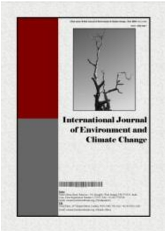

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Carbon Sequestration for Major Land Use/ Land Cover Types of Urmodi Basin of Maharashtra, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The goal is to calculate total biomass, carbon stock, and total CO_2 sequestered by forest and crop in the watershed. To create a thematic map to investigate spatial variation.

Place and Duration of Study: The study took place in the Urmodi basin in Satara, Maharashtra (India) between June 2015 and June 2016.

Methodology: In this study, carbon stocks in different land use categories in the Urmodi basin were assessed using in situ destructive and non-destructive biomass estimating methods. To investigate the spatial variance of carbon stock values in the Urmodi basin, thematic maps were created.

Results: The carbon stock value of vegetation in the Urmodi basin was 0.53 million tonnes of carbon. The amount of CO_2 sequestered by vegetation in the Urmodi basin was 1.973 million tonnes.

Conclusion: In micro watersheds, low carbon stock values were linked to damaged land. If fresh plant cover is formed on damaged lands, they have a great potential to store carbon in the soil. By sequestering a significant amount of CO_2 from the atmosphere, vegetation plays a vital part in the global carbon cycle. As a result, carbon sequestration through forest growth is the most cost-effective method of mitigating global climate change.

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Keywords: Biomass; Carbon stock; Carbon sequestration; Geographical Information System.

1. INTRODUCTION

Rapid changes in land use patterns have resulted in forest degradation, land degradation, soil erosion, and a negative impact on global climate due to greenhouse gas (GHG) emissions from the atmosphere. Climate change and increasing carbon dioxide emissions have heightened awareness of the need for high-quality monitoring devices to assess the amount of carbon in terrestrial systems. The Global potential for enhancing carbon storage in forest and agricultural ecosystems may be as much as 60-90 penta grams of carbon [1]. Forests act as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial above ground, and 40% of terrestrial below ground carbon storage [2,3].

The forest ecosystem plays a very important role in the global carbon cycle. Forests provide various goods and services for human beings. The transfer of greenhouse gases from the atmosphere into sinks (forests and soil) is one way of mitigating climate change [4]. Currently, climate change is a global concern, and forests plays vital role in climate change regulation and mitigation through reducing CO_2 concentrations in the atmosphere [5]. However, agriculture is among the land-use practices that emit as well as sequester CO_2. It may lose soil organic matter due to intense decomposition following soil plowing, removal of above ground biomass during harvest, and severe soil erosion inherent in these activities. Deforestation is the second most important source of greenhouse gases (GHG) after fossil fuel combustion. Conversion of forest land to other land uses, such as agriculture, grazing land and urbanization enhances decomposition and removal of carbon through harvest. On the contrary, a significant increase (50%) of soil carbon was reported after the conversion of arable land into forest land. Hence, understanding the relationship between land use systems and carbon stocks is essential, as every land use system has either a positive or negative impact on the carbon balance. The watershed are an important constituent of the landscape for maintaining the ecological balance between natural resource development and conservation [6,7]. Assessment of carbon stock from different land use systems is a new area of research which needs to be integrated with watershed development for better planning of natural resources. Besides, considering the potential and constraints of a watershed in relation to carbon stock, it is vital to make recommendations on the maintenance and enhancement of carbon stock [8,9]. Most scientists have focused their research on soil carbon stocks in the watershed and giving much less emphasis to the carbon stock of the various carbon pools in vegetation at watershed level. Under the looming climate change, such information on carbon emissions, carbon stocks and sequestration are essential for developing strategies at watershed level that enhance agricultural productivity and abate greenhouse gas emissions. In view of this backdrop, this study assessed the current carbon stock under different land use types in the Urmodi basin in Satara district of Maharashtra.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was conducted on major land use of the Urmodi basin in Satara district of Maharashtra.The geographical location of the Urmodi basin 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 the Urmodi basin is 43,719 ha. The mean annual rainfall in the basin is of the order of 1250-1800 mm. Urmodi basin has an undulating topography with a slope ranging between 4 to 33%. The dry and moist mixed deciduous forests are found in Urmodi basin. The dominant agricultural crops taken in the study area are paddy (Oryza sativa), wheat (Triticumaestivum), sugarcane (Saccharum officinarum), soybean (Glycine max) and sorghum (Sorghum bicolor).

2.2 Land Use/ Land Cover Map of the Study Area

In the study of global climate change, changes in land use/cover are extremely important. Due to massive agricultural and demographic pressures, land has become increasingly scarce. Land use refers to man's activities and the various uses which are carried out on land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations. Satellite images were used to create a land use/cover map for this investigation. The LU/LC map of the Urmodi basin was created using cloud free satellite data from LANDSAT imagery (ftp.glcf.umd.edu, Row

No.147, Path No.48, February 2009). Physical observation was made to confirm the basic information about the major land use types and topographic variations of the study area. The land use/land cover map of the research area was created using the interpretation of multi-season satellite data. Thematic mapping of various LU/LC was achieved through supervised classification. The LU/LC map of the study period was produced in ArcGIS 10.2 software.

