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A REVIEW ON METHODS AND CASE STUDIES ON CARBON SEQUESTRATION POTENTIAL OF URBAN-GREEN AREAS

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ABSTRACT

Urban-green areas provide various ecosystem services; one such service is that tree species lower the temperature in the atmosphere and have tremendous potential to sequent carbon. The present review particularly focuses on the different methods used for above-ground biomass estimation. Two methods, field methods (destructive and non-destructive), and remote sensing methods (optical remote sensing, RADAR, and LiDAR) are used for biomass estimation. It has been found that all these methods have some advantages and limitations. In addition to this, we have reviewed various case studies of urban tree species' potential to sequester carbon dioxide.

Keywords: Above-ground biomass, Carbon sequestration, Urban-green areas

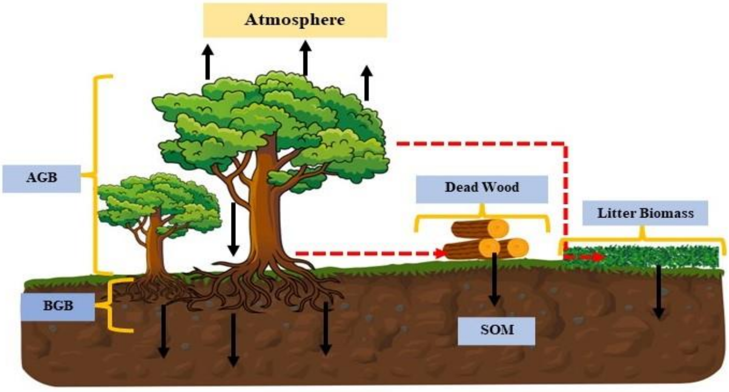
INTRODUCTION

Global warming is a major environmental problem caused by long-term changes in climate and temperature patterns due to an imbalance in the carbon cycle (Bherwani et al., 2022). In past decades, due to the industrial revolution, the atmosphere has experienced an increasing trend in the concentration of CO_2 and other greenhouse gases (GHGs) (Upadhyay, 2019). The United Nations Framework Convention on Climate Change (UNFCC) was established in 1992 in Rio de Janeiro in response to climate change and global warming for stabilizing atmospheric CO_2 and other GHGs. Later, the Kyoto Protocol was implemented to combat climate change, which included the Clean Development Mechanism (CDM) to reduce carbon emissions by managing and carrying out restoration programs for natural forests. (Ramachandran et al., 2007; Singh et al., 2011; Upadhyay, 2019). Two approaches are used in research on the issue of rising atmospheric CO_2: (1) lowering carbon emissions to keep the associated rise in global temperatures below a specific level, and (2) lowering atmospheric CO_2 concentrations through carbon capture and sequestration (CCS) (Bherwani et al., 2022). In urban cities, the atmospheric levels of CO_2 have risen from 280 ppm in the pre-industrial era to the present level of 375 ppm due to the use of fossil fuels (Ramachandran et al., 2007). According to the reports of the International Council of Local Environmental Initiatives (ICLEI), India's metropolitan cities have greater average per capita carbon emissions of 1.19 metric tonnes than non-metropolitan cities, which have lower average per capita emissions of 0.90 metric tonnes (Singh et al., 2021).

Vegetation on land and in the ocean acts as a major scrubber of atmospheric CO_2 as they fix carbon and store it in the biomass during photosynthesis, while the carbon returns to the atmosphere when the plant debris is consumed by animals or burned in fires (Jaiswal, 2018; Upadhyay, 2019). The forest ecosystem contributes to a large amount of biomass as they have large canopy cover and tree diversity (Houghton, 2005; Lü et. al. 2010). Natural forest is the largest carbon sink after marine ecosystem, it has the potential to stabilize 2-4 Gt (Gigatons) of atmospheric CO_2 concentrations annually through sequestration (Houghton, 2005; Lü et al. 2010; Qureshi et al. 2012; Hansen et al. 2013).

