil erosivity in study area at a fine resolution.

2 MATERIAL AND METHODOLOGY

2.1 Study area

The small mountainous sub-watershed in Shivganga river basin (BM-57) of Upper Nira watershed, in catchment of Upper Bhima is selected for this study. The areal extent of Shivganga watershed is 173.93 km2 which is a part of Pune district, Maharashtra, India (Figure 1). The area show topography with high runoff characteristics of Western Ghats, with an average height

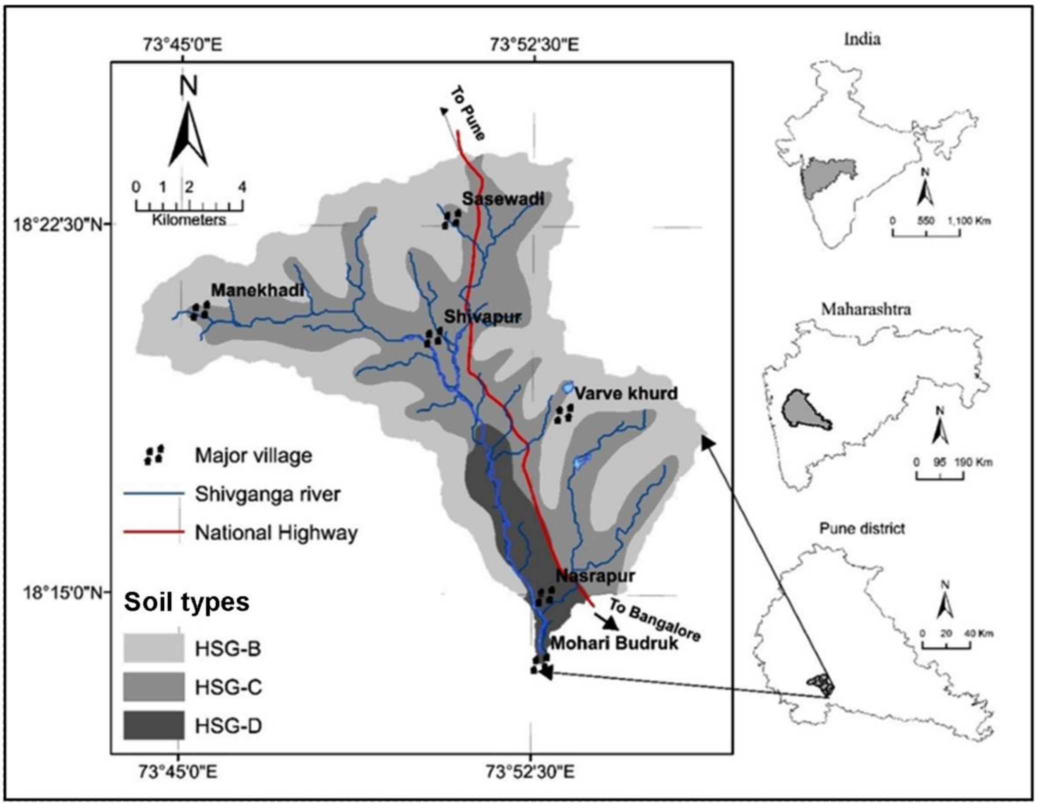

Figure 1. Study area with major soil types

of 815m from MSL [mean sea level] and Northwest ground slopes. It receives an annual average rainfall of 950 mm (last 65 years average) and shows a semi-arid climatic condition. The watershed is majorly having waste land followed by vegetation/forest and agriculture land as land use pattern. As semi-urbanised watershed built-up land is also increase along national high way passing through the area. The entire catchment has rugged terrain and basaltic under rocks which favors shallow soils and high soil loss at a places where green growth is less (Kadam *et al.*, 2017). The river basin exhibits different landforms namely a Butte, Escarpment, mesa, Plateau highly dissected, Plateau moderately dissected, Plateau shallow weathered, Plateau slightly dissected and Plateau weathered. Butte, Escarpment and mesa show high loss and high surface runoff present at the fringe of study stretch. Plateau highly dissected indications less runoff rate results into the low potential of loss (Kadam *et al.*, 2018).

Major soil types of Shivganga river basin are forest soils developed on basaltic rocks under the tropical forest cover. Major soil series of Shivganga river basin are the clay and clay loams. Shivganga river basin shows a high species diversity eco-region.

