

Carbon sequestration for Major land use/land cover types of Urmodi basin of Maharashtra, India

Abstract:

Aim: To estimate total biomass, carbon stock and total amount of CO₂ sequestered from forest and crop from watershed. To develop the thematic map to study the spatial variation.

Place and Duration of Study: Urmodi basin of Satara, Maharashtra (India) during June 2015-16.

Methodology: In this research in situ destructive and non-destructive biomass estimation methods were used for assessing carbon stocks in different land use categories in Urmodi basin. Thematic maps were developed to study the spatial variation of carbon stock values in Urmodi basin.

Results: Carbon stock value of vegetation was 0.53 million tonnes of carbon from Urmodi basin. Amount of CO₂ sequestered by vegetation was 1.973 million tonnes of CO₂ for Urmodi basin..

Conclusion: 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 important role in the global carbon cycle by sequestering a substantial amount of CO₂ from the atmosphere. So, Carbon sequestration by growing forests is the cost-effective option for mitigation of global climatic change

Keywords: Biomass, Carbon stock, Carbon sequestration, Geographical Information System

1.INTRODUCTION

The rapid changes in land use pattern have resulted into forest degradation, land degradation, soil erosion and its adverse impact on global climate due to the emissions of greenhouse gases (GHGs) from atmosphere. Climate change with high carbon dioxide emissions have focused attention on the need for high-quality monitoring systems to assess how much carbon is present in terrestrial systems. Global potential for enhancing carbon storage in forest and agricultural ecosystems may be as much as 60-90 penta grams of carbon[4]. 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 [5,10].

Forest ecosystem plays very important role in the global carbon cycle. Forests provide various goods and services to the human beings. The transfer of greenhouse gases from the atmosphere into sinks (Forest and Soil) is one way of mitigating climate change [6]. However, agriculture is among the land use practices that emit as well as sequester CO₂. 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 stock is essential, as every land use system has either positive or negative impact on the carbon balance. Watershed is an important constituent of landscape for maintaining the ecological balance between natural resources development and conservation. Assessment of carbon stock from different land use

system is 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 is vital to set recommendation on the maintenance and enhancement of carbon stock. Most of scientists have focused their research on soil carbon stocks in 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 emission, carbon stock and sequestration are essential for developing strategies at watershed level that enhances 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 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 Urmodi basin in Satara district of Maharashtra. The geographical location of 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 Urmodi basin is 43,719 ha. Mean annual rainfall in the basin is of the order of 1250-1800 mm. Urmodi basin is having an undulating topography with slope ranging between 4 to 33%. The dry and moist mixed deciduous forests are found in Urmodi basin. The dominant agricultural crops taken in study area are paddy (*Oryza sativa*), wheat (*Triticum aestivum*), sugarcane (*Saccharum officinarum*), soybean (*Glycine max*) and sorghum (*Sorghum bicolor*).



Fig. 1 Study area

2.2 Land use/land cover Map of the Study Area

Changes in land use/land cover play a major role in the study of global climate change. Land has become scarce resource due to immense agricultural and demographic pressure. 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. For the present study land use/land cover map was derived from satellite images. The cloud free satellite data downloaded from LANDSAT imageries (<ftp.glcf.umd.edu>, Row No.147, Path No.48, February 2009) was used to prepare LU/LC map of Urmodi basin. Interpretation of multi-season satellite data was carried out to generate the land use/land cover map of study area. Thematic mapping of the different land use/land cover classes was achieved through supervised classification.

2.3 Carbon Sequestration

Carbon sequestration implies transferring atmospheric CO₂ into long-lived pools and storing it securely so that it should not be immediately reemitted. About two-thirds of terrestrial carbon is sequestered in the standing forests, forest under storey plants, leaf and forest debris and in forest soils[25]. 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

Forests play an important role in the global carbon cycle with a significant impact on climate change. Forests switch between being a source or a sink for carbon [15]. Forest ecosystems store 20–100 times more carbon per unit area than croplands and hence play a critical role in reducing ambient CO₂ levels, by sequestering atmospheric carbon in the growth of woody biomass through the process of photosynthesis and thereby increasing the SOC content [2].

