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Study of evaluation of soil and water conservation measures on soil erosion at micro-watershed scale using RUSLE model and GIS

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ABSTRACT

In this study, the impact of soil and water conservation (SWC) measures implemented under Integrated Watershed Management Programme (IWMP) on the reduction of the rate of soil erosion in Krishnagiri watershed, Tamil Nadu was carried out. Revised universal soil loss equation (RUSLE) in geographical information system (GIS) provided a spatial distribution of soil erosion risk areas. The average annual rainfall erosivity (R) of the RUSLE estimated from daily rainfall depth for 30 years period was found to be 2552.5 MJ mm ha^{-1} yr^{-1}. The soil erodibility (K) factor ranged from 0.10 to 0.35 Mg h $MJ^{-1}mm^{-1}$. Digital elevation model (DEM) of the study watershed provided slope length and slope steepness (LS) factor. Land use (LU) map of the watershed was used to derive the cover management factor (C) map. Integrating the thematic layers of RUSLE in GIS environment gave the spatial distribution of the rate of soil loss during pre-treatment and post-treatment (field bund and stone wall) at micro-watersheds. The changes in the rate of soil loss and total soil loss between pre-treatment and post-treatment represent the impact of conservation practices on the soil loss of the watershed. The reduction of the rate of soil loss is from 7.64 t ha^{-1} yr^{-1} to 6.4 t ha^{-1} yr^{-1} with the prediction of total soil reduction from 71831 t yr^{-1} to 60172 t yr^{-1}. Simulation of alternative conservation practices showed mulching is better than strip-cropping in controlling the soil erosion.

1. INTRODUCTION

Soil erosion remains one of the significant environmental problems worldwide, posing a severe threat all over the world including India (ISCO, 2002). It is a complex dynamic process of land denudation by which productive surface soils were detached, transported and accumulated at a distant place (Jain and Goel, 2002; Jain *et al.*, 2003). Land degradation from water-induced soil erosion is a serious problem in India and this was noticed in the early 1980's (Narayana and Babu, 1983). Successful reduction of soil erosion requires accurate conceptual and quantitative models of erosion and transport processes responsible for sediment delivery to the impoundment (Morris and Jiahua, 1998). Erosion processes have been intensively studied for many decades by several researchers all over the world (Jain and Kothyari, 2000; Hessel *et al.*, 2003; Ning *et al.*, 2006; Jain *et al.*, 2010; Zhang *et al.*, 2010; Hudek e*t al.*, 2014; Durbue, 2015; Chandra *et al.*, 2016). The computational tools for modeling soil erosion and related watershed processes are undergoing rapid change and enhancement. Though many physical based models are available to estimate soil erosion and sediment yield, simple empirical models are still popular and most widely used (Prasannakumar *et al.*, 2012). This is due to the fact that the data requirements for most of the process based models are complex and are often very difficult to measure at the required scale. Due to the simplicity and robustness of the models like universal soil loss equation (USLE) (Wischmeier and Smith, 1978), modified universal soil loss equation (MUSLE) (Williams, 1975) and RUSLE (Renard *et al*., 1997), these models can be used at a regional scale very effectively.

Efforts at combining USLE with other models have also been attempted by many authors (Ozcan *et al*., 2008). For example, Vemu and Udaya (2011) prioritized 15 sub-watersheds for soil conservation in Upper Indravati reservoir catchment area in India, combining USLE with watershed erosion response model (WERM) in GIS environment. Outfall total suspended sediments (TSS) and percentage reduction in TSS assessed in a study on Santubong River in Malaysia (Kuok *et al*., 2013) showed the effectiveness of conservation practice (P) factors as Terracing>contour strip cropping> simple contouring > no support practice, based on the efficiency of sediment retention. These studies show the wide applicability of RUSLE modeling approaches in soil erosion studies. The present study also utilized the RUSLE model to estimate soil erosion rates at micro-watersheds and help discern the best feasible measures in the local context with the help of GIS. The aim of this study is (i) to identify soil erosion risk areas, (ii) to evaluate the impact of soil conservation measures implemented on soil erosion rates in the watersheds and (iii) to estimate the impact of soil conservation measures under new conservation practices scenario on soil erosion rates in the watersheds.