2.2 Average Annual Soil Loss

Revised universal soil loss equation (RUSLE) (equation (1)) is used to calculate the average annual soil loss and sediment yield by different types of erosion.

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

where, A is an average annual soil loss in t/ha/yr, R is rainfall-runoff erosivity factor in MJ.mm/ha.h.yr, K is soil erodibility factor in t.ha.h/ha.MJ.mm, LS is topographic or slope length/steepness factor, C is cover and cropping management factor, and P is factor of supporting practices (land use).

2.3 Rainfall Runoff Erosivity Factor (R)

The rainfall-runoff factor reveals the influences of numerous precipitation physiognomies such as period and intensity and soil loss (Markose and Jayappa, 2016). R-factor signifies the main culprit of different erosion by rainfall-runoff (Naqvi *et al.*, 2013). The river basin experiences wide difference in precipitation intensity. Monthly precipitation data (1985 to 2015) of four rain gauge station (Pune city, Bhor, Velhe, and Purandhar) collected from IMD, Pune. The rainfall map was prepared by theisen polygon method in GIS environment (Figure 2) and updated with remote sensing based Tropical Rainfall Measuring Mission (TRMM) monthly rainfall data from NASA. It was used for the calculation of R-factor. Then, the TRMM precipitation grid-based data was added and averaged by 'grid add' and 'grid average' functions of GIS environment to produce annual average rainfall map of the study area. R-factor was computed using the formula proposed by Arnoldus (1980) (equation (2)).

$$R = P \times 0.5 \qquad \text{(Roose, 1975)} \qquad (2)$$

where, R is the rainfall erosivity factor and P is the mean annual precipitation in mm.

2.4 Soil Erodibility Factor (K)

The soil erodibility factor (K) signifies the properties of soil and its physiognomies to the soil attrition (Markose and Jayappa, 2016). The soil erodibility is function textural properties of soil (sand, silt, and clay composition), percent orogenic material, and perviousness of soil and also the elemental concentration Fe, Al, and Na in soil (Markose and Jayappa, 2016, Kadam *et al.*, 2012).

Soil map from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur (1:500,000) (Table 1) was used to derive 'K' factor. The map shows clayey (HSG-D) (8.01%), clay loamy (HSG-C) (42.37%) and sandy clayey loamy (HSG-B) (49.63%) types of soils (Figure 3). Stone and Hilborn (2000) were given K values for soil groups as: 0.22 for HSG-D, 0.3 for HSG-C, and 0.02 for HSG-B (Table 4).

Table 1. Data used

Data	Sources	Map	Description
Topo-sheet	Survey of India (SOI), 1: 50,000 scale	Study area boundary	Topo-sheet was used to demarcate watershed boundary.
Rainfall	Tropical Rainfall Measuring Mission (TRMM)	Rainfall map	Rainfall map was used to calculate the R-factor
Soil series data	National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), Nagpur.	Soil map	Soil map was used for calculation of K-factor (soil erodibility)
ASTER-GDEM	NASA's Land Processes Distributed Active Archive Center (LP DAAC)	Digital elevation model (DEM) and Slope	Digital elevation map (DEM) and slope map was used to calculate the LS-factor
Satellite imagery	Landsat-8 (2016)	Land use / land cover (LULC)	LULC map was used for calculation of P- and C-factors.

2.5 Slope Length and Steepness Factor (LS)

LS-factor symbolizes the impact of slope length (L) and its steepness (S) on the soil erosion. LS-factor in USLE characterizes the ratio of soil loss on given slope length and steepness to soil loss (Remortel *et al.*, 2001; Pham *et al.*, 2018). ASTER-GDEM was used to calculate for LS-factor in the model maker using ArcGIS environment. LS-factor calculated as (equation (3)):

$$LS = Power\ (flow\ accumulation \times pixel\ size\ /\ 22.1, 0.4) \times Power\ (Sin\ (slope\ in\ degree \times 0.01745)\ /\ 0.09, 1.4) \times 1.4 \quad (3)$$

where, LS is collective slope length and steepness factor. Flow accumulation was derived from DEM having cell size 30 m and sin slope is nothing but sin of slope angle in degrees. LS-factor varies from 0 to 7.45 (Figure 4).