2.3 Carbon Sequestration

Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so that it should not be immediately remitted. About two-thirds of terrestrial carbon is sequestered in standing forests, forest under storey plants, leaf and forest debris and in forest soils [10]. Biomass and soil carbon are the two major carbon pools. In the present study, total carbon stock values were calculated as carbon stock present in biomass (forest land and crop land).

2.4 Carbon Stock in Forests

Forest ecosystems play an important role in global biogeochemical cycles and climate change mitigation [11]. Forests switch between being a source or a sink for carbon [12]. Forest ecosystems store 20–100 times more carbon per unit area than croplands and hence play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric carbon in the growth of woody biomass through the process of photosynthesis and thereby increasing the SOC content [13]

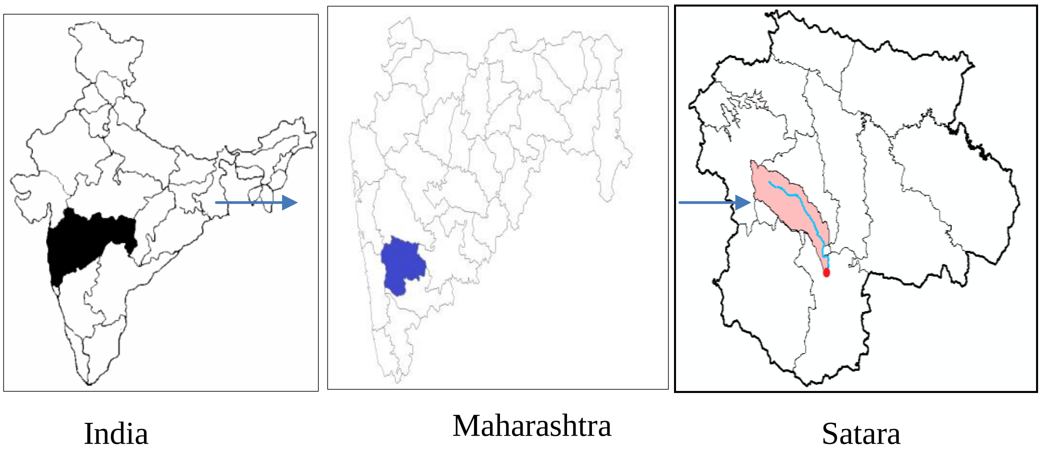
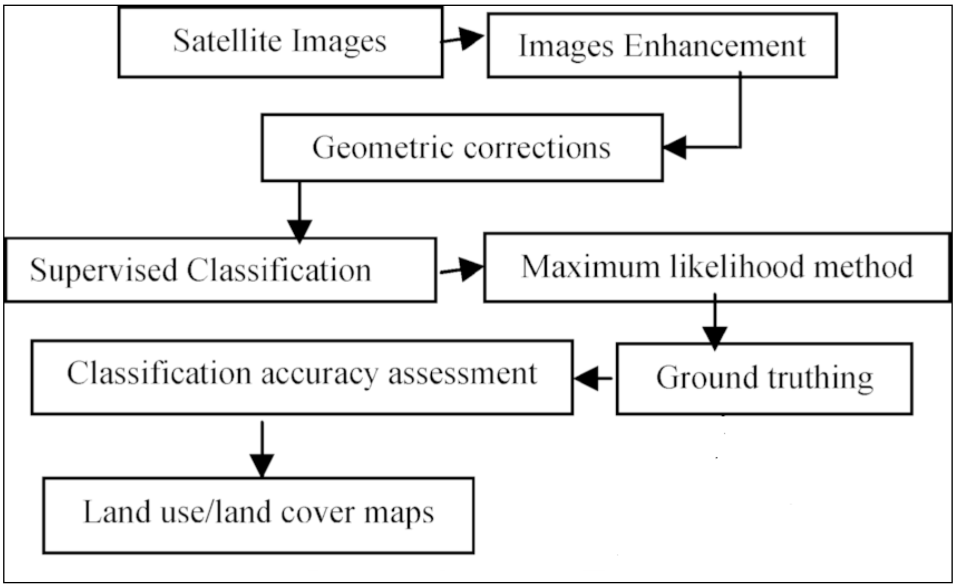