The term "trees outside forests" (TOF) is used for non-forest trees like agroforests, urban forests, and rural forests, which play a vital role in the sequestration of carbon (Thomas et al., 2021; Bherwani et al., 2022**)**. Urban green space includes vegetation in and around urban areas that gives social, economic, environmental, and aesthetic benefits; this includes city parks, gardens, natural vegetation, green spaces on campus, private property, and roadside trees (Chaudhry & Tewari, 2011; Bherwani et al., 2022). Urban forest areas not only sequester carbon but also provide various ecosystem services such as biodiversity conservation, reduces temperature, microclimate regulation, stabilizing soil, groundwater recharge, and prevention of soil erosion (Singh et al., 2021). Studies conducted by several researchers observed that urban green areas play a significant role in limiting the city's carbon footprint (Strohbach et al., 2012). Urban forestry initiatives offer carbon benefits, especially in the near future, if they are integrated with social, cultural, and developmental objectives (Prabha et.al., 2013)

Biomass and Carbon Pools:
The Intergovernmental Panel on Climate Change (IPCC) divided the terrestrially stored carbon biomass into five pools, which are listed in Figure 1.



Living Biomass	i. Above-ground biomass (AGB) ii. Below-ground biomass (BGB)
Dead Biomass	i. Dead Wood ii. Litter
Soil Biomass	Soil organic matter (SOM)

Figure 1: Various pools of Carbon Biomass (**Prepared from ISFR, 2017 & ISFR, 2021**)

The "Good Practise Guidance" (GPG) developed by the IPCC (2003) has universally identified six land use classes (LULUCF): forest land, cropland, grassland, wetland, settlement, and other lands for the assessment of carbon stocks (**ISFR**, 2017).

METHODS USED FOR CARBON STOCK ESTIMATION:

There are two methods destructive and non-destructive methods for evaluating the carbon sequestration of various tree species, where field data is collected. In addition, remote sensing techniques are also integrated with the traditional field method. The estimation of biomass for trees typically consists of three components: below-ground biomass, which includes roots; dead above-ground biomass, such as litter and fallen branches; and live above-ground biomass, which includes trees and plants (Ugle et al., 2010; Pascua et al., 2021). The living biomass above the soil above-ground biomass of tree species is widely examined through field measurements (Ugle et al., 2010; Vashum & Jayakumar, 2012). The main objective of the paper was to review various approaches for biomass estimation and studies on carbon sequestration in urban areas.