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 stem, stump, branches, bark, seeds, and foliage [8]. 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 this study second method of 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 [21]. In this study 10 x 10 m plot were selected from forest area of each village in Urmodi basin. Number of trees were counted and girth at breast height (circumference) at 1.3 m from the ground surface was measured for estimation of carbon stock of trees from the forest area of Urmodi basin. Total 2220 trees readings were taken to estimate carbon stock values.

2.7 Estimation of above ground biomass and below 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. Diameter of tree was then calculated by dividing the π (3.14) to the girth of tree. Depending upon the girth at breast height and climatic conditions regression equations developed by Food and Agricultural Organization [7] were used to estimate above ground biomass of individual tree in Kg. The below ground biomass was calculated by multiplying above ground biomass taking 0.26 as the root to shoot ratio [3, 22].

Table No. 1. Regression equations based on DBH for different climatic zone

Source	Equation	DBH (cm)	Climatic Zone
[7]	$Y = \exp\{-1.996 + 2.32 \times \ln(\text{DBH})\}$	5 - 40	Dry (< 1500 mm)
[7]	$Y = 42.69 - 12.800 \times D + 1.242 \times D^2$	5 - 148	Moist (1500-4000 mm)

[7]	$Y = 21.297 - 6.953 * D + 0.740 * D^2$	4 -112	Wet (> 4000 mm)
-----	--	--------	-----------------

2.8 Generation of above ground biomass map and below ground biomass map of forest

Above ground and below ground biomass values were assigned in attribute table in Arc GIS 10.2 to get above ground and below ground biomass map of forest.

2.9 Estimation of total biomass and generation of map of forest

Total biomass of forest includes the above ground biomass and below ground biomass. Total biomass values of each forest area were assigned in attribute table in Arc GIS 10.2 to generate 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 biomass to carbon was used [5,23]. Carbon stock value of forest was calculated. These values were assigned in attribute table in Arc GIS 10.2 to get the carbon stock map of 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 [24]. The biomass (dry weight) is calculated by applying the moisture loss of the samples [16]. 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 [13]. At every sampling stage crops from $1 \times 1\text{m}$ 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 hot air oven at 60°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 to 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

Total biomass of crop was multiplied by 0.5 to get carbon stock values of crops. Carbon stock values were calculated for forest (above and below ground biomass) and crops. 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 attribute table in Arc GIS 10.2 to get carbon stock map of vegetation of Urmodi basin.

2.13 Amount of CO₂ sequestered by vegetation

The build-up of each ton of carbon removes 3.667 tonnes of CO₂ from the atmosphere [1]. Amount of CO₂ sequestered by each micro watershed was calculated from carbon stock values of forest and crop and then sum up to get the amount of CO₂ sequestered from Urmodi basin. This value represents the amount of CO₂ 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 CO₂ 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;

Table No. 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

It was found that almost 66.81 % of the land is covered under major two 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 detail land use land cover class is depicted in Fig. 5,6 and 7. Majority of area from 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. 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. Forest area covered under the Urmodi basin was 5138.30 ha. Diameter class distribution of dry, moist and wet zone were shown in Fig.2,3 and 4. From 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 Table 3. Values of above ground biomass indicate that tree diameter increases 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 total biomass of tree. These values were coinciding with many studies giving percentages of aboveground biomass, e.g. 81.9 % (Nascimento and Laurance, 2002) and 81 % [11]. 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 ranges 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 [20].