Fig. 1. Study area



Graph 1. Flowchart methodology for land use land cover

2.5 Carbon Stock in Biomass

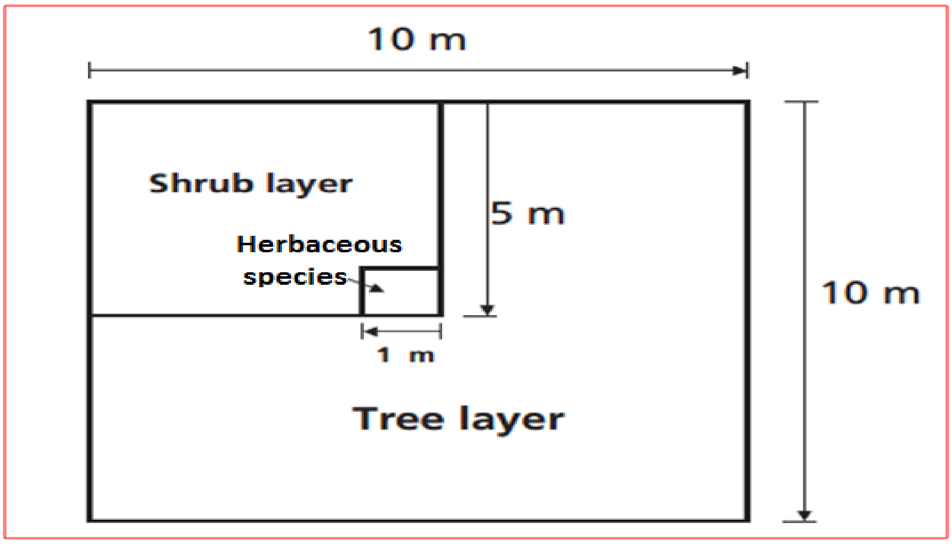
Biomass is an important element in the carbon cycle, specifically in carbon sequestration. Biomass is defined here as the total amount of live and inert organic matter (IOM) above ground and below ground expressed in tonnes of dry matter per unit area. Biomass is a function of density of stems, height of the trees and basal area of the trees in a given location. According to the IPCC good practice guidance for land use land-change and forestry, the carbon pools of terrestrial ecosystems involving biomass are divided into above ground and below ground biomass, dead mass and litter. Above ground biomass includes all living biomass above the soil including stems, stumps, branches, bark, seeds, and foliage [14]. Below ground, biomass includes all living biomass of live roots. The methods for measurement of biomass are in situ destructive direct biomass measurement and in situ non-destructive biomass estimations (using regression equations or conversion factors). In in situ destructive direct biomass measurement method involves harvesting of all the trees in the known area and measuring the weight of the different components of the harvested tree like the tree trunk, leaves and branches and measuring the weight of these components after they are oven dried. In situ non-destructive biomass method the biomass of a tree was calculated without felling. In this method, tree height and diameter is measured using some field gears like range finder or clinometer and tape etc. This method includes sampling measurements that do not require harvesting trees and uses allometric or conversion factors to extrapolate biomass to unit ground area. In this study, a second in situ non-destructive biomass estimation method was used.

2.6 Number of Trees for Measurement

Sampling quadrants of regular shape of dimensions 10 x 10 m for tree layer, 5 x 5 m for shrub layer and 1 x 1 m for grasses, nested within each other, were defined as the units for sampling for measurements of biomass [15]. In this study, 10 x 10 m plots were selected from the forest area of each village in Urmodi basin. The number of trees were counted and girth at breast height (circumference) at 1.3 m from the ground surface was measured for estimation of the carbon stock of trees from the forest area of Urmodi basin. A total of 2220 tree readings were taken to estimate carbon stock values. The location of each sampling point was recorded using GPS.

2.7 Estimation of above Ground Biomass

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. The diameter of the tree was then calculated by dividing the (3.14) to the girth of the tree. Depending upon the girth at breast height and climatic conditions, regression equations developed by the Food and Agricultural Organization [16] were used to estimate the above ground biomass of individual trees in Kg.



Graph 2. Quadrants size for tree, shrub layer and herbaceous species

Table 1. Regression equations based on DBH for different climatic zone [17]

Equation No.	Equation	DBH (cm)	Climatic Zone
2.1	$Y = \exp\{-1.996 + 2.32 \times \ln(DBH)\}$	5 - 40	Dry (< 1500 mm)
2.2	$Y = 42.69 - 12.800{*}D + 1.242{*}D^2$	5 -148	Moist (1500-4000 mm)
2.3	$Y = 21.297 – 6.953{*}D + 0.740{*}D^2$	4 -112	Wet (> 4000 mm)

2.8 Estimation of below Ground Biomass

The below ground biomass was calculated by multiplying the above ground biomass, taking 0.26 as the root to shoot ratio [18,19]. Below ground, biomass was calculated for each forest area of a village in Urmodi basin. These values were assigned in the attribute table in Arc GIS 10.2 to get below-ground biomass map of forest.

Below ground biomass (t/ha) = 0.26 x above ground forest biomass (t/ha) ... (2.4)

2.9 Estimation of Total Biomass and Generation of Map of Forest

Above ground and below ground biomass values were assigned in the attribute table in Arc GIS 10.2 to get the above ground and below ground biomass map of forest. The total biomass of forest includes the above ground biomass and below ground biomass. Total biomass values of each forest area were assigned in the attribute table in Arc GIS 10.2 to generate a total biomass map of Urmodi basin.