2. MATERIALS AND METHODS

Study Area

The study area comprises of ten micro-watersheds (Fig. 1) of total area 9032 ha in the Sulagiri block of Krishnagiri district, Tamil Nadu located at the latitudes of 12°34'26.4"N to 12°50'42"N and longitudes of 77°55' 8.4"E to 78°7'1.2"E. The watershed falls under the tropical zone with average annual precipitation of 860 mm. Chinnar river is the major river flows through the watershed from northwest to south east direction which drains into Krishnagiri reservoir. The topo-graphical elevation varies from 600 m to 900 m decreasing from north-west to southeast direction.

Revised Universal Soil Loss Equation (RUSLE) Model

RUSLE is the improved form of USLE that has been most widely used and robust model for estimation of soil erosion loss. The use of remote sensing and GIS techniques in RUSLE later made soil erosion estimation and its spatial distribution in watershed possible with reasonable costs and better accuracy. The RUSLE model (Renard *et al*., 1997) structure is expressed as:

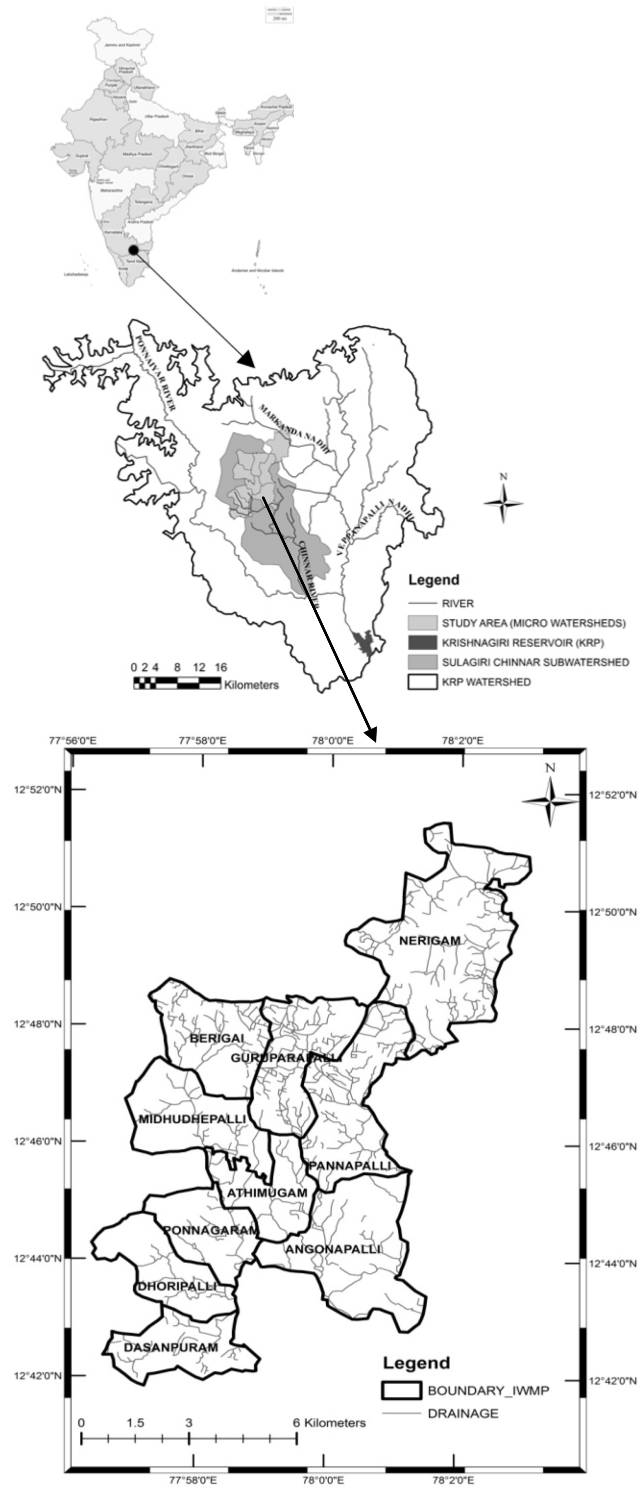

Fig. 1. Index map of the micro-watershed in the Sulagiri watershed

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

Where, A is the average soil loss per unit area by erosion (t $ha^{-1}yr^{-1}$), R is the rainfall erosivity (MJ mm $ha^{-1}h^{-1}$), K is the soil erodibility (Mg h $MJ^{-1}mm^{-1}$), L is the slope length (dimensionless), S is the steepness of the slope (dimensionless), C is the cover and management factor (dimensionless), P is the conservation support practice factor (dimensionless).

Rainfall Erosivity (R)

Rainfall erosivity is a measure of the capacity of rainfall to cause soil erosion. It is influenced by rainfall characteristics such as amount, intensity, duration, drop size and drop-size distribution and kinetic energy (Renard *et al*., 1997). Average annual erosivity is computed as the sum of the erosivity (EI_{30}), which is the product of the total energy and the maximum 30-min intensity of individual storms.

$$R = E\,I_{30} \quad ...(2)$$

Due to non-availability of self-recording rain gauge in the study area, a simple power function (eq. 3) developed for Krishnagiri watershed to estimate the R factor from the depth of rainfall (Arunbabu and Ravichandran, 2016) was used to derive the rainfall erosivity.

$$R = 0.193\,P^{1.895} \quad ...(3)$$

