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Modelling of soil erosion for improved carbon sequestration in Urmodi basin of Maharashtra using RS and GIS

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Abstract

An increase in the concentration of atmospheric CO_2 by 31% since 1750 necessitates the identification of strategies for mitigating the threat of global warming. Soil erosion is the major land degradation process that removes organic carbon from the soil. Estimates of soil loss and their conservation planning are essential steps to improve soil quality, increase biodiversity and enhance soil organic carbon storage which in turn improves carbon sequestration. Therefore, there is a need to study the magnitude of the impact of conservation measures on carbon sequestration on a watershed basis. The average annual soil loss from the Urmodi basin was 30 t/ha/yr before the adoption of soil and water conservation measures and 8.39 t/ha/yr with scientific planning and execution of soil and water conservation technologies. Total carbon sequestration was expected to increase by 8.35% to the level of 6.81 million tonnes of CO_2 from Urmodi basin after adoption of soil and water conservation measures and water harvesting structures. So, it is concluded that these conservation technologies would improve soil quality, enhances organic carbon and leads to better productivity of agricultural land.

Keywords: Carbon sequestration, RS&GIS, USLE, SWC measures

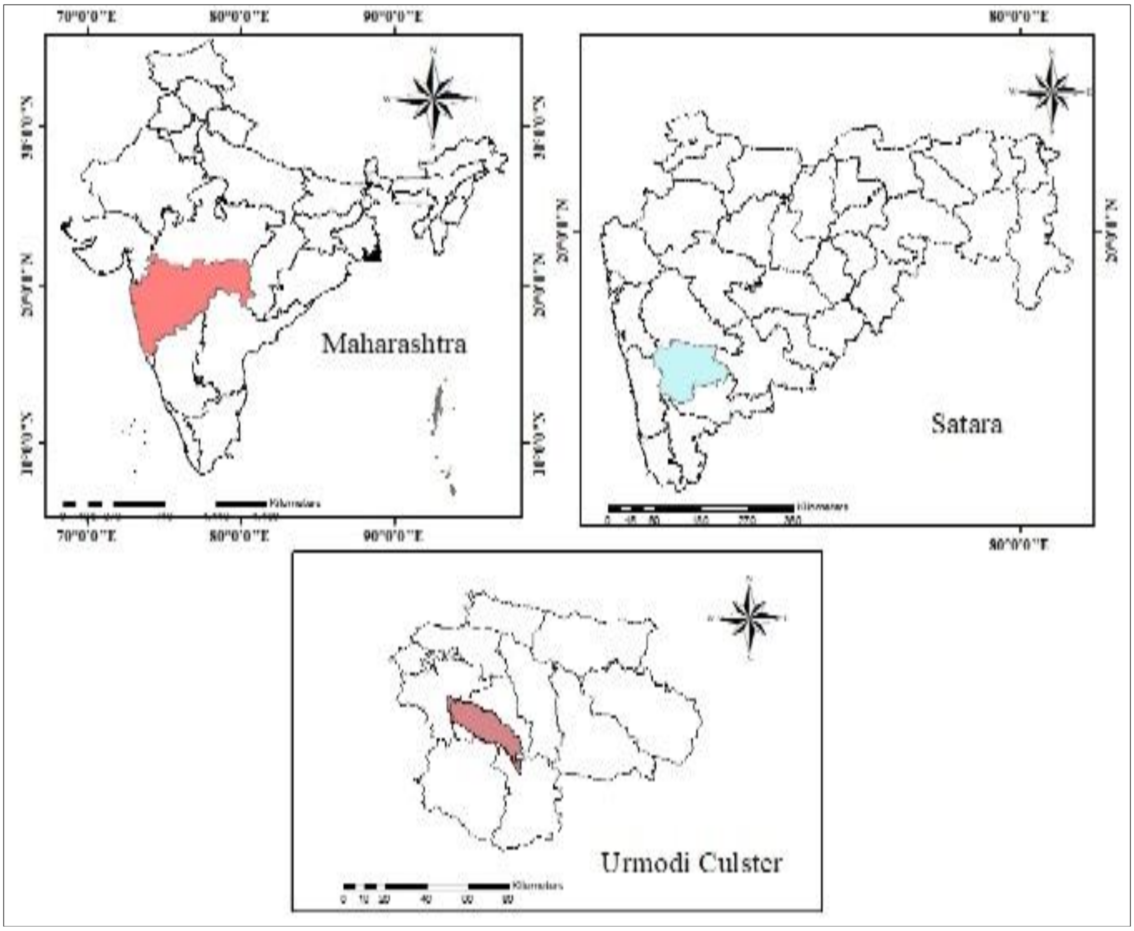
Introduction

Land and water resources are limited and their extensive utilization is imperative, especially for countries like India where the population pressure is increasing continuously. Deforestation, forest degradation, forest fire and the burning of fossil fuel causes the emission of greenhouse gases (GHGs) into the atmosphere. The increasing amount of GHGs adversely affects the global environment. The current rate of carbon loss due to land-use change (Deforestation) and related land-change processes is between 0.7 and 2.1 Gt carbon per year (World Bank Report 2012a) [27]. Soil erosion is the major land degradation process that removes organic carbon from soil and impairing environmental quality (World Bank Report 2012b) [27]. Soil erosion per year in Maharashtra state is 773.5 m tonnes (Durbude, 2015) [7]. So, studies on soil erosion and their conservation planning for carbon restoration are essential in India. Development of relation among soil erosion and soil carbon in the form of carbon sequestration will give right platform for better planning of soil and water conservation measures in watershed.

Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so it is not immediately reemitted. The transfer of greenhouse gases from the atmosphere into sinks (Forest and soil) is one way of mitigating climate change (EPA 2007) [8]. Carbon sequestration by growing forests is the cost-effective option for mitigation of global climatic changes (Andrasko 1990) [2]. Topsoil management, soil water conservation and management, soil fertility regulation and erosion control are main ways for improvement of carbon sequestration in soil (Carter and Hall 1995) [4]. Therefore, soil and water management on watershed basis is highly critical for adaptation to climate change. Assessment of carbon sequestration is new area of research which needs to be integrated with soil and water conservation studies for better planning of natural resources and to mitigate climate change. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) [25] has been widely used to predict soil loss. The integrated use of Remote Sensing (RS) and Geographical Information System (GIS) helps to assess quantitative soil loss at various scales and also to identify areas that are at potential risk of soil erosion. Urmodi basin (KR-14 watershed) of Krishna river lies in Satara district of Maharashtra state has higher potential of soil erosion and runoff due to undulating topography, very steep slopes and ignorance about soil and water conservation measures. Hence, there is need to develop watershed based various soil and water conservation strategies to improve agricultural productivity and to increase soil carbon pool for mitigation of climate change.

Materials and Methods

Study Area



The study area of Urmodi basin (KR-14 watershed) lies between 17°30' N to 17°45' N latitude and 73°45' E to 74°00' E longitude. The total valley area covered by Urmodi basin is 43,719 ha.

Assessment of Carbon Sequestration from the Watershed

Forests play an important role in the global carbon cycle with a significant impact on climate change. Biomass is defined here as the total amount of live and inert organic matter (IOM) above ground and below ground expressed in tonnes of dry matter per unit area.

Estimation of above ground biomass of forest using regression equations

Regression equations were used in this study to estimate the above ground biomass. Girth of each individual tree at 1.3 m above the ground surface was measured using tape. Diameter of tree was then calculated by dividing the π (3.14) to the girth of tree. Following regression equations were used to estimate above ground biomass of individual tree in Kg.

Table 1: Regression equation based on DBH and climatic condition

Source	Equation	DBH (cm)	Climatic Zone
FAO (1997)	$Y = \exp\{-1.996 + 2.32 \times \ln(DBH)\}$	5 - 40	Dry (< 1500 mm)
FAO (1997)	$Y = 42.69 - 12.800*D + 1.242*D^2$	5 -148	Moist (1500-4000 mm)
FAO (1997)	$Y = 21.297 – 6.953*D + 0.740*D^2$	4 -112	Wet (> 4000 mm)

Number of trees for measurement: In this study 10 x 10 m plot were selected randomly at 10 locations from forest area of each village in Urmodi basin. Number of trees was counted and girth at breast height (circumference) of each tree from plot was measured.