2.10 Generation of Carbon Stock Map of Forest

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. This coefficient is widely used internationally, thus it may be applied on a project basis. Therefore, the coefficient of 0.5 for the conversion of biomass to carbon was used [2,20]. The carbon stock value of a forest was calculated. These values were assigned in the attribute table in Arc GIS 10.2 to get the carbon stock map of the forest.

2.11 Estimation of Biomass of Crops

The assessment of non-woody biomass such as in grasslands and croplands is generally based upon the root/shoot ratio since the above ground biomass is harvested entirely [21].The biomass (dry weight) is calculated by applying the moisture loss of the samples [22]. This method was used for crops such as Wheat, Sorghum, Soybean and Paddy for that the plant samples were collected at different time interval viz. 30, 60, 90 days after sowing and at crop maturity for analysis [23]. At every sampling stage crops from 1 × 1m area harvested was collected in bags. Plant samples were collected from 5 locations in study area. Initial weight of crops was measured. These samples were further allowed to air dry for 2–3 days and then placed in a hot air oven at $60^{o}C$ for 24 h. Final dry weight of crops after oven drying was taken. Carbon stock present in such crops was calculated by multiplying 0.5 by biomass content. As an annual crop, sugarcane was harvested at 60,180,240 days after sowing and at the time of harvesting. Biomass of sugarcane was calculated following the above procedure.

2.12 Estimation of Carbon Stock of Crops and Generation of Vegetation Map

The total biomass of crops was multiplied by 0.5 to get the carbon stock values of crops. Carbon stock values were calculated for forest (above and below ground biomass) and crops. The weighted value of carbon stock was calculated for each micro watershed based on forest area and cropland. These weighted values of carbon stock were assigned in the attribute table in Arc GIS 10.2 to get a carbon stock map of the vegetation of Urmodi basin.

2.13 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 [24]. Amount of CO_2 sequestered by each micro watershed was calculated from carbon stock values of forest and crop and then sum up to get the amount of CO_2 sequestered from Urmodi basin. This value represents the amount of CO_2 sequestered forest area (above ground biomass & below ground biomass) and crop land (wheat, paddy, soybean, sorghum and sugarcane). These values were assigned in attribute table in Arc GIS 10.2 to get CO_2 sequestration by vegetation from corresponding micro watershed of Urmodi basin.

3. RESULTS AND DISCUSSIONS

3.1 Land Use/ Land Cover

The land use/land cover characteristics were described using land use/land cover (LU/LC) maps of Urmodi basin. Study area was classified as;

It was found that almost 66.81% of the land is covered under two major classes; agriculture and forest. There is no urbanization and industrialisation in this watershed. So, residential area is scattered and is not very significant.Spatial distribution of detailed land use land cover class is depicted in Figs. 5,6 and 7. The majority of the area of agricultural land comes under Kharif 14447.07 ha, followed by Rabi 5850.79 ha and Kharif + Rabi 3773.80 ha. Waste land area was classified into land with scrub and land without scrub. The area covered under land with scrub was 11567.91 ha and land without scrub 541.14 ha.

3.2 Estimation of above Ground and below Ground Biomass of Forest

Knowledge of above ground biomass, below ground biomass, total biomass and total carbon stock of forest is important for assessing the contribution of forest lands to the global carbon cycle. The forest area covered under the Urmodi basin was 5138.30 ha. Diameter class distribution of dry, moist and wet zones were shown in Figs. 2,3 and 4. From the graph it was observed that there is large variation in diameter classes in different zones of Urmodi basin. Values of above ground below ground biomass of dry, wet and moist zone are shown in Table3. Values of above ground biomass indicate that tree diameter increases and the value of above ground biomass increases. The potential of forests to sequester carbon depends on the forest type, age of forest and diameter of trees. Values of above ground biomass were low in dry zone as compared to the moist and wet zone. Above ground biomass accumulated in each tree was 80% of the total biomass of the tree. These values coincide with many studies giving percentages of aboveground biomass, e.g. 81.9% (Nascimento and Laurance, 2002) and 81% [25]. A higher proportion of above ground biomass in the higher diameter classes emphasizes the importance of large trees in carbon storage. Similar results of above ground biomass range from 3.45 to 133.73 tonnes/0.5 ha and below ground biomass from 0.52 to 20.06 tonnes/0.5 ha observed in Chitteri reserve forest of the eastern ghats in India [26].

3.3 Generation of above Ground and below Ground Biomass and Total Biomass Map of Forest

Above ground and below ground biomass values for forest area of each village were assigned in attribute table in Arc GIS 10.2 to get the above ground and below ground biomass map of forest area as shown in Fig.8 and 9. Above ground biomass values were low in southern part of watershed which comes under dry zone of Urmodi basin. Above ground biomass was observed higher on northen side of Urmodi basin. North part of basin was covered under moist and wet zone. Total biomass values of forest were ranging from 84.53 to 186.63 tonnes/ha in study area. Total biomass map of forest was shown in Fig. 10. Similar results of total biomass were found in the range of 114.9 to 202.6 tonnes/ha for semi evergreen forests, Western ghats of Maharashtra [27]. The estimated total biomass for Kasewe plantation forest ranges from 47 to 141 t/ha with a mean of 94 t/ha [28].