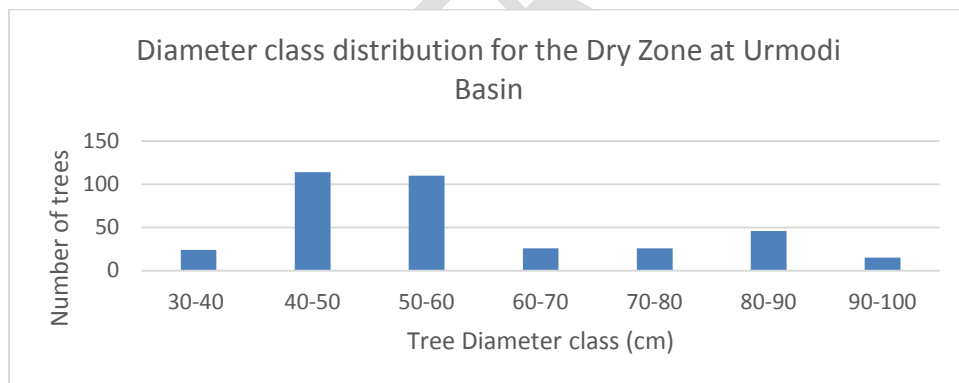


Fig.2 Diameter class distribution for Dry Zone at Urmodi Basin

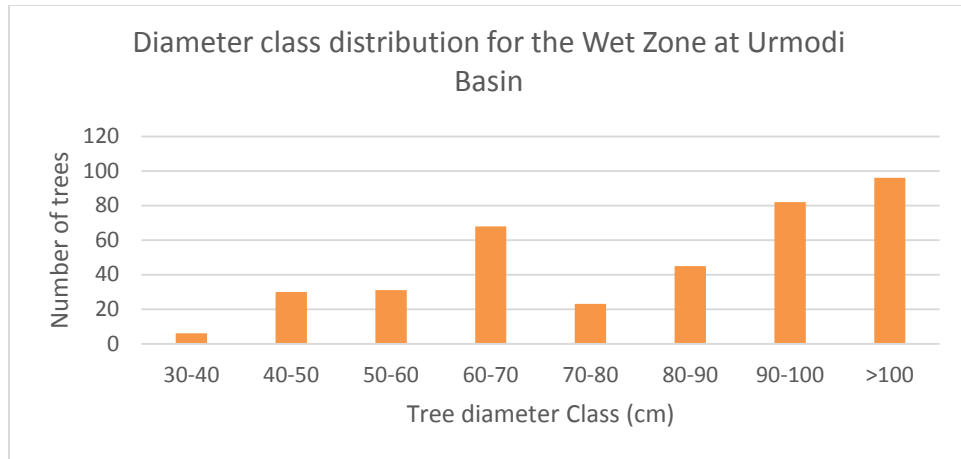


Fig.3 Diameter class distribution for Moist Zone at Urmodi Basin

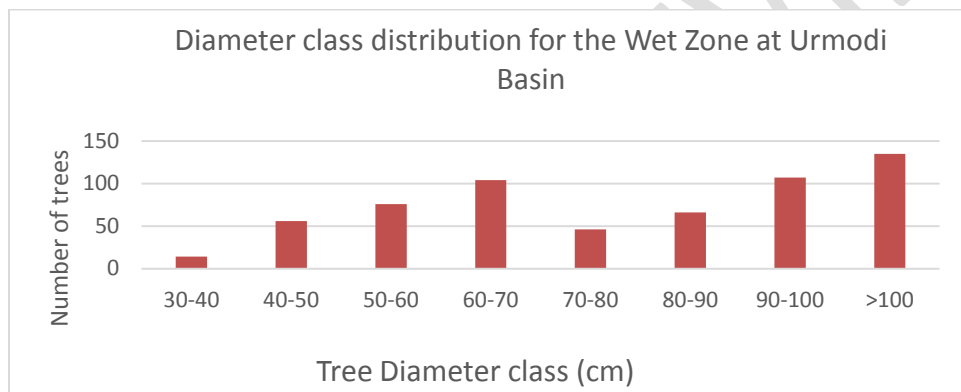


Fig.4 Diameter class distribution for Moist Zone at Urmodi Basin

Table No. 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 (tonnes of carbon/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

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 northern 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 [9].

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. Forest carbon stock map of Urmodi basin is shown in Fig.11. Similar values of forest carbon stock ranges from 36 to 68 tonnes/ha observed in private forest of North Western ghats, Maharashtra [19].

