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# Estimation of Soil Loss Under Changing Climatic Scenarios in Semi-Arid Watersheds

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**ABSTRACT:** Spatial and temporal estimation of soil loss is very essential for the sustainable planning and management of watersheds. In the present study, an attempt was made to estimate the soil loss spatially and temporally using RUSLE from a dry semi-arid watershed (Goparajpalli in Warangal District) and a wet semi-arid watershed (Seethagondi in Adilabad District) under changing climatic scenarios using PRECIS data. In the dry semi-arid watershed, the annual rainfall varied from 390 to 1181 mm with a mean value of 735 mm and a mean erosivity of 6260 MJ mm/ha/h/y. The mean annual rainfall during the base line period (1961-1990), mid (2021-2050) and end centuries (2071-2098) in this watershed were 738, 835 and 777 mm, respectively. The mean erosivity during these periods were 5657, 9253 and 7170 MJ mm/ha/h/y and soil loss from crop land were 2.39, 4.02 and 3.14 t/ha/y, respectively. In the wet semi-arid watershed, the annual rainfall varied from 508 to 1351 mm with a mean value of 950 mm and a mean erosivity of 6789 MJ mm/ha/h/y. The mean annual rainfall during base line, mid and end centuries in this wet semi-arid watershed were 956,1088 and 1124 mm and erosivities were 10547,14437 and 14755 MJ mm/ha/h/y, respectively. Similarly, the soil loss from crop land during these periods were 9.18, 13.11 and 14.11 t/ha/y. Even though, the soil loss from the dry semi-arid watershed was relatively lower than the wet semi-arid watershed, it showed an increasing trend in the mid century and a decreasing trend in the end century whereas, in the wet semi-arid watershed, it showed an increasing trend in both mid and end centuries. Considerable spatial variation in the mean annual soil loss was observed in both the wet and dry semi-arid watersheds during base line period, mid and end centuries.

**Key words:** Climate change, GIS, RUSLE, semi-arid watershed and soil loss

## Introduction

Soil erosion results in 85% of the land degradation in the world and causing 17% reduction in crop productivity (Vaezi *et al.,* 2010). Land degradation resulting from soil erosion from water is a serious problem in India which results in many economic problems. In India, 53% of total geographical area suffers from soil erosion with an average rate of 16 t/ha/y (Pandey *et al.,* 2009; Prasannakumar *et al.,* 2011). The intensive cultivation and socio-economic pressure for more land for feeding the increasing population have accelerated the rate of soil erosion on sloping lands (Shi *et al.,* 2004). The soil erosion removes the fertile top soil and organic matter from the soil surface which in turn affect the soil fertility and the reduction of crop yields (Ismail and Ravichandran, 2008). In semi-arid countries like India, the decline in soil fertility brings a series of negative impacts of environmental problems, and has become a threat to sustainable agricultural production and water quality in this region (Prasanna kumar *et al.,* 2012).

The spatial estimation of runoff and soil loss are essential for evaluating the risk of sediment transport and sustainable planning of *in-situ* and *ex-situ* soil and water conservation interventions for management of watersheds (Rejani *et al.,* 2016a; Rejani *et al.,* 2015a). The estimation of soil loss in sub watersheds were carried out using different prediction techniques (Shrestha, 1997; Dougals, 2006; Van De *et al.,* 2008). Watershed forms a natural boundary to focus on runoff, and hence a systematic assessment of runoff and soil erosion within the watershed would provide reliable information to draw strategies for sustainable development of watershed resources (Balasubramani *et al.,* 2015). The major models applied worldwide to estimate soil loss are Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), Soil Erosion Model for Mediterranean Regions (SEMMED), Soil and Water Assessment tool (SWAT), European Soil Erosion Model (EUROSEM), Agricultural Non-Point Source Pollution Model (AGNPS) etc. Among these, USLE and RUSLE are widely used to predict long term average annual soil loss using rainfall, soil type, topography, crop systems and management practices. RUSLE helps to predict the soil erosion from unguaged watersheds at reasonable cost and better accuracy by considering the hydro climatic conditions and spatial heterogeneity of the soil (Angima *et al.,* 2003). The RUSLE has been widely adopted for soil loss estimation at watershed scale because of its convenience in computation and application (Balasubramani *et al.,* 2015).