Where, R is the rainfall erosivity and P is the depth of rainfall in mm.

Soil Erodibility Factor (K)

Soil erodibility is usually regarded as the susceptibility of a soil to erode (Wang *et al.*, 2013; Kaushal Kumar *et al*., 2017). Soil atlas prepared by Soil Survey and Land Use organization, Dharmapuri district depicted the soil taxonomical classification of the watershed. Soil samples were collected from each soil series of the watershed. The soil samples were analysed for particle size distribution and the organic matter content in the laboratory. The results of the soil analyses fed into the eq. 4 estimated the soil erodibility factor (K) based on the USLE nomograph using the multi-regression equation developed by Wischmeier and Smith (1978) and modified to the international system of unit (SI unit) by Rosewell (1993).

$$K = 2.8 \times 10^{-7} M^{1.14} (12-a) + 4.3 \times 10^{-3} (b-2) + 3.3 \times 10^{-3} \times (c-3) \quad ...(4)$$

Where, K is the Soil erodibility factor (Mg h MJ^{-1} mm^{-1}), M is Particle size parameter (% silt + % very fine sand) * (100 - % clay), a is the Percentage of organic matter content in the soil, b is soil structure code (very fine granular (1), fine granular (2), medium to coarser (3), blocky platy or massive (4), c is the profile permeability class (rapid - 1, moderate to rapid - 2, slow to moderate - 3, slow - 4 and very slow - 5).

Slope Length and Steepness Factor (LS)

The combined LS-factor was computed for the watershed in ArcGIS Spatial analyst extension using the DEM following the equation (5) proposed by Moore and Burch (1986) and used by researchers (Bizuwerk *et al*., 2008; Ozcan *et al*., 2008; Csafordi *et al*., 2012).

$$LS= (X/22.1)^m (0.065 + 0.045S + 0.0065S^2) \quad ...(5)$$

Where, X = (Flow Accumulation * Cell value) *i.e.* slope length (m), S = slope gradient (%), m = slope contingent variable that depends on slope percentage.

These factors are estimated using the DEM from ASTER data of 30 m spatial resolution. Spatial analyst tool in ArcGIS 10.1 version categorized the variation of slope in percentage. Flow fill, flow direction, and flow accumulation tools from hydrology extension in ArcGIS were executed for ASTER DEM to derive the drainage network (flow accumulation) of the study watershed. The spatial distribution of the slope length and slope steepness factor (LS) determined by executing the eq. 5 in the raster calculator of ArcGIS.