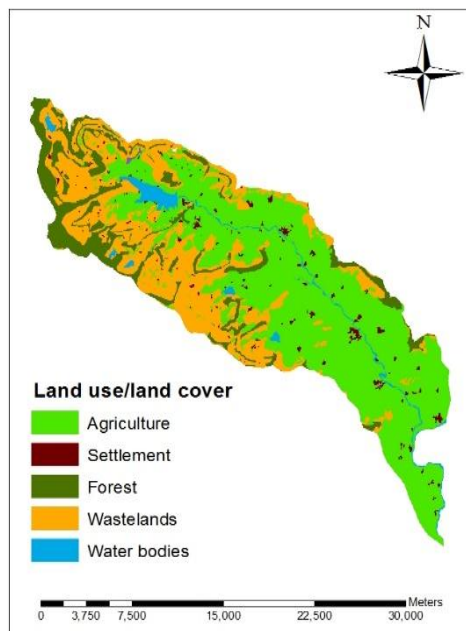


Fig.5 Land use/land cover map (I) of Urmodi basin

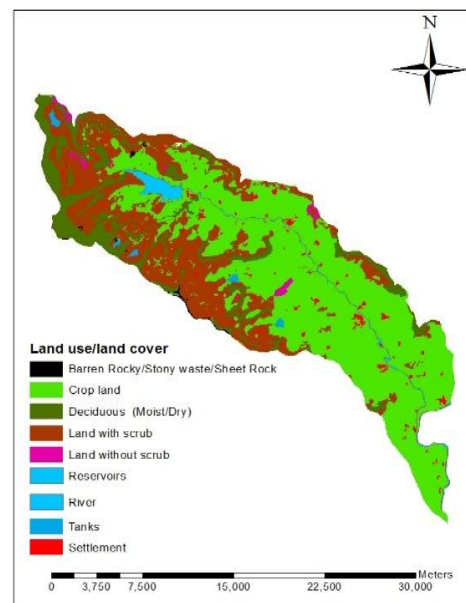


Fig.6 Land use/land cover map (II) of Urmodi basin

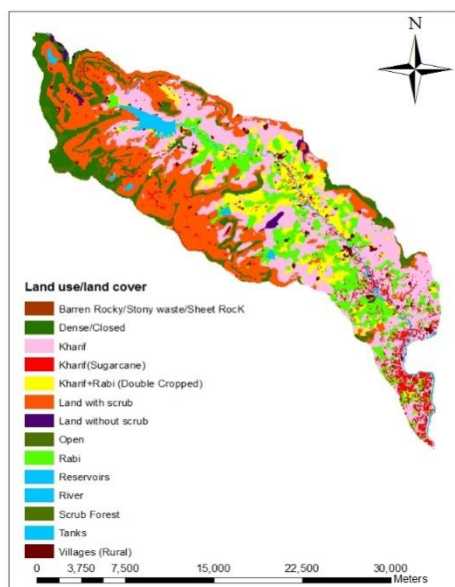


Fig. 7 Land use/land cover map (III) of Urmodi basin

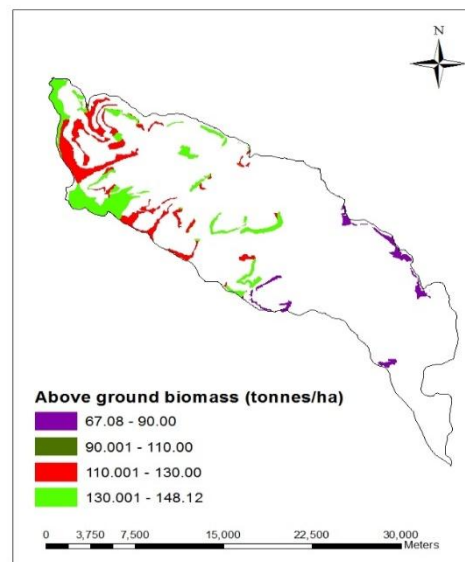


Fig. 8 Above ground biomass map of forest in Urmodi basin

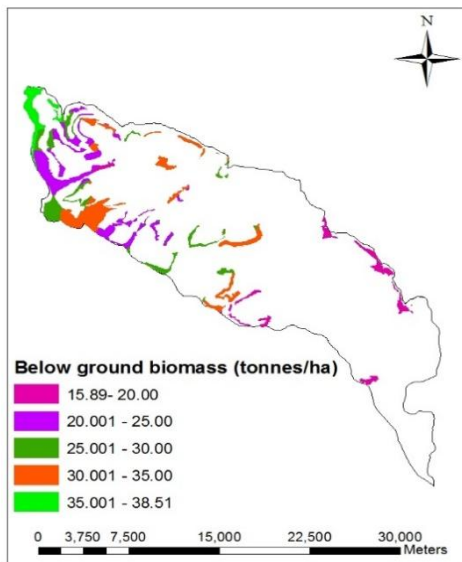


Fig. 9 Below ground biomass map of forest in Urmodi basin

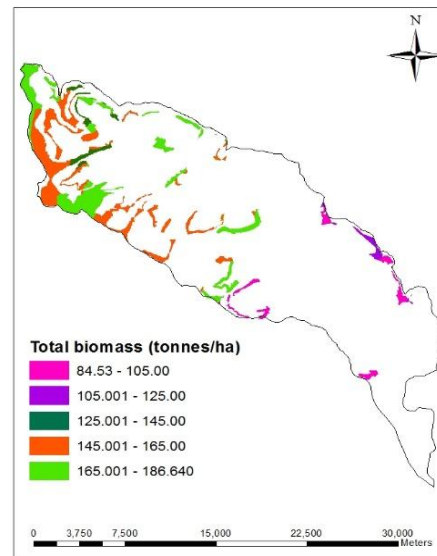


Fig. 10 Total biomass map of forest in Urmodi basin

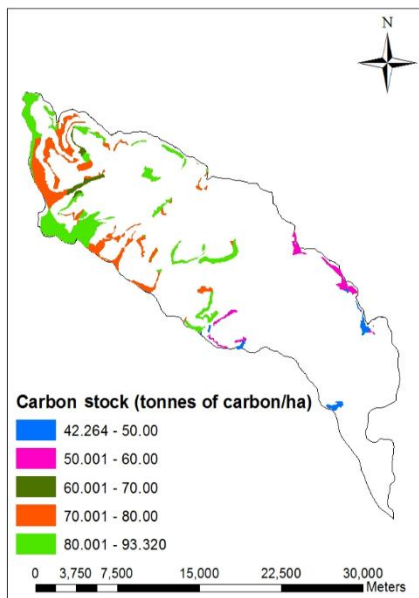


Fig. 11 Forest carbon stock map of forest in Urmodi basin

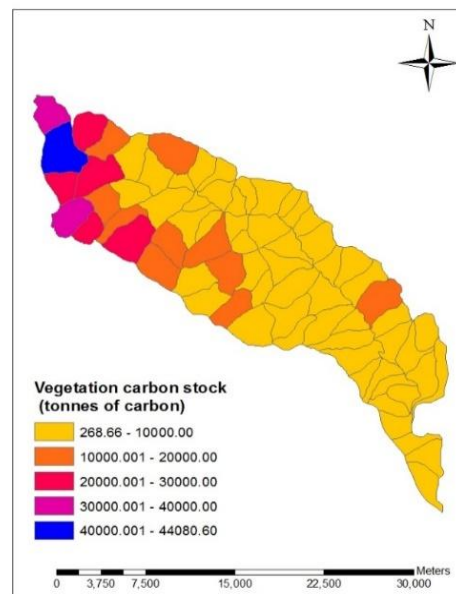


Fig. 12 Vegetation Carbon stock (Forest + Crop) map of Urmodi basin

3.5 Estimation of biomass and carbon stock of crops

Area covered under the agricultural land in Urmodi basin was 24071.66 ha. 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 soybean. 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 [13]. Carbon stock values increased with crop growth period. It may be due to cumulative increase in the accumulation of biomass through photosynthesis. It is observed that sugarcane has a highest capacity of absorbing CO₂ from atmosphere, resulting in net storage of CO₂ inside the soil, helping in the mitigation of the greenhouse gas effect [12]. Similar values of carbon stock observed in wheat ranges from 2.00 to 4.94 tonnes of carbon/ha and for paddy ranges from 4.97 to 7.32 tonnes of carbon/ha [13], for sorghum it ranges from 3.4 to 7.2 tonnes of carbon/ha [13] and for sugarcane ranges from 4.5 to 14.3 tonnes of carbon/ha [18]. Average biomass and carbon stock values for different crops were shown in Fig. 13.

Table No. 4 Biomass and carbon stock values for each crop

Sr. No.	Crop	Biomass range (t/ha)	Average biomass (t/ha)	Carbon stock range (t of carbon/ha)	Average carbon stock (t of carbon/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