The impacts of climate change are global, but countries like India are more vulnerable in view of the high population depending on agriculture. The changes in the intensity of rainfall and prolonged dry spells attributes to the climate change effects in Indian agriculture (Srinivasarao *et al.,* 2014). In India, the surface temperature is predicted to increase by 2 to 40$^o$C (Ranuzzi and Srivastava, 2012). Also, changes in the distribution and frequency of rainfall, decrease in the number of rainy days, increase in rainfall intensities and intensity of cyclonic storms are also projected by 2030. The soil erosion rates may be expected to change in response to changes in the erosive power of rainfall (Nearing, 2001; Nearing *et al.,* 2004) and changes in plant biomass. The prediction of future soil erosion can help in the management of valuable cropland by suggesting the need for changing soil conservation strategies (Neal *et al.,* 2005). The objective of the study is to estimate the impact of climate change on soil erosion rates in a dry semi-arid watershed and wet semi -arid watershed for its sustainable planning and management.

## Materials and methods

### *Study Area*

The study area consists of a dry semi-arid watershed in Goparajpalli and a wet semi-arid watershed in Seethagondi. Goparajpalli watershed, covers an area of 1660 ha, lies in the Warangal District of Telangana in Southern India (Figure 1) and lies between 17°46' and 17°50' N latitude and 79°4' and 79°8' E longitude (Rejani *et al.,* 2015b). Seethagondi watershed cluster having an area of 3671 ha is located in the Adilabad District of Telangana state, lies between $78^0$ 29'3'' to $78^0$ 33'35'' E longitude and $19^0$ 31'40'' to $19^0$ 36'58'' N latitude (Figure 1). Goparajpalli watershed lies in Krishna basin and Seethagondi watershed cluster lies in the Godavari river basin. The mean annual rainfall of the Goparajpalli watershed is around 735 mm with 80% of its contribution during southwest monsoon (June to September). The area is characterized by moderate to very deep soil with clayey and cracking clayey texture with major portion having slopes below 5% (Rejani *et al.,* 2016b).

Seethagondi watershed cluster is having a mean annual rainfall of 950 mm and major portion of cluster is characterized by clayey textured soil with moderate to severe erosion and the depth of the soil ranged from moderately shallow to deep soil (Rejani *et al.,* 2016a). This watershed has undulated topography and average land slope varied from 0 to 10 degrees with maximum slope upto 36 degrees. The undulated topography coupled with the sensitive soil makes the cluster erosion prone. Both watersheds are prone to weather shocks like drought/deficient rainfall and delayed monsoon. Changing and increasingly variable climate is recognized as a potential threat to agriculture and food security in these watersheds. In view of this, the present work is focused on the estimation of soil loss under changing climatic scenarios for the sustainable planning and management of the two semi-arid watersheds.

### *Thematic layers*

Different thematic layers were generated to estimate the soil loss spatially. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) (30 m resolution) was used to delineate the watersheds using Hydro tool in ARCGIS (Rejani *et al.,* 2014a). The land use land cover (LULC) map of National Remote Sensing Centre (NRSC) Hyderabad, Aphrodite daily rainfall grid data ($0.25^0$ x $0.25^0$) for the period 1951 to 2007 and soil map of National Bureau of Soil Science and Land Use Planning (NBSS & LUP) was also used. The flow accumulation map and the slope map was generated.

### Soil erosion estimation using Revised Universal Soil Loss Equation (RUSLE)

A quantitative assessment of average annual soil loss in the watershed was made with GIS based RUSLE equation (Eqn. 1) considering rainfall, soil, land use and topographic datasets. The different thematic layers were clipped with watershed boundaries and intersected in ARCGIS 10.

The RUSLE equation was incorporated in GIS and soil loss was estimated spatially (Rejani *et al.,* 2016a) (Figure 2a).

A= R K L S C P (1)

where A = average annual soil loss (t/ha/y); R is the rainfall-runoff erosivity factor (MJ mm/ha/h/y) (Eqn.2); K is the soil erodability factor (t ha h/ha/MJ/mm); LS is the slope length-steepness factor (dimensionless) (Eqn.3); C is the cover management factor (dimensionless, ranging between 0 and 1.5); and P is the conservation practices factor (dimensionless, ranging between 0 and 1).

The rainfall runoff erosivity factor (R-Factor) quantifies the effect of rainfall impact and also reflects the amount and rate of runoff likely to be associated with precipitation events. The equation for R-factor for daily soil loss developed at CRIDA, Hyderabad was used. In the present study 57 years (1951-2007) rainfall data of the watersheds was used.