2.6 Cropping Management Factor (C)

C-factor is another most significant factor that regulates topsoil loss hazard (Patil *et al.*, 2014; Devatha *et al.*, 2015; Pham *et al.*, 2018), and it replicates the consequence of harvesting and administration practices on the soil loss amount (Anache *et al.*, 2014; Devatha *et al.*, 2015; Singh and Panda, 2017; Pham *et al.*, 2018). C-factor is most significant for crop management. Subsequently, C-factors values are not calculated or identify for maximum of Indian crops. Therefore, C-factors suggested by Karaburun (2010) were used to show the outcome of cropping and management practices on rate of soil loss in cultivated lands. The effects of plants canopy and ground covers on deceasing soil loss in forested regions (Renard *et al.*, 1997) changes with period and crop yield scheme. The periodic difference of C-factor rests on numerous aspects such as precipitation, cultivated exercise, type of crops, etc. However, the present practices measured a yearly difference as there is no farming in rabbi season (November-April) in the study area and similarly, no precipitation after October. The comparative influence of management possibilities can simply be likened with variations in C-factor which fluctuates from near zero for a well-protected land use to 1 for barren areas.

Landsat 8 image was classified using supervised classification technique in ERDAS Imagine 9.1 software. The supervised classification technique requires ground truth information for each LULC category which was collected using global position system (GPS) and trained the process for eight LULC class. The overall accuracy of the classification was about 83%.

Shivganga basin was classified into eight LULC classes: water body, forest area, built-up area, land with and without scrubs, agriculture lands, fallow lands and vegetated area (Figure 5). The area related with each LULC classes were premeditated and C-factors were assigned (Table 1). The map of crop management factor (Figure 7) was prepared from LULC map. C-values were used in the present study proposed by Kim *et al.* (2005). LULC map was reclassified based on C-factors to map the C-factor.

2.7 Conservation Practice Factor (P)

The factor of support practices (P-factor) is the soil-loss ratio with a definite support exercise to the matching soil losses with up and down slope of land for growing crops (Renard *et al.*, 1997). In this approach, P-factor map was prepared from LULC and slope map with support factors. The slope map (%) was prepared using DEM in GIS environment and it was merged with LULC using 'union function'. P-values (Table 2) were then assigned to the merged classes to prepare the map of P-factor. P-factor values vary from 0 to 1, where uppermost value is allocated to zones with no management practices (barren land); the lowest values

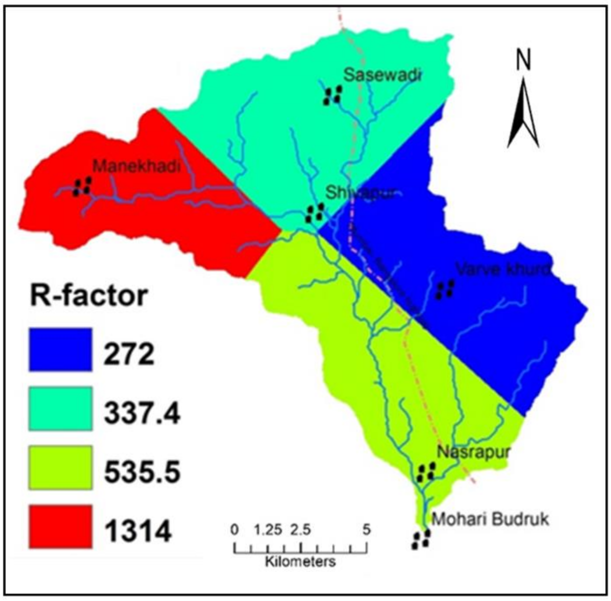

Figure 2. Rainfall erosivity (R-factor)

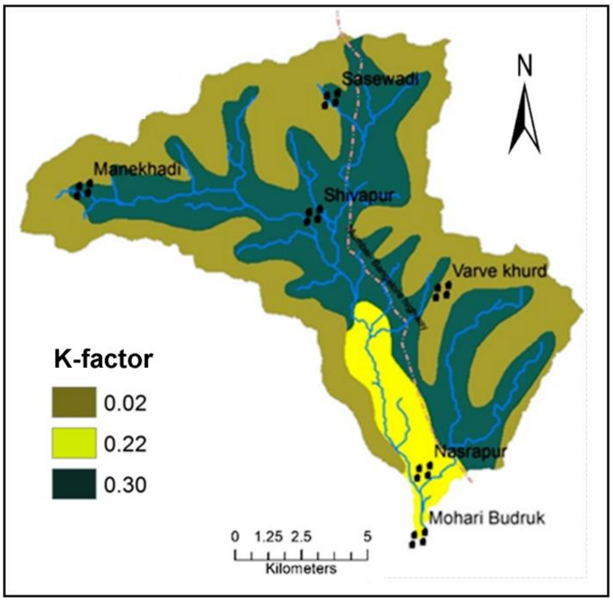

Figure 3. Soil erodibility (K-factor)

