Available online at http://www.ijims.com

ISSN: 2348 – 0343

# Soil Erosion Mapping in Singhanhalli-Bogur Microwatershed in Northern Transition Zone of Karnataka Using Universal Soil Loss Equation and Geographic Information Systems

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## Abstract

Soil erosion which occurs at spatially varying rates is a widespread threat to sustainable resource management at watershed scale. Thus estimation of soil loss and identification of critical area for implementation of best management practices is central to a successful soil conservation programme. The present study was conducted to assess soil erosion using USLE and suggests possible intervention strategies to address soil loss in Singhanhalli-Bogur Microwatershed of Dharwad District in northern transition zone of Karnataka. The average annual soil loss was 27 tons $ha^{-1}yr^{-1}$. About 574 ha of the study area was under slight erosion, 118 ha under moderate erosion and 53 ha under severe erosion. The soil loss under different land uses ranged from 7 tons $ha^{-1}yr^{-1}$ under forest to 40 tons $ha^{-1}yr^{-1}$ under agriculture. The soil loss under plantation and open scrub land uses were 8 and 26 tons $ha^{-1}yr^{-1}$ respectively. Major causes of soil erosion were cultivation without proper soil and water conservation measures in area not suitable for crops, denuded areas without vegetation, cultivated fallow on moderate slopes, degraded forests/pastures on steep slopes and poorly managed forest cover. Appropriate soil conservation and land management techniques for the different soil erosion classes were suggested.

**Key words:** Universal Soil Loss Equation (USLE), Soil Erosion, Singhanhalli-Bogur, Soil Conservation

## Introduction

Soil erosion and related degradation of land resources are highly significant spatio-temporal phenomena in many countries. It is generally associated with agricultural practices, leading to decline in soil fertility, bringing in a series of negative environmental impacts and has become a threat to sustainable agricultural production and water quality in many countries [1]. In India, the problems of land degradation are prevalent in many forms. In many parts of the country, unchecked soil erosion and associated land degradation has made vast areas economically unproductive [2].

About 146.8 million hectare area is suffering from various kinds of land degradation. This included 93.7 million ha due to water erosion, 9.5 million ha due to wind erosion and 14.3 million ha due to water logging/flooding [3]. According to recent report, India loses about 5334 million tonnes of soil annually due to various reasons [4].

In recent years, as part of environment and land degradation assessment policy for sustainable agriculture and development, soil erosion has increasingly being recognized as a hazard which is more serious in mountain areas [5]. Often, a quantitative assessment is needed to infer the extent and magnitude of soil erosion problems so that effective management strategies can be resorted to. The USLE, known as Universal Soil Loss Equation, is the most widely accepted method of assessing soil erosion. It is rated as the standard method for estimating soil loss. This model was designed to predict average annual sheet and rill erosion from cropland east of Rocky Mountains [6]. The USLE has been widely studied and refined and is generally considered as the state-of-the-earth erosion model.

The Universal Soil Loss Equation (USLE) approach has been used throughout the world to estimate the extent of soil erosion [7]. The equation has become a useful tool for management planners to keep soil erosion within permissible limits of soil loss tolerance by managing slope length, terrace spacing and cropping practices [8]. Several studies have been undertaken in Karnataka to evaluate the various factors in the USLE for agricultural lands. Rainfall characteristics, soil properties and ground surface conditions have been reported as major factors influencing the type and severity of soil erosion. However, such studies have not been carried out in the study area. Keeping this in view, the present study was undertaken.

## Materials and methods

### Description of the study area

Singhanhalli-Bogur micro-watershed is located about 10 km away from Dharwad between 15°31'30.30" to 15°34'49.45" N latitude and 74°50'47.46" to 74°53'35.67" E longitude in Dharwad taluk of Dharwad district in the northern transition zone of Karnataka, India (Fig. 1). The study area lies in the Decca plateau in the hot semi-arid agro-ecological region 6 (K4D2) and sub-region 6.4 having medium to high available water content with a length of growing period of 150-180 days.

The climate is characterized by hot and humid summer and mild and dry winter. The study area receives an annual average rainfall of 755.2 mm, which distributed over May to October and annual temperature ranging from 24 - 28 °C. The study area is classified as having Ustic Soil Moisture and Isohyperthermic soil temperature regimes [9]. The highest elevation is 754 m above mean sea level and the relief is very gently to strongly sloping. The general slope is towards the northeast, southeast and southwest but it is more in the southwest direction. The drainage pattern is parallel.

Soils are derived from chlorite schist with shale as dominant parent material containing banded iron oxide quartzite. The soils are coarse textured and shallow at the higher elevations but gradually fineness and depth increases towards the lower elevations. The main soil types are black and red soils but the red soils are in higher proportion than the black soils. The natural vegetation mainly comprised of trees and shrubs including Acacia (Acacia auruculiformis), Neem (Azadirachta indica) and Eucalyptus (Eucalyptus sideroxylon and Eucalyptus regnana).

### Universal Soil Loss Equation

The rate of soil erosion was estimated by the Universal Soil Loss Equation:

$$A= RKLSCP \quad \ldots\ldots \{1\}$$

where, A is the average annual soil loss (tons $ha^{-1}yr^{-1}$) from soil erosion, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover management factor, and P is conservation practice factor.