R factor was derived with the procedure described below (Rejani *et al.,* 2016a):

$$R = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} EI_{30}}{n} x1000/200.6 \quad (2)$$

where R = average annual erosion index (MJ mm/ha/h/y); i = number of years; j = number of days per year, i; EI30 = rainfall erosivity at 30 minutes per day (hundreds t cm/ha/h)

$$EI_{30} = 34.065\, EI_{1440} - 0.2695 \quad (R^2=0.83) \quad (3)$$

where, EI1440 = erosion index per day (hundreds t cm ha/h)

$$EI_{1440} = 3.856\, PI_{1440} - 0.0048 \quad (R^2= 0.89) \quad (4)$$

where, PI1440 = daily precipitation index, $cm^2/h$

$$PI_{1440} = (\text{Rainfall})^2\ /24 \quad (5)$$

where rainfall is in cm.

The daily R value obtained was converted to monthly and annual values and the mean annual erosvity for 57 years was obtained. The value of K for the selected area was 0.015 (Reddy *et al.,* 2005).

The LS factor for RUSLE was computed based on flow accumulation and slope steepness (Tirkey *et al.,* 2013; Rejani *et al.,* 2014b). The LS factor was derived in this study using Eqn.6,

$$LS = \left[\frac{\text{Flow accumulation} * \text{cell value}}{22.1}\right]^m (0.065 + 0.045s + 0.0065s^2) \quad (6)$$

where s = slope of the DEM in degrees and m is a constant depends on slope

For slopes of DEM ≤ 3, m = 0.3; slopes >3 and <5, m = 0.4 and slopes ≥5, m = 0.5

The values of C was derived from MODIS NDVI of 16 days interval (2004 to 2012). C factor was estimated using the methodology [Van der Knijff *et al.,* 2000] given below (Eqn. 7):

$$C = \exp\left(-\propto \frac{NDVI}{\beta - NDVI}\right) \quad (7)$$

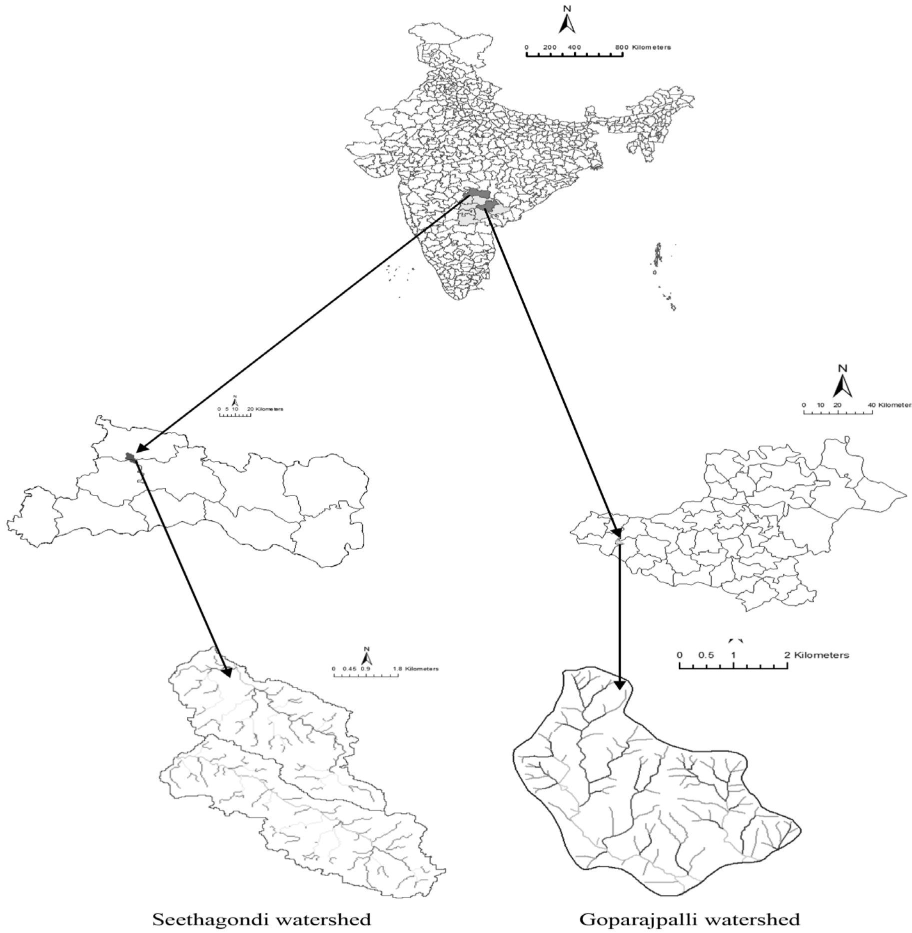


**Fig. 1 : Map of the study area**

where, α and β are the parameters that determine the shape of the NDVI-C curve. The 10-daily NDVI composites were averaged into monthly images to make monthly estimates of C factors for normal and dry years during the selected period. α = 2 and β = 1 gives reasonable results. The years were classified into normal and dry years based on rainfall. Corresponding C factors derived for normal and dry years were used. P factor was selected based on the conservation practices (Reddy *et al.,* 2005) and assumed to be same for baseline period, mid and end centuries.