to built-up-land and vegetated area with strip and contour cropping. More operative the preservation practices show the lowest P-value. Subsequently, there is no ground data available concerning with the conservation practices done in the Shivganga basin.

2.8 Assessment of Possible Soil Erosion

In RUSLE modeling, the precipitation erosivity, soil erodibility and ground aspect can be measured as certainly happening aspects causal to soil loss processes. They can be considered as the erosion vulnerability or possible soil loss for the zone.

2.9 Demarcation of Soil Loss Zones

Annual soil loss from the study area was calculated by integrating the R, K, LS, C and P factors for this catchment, using the raster calculator function available in the ArcGIS for each pixel. Major aspects are considered to be prompting soil loss comprise of LULC, soil characteristics, precipitation strength and gradient. The weightages for discrete layer were allocated by considering part in the soil loss. The maximum value is given to the feature with maximum vulnerability and the least being to the lowest susceptible feature. The analysis for soil loss estimation was done using GIS environment, and spatial data (Figure 6).

Table 2. LULC classes

Land use/land cover	Description	% Area	C-factor values
Built-up land	areas characterized by buildings, asphalt/concrete structures, city gardens, and a systematic street pattern	6.38	0.08
Irrigated crop land	redefined to describe land producing crops requiring annual replanting	14.07	0.7
Fallow land	cropland that is not cultivated for a season; it may or may not be ploughed	31.07	0.7
Water bodies	the part of the Earth's surface arresting water naturally or artificially	0.57	0
Forest	is a large area covered with trees or other woody vegetation	14.27	0.008
Vegetation	one crop is specifically planted for widespread commercial sale	13.84	0.008
Land with scrub	A land in which plant community characterised by vegetation / shrubs	16.94	0.28
Land without scrub	The sloping or hilly land without biomass	2.22	0.28