The rainfall erosivity factor (R) indicates the soil loss potential of a given storm event. The rainfall erosivity factor (R) was calculated using rainfall data collected from the nearest meteorological station located at Main Agricultural Research Station (MARS) of the College of Agriculture, University of Agricultural Science, Dharwad. The daily rainfall for 11 years (2001 – 2011) was used to calculate the rainfall erosivity factor (R). For in-situ erosion studies, the rainfall erosivity is calculated from the kinetic energy and $I_{30}$ of rainfall, generally referred to as $EI_{30}$. In the present study, the rainfall erosivity factor (R) was not calculated from $EI_{30}$. The daily rainfall greater than 2.5 mm were considered because it is believed that rainfall greater than 2.5 mm is likely to cause erosion [8]. The average annual and seasonal rainfall for 11 years were computed from the daily and monthly rainfall data and used to estimate annual and seasonal rainfall erosivity factor (R). Linear correlations were then established between annual erosivity indexes ($R_a$) and annual rainfall ($P_a$) and seasonal erosivity index ($R_s$) and seasonal rainfall ($P_s$).

The regression equations developed were as given below:

$$R_a = 79.15018 + 0.362258P_a \; (r = 0.987) \quad \ldots\ldots [2]$$

$$R_s = 50 + 0.389P_s \; (r = 0.978) \quad \ldots\ldots [3]$$

where $R_a$ is annual R-factor, $R_s$ is seasonal R-factor, $P_a$ is the annual rainfall (mm) and $P_s$ is seasonal rainfall.

The soil erodibility factor (K) is of major importance in soil erosion prediction and its control. It represents the susceptibility of a soil type to erosion. The soil erodibility factor (K) reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow and therefore shows the change in the soil per unit of applied external force of energy. This factor is related to the integrated effect of rainfall, runoff and infiltration and accounts for the influence of soil properties on soil loss during storm events. In the present study, the K factor was determined using data on inherent soil properties [10] and methodology described by [17] from the relationship:

$$K = 1.2917\{(2.1x10\text{-}4M^{1.14}\,(12\text{-}a) + 3.25(b\text{-}2) + 2.5(C\text{-}3)\}/100 \quad \ldots\ldots [4]$$

where M is (per cent silt+very fine sand)(100-per cent clay); 'a' is per cent organic matter; 'b' is the soil structure code used in soil classification and 'C' is the permeability class.

The physical and chemical properties obtained from laboratory analysis were used for estimation of soil erodibility. Weighted mean of soil organic matter, per cent silt, very fine sand and clay were calculated for the depth of profile which was then averaged in proportion to the area of each constituent soil series of a particular mapping unit.

The length of slope (L) and steepness of slope (S) factors were derived as described by [11] using the following equations:

$$L = 1.4\,(A_S/22.13)^{0.4} \quad \ldots\ldots [5]$$

$$S = (\sin \beta / 0.0896)^{1.3} \quad \ldots\ldots [6]$$

where L: length of slope, $A_S$: Catchment area ($m^2$), S: steepness of slope, $\boldsymbol{\beta}$: slope angle in degrees.

Information on cover management (C) and conservation practices (P) factors were collected through field survey. IRS P6 LISS-IV satellite image was used to interpret the land cover classes based on field knowledge of the study area. Crops under agricultural land use in the study area were paddy, wheat, pearl millet, sorghum, maize, jowar, soybean, chickpea sugarcane, pigeon pea, groundnut, cotton, guava, sapota, cabbage, tomato, mango, etc. Based on this information, C and P values for each land use/cover class were assigned based on the guidelines proposed by [8].

**Integration of USLE and GIS**

Remote sensing and GIS were used in the integration of input parameters and accurate mapping of erosion type and severity. The spatially distributed soil loss was estimated through a cell-by-cell summation of input parameters of USLE using Arc Macro Language (AML) procedure in Arc Map of ArcGIS 10.1.

**Generation of thematic maps**

In the present study, the base map was prepared using the Survey of India toposheet (No. 48 I/14) at a scale of 1:50000. Digital Elevation Model (DEM) of the study area was prepared in 30 m cell size using digitized contours from the Survey of India toposheet (Fig. 2). Each input parameter of USLE was integrated into ArcGIS 10.1 as a thematic layer and from these layers, thematic maps were generated.

## Results and discussion

**Rainfall pattern in Singhanhalli-Bogur microwatershed (2001- 2011)**

The results revealed that the average monthly rainfall ranged from 0.4 mm in January to 130.3 mm in July (Table 1). The average seasonal rainfall ranged from 8.1 mm in winter to 490.7 mm in monsoon and the annual rainfall ranged from 175.5 mm in 2003 to 1140.4 mm in 2009 with an average annual rainfall of 755.2 mm. In all cases, monsoon season accounted for 50 per cent of the rainfall. The rainfall intensity index for 2001, 2003 and 2006 showed a negative trend, indicating less raining days. The maximum rainfall of 788.1 mm was received during monsoon season of 2007 and maximum rainfall intensity index in 2009, when average rainy day had about 16.53 mm of rainfall. The months with highest rainfall were August in 2001, October in 2002, April in 2003, September in 2004 and 2005, June in 2006 and 2007, August in 2008, July in 2009, August in 2010 and October in 2011. The highest monthly rainfall of 290.2 mm was received in July of 2005 and the highest seasonal rainfall of 788.1 mm was received in monsoon of 2007. There was a distinct fluctuation in monthly rainfall but what was more surprising was the fact that in 2003, April recorded the highest monthly rainfall. This could be attributed to the changing climate which led to heavy pre-monsoon showers resulting from aberrant weather situations that were most prevalent in the country [9].