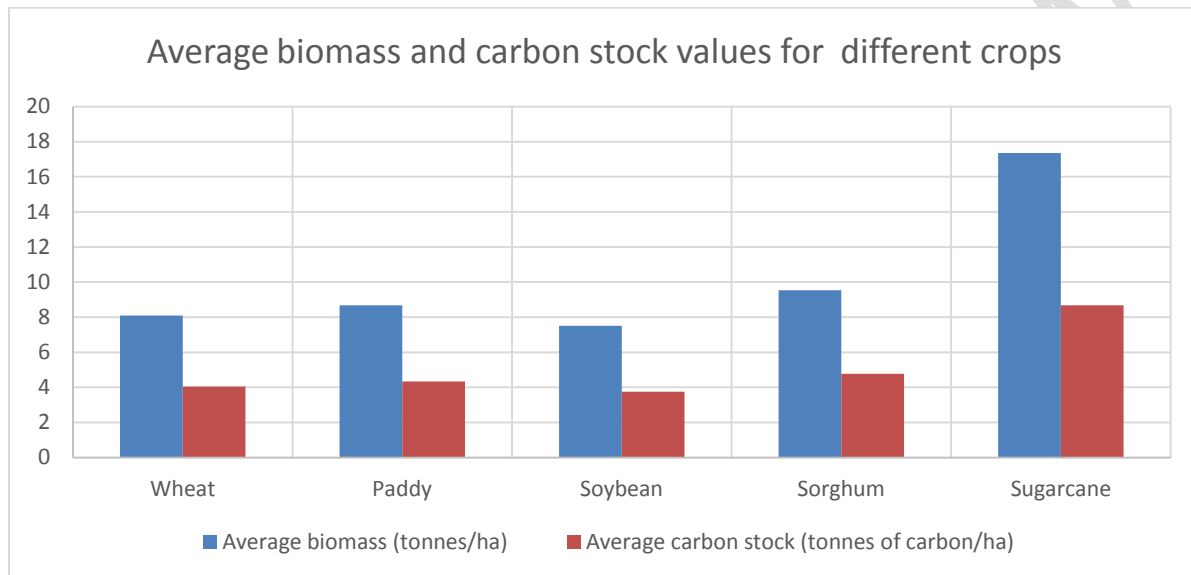


Fig. 13 Average biomass and carbon stock values for different crops

3.5 Generation of carbon stock map of vegetation (forest and crop)

Rate of carbon stock values of each micro watershed were ranging from 0.39 to 61.41 tonnes of carbon/ha. High carbon stock values were observed in those micro watersheds which are having high coverage of forest area and crop land whereas low carbon stock values were associated with high degraded land in micro watersheds. Storage of carbon in vegetation is preferable due to their longer residence time and less risk of rapid release carbon dioxide (CO₂) to the atmosphere [14].

3.6 Estimation of amount of CO₂ sequestered by vegetation (forest and crop)

Total carbon stock value of vegetation from Urmodi basin was 0.53 million tonnes of carbon. Total amount of CO₂ sequestered by vegetation from Urmodi basin was 1.973 million tonnes of CO₂. Thus, vegetation plays important role in the global carbon cycle by sequestering a substantial amount of CO₂ from the atmosphere [26].

4.CONCLUSIONS:

Carbon sequestration in forest and soil is the cost-effective strategy to mitigate climate change. Estimation carbon stock in watershed area gives us an idea about the quantity of carbon available in the particular area. As some part of 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 atmosphere, thereby causing global warming and climate changes. So, estimation of biomass and carbon sequestration is important to monitor the changes in weather and hydrological cycles at watershed level. Carbon sequestration rate of vegetation (forest and crop) was estimated to study amount of CO₂ sequestered from each micro watershed. Rate of carbon stock values of vegetation were ranging from 0.39 to 61.41 Mg of carbon/ha. Carbon stock value of vegetation was 0.53 million tonnes of carbon from Urmodi basin. Amount of CO₂ sequestered by vegetation from micro watersheds were ranging 985.16 to 161643.56 tonnes of CO₂. Amount of CO₂ sequestered by vegetation was 1.973 million tonnes of CO₂ for Urmodi basin. High carbon stock values were observed in those micro watersheds which are having high coverage of forest area 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 important role in the global carbon cycle by sequestering a substantial amount of CO₂ from the atmosphere. Thus, creation of new plantation on degraded areas is better option for carbon storage.