Estimation of below ground biomass of forest: The below ground biomass was calculated by multiplying above ground biomass taking 0.26 as the root to shoot ratio (Cairns *et al*. 1997; Ravindranath and Ostwald 2008) [3, 18]. Below ground biomass was calculated for each forest area of village in Urmodi basin.

Below ground biomass (t ha^{-1}) = 0.26 x above ground forest biomass (t/ha) (1)

Estimation of total biomass of vegetation: Total biomass of forest is above ground biomass plus below ground biomass. The biomass of crop land was calculated by applying the moisture loss for crops such as Wheat, Sorghum, Soybean and Paddy.

Estimation of carbon stock of vegetation: The calculation of carbon stock as biomass consists of multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. The coefficient of 0.5 for the conversion biomass to carbon was used (Dixon *et al*. 1994; Ravindranath *et al*. 1997) [6, 17].

Generation of carbon stock map and Amount of CO_2 sequestered by vegetation: The build-up of each ton of carbon removes 3.667 tonnes of CO_2 from the atmosphere (Bowen and Rovira 1999) [29]. Amount of CO_2 sequestered by each micro watershed was calculated from carbon stock values of forest area and crop land and then sum up to get the amount of CO_2 sequestered from Urmodi basin.

Carbon Stock in Soil: Soil sample data was collected for each village of micro watershed from District Soil Testing Laboratory, Satara. Soil carbon stocks were considered up to 30 cm soil depth only as per the guide lines of IPCC (Guleria *et al*. 2014) [11]. SOC storage values were calculated using following equations given by Ramachandran *et al*. 2007 [16]:

$$\text{SOC density} = \frac{\text{SOC}}{100} \times \text{corrected bulk density} \times \text{layer depth} \times 10^4 \quad (2)$$

$$\text{Corrected bulk density} = \text{Bulk density} \times \frac{\{(100 - \%\ \text{coarse fraction})\}}{100} \quad (3)$$

$$\text{Total SOC storage} = \text{SOC density} \times \text{micro watershed area} \ (4)$$

where, soil organic carbon in %, corrected bulk density in Mg m^{-3}, layer depth in m, bulk density in Mg m^{-3}, soil organic carbon density in Mg ha^{-1}, micro watershed area in ha.

Generation of SOC stock map and amount of CO_2 sequestered by soil: These values were assigned in attribute table in Arc GIS 10.2 to get SOC stock map and amount of CO_2 sequestered by soil from each micro watershed of Urmodi basin.

Total Carbon Stock Map and Amount of CO_2 Sequestered by Urmodi basin: Carbon stock values from vegetation and soil were added together to get total carbon stock values of each micro watershed. Amount of CO_2 sequestered from the Urmodi basin was total CO_2 sequestered from vegetation and soil.

Soil Erosion Model-USLE: The Universal Soil Loss Equation was used for estimating the rate of soil erosion. Basically, USLE predicts the long-term average annual rate of soil erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. These factors are combined in USLE which computes soil loss per unit area in tonnes/ha/year (Wischmeier and Smith 1978) [26].

Estimation of Average Annual Soil Loss using USLE before recommendation of soil and water conservation measures: The USLE was used in this study for estimating soil loss from Urmodi basin. All the layers *viz*. R, K, LS, C and P (considered as 1) were generated in GIS and were overlaid to obtained the product, which gives annual soil loss (A) of Urmodi basin.

Prioritization of Micro Watersheds for Soil Conservation Measures: Prioritization of micro-watersheds was carried out for fixing the priority of micro watershed based on soil loss from it. Ranking was assigned to the micro watershed based on the annual soil loss from each micro watershed. Soil erosion classification for Indian condition was given by Singh *et al*. 1992 [22].

Identification of Sites Suitable for Soil and Water Conservation Measures: The various types of soil conservation measures can be recommended to control soil loss according to suitability for each micro watershed. Climatic condition, soil characteristics (depth and texture) and topographic characteristics of the region were key parameters for deciding suitable land use and identifying the areas for appropriate soil and water conservation measures in the watershed.