The result of seasonal rainfall distribution in summer and post-monsoon seasons revealed successive fluctuations with high degree of variability, thus, indicating the erratic nature of rainfall events in these seasons. The average seasonal rainfall amounts were 8.1 mm for winter, 121.4 mm for summer, 490.7 mm for monsoon and 134.9 mm for post-monsoon. The total winter rainfall ranged from 0.8 mm to 21.6 mm with a mean of 8.1 mm. In most years, the monsoon season recorded the highest amount of rainfall compared to other seasons, but unusually in 2002, winter season recorded higher rainfall than summer season.Similarly, in 2005, 2010 and 2011, the post-monsoon season recorded higher rainfall than the summer season. The annual rainfall distribution showed a sharp variation ranging from 175.8 mm to 1140.4 mm with an average of 755.2 mm, thus, indicating seasonality of the rainfall parameter to cause soil erosion. The highest annual rainfall of 1140.4 mm was received in 2009.

As the study area falls in the semi-arid zone of the country, this annual rainfall amount is within the range (750-1150 mm) categorized by ICAR for such zones. However, the annual rainfall received in 2001-2004 was well below the minimum (750 mm) for semi-arid zones. The annual rainfall during this period falls within the arid limit of rainfall indicating drought situation [9].

**Rainfall erosivity factor (R)**

The average monthly and annual rainfall erosivity indices and seasonal and annual rainfall erosivity indices revealed that July posed the highest erosivity risk than any other month in the study area, whereas for seasonal erosivity risk; monsoon posed the highest risk followed by summer and post-monsoon (Table 2). The average monthly rainfall erosivity was higher in July (62.9 MJ $ha^{-1}mm.h^{-1}$) and lower in January (0.2 MJ $ha^{-1}mm.h^{-1}$) and the average annual rainfall erosivity factor was higher in 2009 (41.1 MJ $ha^{-1}mm.h^{-1}$) and lower in 2003 (11.9 MJ $ha^{-1}mm.h^{-1}$).The monthly rainfall erosivity followed an undulating trend that was indicative of the amount and intensity of rainfall. The monthly rainfall erosivity ranged from 11.2 - 38.1 MJ $ha^{-1}mm.h^{-1}$ in 2001; 4.1 - 60.1 MJ $ha^{-1}mm.h^{-1}$ in 2002; 1.5 - 44.2 MJ $ha^{-1}mm.h^{-1}$ in 2003; 0.3 - 109.8 MJ $ha^{-1}mm.h^{-1}$ in 2004; 2.1 - 85.8 MJ $ha^{-1}mm.h^{-1}$ in 2005; 0.7 - 96.5 MJ $ha^{-1}mm.h^{-1}$ in 2006; 5.6 - 96 MJ $ha^{-1}mm.h^{-1}$ for 2007; 4.9 - 96.5 MJ $ha^{-1}mm.h^{-1}$ in 2008; 12.9 - 111 MJ $ha^{-1}mm.h^{-1}$ in 2009; 0.3 - 85.8 MJ $ha^{-1}mm.h^{-1}$ in 2010; and 0.4 - 98.6 MJ The highest monthly rainfall erosivity was recorded in July of 2009 (111 MJ $ha^{-1}mm.h^{-1}$). The highest summer rainfall erosivity of 127.1 MJ $ha^{-1}mm.h^{-1}$ was recorded in 2008. For monsoon and post-monsoon seasons, 2007 and 2010 respectively recorded the highest monsoon and post-monsoon rainfall erosivity (356.6 MJ $ha^{-1}mm.h^{-1}$ and 155.2 MJ $ha^{-1}mm.h^{-1}$ respectively). The monsoon rainfall erosivity was initially 119 mm but reduced to 77.3 mm between 2002 and 2003 and later sharply rose to 351.3 mm from 2004 to 2006 and after which it fluctuated with the highest monsoon rainfall erosivity of 356.6 mm in 2007.

According to [9], in discussing rainfall erosivity, winter months are not considered, as monthly rainfall erosivity values for winter months are not reliable enough because of the prevailing heavy winds that may cause higher error of probability in precipitation measurements. Therefore, the seasons considered in the present study were summer, monsoon and post-monsoon seasons. Differences in rainfall erosivity factor (R) reflect differences in precipitation patterns between regions and high R values indicate more erosive weather conditions. The highest deviation was estimated for monsoon season (356.6 MJ $ha^{-1}mm.h^{-1}$) in 2007 with the annual rainfall erosivity of 471.4 MJ.$ha^{-1}mm.h^{-1}$ as compared to 2008 which recorded the highest annual rainfall of 493 MJ $ha^{-1}mm.h^{-1}$ but lower monsoon rainfall erosivity (323.4 MJ $ha^{-1}mm.h^{-1}$). The high rainfall erosivity value estimated for monsoon season (356.6 MJ $ha^{-1}mm.h^{-1}$) in 2007 correlated with the high rainfall (788.1 mm) received in this season, which could be attributed to storm events within this season resulting from rainfall amounts that exceeded 2.5 mm in 30 minutes [9]. The erosivity values calculated for 2001 and 2003 indicated a low risk of soils to erosive weather conditions.

For 2002, 2004 and 2006, the erosivity values indicated a moderately high risk of soils to erosive weather conditions, whereas for 2005, 2007, 2008, 2009, 2010 and 2011, the erosivity values indicated a strongly high risk of soils to erosive weather conditions in the study area. However the erosivity values for 2001 and 2003 were clearly lower than expected which could be attributed to the fact that in these years, intensive rain events did not occur in the study area [9]. Only in August 2001 and April 2003, that the highest monthly rainfall of 58.1 mm and 54.4 mm respectively were received. As a matter of fact, these years were categorized as drought years in Karnataka [12].