### Estimation of soil loss under changing climatic scenarios

In their study, erosion rates were computed for historic, current, and future conditions using RUSLE (Figure 2a). The daily precipitation data predicted for base line (1961-1990), mid-century (2021-2050) and end century (2071-2098) of PRECIS model was used.

## Results and Discussion

### Spatial variation of soil loss

Considerable variation of soil loss was observed across the wet semi-arid watershed compared to dry semi-arid watershed. The soil loss from wet semi-arid watershed ranged from 0.2 to 80.0 t/ha/y with major portion below 20.0 t/ha/y (moderate to severe erosion) (Figure 2b) whereas the soil loss from dry semi-arid watershed ranged from 0.0 to 34.1 t/ha/y with major portion below 5.0 t/ha/y (slight erosion) (Figure 3).

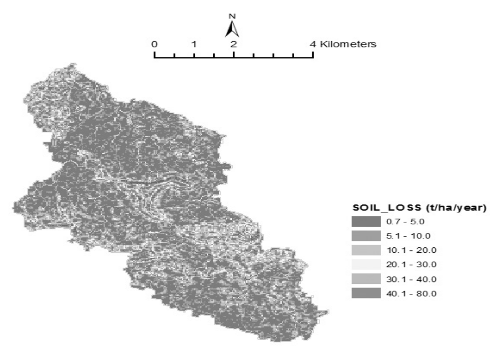


**Fig. 2b : Spatial variation of soil loss during normal year at Seethagondi**

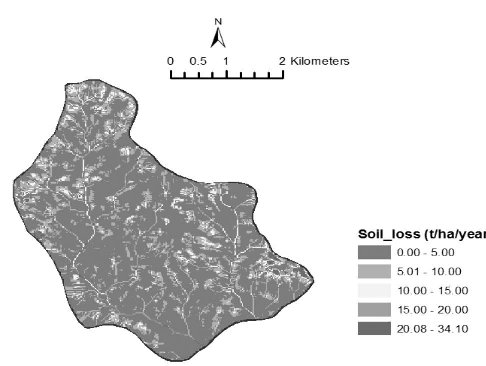


**Fig. 3 : Spatial variation of soil loss during normal year at Goparajpalli watershed**

wet semi-arid watershed, it showed an increasing trend in the mid century and a decreasing trend in the end century whereas, in the wet semi-arid watershed, it showed an increasing trend in both mid and end centuries. Considerable variation in the mean annual soil loss was observed in both the wet and dry semi-arid watersheds during base line period, mid and end centuries.

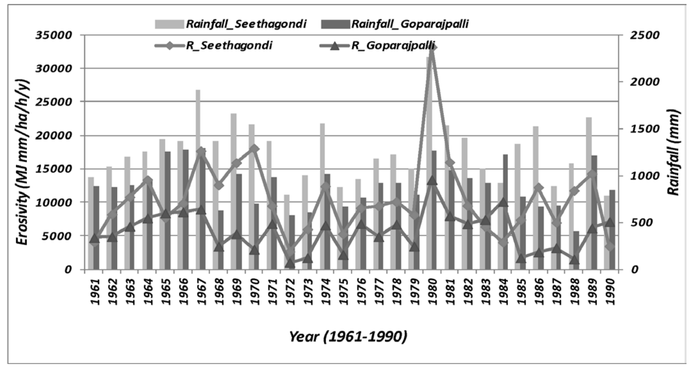


Fig. 4a : Temporal variation of rainfall and erosivity during baseline period at Goparajpalli and Seethagondi