3.4 Generation of Carbon Stock Map of Forest

Carbon stock values of each climatic zone of forest in Urmodi basin are shown in Table 3. The forest carbon stock map of Urmodi basin is shown in Fig.11. Similar values of forest carbon stock range from 36 to 68 tonnes/ha as observed in private forest of North Western ghats, Maharashtra [29]. The carbon stock ranges from Kasewe plantation forest from 22 to 66 t/ha with a mean of 44 t/ha [29].

Table 2. Spatial coverage of LU/LC classes in Urmodi Basin

Sr. No.	Land use/land cover	Area covered (ha)	Area (%)
1.	Agriculture	24071.66	55.06
2.	Water body	1603.369	3.67
3.	Forest	5138.301	11.75
4.	Wasteland	12109.05	27.70
5.	Built up	796.622	1.82

Table 3. ABG, BGB and carbon stock values of different climatic zones of Urmodi basin

Climatic zone	ABG (t/ha)	BGB(t/ha)	Total biomass (t/ha)	Carbon stock (t C/ha)
Dry	67.08-110.00	15.89-23.00	84.53-133.00	42.26-66.50
Wet	110.01-130.00	23.01- 31.25	133.01-161.25	66.50-80.62
Moist	130.01-148.12	31.26 – 38.51	161.27-186.63	80.63-93.31