Cover Management Factor (C)

Cover management factor (C) represents the effect of cropping and management practices in the agricultural system, and the effect of ground cover, tree canopy, and grass covers in reducing soil loss in non-agricultural condition. Satellite imagery acquired on 23rd March 2007 from IRSP6 LISS III sensor was used for preparing the LU and land cover (LC) map for the Sulagiri watershed. Supervised classification using maximum likelihood algorithm is performed on the imagery to designate the pixels into six classes as mixed crop area, forest, settlement, sparse vegetation, barren land, and water body. To evaluate the accuracy of the classification system, 28 reference test pixels were identified. The accuracy assessment showed an overall accuracy derived from the equalized random sampling method for classified images was 90.1%

with an overall Kappa statistic of 0.9 which is rated as good classification performance (Lillesand *et al*., 2004). The cover management factor values for each LU classes (Table 1) were assigned from the earlier study (Ismail and Ravichandran, 2008) done at a sub-watershed of Krishnagiri watershed. The LU an LC map was then reclassified into cover management factor map in ArcGIS environment.

Potential Erosion and Impact Assessment

The thematic layers on soil erodibility, slope length and steepness factor, cover factor were integrated into ArcGIS using the raster calculator for estimating the potential soil loss in the watershed. Rainfall erosivity, soil erodibility, the slope of the terrain and existing LU and LC is considered as naturally occurring processes that determine the potential soil loss of the study watershed without any conservation practices (P). The soil loss determined without considering the conservation practices were designated as pre-treatment soil loss whereas the soil loss estimated including the conservation practices (P) (Field bund and stone wall) were designated as post-treatment soil loss. The sites where SWC measures implemented (TAWDEVA, 2002) in the study watershed are shown in Fig. 2. P factors were assigned logically (Table 2) at the appropriate locations where soil conservation practices such as Field bunds and stone wall were implemented. In areas with more than one type of practice in use, a weighted value of P as per the area under each practice is considered and in areas where there are no conservation practices a value of 1 is assigned. The changes in the rate of soil loss and total soil loss between pre-treatment and post-treatment represent the impact of conservation practices on the soil loss of the watershed.

3. RESULTS AND DISCUSSION

The average annual rainfall erosivity of the watershed using daily rainfall depth measured at Sulagiri rain gauge station for 30 years period was found to be 2552.5 MJ mm $ha^{-1}yr^{-1}$. The soil erodibility factor (K) determines the susceptibility of the soil to erosion that ranges between 0.1 and 0.35 Mg h MJ^{-1} mm^{-1}. The spatial variation of the soil erodibility shows that the (Fig. 3) southeast part of the watershed has high erodibility than the other parts of the watershed. A significant portion of the watershed has a slope greater than 5% and LS factor varies from 0 to 327.49 (Fig. 4). LU and LC classification of the