Conservation Practice Factor (P) after Conservation Measures: Based on estimated erosion values of the micro watershed, soil and water conservation were recommended. After recommendation of soil and water conservation measures the conservation practice factor (P) was derived for each conservation measures.

Estimation of Annual Soil Loss after Recommendation of Conservation Measures: All the layers *viz*. R, K, LS, C and P (After conservation measures) were generated in GIS and were overlaid to obtained the product, which gives annual soil loss (A) of Urmodi basin.

Impact of Soil Conservation Measures on Carbon Sequestration: Adoption of conservation tillage, mulch farming techniques, maintenance of soil fertility, soil and water conservation and adoption of complex rotations improves the soil carbon sequestration. After the recommendation of soil and water conservation measures carbon sequestration was estimated for each micro watershed of Urmodi basin.

Results and Discussion

Estimation of above ground biomass and below ground biomass of forest: Above ground biomass values were ranging from 107 t ha^{-1} to 148.26 t ha^{-1} in moist and wet zone. Values of above ground biomass in dry zone were ranging from 67 to 107 t ha^{-1}. A higher proportion of above ground biomass in the higher diameter classes emphasises the importance of large trees in carbon storage. Below ground biomass values of study area were ranging from 15.89 to 38.514 t ha^{-1}.

Generation of total biomass map of forest and crops: Total biomass of forest is sum of above ground biomass and below ground biomass of forest. Total biomass values of forest were ranging from 125.01 to 186.64 t ha^{-1} in moist and wet zone of study area. Total biomass values of forest in Urmodi basin were ranging from 84.53 to 125 t ha^{-1} in dry zone of study area. Biomass values were highest in sugarcane crop followed by sorghum crop, rice and wheat crop. Low biomass values were observed in soyabean crop.

Estimation of carbon stock values of vegetation (forest and crop): Carbon stock values of forest were ranging from 42.264 to 93.32 tC ha^{-1}. Carbon stock values for dry zone were ranging from 42.264 to 62 tC ha^{-1}. Carbon stock values for moist and wet zone were ranging from 62.01 to 93.32 tC ha^{-1}. Carbon stock values for each crop were calculated. It was observed that the sugarcane crop has highest carbon stock values as compared to other crops. Carbon stock value for wheat was 4.04 tC ha^{-1}, Paddy was 4.34 tC ha^{-1}, Soyabean 3.75 tC ha^{-1} ha, Sorghum 4.77 tC ha^{-1} and for Sugarcane8.68 tC ha^{-1}.

Generation of carbon stock map of vegetation (forest and crop): Weighted carbon stock value was estimated for each micro watershed of the Urmodi basin. These values were assigned in attribute table in ArcGIS 10.2 to get carbon stock map of forest and crop of each micro watershed. Carbon stock values of each micro watershed were ranging from 268.66 to 44080.60 tonnes of carbon. Rate of carbon stock values of each micro watershed were ranging from 0.39 to 61.41 tC ha^{-1} (figure 1). High carbon stock values were observed in those micro watersheds which is having high coverage of forest area and crop land. Low carbon stock values were associated with high degraded land in micro watersheds. The degraded areas have a large potential to sequester carbon in the soil if new vegetation cover is established on it.

Estimation of amount of CO_2 sequestered by vegetation (forest and crop): Total amount of CO_2 sequestered by vegetation from Urmodi basin was 1.973 million tonnes of CO_2. Thus, vegetation plays important role in the global carbon cycle by sequestering a substantial amount of CO_2 from the atmosphere (Vashum and Jaykumar 2012) [24].

Determination of soil carbon stock: Rate of soil carbon stock storage of micro watersheds was ranging from 3.56 to 60.73 t C ha^{-1} (figure 2). Soil carbon stock values were high in forest area, where low soil carbon stock values were observed in agriculture land.

Estimation of amount of CO_2 sequestered by soil: Amount of CO_2 sequestered by soil from each micro watershed were ranging from 9118.25 to182707.47 tonnes of CO_2. Total soil carbon stock value from whole Urmodi basin was 1.176 million tonnes of carbon. This soil carbon stock value is equivalent to 4.312 million tonnes of CO_2. Thus, soils are largest sink of carbon due to relatively large area and long residence time of organic carbon in soil.