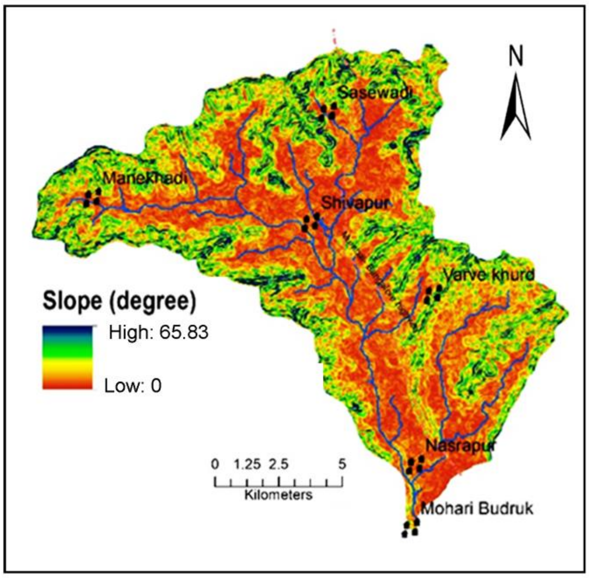

Figure 4. Slope

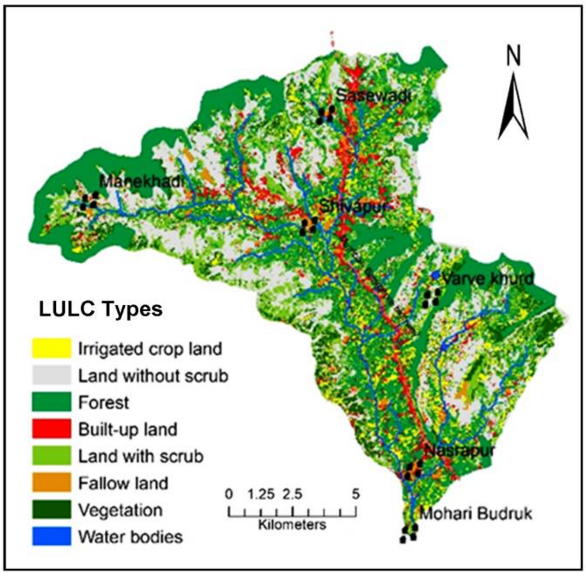

Figure 5. Land use land cover

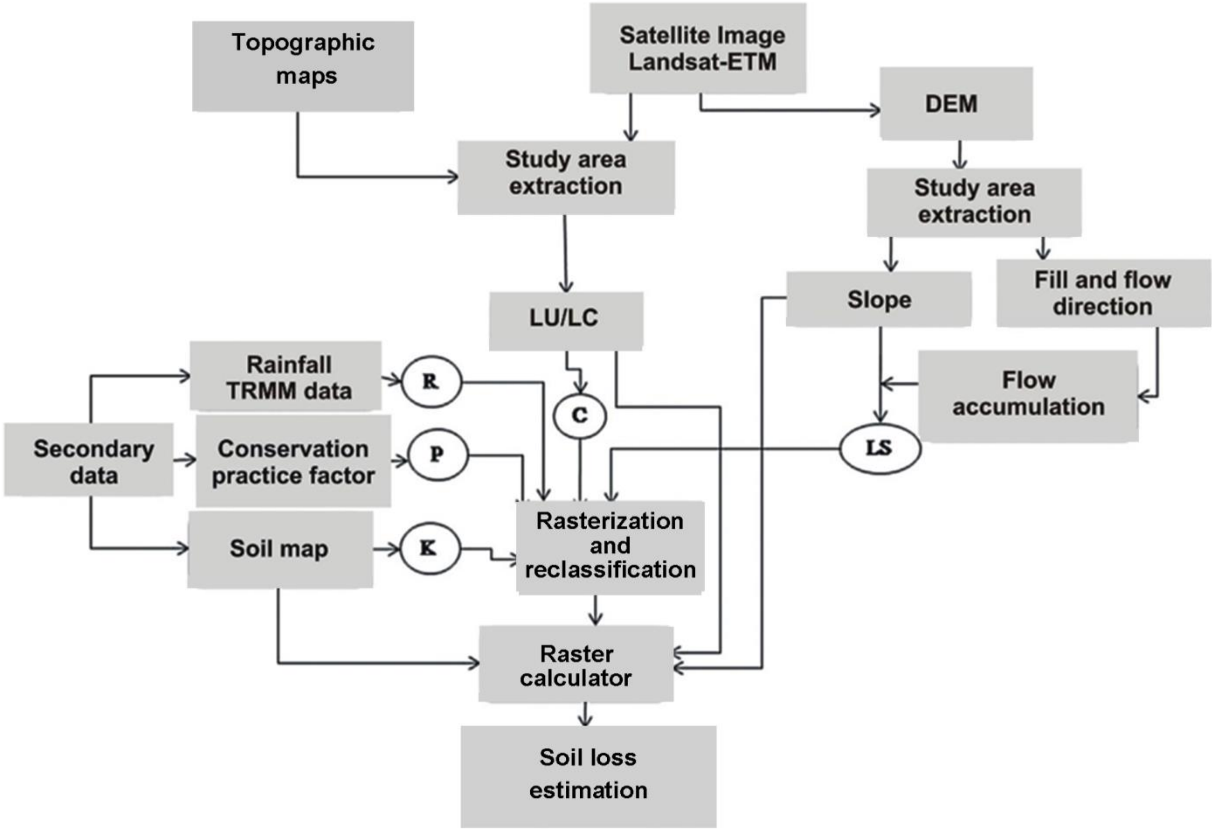

Figure 6. Methodology

3 RESULT AND DISCUSSION

3.1 Rainfall Erosivity Factor (R)

Several studies (Vaezi *et al.*, 2017; Kayet *et al.*, 2018) show that the soil erosion rate in the study area is more dependent on precipitation area. The precipitation is a good indicator of variation in the rate of soil losses to describe the periodic dispersal of deposit yield. Though the advantages with use of annual precipitation comprises its ready obtainability, simple of calculation and better provincial constancy of the advocate (Shinde *et* al., 2010). Consequently, in the current study, average yearly (ratio of total precipitation by the total number of rainy days) precipitation was used for calculation of R-factor (equation (2)). R-factor values varies from 272 to 1314 MJ.mm/ha.h.yr (Table 3) with a mean value of 559.42 MJ.mm/ha.h.yr. with standard deviation of 385.62 MJ.mm/ha.h.yr. It is found that precipitation is high in study region.