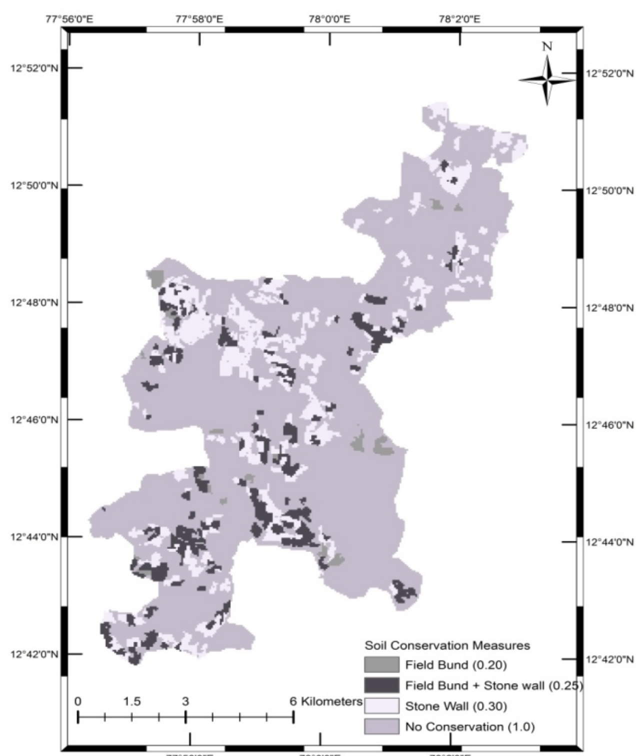

Fig. 2. Soil conservation measures implemented in the Sulagiri watershed

Table: 1
Land use Land cover and C factor adopted for the micro-watershed

Land use and Land cover	Area (%)	C factor
Mixed Crop area	56.73	0.39
Settlement	3.28	0.15
Forest	7.13	0.002
Barren	11.06	0.60
Sparse vegetation	21.51	0.12
Water	0.28	0

Table: 2
Conservation measures and the P factor of RUSLE from literature

Conservation measures	P factor	Reference
Field bund	0.30	Teshome *et al.,* 2013; Ghanshyamdhas, 2004
Stonewall	0.20	Teshome *et al.,* 2013
Mulching	0.15	Hessel and Tenge, 2008; Sheikh *et al.,*2011; Ghanshyamdhas 2004
Strip cropping	0.37	Renard *et al.,*1997; Pal and Samanta, 2011
No Conservation	1.00	Renard *et al.,*1997; Ghanshyamdhas, 2004; Biswas and Pani, 2015

watershed showed 56.73% of the area is under vegetation and classified as mixed crop area.

Potential Erosion

The potential erosion of the micro-watersheds ranges from nil to 1119.48 t $ha^{-1}yr^{-1}$. The rate of soil erosion is divided into five classes (0-5 t $ha^{-1}yr^{-1}$ - very low, 5-10 t $ha^{-1}yr^{-1}$ - low, 10-15 t $ha^{-1}yr^{-1}$ - moderate, 15-20 t $ha^{-1}yr^{-1}$ - moderately high, 20-40 t $ha^{-1}yr^{-1}$ - high and > 40 t $ha^{-1}yr^{-1}$ - very high) (Singh *et al*., 1981; Balasubramani *et al*., 2015). The spatial distribution of the rate of soil loss is mapped during pre-treatment and post-treatment (field bunds and stone wall) periods as shown in Fig. 5. Comparison of these two maps clearly indicates that there is a significant reduction in the rate of soil loss under conservation measures such as field bund and stone wall. The erosion risk areas under different erosion categories (Table 3) indicate that 67.41% of the watershed experience soil erosion at the rate of nil to 5 t $ha^{-1}yr^{-1}$ when no conservation practices are implemented. Moderate (6.75%) to very high (3.57%) erosion risk areas are spread in the watershed due to sloping topography and heterogeneous LU conditions within the micro-watersheds. The impact of construction of field bund and stone wall in the study watershed can be seen from the reduction in erosion risk areas in moderate, moderately high, high and very high categories of the post-treatment. The reduction in the erosion risk areas is from 12.1% to 10.6% under the low erosion category, from 6.75% to 5.52% under the moderate category. A similar reduction from 4.05% to 3.21%, 6.10% to 4.92% and 3.57% to 3% was observed in moderately high, high and very high categories, respectively.

Field bund and stone wall reduced soil erosion rates in the watershed which can be judged as the area under very low categories increased by 464.83 ha during post-treatment. This is due to the fact that few areas which were under low erosion category during pre-treatment have changed to very low erosion category due to the implementation of field bund and stone wall and hence there is an increase in percentage area in the very low category in post-treatment. The conservation measures implemented has decreased the velocity of flow of water which subsequently increased the retention time of water and hence the reduction of soil loss is possible during post-treatment (Renard *et al*., 1997; Hessel and Tenge, 2008).