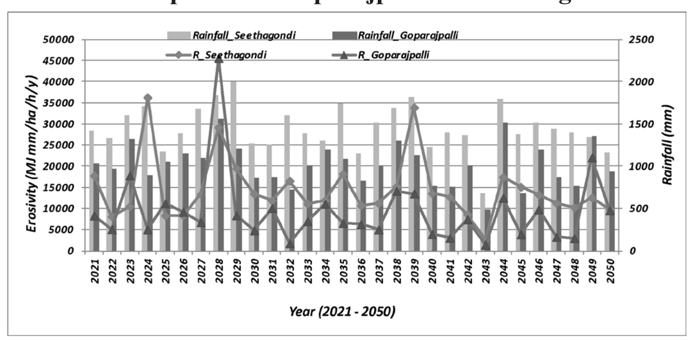


Fig. 4b :Temporal variation of rainfall and erosivity during mid century at Goparajpalli and Seethagondi

## Rainfall, erosivity and soil loss under changing climatic scenarios

In the dry semi-arid watershed, the annual rainfall varied from 390 to 1181 mm with a mean value of 735 mm and a mean erosivity of 6260 MJ mm/ha/h/y (Aphrodite, 1951 to 2007). The mean annual rainfall during the base line period (1961-1990), mid (2021-2050) and end centuries (2071-2098) in this watershed were 738, 835 and 777 mm and mean erosivity were 5657, 9253 and 7170 MJ mm/ha/h/y, respectively and it varied considerably across the years (Figure 4a-c). The soil loss from crop land during these three periods were 2.39, 4.02 and 3.14 t/ha/y, respectively and it also varied considerably over the years (Figure 5a-c). The erosivity and soil loss in dry semi-arid watershed is predicted to increase in mid century due to high intensity rainfalls and it showed a declining trend in the end century.

In the wet semi-arid watershed, the annual rainfall varied from 508 to 1351 mm with a mean value of 950 mm and a mean erosivity of 6789 MJ mm/ha/h/y (Aphrodite data, 1951-2007). The mean annual rainfall during base line, mid and end centuries in this wet semi-arid watershed were 956,1088 and 1124 mm and erosivity were 10547,14437 and 14755 MJ mm/ha/h/y, respectively and it varied considerably across the years (Figure 4a-c). Similarly, the soil loss from crop land during these periods were 9.18, 13.11 and 14.11 t/ha/y and it also varied considerably across the years (Figure 5a-c). The erosivity and soil loss are predicted to increase in mid and end centuries due to high intensity rainfalls in this watershed. Even though, the soil loss from the dry semi-arid watershed was relatively lower than the