Total Carbon Stock of Vegetation and Soil: Total carbon stock value of Urmodi basin was 1.71 million tonnes of carbon. The ratio between soil carbon stock and biomass carbon stock was 2.18:1. In general also the ratio between soil carbon stock and biomass carbon is 2.5 to 3 times in the terrestrial ecosystem (Post *et al*. 1990) [14]. The present study indicated that the soil carbon stock was higher than that of the biomass carbon, but not as high as 2.5 to 3 times of biomass carbon as recorded in well managed terrestrial ecosystems.

Estimation of total amount of CO_2 sequestered by vegetation and soil: Amount of CO_2 sequestered by vegetation was 1.973 million tonnes of CO_2. Amount of CO_2 sequestered by soil was 4.312 million tonnes of CO_2. Total amount of CO_2 sequestered by Urmodi basin was 6.285 million tonnes of CO_2. Amount of CO_2 sequestered by soil was 69% of the total CO_2 sequestered of the study area and the remaining 31% was CO_2 sequestered the tree biomass and crops. It shows that the soils are largest sink of atmospheric CO_2 in terrestrial ecosystem.

USLE parameters

Rainfall Erosivity (R) Factor. Annual erosivity values of Kas region were ranging between 4552.91 to 15477.60 MJ-mm $ha^{-1}hr^{-1}$. Daily erosivity index of Parali, Nagthane, Upshinge and Jawalwadi raingauge stations was estimated by using regression equation $Y = 0.026x^2+0.144x+7.868$ developed for study area. Highest erosivity values were observed towards northern part of Urmodi basin due to high intense storms and lowest values was observed towards southern part of Urmodi basin.

Soil Erodibility (K) factor: Various soil parameters like sand (%), Silt (%), clay (%), texture, structure, organic matter content and permeability were very significant in determining soil erodibility. The weighted soil erodibility factor for each micro watershed was ranging between 0.011 to 0.0257 t-ha-hr $ha^{-1}MJ^{-1}mm^{-1}$. Soils were more susceptible to erosion on the remote side of the Urmodi basin.

Topographic Factor (LS): Digital Elevation Model (DEM) of the study area was used to generate slope map, which was downloaded from Shuttle Radar Topography Mission (SRTM) images (http://.srtm.csi.cgiar.org). Slope map was used to generate slope length (L) and slope gradient(S) maps. The values of LS factor for micro watersheds were found in the range of 1.432 to 10.233.

Crop Cover and Management Factor (C): RS and GIS techniques have a potential to generate a thematic layer of land use/land cover of a region. Land use/land cover map of Urmodi basin was generated using LANDSAT imageries using supervised classification. Crop management factor (C) values of Urmodi basin were ranging from 0.057 to 0.302.

Conservation Practice Factor (P): The Urmodi basin was fully untreated without any soil and water conservation measures. Therefore, the value of P factor was considered as 1 for all micro watersheds assuming all micro watersheds were untreated.

Average Annual Soil Loss using USLE: Average annual soil loss from Urmodi basin was 30 t $ha^{-1}yr^{-1}$ (figure 3). Weighted value of soil loss from each micro watershed was calculated and ranking was assigned to the micro watershed based on the annual soil loss from each watershed. Prioritization was done to find out the micro watersheds having maximum average annual soil loss for conservation measures policies. In Urmodi basin about 50% of area comes under high to very high erosion class which was cause of concern. This proves the high need of soil and water conservation measures in the watershed for the sustainable management of natural resources.

Recommended Soil and Water Conservation Measures: Soil and water conservation measures for micro watersheds were recommended based on climatic, soil (Depth and texture) and topographical characteristics of Urmodi basin (Srivastava *et al*. 2010) [23]. Different soil and water conservation measures such as Bench terracing, contour farming, contour trenching, broad base terracing, strip cropping and graded bunding are expected to help to reduce the slope length, protect the land from degradation and help to control the soil erosion from the watershed.

Conservation Practice Factor (P): Area under each conservation measure was determined and conservation practice factor values assigned to it. Weighted value of conservation practice factor (P) for each micro watershed was calculated from area under various measures. After recommendation of soil and water conservation measures conservation practice factor was ranging from 0.16 to 0.42.