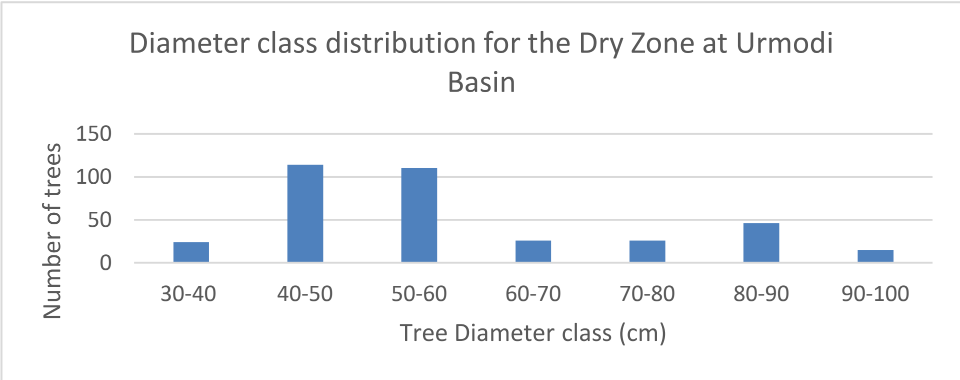


Fig. 2. Diameter class distribution for Dry Zone at Urmodi Basin

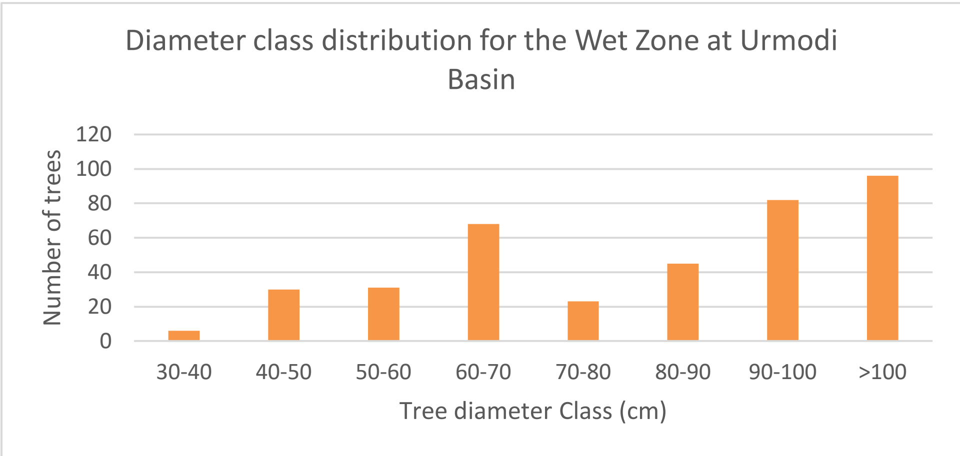


Fig. 3. Diameter class distribution for MoistZone at Urmodi Basin

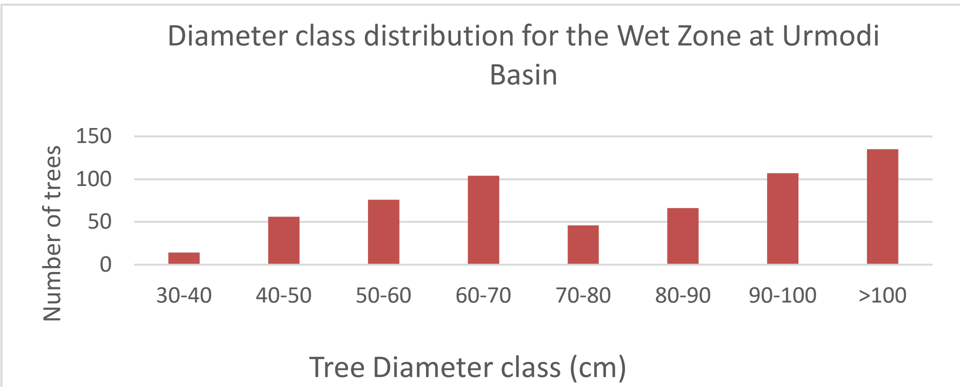


Fig. 4. Diameter class distribution for Moist Zone at Urmodi Basin

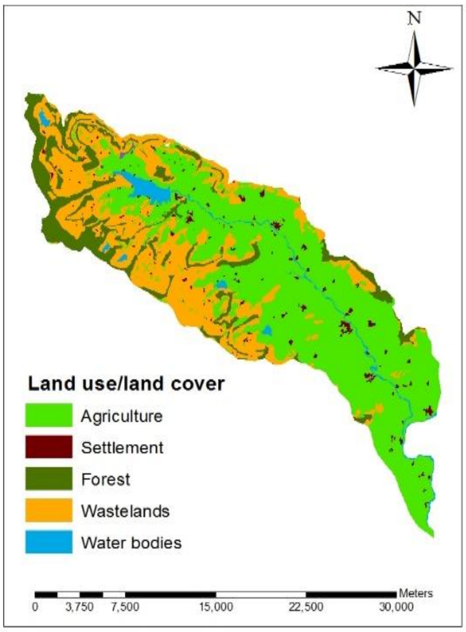


Fig. 5. Land use/land cover map (I) of Urmodi basin

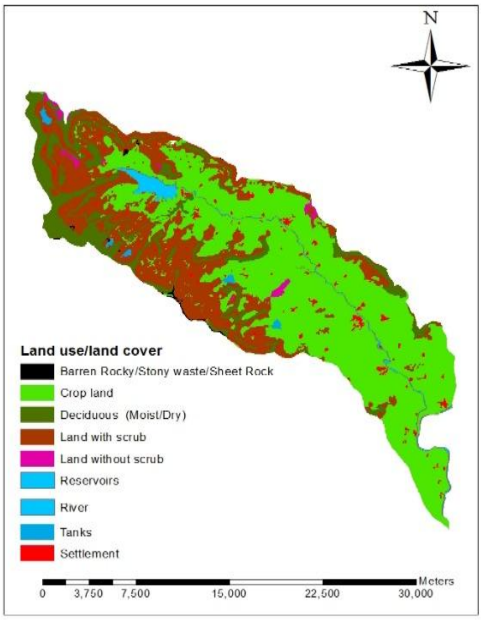


Fig. 6. Land use/land cover map (II) of Urmodi basin

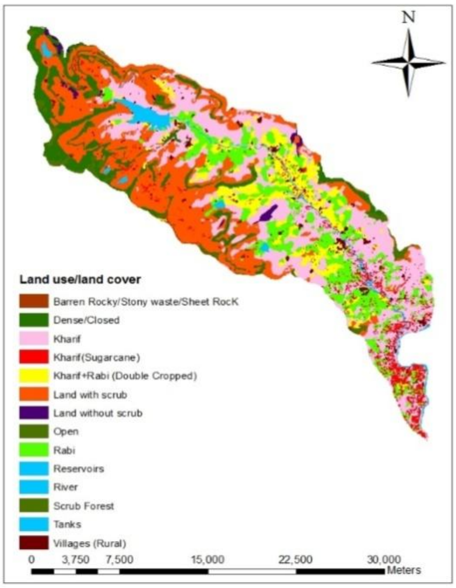


Fig. 7. Land use/land cover map (III) of Urmodi basin

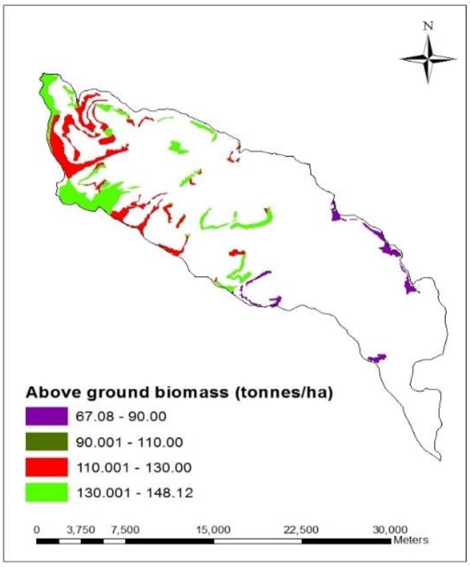


Fig. 8. Above ground biomass map of forest in Urmodi basin

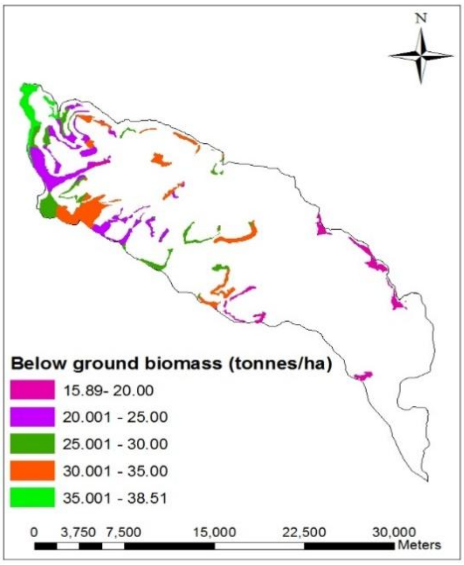


Fig. 9. Below ground biomass map of forest in Urmodi basin

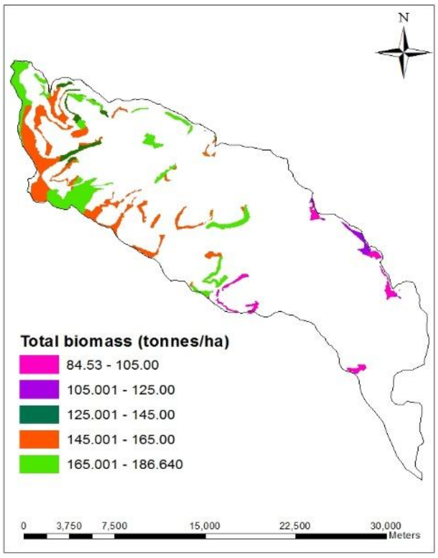


Fig. 10. Total biomass map of forest in Urmodi basin

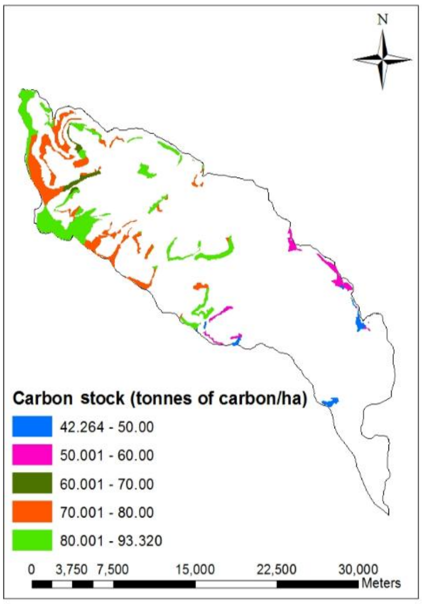


Fig. 11. Forest carbon stock map of forest in Urmodi basin

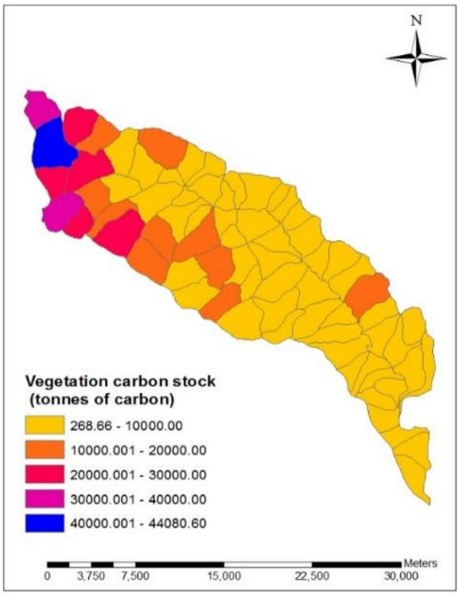


Fig. 12. Vegetation Carbon stock (Forest + Crop) map of Urmodi basin

3.5 Estimation of Biomass and Carbon Stock of Crops