**Soil erodibility factor (K)**

Soil erodibility factor (K) is an intrinsic property of the soil and is governed by soil characteristics like texture, structure, organic matter content and permeability. According to [13], K factor ranged from 0.05 to 0.78 in metric units. The K factor of the study area ranged from 0.07 to 0.19 (Table 3). Similar K factors have been reported: 0.15 to 0.41 for soils of Delhi [14]; 0.11 to 0.39 for soils of Coimbatore district of Tamil Nadu [15]; 0.10 to 0.69 for soils of Hawaii, USA [16] and 0.03 to 0.69 for soil of United States of America [17]. Soils having lower K factor values are less susceptible to erosion and vice-versa. [15] classified soils as less erodible ($K \leq 0.19$); moderately erodible ($0.20 \leq K \geq 0.39$) and highly erodible ($K \geq 0.40$). Based on the results in Table 3, soils of the study area were classified as less erodible, i. e., less susceptible to erosion.

However, considering the mean K factor of 0.137, soils were further grouped into two classes based on the classes given by [13]. These were 1) soils having K factors of $0.0 \leq K \geq 0.10$ and 2) soils having K factors of $0.11 \leq K \geq 0.20$ (Table 4).

**Length and steepness of slope factors (LS)**

The LS factor is the combined factor for slope length and slope steepness and was calculated from the equation of[11] and then compared with the table prepared by [18]. The study revealed that the length and steepness of slope (LS factor) of the study area ranged from 0.013 to 1.94 with a mean of 0.718 (Table 3), thus, signifying the presence of almost flat slope to moderately steep slopes in the study area. The LS factors for the study area was classified into four classes viz., $0.0 \leq LS \geq 0.09$ (very low), $0.10 \leq LS \geq 0.49$ (low); $0.50 \leq LS \geq 0.70$ (medium) and $LS \geq 0.71$ (high) (Table 4).

The data in Table 4 revealed that only 144 ha covering 18.9 per cent of the study area was under nearly level to very gently sloping (0 - 3 % slope) lands (i.e., lowlands) having LS values $0.0 \leq LS \geq 0.09$. A larger portion (about 359.4 ha), covering 47.3 per cent of the study area was under gently sloping to moderately sloping (3 - 10 % slope) lands (i. e., undulating midlands) having LS values $0.10 \leq LS \geq 0.70$, whereas 241.1 ha covering 31.7 per cent of the study area was under strongly sloping (10 - 15 % slope) lands (i.e., uplands) having LS values $K \geq 0.71$. It was observed that cultivation in the study area was not based on slope but rather on nature and productivity of soils. This decision might be due to the physiography-soil and soil-landscape relationship, which was prominent in the study area.

**Cover management factor (C)**

The crop cover factor (C) of the study area ranged from 0.105 to 0.845 with a mean of 0.318 (Table 3). The C factors for the study area were classified into four classes viz., $0.0 \leq LS \geq 0.20$ (high cover), $0.21 \leq K \geq 0.40$ (moderate cover); $0.41 \leq K \geq 0.70$ (low cover) and $K \geq 0.71$ (very low cover) (Table 8). The lower the C factor value, the higher or better the cover and vice versa. Based on these data, it was observed that 224.8 ha representing 29.6 per cent of the study area was under high cover; 364.6 ha representing 47.9 per cent of the study area was under moderate cover; 121.3 ha representing 16.0 per cent of the study area was under low cover and 33.8 ha representing 4.5 per cent of the study area was under very low cover. The high cover areas were due to the presence of forests, stony wastes and rocky outcrops in these areas. The stony wastes and rocky outcrops, though were present in negligible forms, might have been very effective cover in reducing the impact of rainfall on the soil surface. The moderate cover was obtainable in agriculture and plantations. The cover in these land uses were observed to be under constant disturbance due to cultivation.

**Conservation practice factor (P)**

The conservation practice factor (P) of the study area ranged from 0.5 to 0.7 with a mean of 0.54 (Table 3). Based on these data, the P factors for the study area were classified under one class, i.e., 0.50 - 0.80, which falls under the category of contour farming. All P factors of mapping units fall within this range and therefore the study area was categorized as under contour farming. However, in the higher slopes areas (i. e., uplands), no specific soil conservation measures were observed. These areas were the erosion-prone areas that needed urgent attention for soil conservation and management. Terracing with graded channel in varying slope gradient, bench terracing on slopes greater than 8 per cent as well as contour farming should be adopted by farmers especially in higher slopes areas under plantation along the main highway. These measures, though, somehow expensive, might prove very effective in reducing soil loss even for many years after their construction.

**Soil loss in Singhanhalli-Bogur microwatershed**

The quantification of soil loss in the study area was done with the computation of the various USLE factors (Table 3). The values of annual soil loss were categorized into three different erosion classes. The spatial distribution of different classes of soil loss in the study area was generated using ArcGIS techniques in the form of soil erosion map (Fig. 3). Overall, the annual soil loss based on mapping unit ranged from 0.12 tons $ha^{-1}yr^{-1}$ to 11.63 tons $ha^{-1}yr^{-1}$ (Table 3). The average annual soil loss of the study area was 27.0 tons $ha^{-1}yr^{-1}$. [19] computed average soil loss at 26.0 tons $ha^{-1}yr^{-1}$ for soils of Yelberga taluk in Koppal district in Karnataka state.