Average Annual Soil Loss Estimation after Proposed Soil and Water Conservation Measures: Average annual soil loss from Urmodi basin was expected to be 8.39 t $ha^{-1}yr^{-1}$ after the adoption of soil and water conservation measures. Thus, soil loss can be reduced by 21.61 t $ha^{-1}yr^{-1}$ (72.03%) with scientific planning and execution of soil and water conservation technologies. Recommended soil and water conservation measures in Urmodi basin are shown in figure 4.

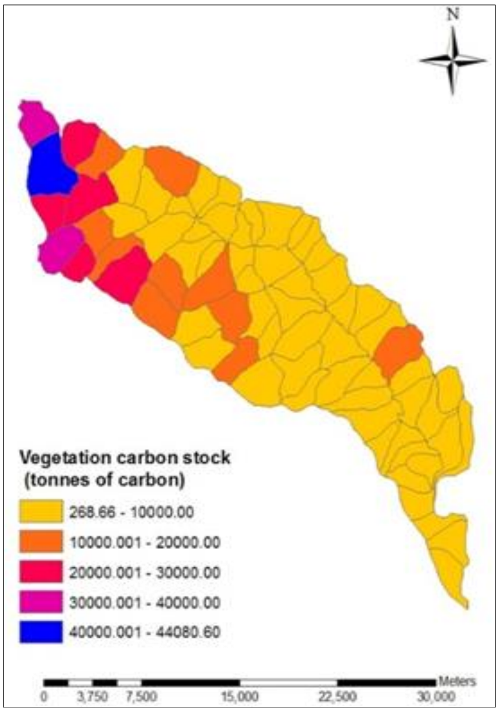


Fig 1: Vegetation (Forest and crop) carbon stock map of Urmodi basin

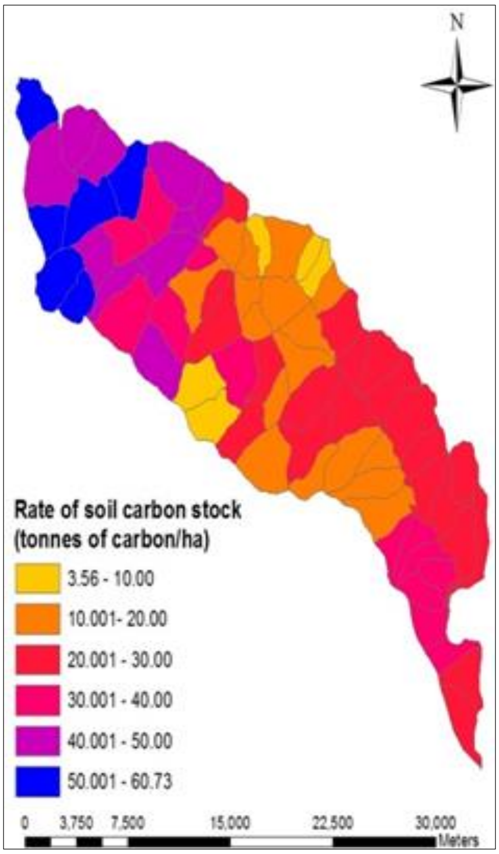


Fig 2: Rate of soil carbon stock map of Urmodi basin

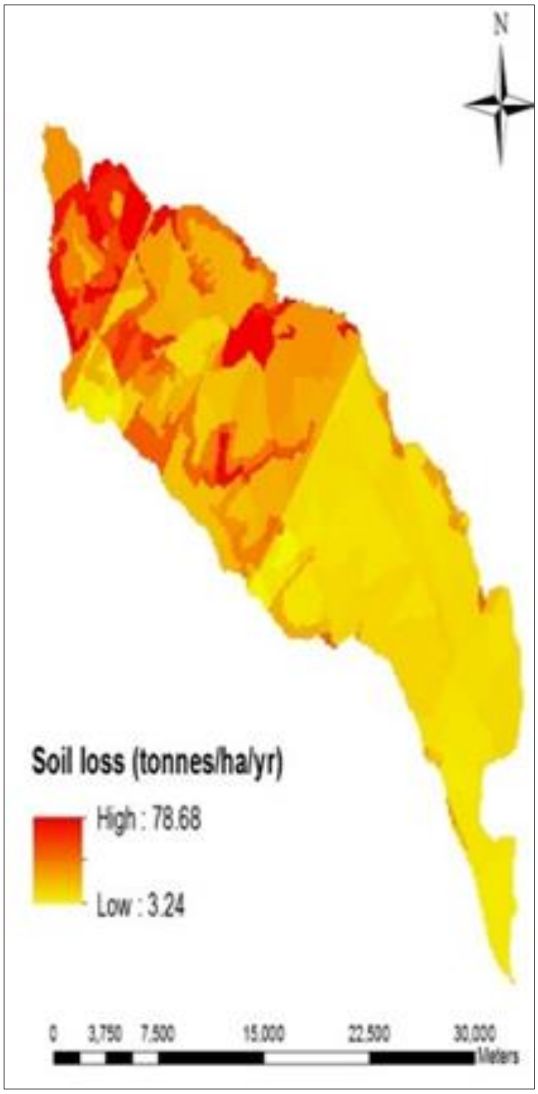


Fig 3: Average annual soil loss map of Urmodi basin before conservation measures

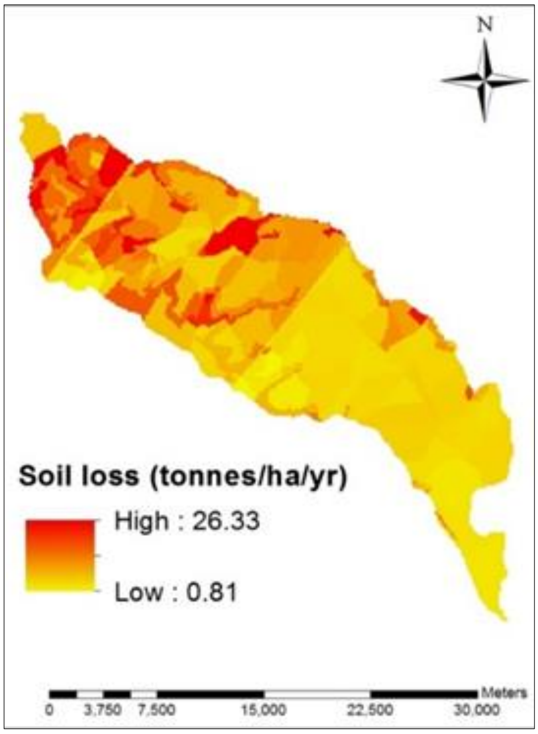


Fig 4: Average annual soil loss map of Urmodi basin after conservation measures

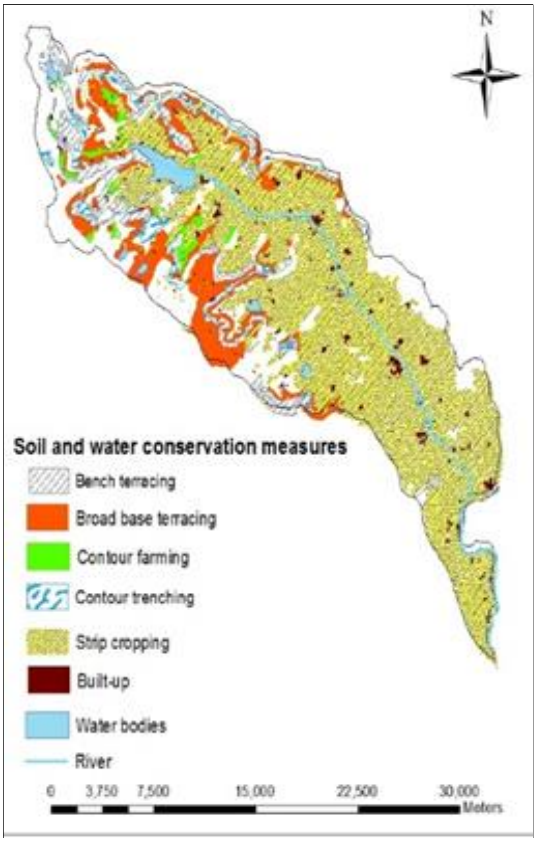


Fig 5: Recommended soil and water conservation measures map of Urmodi basin

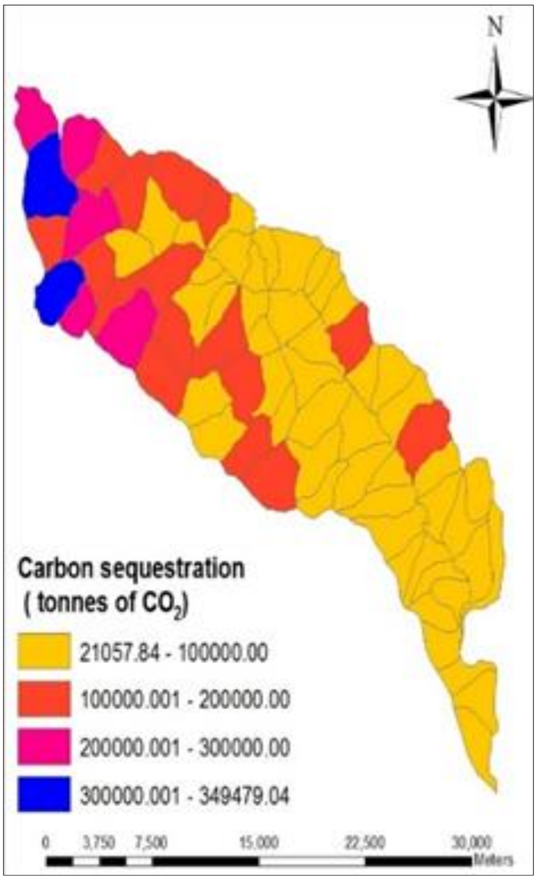


Fig 6: Improved carbon sequestration map after conservation measures from each micro watershed of Urmodi basin