The area covered under the agricultural land in Urmodi basin was 24071.66 ha. The major crops in Urmodi basin were wheat, paddy, soybean, sorghum and sugarcane. Biomass and carbon stock values of different crops in the area are given in Table 4.Average biomass values were calculated in tonnes/ha.Total plant biomass was highest at 90 days after sowing in all crops. Biomass values were highest in sugarcane, followed by sorghum, rice and wheat. Low biomass values were observed in soybeans. Similar values of plant biomass were observed in sorghum, paddy and soybean varied between

7.46 to 28.6, 4.14 to 21.8 and 4.56 to 17.29 g, respectively [27].Carbon stock values increased with the crop growth period. It may be due to a cumulative increase in the accumulation of biomass through photosynthesis. It is observed that sugarcane has the highest capacity for absorbing CO_2 from the atmosphere, resulting in net storage of CO_2 inside the soil, helping in the mitigation of the greenhouse gas effect [28]. Similar values of carbon stock observed in wheat range from 2.00 to 4.94 t C/ha and for paddy it ranges from 4.97 to 7.32 t C/ha [27], for sorghum, it ranges from 3.4 to 7.2 t C/ha [27] and for sugarcane ranges from 4.5 to 14.3 t C/ha [29]. Average biomass and carbon stock values for different crops were shown in Fig. 13.