Table 3. Mean annual rainfall and R-factors

Station name	Mean annual rainfall (mm)	R-factor (MJ.mm/ha/h)
Pune city	674.8	337.4
Bhor	1071	535.5
Velhe	2628	1314
Purandhar	544	272

3.2 Topographic Factor (LS)

Topographic factor signifies the effect of slope length and slope steepness on soil loss process. LS-factor was designed by considering the flow accumulation and slope in percentage. LS-factor increases as it varies from 0.005 to 7.45 as the flow accumulation and slope increases (Figure 7).

Table 4. Soil types and K values

Soil type	Soil texture	K-values (t.ha.h/ha.MJ.mm)
HSG-B	sandy clayey loamy	0.02
HSG-C	Coarse loamy soils	0.22
HSG-D	Clayey soil	0.30

3.3 Soil Erodibility Factor (K)

K-factor values are assigned based on respective soil types in the region to prepare soil erodibility map. K-factor values range from 0.02 to 0.3 t.ha.h/ha.MJ.mm, but majority of the area shows the value of 0.3 to 0.02 t.ha.h/ha.MJ.mm (Table 4). The lesser value of K-factor is related with the soils having less porousness, little antecedent humidity content.

3.4 Crop Management Factor (C)

Information on LULC documents a good considerate of the land use features of cropping form, fallow land, forest, land with and without scrub, vegetation and surface water bodies, which are main for progressive arrangement/soil loss studies. Remote sensing and GIS technique has a potential to produce a thematic map of LULC. Crop management factor was assigned to different land use patterns using the values given in table 1. Using LULC map and C-factor value, the C-factor map was prepared. C-factor varies from 0 to 1 and support practice factor P-value is observed in between 0.1 and 1 in the watershed (Figure 8).

3.5 Conservation Practice Factor (P)

LULC influences the soil loss by the P-and C-factors. The plantation protects soil losses and avoids erosion dependent on the soil and land use types (Pham *et al.* 2018). For each land use pattern having land use practice that affects the P-value. For instance, the irrigated crops in slope regions, agriculturalists will go for contour framing, which decreases the rate of soil loss. P-factor assigned 1 for forest land (14.27%) mainly present at the peripheral part of study area with steep slopes (Table 4; Figure 9). The factor (P) of conservation practices was calculated for study area by different LULC types and slope degrees as proposed by Shin (1999). The estimated values vary from 0 to 1.00 (Table 4; Figure 9).

3.6 Potential Annual Soil Erosion Estimation

The remote sensing and GIS analysis was carried out using RUSLE for evaluation of annual soil loss, pixel-by-pixel basis and the spatial dispersal of the soil loss in the study area. The final USLE map with average annual soil loss of the Shivganga river basin was prepared (Figure 10). The highest amount of estimated soil loss potential was 688.397 t/ha/yr. The mean annual soil loss is 3.64 t/ha/yr. The highest soil loss was estimated for the main watercourse, since of slope length and steepness factor value. The potential soil loss in the study area has been categorized into five types viz., slight, moderate, high, very high and sever erosion based on the rate of erosion (t/ha/yr). More erosion corresponds to sever erosion and low rate of soil loss correspond to slight erosion (Table 5).

According to USLE study, only 0.014% area is under slight loss class, whereas only 14.09% area is under very severe class (Table 6). This was primarily due to less quantity of check dams constructed across river and its tributaries. It is detected that small parts of the study area have higher values of soil loss, which may be due to the steep slopes. It is experiential that large part of the study area having less soil loss, which mainly present areas where very high erosion happens only in a small area wherever the sharp gradient with barren land exists. Modest soil loss happens in the slopes of Western Ghats of the study area where cultivated area with minor slope exists.