About 573.7 ha representing 75.4 per cent of the study area recorded an annual soil loss less than 5 tons $ha^{-1}yr^{-1}$ (Table 5). An annual soil loss up to 5 tons $ha^{-1}yr^{-1}$ could be termed well within safe limit and is, designated as very slight [13]. The slight erosion in the study area might be due to plain lands with varying crop, low rainfall erosivity and soil erodibility, cultivation in plains of medium to high erosivity and erodibility and good forest cover on moderately sloping lands. In addition, there were patches of erosion promoting crops in the study area especially in the undulating midlands and along the stream courses. These erosion permitting crops might have been very effective in reducing erosion in these areas. Another reason was that farmers practice fallowing during Kharif/monsoon season in some part of the watershed especially in sloping areas. This practice might have contributed to reducing erosion.

Moderate erosion (5 - 10 tons $ha^{-1}yr^{-1}$) occurred in 118.0 ha, representing 15.5 per cent of the study area. This type of erosion in the study area might be due to farmers cultivating in areas not suitable for crops but without proper soil conservation measures, denuded hills with little or no vegetation and cultivated fallow on moderate slopes. However, annual soil loss of less than 10 tons $ha^{-1}yr^{-1}$ has been included within the threshold limit for alluvial soils based on the findings of [8, 20]. Based on these reported findings, it is concluded that 691.6 ha representing 90.9 per cent of the study was within the safe limit. The quantity of soil loss in this area can be reduced further if appropriate soil conservation practices are adopted by farmers.

About 52.9 ha representing 7.0 per cent of the study area was suffering from severe erosion (10 - 15 tons $ha^{-1}yr^{-1}$). The very high soil erosion in these areas might be attributed to cultivation on steep slopes coupled with inappropriate soil conservation during monsoon seasons under rainfed agriculture. In addition, in these areas, there were lots of degraded forest/pastures, denuded hills without vegetation, cultivated fallow on steep slopes, farmers cultivating crops on moderate to steep slopes without proper soil conservation measures and poorly managed forest cover. Therefore, these areas require soil and water conservation measures for its management. Similar results were also obtained by [21].

The soil loss under different land uses ranged from 7.34 tons $ha^{-1}yr^{-1}$ under forest land use covering 59.4 ha area representing 7.8 per cent, to 39.92 tons $ha^{-1}yr^{-1}$ under agriculture land use covering 490.6 ha area representing 64.5 per cent (Table 5). The spatial distribution of soil loss under different land uses is presented in Fig. 4. The soil loss under plantation and open scrub land uses were 7.5 and 26.4 tons $ha^{-1}yr^{-1}$ covering 139.5 ha (18.4 %) and 55.0 ha (7. 2 %) respectively, of the study area. The slight soil loss in forest and plantations might be due to the covering of land surface by vegetation, hence, reducing the impact of raindrops in these areas. In agriculture and scrub lands, the lack of complete ground cover might have resulted to the high soil losses. Soil loss was slight under forest and plantation land uses, moderate under open scrub and high under agriculture land uses. These results are in conformity to the results reported by [21, 22].

**Soil and water conservation planning**

The severity of soil erosion determines the type of soil and water conservation measures to be adopted. The study identified three soil erosion classes viz., slight, moderate and severe having soil loss ranging between 0 - 5, 5 - 10 and 10 - 15 tons $ha^{-1}yr^{-1}$ respectively.

The factors responsible for the different rates of erosion were identified and these are summarized in Table 6. Accordingly, the soil and water conservation measures for these different erosion rates are also summarized in Table 7. These include agronomic measures like sowing of close-spaced erosion-resistant crops, intercropping, strip cropping with cover management practices to improve organic matter and structure, which will help to further reduce K factor. Land levelling and bench terracing are highly recommended to reduce high LS factors in the study area.

Presently, there are no watershed development programmes in the study area. However, the different classes of soil erosion exist in continuity in the study area and therefore, an integrated watershed approach is needed in the study area to protect the limited forests and erosion-prone areas. For such programme to be successful in the area, it must be implemented with people's participation including site-based land use planning, harvesting and recycling of excess run-off, rehabilitation of the denuded areas and resource conserving land uses viz., silvi-pastoral, horti-pastoral, agro-horticultural and other suitable multi-tier and high density plantation systems.

## Conclusion

The study identified three major classes of soil loss in the study area, viz., slight, moderate and severe soil losses. Major portion of the study area was under slight soil loss class. Slight soil losses in the study area were due to the topographic position of the land coupled with varying crop, rainfall erosivity and soil erodibility, cultivation in areas having medium to high erosivity and erodibility and good forest cover on moderately sloping lands. In addition, the presence of patches of erosion promoting crops especially in undulating midlands and along the stream courses might have further reduced soil erosion. Another reason was that farmers practice fallowing during Kharif/monsoon season in some part of the watershed especially in high slopes. Moderate soil losses were as a result of cultivation in areas not suitable for crops but without proper soil conservation measures, denuded uplands with little or no vegetation and cultivated fallow on moderate slope. The severe soil losses were attributed to steepness of slopes coupled with cultivation during monsoon seasons under rainfed agriculture. In addition, degraded forest/pastures, denuded uplands without vegetation, cultivated fallow on steeper slopes, farmers cultivating crops on moderate to steeper slopes without proper soil conservation measures and poorly managed forest cover were observed in these areas. These have exacerbated the problem. The soil losses under plantation and forest land uses were slight but moderate in open scrub and severe in agricultural land. The slight soil loss in forest and plantations was attributed to the covering of land surface by vegetation. In agriculture and scrub lands, the lack of complete ground cover was the main reason for the high soil loss. The proposed soil conservation and land management techniques for the different soil erosion classes should be given due attention in order to reduce soil erosion in the study area.