3.6 Generation of Carbon Stock Map of Vegetation (Forest and Crop)

The rate of carbon stock values of each micro watershed ranged from 0.39 to 61.41 t C/ha. High carbon stock values were observed in those micro watersheds which have high coverage of forest areas and crop land areas, whereas low carbon stock values were associated with high degraded land in micro watersheds. Storage of carbon in vegetation is preferable due to its longer residence time and less risk of rapid release of carbon dioxide (CO_2) to the atmosphere [29].

3.7 Estimation of Amount of CO_2 Sequestered by Vegetation (Forest and Crop)

The total carbon stock value of vegetation the Urmodi basin was 0.53 million tonnes of carbon. The total amount of CO_2 sequestered by vegetation from Urmodi basin was 1.973 million tonnes of CO_2. Thus, vegetation plays an important role in the global carbon cycle by sequestering a substantial amount of CO_2 from the atmosphere [29].

Table 4. Biomass and carbon stock values for each crop

Sr. No.	Crop	Biomass range (t/ha)	Average biomass (t/ha)	Carbon stock range (t C/ha)	Average carbon stock (t C/ha)
1.	Wheat	7.07 - 9.11	8.09	3.54 - 4.56	4.04
2.	Paddy	8.26 - 9.37	8.68	4.13 - 4.68	4.34
3.	Soybean	6.63 - 8.23	7.50	3.31 - 4.11	3.75
4.	Sorghum	8.87 - 10.18	9.54	4.44 - 5.09	4.77
5.	Sugarcane	16.24 -18.13	17.36	8.12 - 9.06	8.68

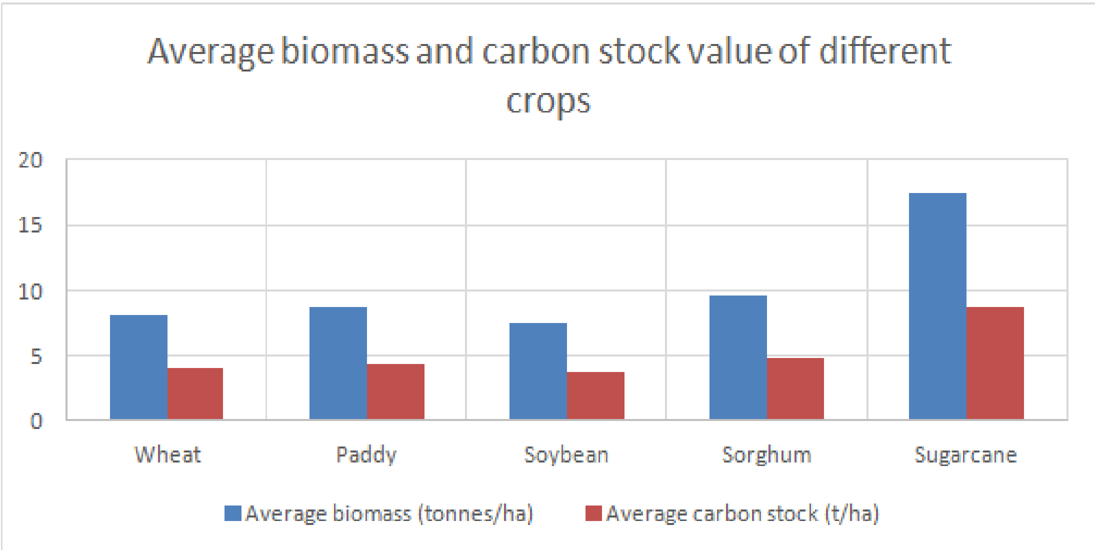


Fig. 13. Average biomass and carbon stock values for different crops

4. CONCLUSIONS

Carbon sequestration in forest and soil is the cost-effective strategy to mitigate climate change. Estimating carbon stocks in areas gives us an idea about the quantity of carbon available in the particular area. As some part of the carbon stock appears as run-off in rivers and finally goes to reservoirs and lakes where it is degraded via aerobic/ anaerobic degradation into GHGs which are emitted to the atmosphere, thereby causing global warming and climate change. So, estimation of biomass and carbon sequestration is important to monitor the changes in weather and hydrological cycles at watershed level. The carbon sequestration rate of vegetation (forest and crop) was estimated by the amount of CO_2 sequestered from each micro watershed. The rate of carbon stock values of vegetation ranged from 0.39 to 61.41 Mg of carbon/ha. The carbon stock value of vegetation was 0.53 million tonnes of carbon from Urmodi basin. The amount of CO_2 sequestered by vegetation from micro watersheds ranged from 985.16 to 161643.56 tonnes of CO_2. The amount of CO_2 sequestered by vegetation was 1.973 million tonnes of CO_2 for Urmodi basin. High carbon stock values were observed in those micro watersheds which have high coverage of forest areas, whereas 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. Vegetation plays an important role in the global carbon cycle by sequestering a substantial amount of CO_2 from the atmosphere. Thus, creation of new plantations in degraded areas is a better option for carbon storage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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