Table 5. Factors of support practices

Land use type	Slope (º)					
	0 - 0.286	0 - 5	5 - 8	8 -10	10 -15	>15
Forest, barren land	1.00	1.00	1.00	1.00	1.00	1.00
Vegetation, Scrub land	0.55	0.55	0.89	0.89	0.89	0.89
Agricultural land	0.10	0.10	0.89	0.89	0.89	0.89
Built-up land	0.029	0.029	0.029	0.029	0.89	0.89
Water-bodies	0.0	0.0	0.0	0.0	0.0	0.0

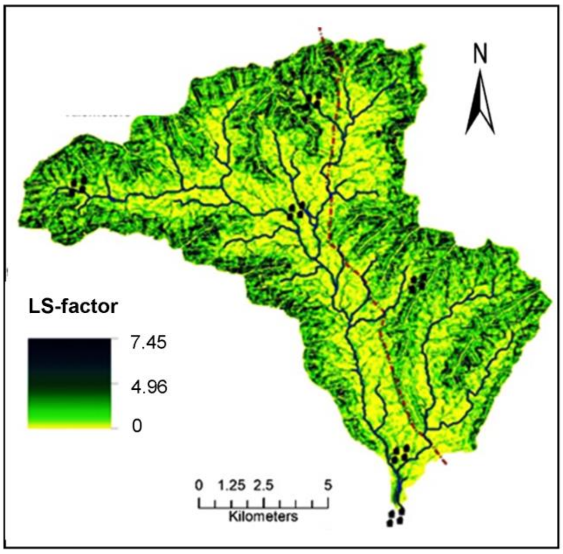

Figure 7. Slope length and steepness (LS-factor)

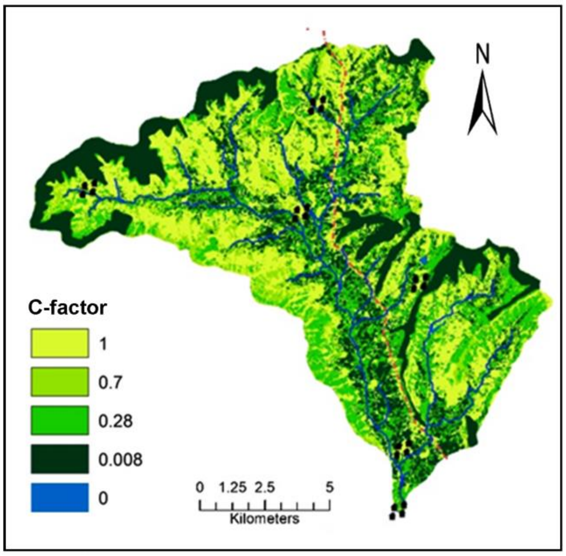

Figure 8. Crop management (C-factor)

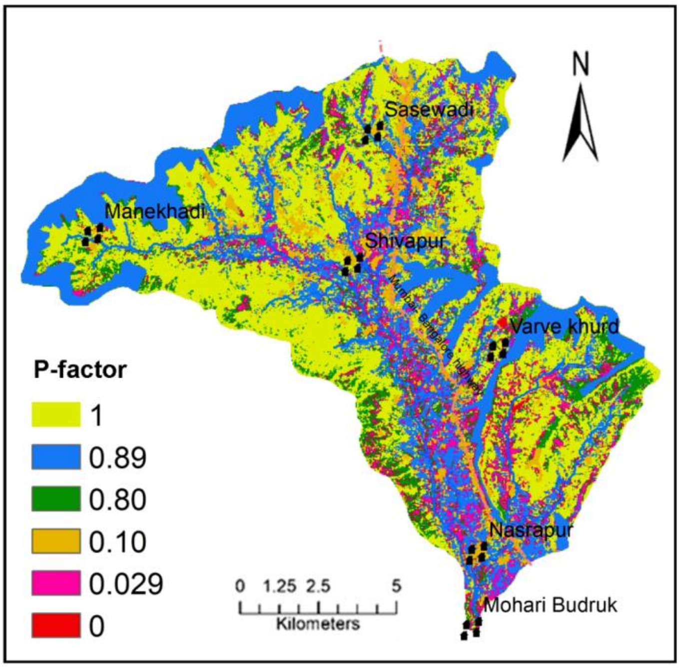

Figure 9. Crop management (P-factor)