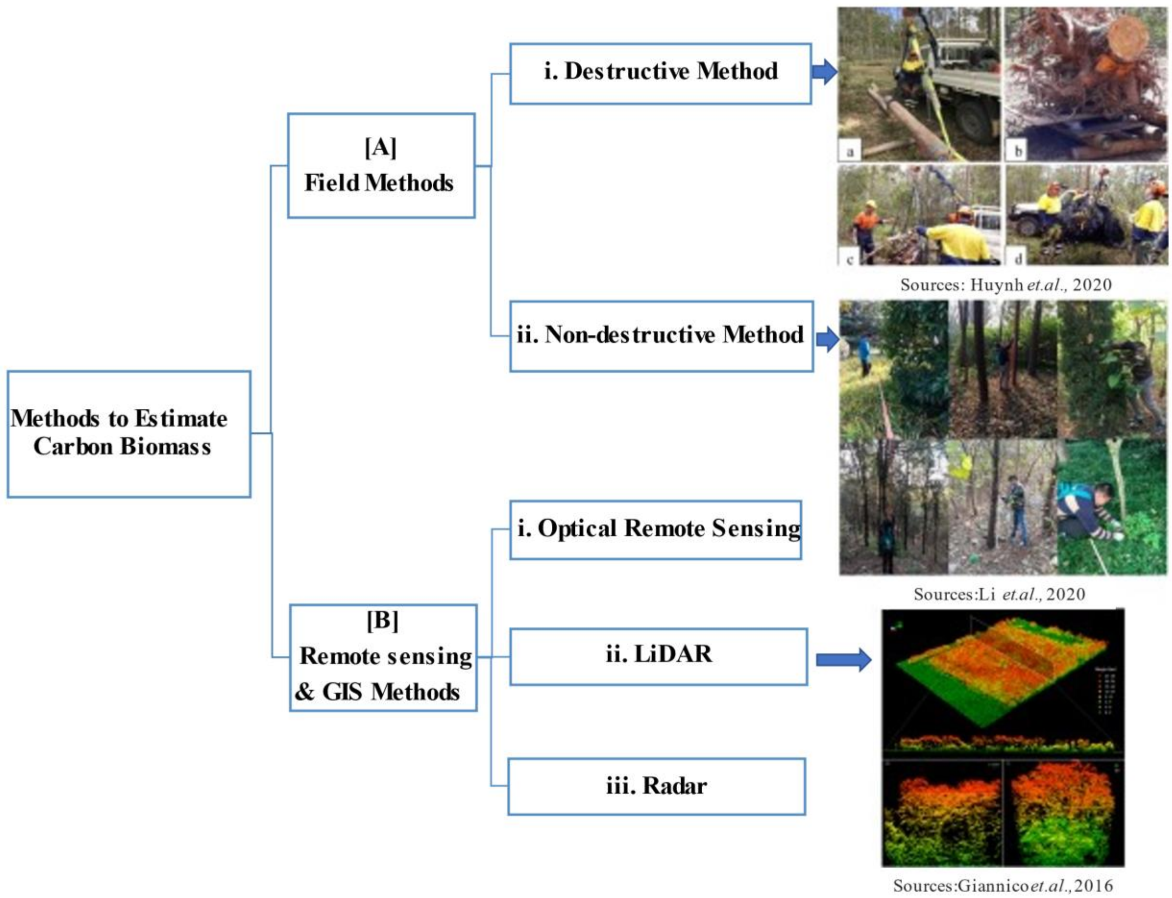


Figure 2: Different Methods to Estimate Carbon Biomass
(Image sources: Giannico et.al., 2016; Huynh et.al., 2020; Li et.al., 2020)

A. Field Methods.

i. Destructive methods:

The direct approach for estimating above-ground biomass and the carbon stocks stored in natural forests is called the destructive method, also known as the "harvest method." (Jaiswal, 2018). This method involves the harvesting of various parts of the tree, like the trunk, leaves, and branches, for both fresh weight measurement and oven-dry weight measurement (Tadese et al., 2019). By using this technique, it is possible to derive allometric equations due to its high accuracy because this method can determine individual tree biomass (Ravindranath and Ostwald, 2008; Tadese et al., 2019). There are certain difficulties of the harvest method, like that it is time-consuming, expensive, limited to a small area, and cannot be used for rare species. (Montès et al., 2000; Upadhyay, 2019).

ii. Non-destructive methods:

A non-destructive technique estimates a tree's biomass without cutting it down. When it comes to areas with rare or protected tree species, this method of biomass estimation is particularly useful (Montès et al., 2000; Jaiswal, 2018; Tadese et al., 2019). For estimation of the above-ground biomass, the diameter at breast height (DBH) or girth at breast height (GBH), tree height, canopy, and wood density are measured (table 1) (Ugle et al., 2010; Upadhyay, 2019). In the non-destructive method, biomass is estimated by simply multiplying the plant volume by the density of the wood in the plant (Vashum & Jayakumar, 2012**;** Upadhyay, 2019). According to Montès et al. (2000), using non-destruction methods for biomass assessment can lead to 2.5–7.5% per tree error.