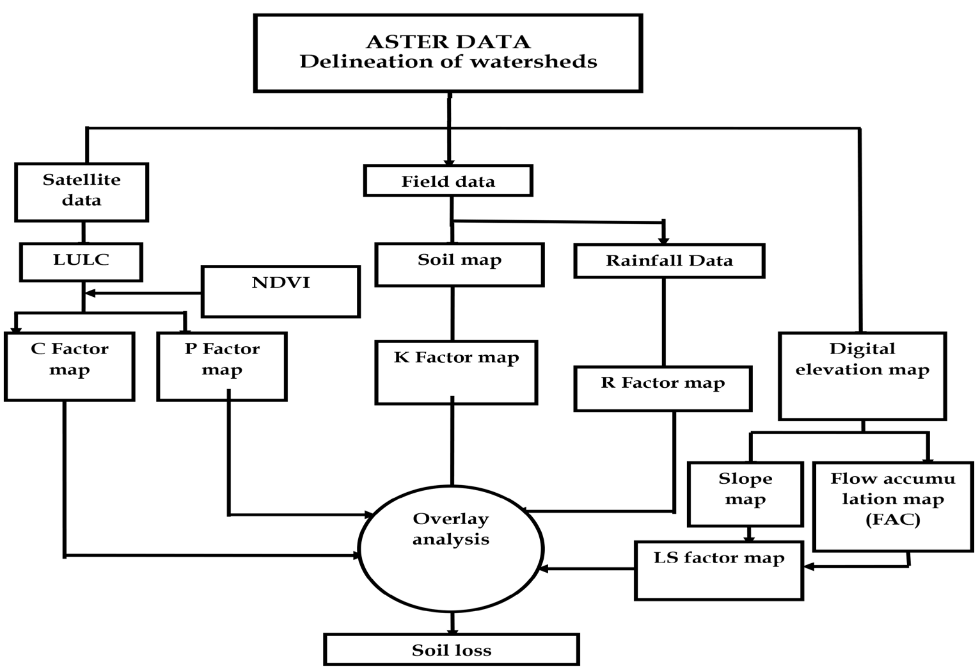


Fig. 2a : Flow chart for soil erosion estimation

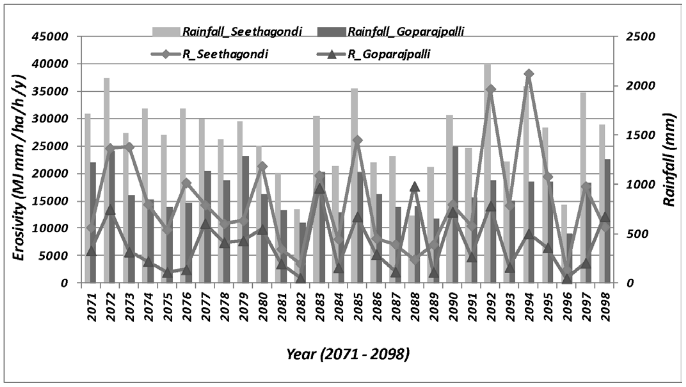


**Fig. 4c : Temporal variation of rainfall and erosivity during end century at Goparajpalli and Seethagondi**

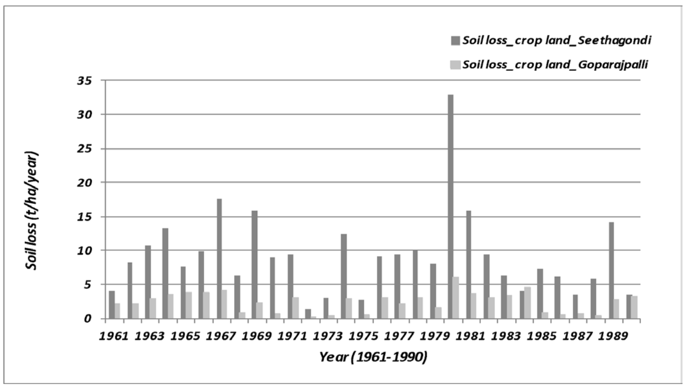


**Fig. 5a : Temporal variation of soil loss during baseline period at Goparajpalli and Seethagondi**

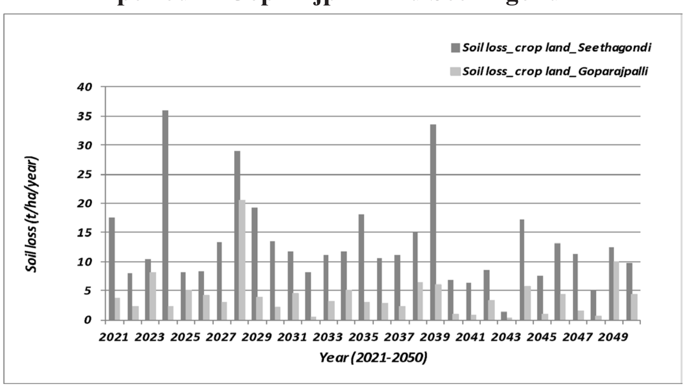


**Fig. 5b :Temporal variation of soil loss during mid century at Goparajpalli and Seethagondi**

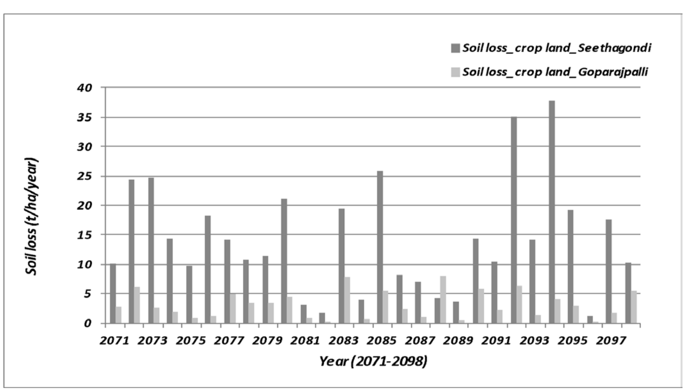


**Fig. 5c : Temporal variation of soil loss during end century at Goparajpalli and Seethagondi**

## Conclusions

Spatial estimation of soil loss is very essential for planning interventions in watersheds. The temporal and spatial variation of soil loss under changing climatic scenarios gives an idea to plan interventions for future sustainability. Considerable temporal and spatial variation in the mean annual soil loss was observed in both wet and dry semi-arid watersheds. The soil loss in dry semi-arid watershed is predicted to increase in mid century due to high intensity rainfalls and it showed a declining trend in the end century due to less intensity rainfalls. In wet semi-arid watershed, the soil loss is predicted to increase in both mid and end centuries due to high intensity rainfalls.

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