Table 6. Soil loss

Erosion class	Soil loss (t/ha/yr.)	Area (%)
Slight	< 0.054	0.014
Moderate	0.05 - 3.40	46.27
High	3.41 - 11.80	26.32
Very high	11.81 - 83.60	13.29
Severe	> 83.61	14.09

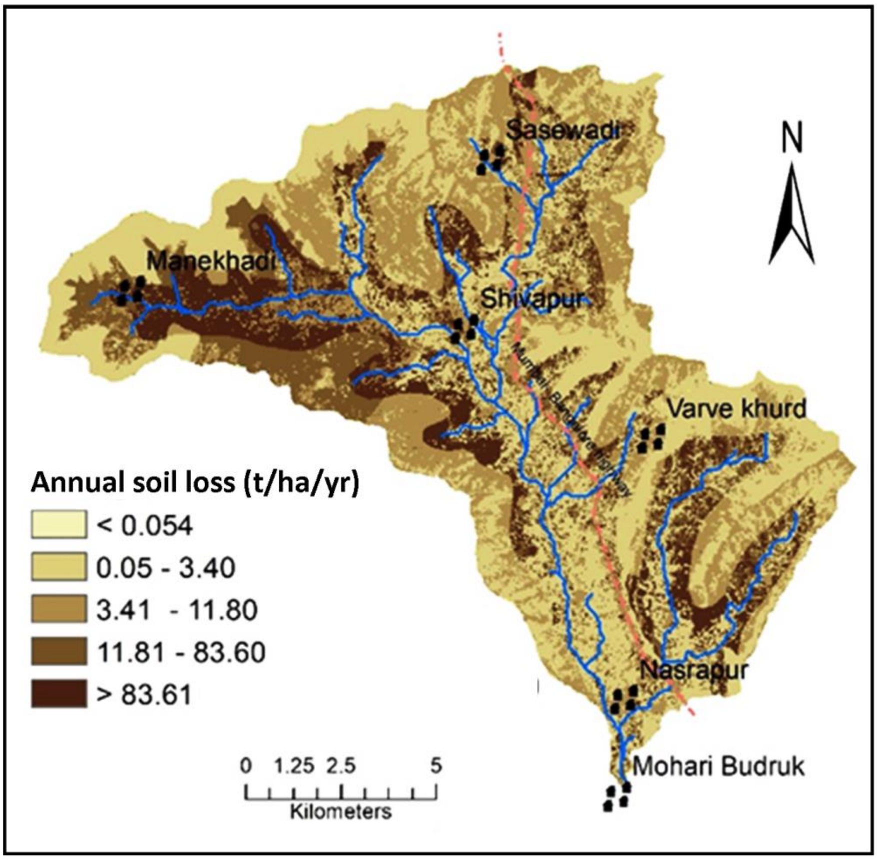

Figure 10. Distribution of soil loss

4 CONCLUSION

A quantifiable evaluation of average annual soil loss for Shivganga river basin was made using remote sensing and GIS with well-known RUSLE equation take into account thematic layer such as precipitation, soil erosion, land use and topographic datasets. The TRMM based RUSLE analysis gives the fine resolution in result. In the western basin the soil is prone to erosion due high rainfall runoff ratio shows that parts with natural forest cover in the periphery regions have least rate of soil loss, whereas areas with human intrusion have high rate of soil erosion (> 5t/ha/yr). Topography changes along with high LS-factor and precipitation swift these parts to be more vulnerable to soil loss. The projected quantity of soil loss and its areal distribution can offer a base for complete organization and sustainable land use for the basin. The areas with high and extreme soil loss warrant special precedence for the execution of control actions. Though the current RUSLE systematic model helps mapping of susceptibility zones, pixel level precipitation intensity, soil texture and field quantities can enhance the forecast competence and correctness of remote sensing and GIS based analysis.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

GIS: Geographic Information System; **GPS**: Global Position System; **HSG**: Hydrological Soil Groups; **IMD**: Indian Meteorological Department; **LULC**: Land use/land cover; **NBSSLUP**: National Bureau of Soil Science and Land Use Planning; **MJ.mm/ha.h.yr**: megajoule millimeter / hectare hour year; **RS**: Remote Sesning; **RUSLE**: Revised Universal Soil Loss Equation; **t.ha.h/ha.MJ.mm**: ton hectare hour / hectare megajoule millimeter; **TRMM**: Tropical Rainfall Measuring Mission.

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