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Table 1: Rainfall distribution pattern of the study area

Monthly rainfall distribution pattern

| Month | Year | | | | | | | | | | | Mean monthly |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | |
| January | 0 | 0 | 0 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0.44 |
| February | 0 | 61.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21.6 | 7.59 |
| March | 0 | 0 | 0 | 0 | 0 | 5.2 | 12.8 | 11 | 29.8 | 0 | 0.8 | 5.42 |
| April | 52.1 | 15.6 | 54.4 | 24.4 | 75 | 1.5 | 86.4 | 28.8 | 52.8 | 38.4 | 77.4 | 46.07 |
| May | 23.2 | 44 | 0 | 61.4 | 29.4 | 166.8 | 65 | 58.3 | 91.6 | 63.1 | 66.6 | 60.85 |
| June | 32.5 | 60.5 | 31.3 | 43.8 | 151 | 212.4 | 220.1 | 101.6 | 144.4 | 63.4 | 194 | 114.09 |
| July | 33.1 | 17 | 16.7 | 24.8 | 290.2 | 176.1 | 211.2 | 121 | 256.8 | 155 | 131 | 130.26 |
| August | 58.1 | 49 | 8.6 | 160.7 | 138.8 | 115.2 | 176 | 213.2 | 72.2 | 194.3 | 124.2 | 119.12 |
| September | 53.6 | 3.9 | 14.1 | 222.1 | 194.5 | 91.4 | 180.8 | 162.4 | 229 | 164.9 | 82.8 | 127.23 |
| October | 17 | 103.4 | 48.8 | 64.6 | 89.4 | 38.6 | 74.8 | 60.4 | 141 | 177 | 219.7 | 94.06 |
| November | 0 | 7 | 1.9 | 0.6 | 38 | 55.4 | 54 | 72.2 | 46 | 92.8 | 4.6 | 33.86 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76.4 | 0.6 | 0 | 7 |

Seasonal and annual rainfall distribution pattern of the study area

| Season | Year | | | | | | | | | | | Mean seasonal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | |
| Winter | 0 | 61.9 | 0 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0.8 | 21.6 | 8.1 |
| Summer | 75.3 | 59.6 | 54.5 | 85.8 | 104.4 | 173.5 | 164.2 | 198.1 | 174.2 | 101.5 | 144.8 | 121.4 |
| Monsoon | 177.3 | 130.4 | 70.1 | 451.4 | 774.5 | 595.1 | 788.1 | 598.2 | 702.8 | 577.6 | 532 | 490.7 |
| Post-monsoon | 17 | 110.4 | 50.6 | 65.2 | 127.4 | 94 | 128.8 | 132.6 | 263.4 | 270.4 | 224.3 | 134.9 |
| Annual | 269.6 | 362.3 | 175.8 | 602.4 | 1011.1 | 862.6 | 1081.1 | 928.9 | 1140.4 | 950.3 | 922.7 | 755.2 |

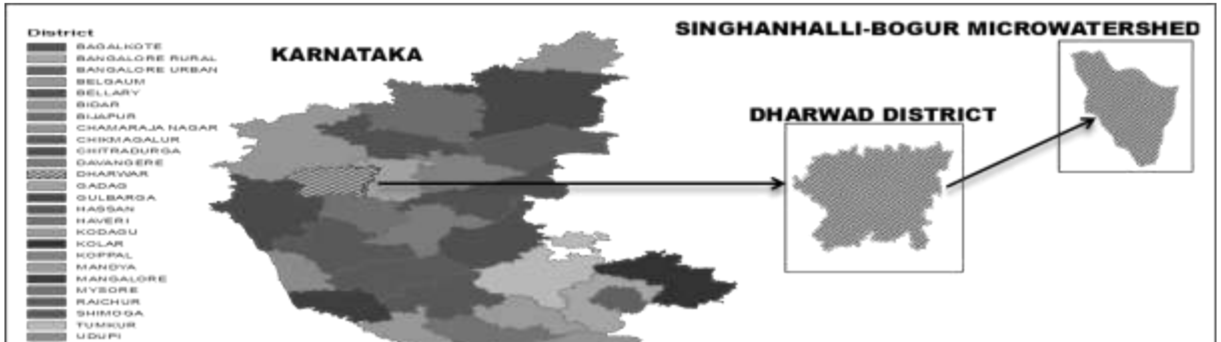


FIG. 1: LOCATION OF THE STUDY AREA

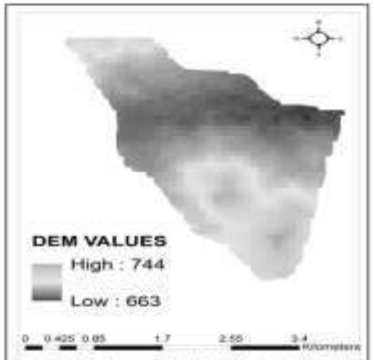


Fig. 2: Digital elevation model (DEM) of Singhanhalli-Bogur microwatershed

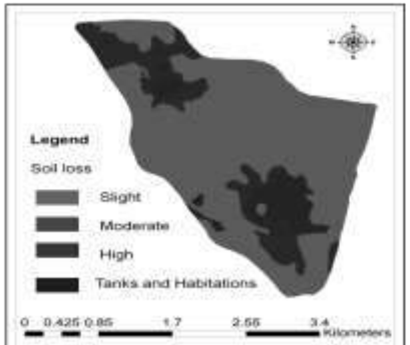


Fig. 3: Soil loss status of Singhanhalli-Bogur microwatershed

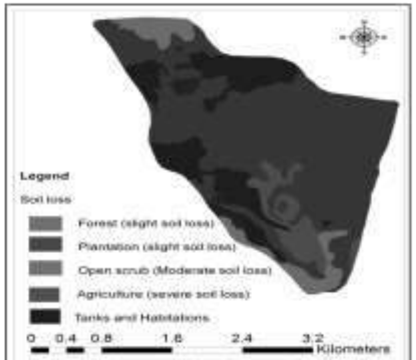


Fig. 4: Soil loss status by land use in Singhanhalli-Bogur microwatershed

Table 2: Rainfall erosivity pattern of study area

Monthly rainfall erosivity factor (R)

| | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Mean monthly |
| January | 0 | 0 | 0 | 0 | 2.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| February | 0 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.7 | 4.2 |
| March | 0 | 0 | 0 | 0 | 0 | 2.4 | 5.6 | 4.9 | 12.9 | 0 | 0.4 | 2.4 |
| April | 34.2 | 9.1 | 44.2 | 12.1 | 33.1 | 0.7 | 37.7 | 12.9 | 22.8 | 17 | 34.7 | 23.5 |
| May | 15.2 | 25.5 | 0 | 30.3 | 13 | 75.8 | 28.3 | 26.7 | 39.6 | 27.9 | 29.9 | 28.4 |
| June | 21.3 | 35.2 | 25.4 | 21.6 | 66.6 | 96.5 | 96 | 46.5 | 62.4 | 28 | 86.9 | 53.3 |
| July | 21.7 | 9.8 | 13.6 | 12.3 | 128 | 80 | 92.2 | 95.6 | 111 | 68.5 | 58.8 | 62.9 |
| August | 38.1 | 28.4 | 7 | 79.4 | 61.2 | 52.3 | 76.7 | 96.5 | 31.4 | 85.8 | 55.7 | 55.7 |
| September | 35.2 | 2.3 | 11.5 | 109.8 | 85.8 | 41.5 | 78.8 | 73.5 | 99 | 72.8 | 37.1 | 58.8 |
| October | 11.2 | 60.1 | 39.6 | 31.9 | 39.4 | 17.5 | 32.6 | 27.3 | 61 | 78.2 | 98.6 | 45.2 |
| November | 0 | 4.1 | 1.5 | 0.3 | 16.8 | 25.2 | 23.5 | 32.3 | 19.9 | 41.2 | 2.1 | 15.2 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 0.3 | 0 | 3 |

Seasonal and annual rainfall erosivity factor (R) of the study area

| | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Seasonal Average |
| Winter | 50.4 | 70.1 | 50.5 | 50.4 | 51.9 | 50.4 | 50.4 | 50.4 | 50.4 | 50.3 | 58.4 | 53.1 |
| Summer | 79.3 | 73.2 | 71.2 | 83.4 | 90.6 | 117.5 | 113.9 | 127.1 | 117.8 | 89.5 | 106.3 | 97.3 |
| Monsoon | 119 | 100.7 | 77.3 | 225.6 | 351.3 | 281.5 | 356.6 | 282.7 | 323.4 | 274.7 | 256.9 | 240.9 |
| Post-monsoon | 56.6 | 92.9 | 69.7 | 75.4 | 99.6 | 86.6 | 100.1 | 101.6 | 152.5 | 155.2 | 137.3 | 102.5 |
| Annual (total) | 176.9 | 210.5 | 142.8 | 297.7 | 446 | 391.9 | 471.4 | 416.2 | 493 | 419.7 | 413.9 | 352.7 |

Table 3: Soil erosion potential of Singhanhalli-Bogur microwatershed

| Soil mapping unit | R Factor | K Factor | LS Factor | C Factor | P Factor | Soil Loss (tons $ha^{-1}yr^{-1}$) | % of study area |
|---|---|---|---|---|---|---|---|
| SGH-c-d4/Be1 | 352.7 | 0.175 | 0.013 | 0.25 | 0.6 | 0.120 | 0.15 |
| MGL-cl-d3/De2 | 352.7 | 0.18 | 0.95 | 0.105 | 0.5 | 3.166 | 3.90 |
| BGR1-sl-d4/Ce2 | 352.7 | 0.12 | 0.92 | 0.18 | 0.5 | 3.504 | 4.32 |
| BGR2-c-d5/Be1 | 352.7 | 0.185 | 0.07 | 0.25 | 0.6 | 0.685 | 0.84 |
| BGR3-sl-d4/Ce3 | 352.7 | 0.145 | 1.8 | 0.215 | 0.5 | 9.896 | 12.20 |
| BGR4-cl-d5/Ce2 | 352.7 | 0.09 | 0.621 | 0.215 | 0.5 | 2.119 | 2.61 |
| VKP1-sc-d4/Ce2 | 352.7 | 0.067 | 0.871 | 0.18 | 0.5 | 1.852 | 2.28 |
| VKP2-sl-d3/Ee4 | 352.7 | 0.103 | 1.28 | 0.35 | 0.7 | 11.392 | 14.04 |
| VKP3-c-d5/Be1 | 352.7 | 0.19 | 0.13 | 0.115 | 0.6 | 0.601 | 0.74 |
| VKP4-sl-d2/Be1 | 352.7 | 0.15 | 0.126 | 0.18 | 0.6 | 0.720 | 0.89 |
| VKP5-scl-d4/De3 | 352.7 | 0.117 | 0.701 | 0.64 | 0.5 | 9.257 | 11.41 |
| VKP5-scl-d3/De2 | 352.7 | 0.15 | 1.94 | 0.112 | 0.5 | 5.748 | 7.08 |
| VKP5-scl-d3/Ce2 | 352.7 | 0.12 | 0.656 | 0.268 | 0.5 | 3.720 | 4.59 |
| VKP5-scl-d4/Be2 | 352.7 | 0.08 | 0.133 | 0.845 | 0.6 | 1.903 | 2.35 |
| VKP6-cl-d4/Ce2 | 352.7 | 0.16 | 0.325 | 0.455 | 0.5 | 4.172 | 5.14 |
| VKP7-sl-d2/De3 | 352.7 | 0.153 | 0.701 | 0.615 | 0.5 | 11.632 | 14.34 |
| VKP8-sl-d4/De3 | 352.7 | 0.145 | 0.968 | 0.43 | 0.5 | 10.644 | 13.12 |