Table 1: Instruments used for Above-ground biomass of tree species

Non-destructive methods	Instruments Used
Tree Girth (DBH or GBH)	Measure tape and Tree calipers

Tree height:	Suunto clinometer, Vertex digital hypsometer Forestry laser rangefinder, Blume-Leiss or Haga Altimeter
Wood density:	Weight balance and Oven

(Sources: Jaiswal, 2018 & https://www.monumentaltrees.com/en/content/measuringheight/)

Remote Sensing methods:

Field surveys are the most common and accurate method for estimating the biomass of different tree species, but they are also time-consuming, costly, and only applicable to a small area. The integration of remote sensing technology with established methodologies can be a practical and affordable way to gather data over a large area (Vashum & Jayakumar, 2012). There are three different categories of remote sensing techniques, namely optical remote sensing, radio detection and ranging (RADAR), and light detection and ranging (LiDAR) (**Sodhi, 2021)** for biomass estimation.

On the basis of spatial resolution, optical remote sensing sensors can be divided into three categories: coarse spatial resolution (more than 100m) like MODIS, SPOT, medium-resolution data (10–100 m) Landsat 4 5 7 8 TM Enhanced TM+, Sentinal, LISS II, and fine spatial resolution data (5 m) Quick Bird, IKONOS, Worldview (Kumar et al., 2015; Tadese et al., 2019). It is observed that the spatial resolution is lower, the information on biomass estimation is more accurate. Optical data are ideal for studying horizontal vegetation features like canopy cover rather than vertical vegetation like tree height (Lu et.al., 2016).

RADAR data are frequently employed in the assessment of forest stand parameters due to their ability to work day and night and capture backscattering from the upper canopy and woody biomass. In addition to this, it has cloud penetration ability (Yaklaşmlar, 2012; Sodhi, 2021). Synthetic aperture radar (SAR) data is a promising approach for biomass estimation it is collected in the X, C, L, and P bands (Lu et.al., 2016). These L-bands are widely used for biomass estimations due to their longer wavelengths and deep penetration into the canopy of the tree. SAR data has four polarisations: HH, HV, VH, and VV (**ISFR** 2021**,** Sodhi, 2021) The most common RADAR data source for biomass estimation is JERS-1 (the early 1990s), ALOS/PALSAR 1, ALOS/PALSAR 2 (2014), ERS 1-2, Envisat 1–2 up to 2002, and RadarSat 1 (1995) and RadarSat 2 (2007) (Tadese et al., 2019). LiDAR is an active RS technique; it is the equipment used for biomass estimation that emits laser when placed in the study area and measures the energy reflected and the interval between the pulse's emission and receipt (Yaklaşmlar, 2012; Sodhi, 2021). LiDAR can study the ground's and canopy's spatial variance, giving accurate structural information on the vegetation. This leads to more accurate estimations of basal area, crown size, tree height, and stem volume. (Tadese et al., 2019; Vashum & Jayakumar, 2012). But for the purpose of estimating biomass in larger regions, the LiDAR data acquisition method is expensive and time-consuming (Kumar et al. 2015). Both RADAR & LiDAR data can give an idea about horizontal and vertical vegetation features.

All of these RS methods can measure factors that can be correlated to biomass, such as height, canopy, LAI, and many others, but they cannot quantify the amount of biomass that is present in the forest. This method is used for prediction models and cannot be used to develop species-specific allometric equations (Vashum & Jayakumar, 2012). Thus, to validate remote sensing data, ground truthing is necessary.

Case studies on carbon sequestration in urban-green areas

There have been a few research from different parts of India that have contributed for understanding the role of urban trees to store carbon. This section reviews a few such studies.

Waran & Patwardhan (2001) calculated the above-ground biomass of the trees in Pune City. The outcomes revealed that Pune has numerous industries with a potential annual carbon emission and sequestration of 15,000 metric tonnes and emits 780,000 metric tonnes of carbon per year, but its tree cover is only 2%, thus the atmosphere is overburdened with GHG emissions (Waran & Patwardhan, 2001; Bherwani et.al., 2022). The carbon sequestration of the roadside trees in Vadodara city was investigated **(Kiran & Kinnary, 2011)** at various sites, and found that amount of carbon trapped by these roadside trees was 73.59 tonnes of CO2 per year. Small trees with less mean trunk girth contribute less to biomass and carbon sequestration, as was concluded from an analysis of trees near the Cooum river bank in Chennai city (Pachiappan & Ushalaya, 2013).