For further understanding, the erosion risk areas were discretized under the micro-watershed boundaries

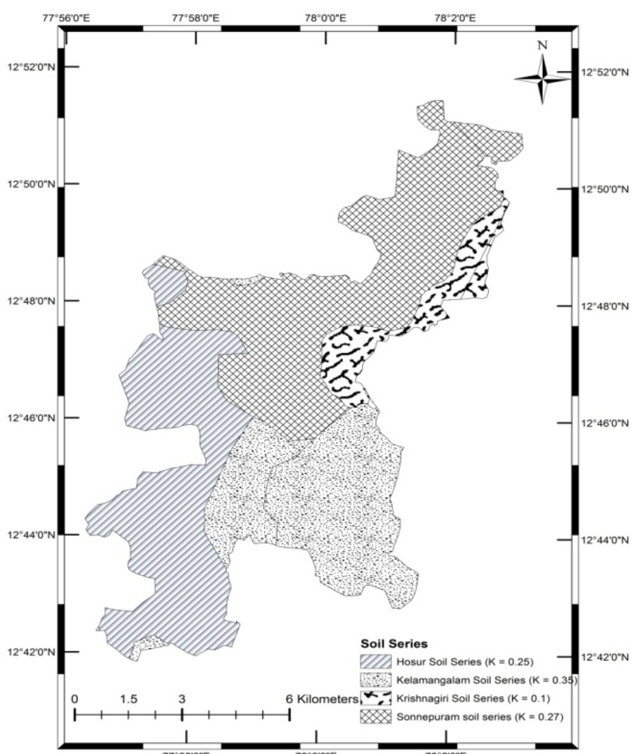

Fig. 3. Soil taxonomical classification and K factor of the Sulagiri watershed

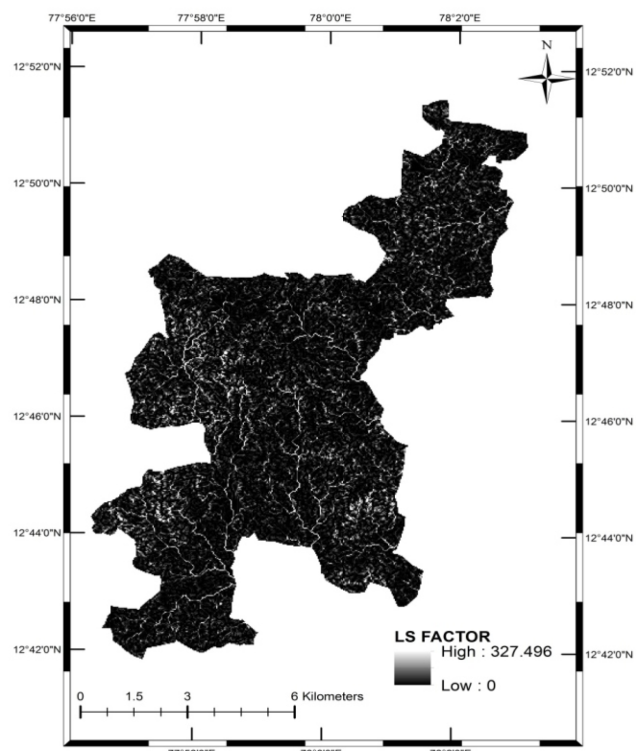

Fig. 4. LS factor of the Sulagiri watershed

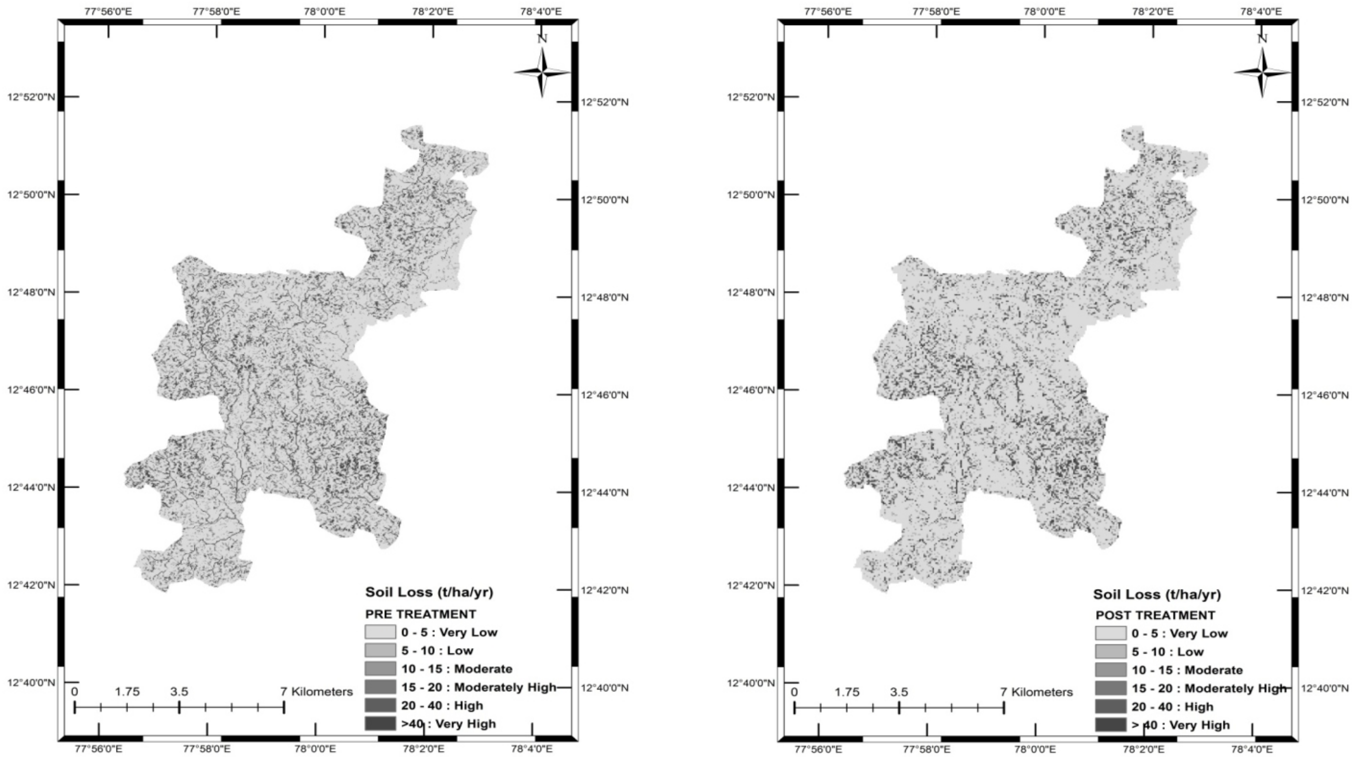

Fig. 5. Spatial variation of the rate of soil loss during pre-treatment and post-treatment

Table: 3
Estimated erosion risk areas under the different rate of soil loss during pre-treatment and post-treatment

Erosion Categories	Rate of soil loss ($t\ ha^{-1} yr^{-1}$)	Erosion risk areas							
		Pre-treatment (No conservation)		Post-treatment (Field bund and Stonewall)		Simulated Soil conservation Scenarios			
						Mulching		Strip-cropping	
		(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)
Very low	0-5	67.41	6088.70	72.56	6553.53	74.17	6698.71	69.58	6284.68
Low	5-10	12.12	1094.30	10.80	974.60	9.75	871.10	11.87	1072.80
Moderate	10-15	6.75	609.90	5.52	498.15	5.23	472.52	6.31	569.25
Moderately High	15-20	4.05	365.80	3.21	289.56	3.10	279.72	3.72	336.38
High	20-40	6.10	551.30	4.92	444.95	4.80	440.85	5.49	496.29
Very High	>40	3.57	322.10	3.00	271.31	2.95	269.20	3.02	272.70

to indicate which micro-watershed experience more soil loss. Among the ten micro-watersheds, Nerigam micro watershed located in the northern side experiences high erosion rates in moderate, moderately high, high and very high categories followed by Angonapalli and Pannapalli micro-watershed. The erosion rates vary in each watershed can be attributed to steeper slopes, LU and LC characteristics, nature of the soil and rainfall characteristics of the location. Among the micro-watersheds, Dhoripalli shows less percentage area in all the erosion risk categories.