Table 4: Soil erodibility (K), LS and C factor classes of study area

Soil erodibility (K) classes

| SI. No. | Range (K factor) | Area | |
|---|---|---|---|
| | | ha | % of study area |
| 1 | $0.0 \leq K \geq 0.10$ | 102.5 | 13.5 |
| 2 | $0.11 \leq K \geq 0.20$ | 642.0 | 84.5 |

LS factor classes

| SI. No. | Range (LS factor) | Area | |
|---|---|---|---|
| | | ha | % of study area |
| 1 | $0.0 \leq LS \geq 0.09$ (very low) | 144 | 18.9 |
| 2 | $0.10 \leq LS \geq 0.49$ (low) | 158.5 | 20.9 |
| 3 | $0.50 \leq LS \geq 0.70$ (medium) | 200.9 | 26.4 |
| 4 | $LS \geq 0.71$ (high) | 241.1 | 31.7 |

C factor classes

| SI. No. | Range (C factor) | Area | |
|---|---|---|---|
| | | ha | % of study area |
| 1 | $0.0 \leq C \geq 0.20$ (high cover) | 224.8 | 29.6 |
| 2 | $0.21 \leq C \geq 0.40$ (moderate cover) | 364.6 | 47.9 |
| 3 | $0.41 \leq C \geq 0.70$ (low cover) | 121.3 | 16.0 |
| 4 | $C \geq 0.71$ (very low cover) | 33.8 | 4.5 |

Table 5: Soil loss status of study area

Soil loss classes and their extent of coverage as per erosion class

| SI. No. | Range of soil loss (tons $ha^{-1}yr^{-1}$) | Erosion class | Area | | Total soil loss (tons $ha^{-1}yr^{-1}$) |
|---|---|---|---|---|---|
| | | | ha | % of study area | |
| 1 | <5 | Slight | 573.7 | 75.4 | 22.7 |
| 2 | 5 - 10 | Moderate | 118.0 | 15.5 | 24.9 |
| 3 | 10 - 15 | Severe | 52.9 | 7.0 | 33.7 |

Soil loss status under different land uses

| Land use | Soil loss class (severity) | Amount of soil loss (tons $ha^{-1}yr^{-1}$) | Area under soil loss (ha) | % of study area |
|---|---|---|---|---|
| Forest | Slight | 7.4 | 59.4 | 7.8 |
| Plantation | Slight | 7.5 | 139.5 | 18.4 |
| Open scrub | Moderate | 26.4 | 55.0 | 7.2 |
| Agriculture | Severe | 39.9 | 490.6 | 64.5 |

Table 6: Factors responsible for different classes of soil erosion in Singhanhalli-Bogur microwatershed

| SI. No. | Soil erosion class | Causative factors for varying rates of soil erosion |
|---|---|---|
| 1. | Slight | Flat lands with varying crop, low rainfall erosivity and soil erodibility; cultivation in areas of medium to high erosivity and soil erodibility; lack of good forest cover on moderately sloping lands; erosion-promoting crops on soils having high erodibility and the practice of fallowing during Kharif/monsoon season. |
| 2. | Moderate | The practice of fallowing during Kharif/monsoon season; cultivation in area not suitable for crops but without proper soil and water conservation measures; erosion-promoting crops on gentle slopes; denuded areas with no vegetation and cultivated fallow on moderate slopes. |
| 3. | Severe | Degraded forests/pastures on steep slopes; denuded hilly areas with no vegetation; cultivated fallow on moderate slopes; cultivated fallow on moderate slopes; crop cultivation on moderate slopes without proper soil and water conservation measures; and poorly managed forest cover. |

Table 7: Proposed soil conservation and land management techniques for the different soil erosion classes

| SI. No. | Soil conservation and land management techniques | Soil erosion class | | |
|---|---|---|---|---|
| | | Slight | Moderate | Severe |
| 1 | Use of organic manures and crop residues. | √ | √ | - |
| 2 | Cultivation of deep rooted and erosion resistant crops. | √ | √ | - |
| 3 | Incorporation of soil binding/nitrogen fixing legumes in rotation. | √ | √ | - |
| 4 | Agronomic measures like intercropping, strip cropping and contour farming. | - | √ | √ |
| 5 | Tree based perennial vegetation in degraded lands. | - | √ | √ |
| 6 | Land leveling with bunding, contour bunding, and contour ditch to reduce slope length in moderately sloping lands. | - | √ | √ |
| 7 | Safe disposal mechanisms for removal of excess runoff. | - | √ | √ |
| 8 | Silvi-pastoral, horti-pastoral or forest cover improvement techniques. | - | √ | √ |
| 9 | Bench terracing for field crops and contour trenching for other land uses. | - | - | √ |
| 10 | Rainwater harvesting, runoff diversion and gully bed and slope stabilization measures. | - | - | √ |
| 11 | Integrated participatory watershed management programmes for environmental rehabilitation and sustaining productivity. | - | - | √ |