Parmar et.al. 2011 studied the carbon sequestration of vegetation cover in eight major urban districts of Gujarat. To determine the current year (2011) and future year (2021) carbon stocks, values of state-specific annual biomass increment, tree cover area, average annual above and below biomass, the ratio of AGB/BGB, and carbon fraction of the dry matter were used. It was determined that the carbon stock may get increased from 12.86 lakh metric tons in 2011 to 28.74 lakh metric tons by 2021.

Suryawanshi et.al., 2014 studied the AGB and BGB of tree species from selected areas of the North Maharashtra University campus in Jalgaon. A total of 462 individuals of 10 tree species were found from which Moringa olifera was the dominant species and sequestrated 15.775 tons of carbon followed by Azadirachta indica 12.272 tons. Study of the carbon sequestration of trees at Golapbag University in West Bengal, all species had a positive correlation between GBH and carbon sequestration potential, except for Mangifera indica, and the correlation between height and carbon sequestration potential revealed a positive value for all species except Swietenia mahagoni and Albezia saman (Das & Mukherjee, 2015). Estimation of biomass and carbon stocks at Solapur University, Maharashtra, (Gavali and Shaikh 2016) reported that there was a significant correlation between carbon storage and the age of the species. The study also concluded that higher proportions of large trees in urban green spaces are likely to have a wider impact on carbon stocks than in nonurban forests.

Ghosh et.al., 2017 studied four lake parks in Kolkata for assessment of the yearly carbon sequestration potential where water, soil, lawn, grass, and tree species pools were calculated. Singh et. al., 2021, studied the carbon sequestration potential of tree species around the campus of Amity University, Noda, by a non-destructive method. 45 tree species were recorded with 139.86 tons of sequestration potential, Ficus benjamia and Alistonia scholaris, which had the greatest CSPs of 30.53 tonnes and 16.38 tonnes, respectively. Few urban green places like municipal parks and gardens in Pune city for the analysis of different carbon pools such as above-ground biomass, below-ground biomass, leaf litter, and organic carbon in the soil. The research found that native species (80966.55 t) have a greater potential for sequestering carbon than exotic plants (26928.4 t) (Vijayalaxmi and Dnyanesh, 2021).

In a study conducted by Mohan et. al., 2022, the old campus of Jammu University was analyzed for its carbon stocks. Total CO2 sequestration by tree species was 185.84 kg, and 495.65 kg of net oxygen production was calculated from the studied area. The capacity of trees to store carbon at the National Botanical Research Institute, CSIR Lucknow (Behera et.al., 2022), by measuring diameter at breast height, tree height, litterfall, and leaf area index was taken. The maximum above-ground biomass was found to be in Tectona grandis, at 71.94 Mg/ha. A study was carried out using Landsat imagery for five cities in India to evaluate the economic significance of urban green spaces in sequestrating carbon using normalized difference vegetation index (NDVI) (Bherwani et al., 2022) result revealed that the maximum amount of carbon was sequestered in Bengaluru (141.83 MT), whereas lowest (1.51 MT), in Leh's due to cold desert and no urban forest cover. The cities with the highest carbon sequestration and valuation values were Bengaluru and Delhi. The values for carbon sequestration varied from 55 to 5164 million dollars for MPM (market price model) estimates and 69.69 to 6537.15 million dollars for SCC (social cost of carbon) estimates.

CONCLUSION

Trees are an important part of the urban landscape. They play a significant role source and sink of carbon. As a result, they have the potential to play a key role in climate mitigation. So the estimation of carbon biomass is important; it gives an idea about species-specific carbon sequestration potential. Integration of both conventional field measurements and advanced remote sensing will give higher accuracy for the estimation of carbon stocks in urban landscapes. Native trees are found to be ecologically advantageous due to their high carbon fixing efficiency and species might be useful for reducing urban pollution. Thus, to determine which tree species are optimal for carbon sequestration, more study is needed in the areas of urban tree biomass estimation.

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