Scenarios of Soil Conservation Practices

Actual erosion under the SWC measures were derived by considering P factor values for field bund and stone wall (Table 2). In addition, two scenarios were developed to identify the possible reduction in erosion rate. Mulching (M) and strip cropping (SC) were the conservation practices considered for new scenarios. M is a conservation practice in which the entire land surface is covered with crop residue or with polythene sheets to prevent the direct exposure to raindrops and thereby erosion due to runoff whereas SC is the practice of growing strips of crops having good potential for erosion control (Ghanshyamdhas, 2004).

The summary statistics on the comparison of the rate of soil loss with and without conservation and conservation measures using new scenarios are shown in Table 4. The land management by field bund and stone wall greatly affect in reducing the rate of soil loss from 7.64 t $ha^{-1}yr^{-1}$ to 6.4 t $ha^{-1}yr^{-1}$ with the prediction of total soil reduction from 71831 t yr^{-1} to 60172 t yr^{-1}.

The percentage area under different erosion categories simulated using the alternative conservation by M and SC are presented in Table 3. Alternative soil conservation by M also significantly reduced the average rate of soil erosion from 7.64 t $ha^{-1}yr^{-1}$ to 6.26 t $ha^{-1}yr^{-1}$ which is a better reduction than existing practices. Strip-cropping also reduced the rate of soil loss and is not as effective as mulching or by the existing conservation practices.

The Effectiveness of various Conservation Measures on Land Uses

The effectiveness of soil conservation measures on LUs and LC were prepared during pre-treatment, post-treatment using existing measures and for new scenarios. Mixed crop area, sparse vegetation area and barren lands were identified as a major LU where the conservation measures are implemented and hence the impact of conservation measures was evaluated only on these LU categories.

Table 5 shows the reduction in the rate of soil loss feasible from three LU categories of the Sulagiri watershed when different SWC measures are implemented. M appears to be most effective measure with reduction of 23.8% of the rate of soil loss followed by field bund and stone wall. SC measure appears to be least effective with reduction of 14%.

Table: 4
Estimated Rate of soil loss in the watershed (t $ha^{-1}yr^{-1}$)

Description	Minimum	Mean
Pre-treatment (No Conservation)	0	7.64
Post-treatment (Field Bund and Stonewall)	0	6.40
Soil conservation Scenarios		
Mulching	0	6.26
Strip-cropping	0	7.10

Table: 5
Rate of soil loss in Land use categories

S.No.	Land use Land cover	Rate of soil loss (t $ha^{-1}yr^{-1}$)			
		Pre-treatment (No conservation)	Post-treatment (Field bund and Stonewall)	Simulated Soil conservation Scenarios	
				Mulching	Strip-cropping
1.	Mixed crop area	7.62	6.05	5.8	6.55
2.	Sparse vegetation	9.54	7.56	7.3	8.40
3.	Barren	11.31	7.89	7.59	8.78

4. CONCLUSIONS

The present study demonstrated the use of empirical model RULSE in GIS environment to assess the impact of soil conservation measures in the reduction of the rate of soil loss in the Sulagiri watershed. Estimated erosion rates ranged from 0 to 1119.48 t $ha^{-1}yr^{-1}$. The major portion (67.41%) of the total area of the watershed have nil to very low erosion categories. The existing conservation measures such as field bund and stone wall significantly reduced the erosion risk areas. The land management activities by constructing field bund and stone wall greatly influenced the reduction of the rate of soil loss from 7.64 t $ha^{-1}yr^{-1}$ to 6.4 t $ha^{-1}yr^{-1}$ with the prediction of total soil reduction from 71831 t yr^{-1} to 60172 t yr^{-1}. New scenarios such as M and SC also showed good potential for reduction of soil erosion risk areas. Thus, it can be inferred through this study that the soil conservation measures implemented under IWMP in the Sulagiri watershed help to minimize the soil loss which ultimately reduces a significant portion of soil enter into the reservoirs located downstream.

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