5.REFERENCES:

1. Bowen GD, Rovira AD. The rhizosphere and its measurement to improve plant growth. *Advances in Agronomy*. 1999; 66: 1-102.
2. Brown K, Pearce D. The economic value of non-market benefits of tropical forests carbon storage. In: Weiss, J. (Ed.), *The economics of project appraisal and the environment: new horizon in environment economics*. E. Elgar, Aldershot. 1994; 102–119.
3. Cairns MA, Brown S, Helmer EH, Baumgardner GA. Root biomass allocation in the world's upland forests. *Oecologia*. 1997; 111:1-1.
4. De Jong, Montoya BHJ, Gomez G. An economic analysis of potential for carbon sequestration by forest: evidences from southern Mexico. *Ecological Economics*. 2000; 33: 313-327.
5. Dixon RK, Trexler MC, Wisniewski J, Brown S, Houghton RA, Solomon AM. Carbon pools and flux of global forest ecosystems. *Science*. 1994; 263: 185-190.
6. EPA. Environmental Protection Agency: Carbon sequestration in agriculture and forestry: Local Scale. Accessed on 3 January 2007.
7. FAO.1997. Estimating biomass and biomass change of tropical forests: a primer, by S. Brown.
8. FAO Forestry Paper No. 134, Rome.FAO. 2009.Assessment of the status of the development of the standards for the terrestrial essential climate variables. Biomass global terrestrial observing system Rome, 1-18.
9. Gairola S, Sharma CM, Ghildiyal SK, Suyal S. Live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya (India). *Current Science*, Vol. 2011; 100 (12): 1862-1870.

10. Goodale CL, Heath LS, Houghton RA, Jenkins JC, Kohlmaier GH, Kurz W, Liu S, Nabuurs GJ, Nilsson S, Shvidenko AZ, Apps MJ, Birdsey RA, Field. CB. Forest carbon sinks in the northern hemisphere. *Ecological Applications*. 2002; 12: 891-899.
11. HenryM, Tittonell P, Manlay RJ, Bernoux M, Albrecht. A. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. *Agriculture Ecosystems and Environment*. 2009; 129: 238-252.
12. Junior LN, De Figueiredo EB, Panosso AR. A review on soil carbon accumulation due to the management change of major Brazilian agricultural activities. *Brazilian Journal of Biology*. 2012; Vol. 72 (3): 775-785.
13. Kushwah SK, Dotaniya ML, Upadhyay AK, Rajendiran S, Coumar MV, Kundu S, Subba Rao A. Assessing carbon and nitrogen partition in kharif crops for their carbon sequestration potential. *National Academic Science Letter*. 2014; 37(3):213-217.
14. Lal R. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Climate Change*. 2001; 51: 35-72.
15. Lindner M, Karjalainen T. Carbon inventory methods and carbon mitigation potentials of forests in Europe: a short review of recent progress. *European Journal of Forest Research*. 2007; 126:149-156.
16. Losi CJ, Siccama TG, Condit R, Morales JE. Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management*. 2003; 184: 355-368.
17. Nascimento HEM, Laurance WF. Total above ground biomass in central Amazonian rainforests: a landscape-scale study. *Forest Ecology and Management*. 2002; 168:311-321.

18. Paes LAD, Marin FR. Carbon storage in sugarcane fields of Brazilian South-Central region. Centro de tecnologia canavieira. Technical report. 2011; 1-13.
19. Patel A, Godbole A, Sarnaik J. Estimation of C-stock in private forest of North Western Ghats, Maharashtra. Bioscience Discovery. 2015; 6 (1-I):27-31.
20. Pragasan LA. Carbon stock assessment in the vegetation of the Chitteri reserve forest of the eastern ghats in India based on non-destructive method using tree inventory data. Earth Science and Climate Change. 2014; 1-9.
21. Raul PH. Assessing carbon stocks and modelling win-win scenarios of carbon sequestration through land-use changes. Food and Agriculture Organization of the United Nations, Rome. 2004; 1-27.
22. Ravindranath NH, Ostwald M. Carbon inventory methods handbook for greenhouse gas inventory, carbon mitigation and round wood production projects. Advances in Global Change Research. Springer-Verlag, Berlin. 2008; 121-154.
23. Ravindranath NH, Somashekhar BS, Gadgil M. Carbon flow in Indian forests. Climate Change. 1997; 35:297-320.
24. Scurlock JMO, Johnson K, Olson RJ. Estimating net primary productivity from grassland biomass dynamics measurements. Global Change Biology. 2002; 8: 736-753.
25. Sedjo RA, Sohngen B, Jagger P. Carbon sinks in the Post-Kyoto World. RFF Climate Issue Brief No. 13, Internet Edition. 1998.
26. Vashum KT, Jaykumar S. Methods to estimate above ground biomass and carbon stock in natural forests - A Review. Journal of Ecosystem Ecography. 2012; 2(4):2-7.