Impact of Soil and Water Conservation Measures on Carbon Sequestration: Carbon sequestration rate of each micro watershed was calculated before and after recommendation of soil and water conservation measures and water harvesting structures. Rate of carbon sequestration in crop rotation system is 0.7 to 1.5 tonnes of CO_2 $ha^{-1}yr^{-1}$. Carbon sequestration rate of terracing practices and construction of slope barriers on sloping land is 2.4 to 5.3 tonnes of CO_2 $ha^{-1}yr^{-1}$. Carbon sequestration rate of water harvesting structures is 3.9 to 4.8 tonnes of CO_2 $ha^{-1}yr^{-1}$. Carbon sequestration rate of fast growing trees to improve fallow land is 8.7 tonnes of CO_2 $ha^{-1}yr^{-1}$. Carbon sequestration rate of pastures improvement is 3.5 tonnes of CO_2 $ha^{-1}yr^{-1}$ (World Bank report 2012b) [27].

Total amount of CO_2 sequestered by Urmodi basin was 6.81 million tonnes of CO_2 after adoption of soil and water conservation measures and water harvesting structures. So, carbon sequestration was expected to increase by 8.35% from the Urmodi basin. Soil and water conservation measures, water harvesting structures, tree plantation and crop rotations conserves soil water, improves soil quality and soil organic carbon which in turn enhances agricultural productivity. Thus, carbon sequestration is a prudent solution to the serious problem of greenhouse gas effect.

Summary and Conclusions

Average soil loss from Urmodi basin after adoption of recommended soil and water conservation measures was expected to reduce to 8.39 t $ha^{-1}yr^{-1}$. Thus soil loss can be reduced by 21.61 t $ha^{-1}yr^{-1}$ (72.03%) with scientific planning and execution of soil and water conservation technologies. Total amount of CO_2 sequestered by Urmodi basin was 6.81 million tonnes of CO_2 after the adoption of conservation measures. Carbon sequestration was expected to increase by 8.35% from the Urmodi basin after adoption of soil and water conservation measures. Thus soil and water conservation can give twin benefits of conservation of natural resources and improved carbon sequestration. Conserved soil and water would lead to better productivity of agricultural land and higher income to farmers. Improved carbon sequestration will have better carbon stock which would help in mitigation of climate change at local scale.

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