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Popular Article

RS and GIS Technology for Estimation of Carbon Sequestration

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Abstract

Estimating carbon sequestration is becoming a crucial part of the fight against global warming. Continuous increase in atmospheric Co_2 levels resulting in global warming and raising sea level threatening to agriculture. CS is essential to reduce the amount of carbon dioxide in the atmosphere. Estimation of CS in forests and other plantings can be obtained by assessing biomass. Though more accurate, traditional assessment methods based on field measurements are expensive, labor-intensive, and challenging to execute on a broad scale; Remote sensing (RS) integrated with Geographic Information Systems (GIS) techniques are widely applied to different natural resources applications and biomass assessment. RS can detect and record forest variables over wide areas with high accuracy and speed at a relatively low cost. The benefits of these technologies will also be increased by modeling RS data in a GIS framework, allowing for the analysis of a variety of supplementary and field data. We tried to provide synthesized information on different methods of estimation of CS with main emphasis on RS and GIS.

1. Introduction

Carbon is found in all living organisms and is the major building block for life on Earth. Carbon exists in many forms, predominately as plant biomass, soil organic matter and as the gas carbon dioxide (CO_2) in the atmosphere and dissolved in seawater. Carbon emission through different sources is a causal factor for global warming and is the most dreaded problem across the world. Over the past many centuries, human activities like burning of fossil fuels, deforestation and urbanization have resulted in high concentration of CO_2 and other greenhouse gases in the atmosphere (Giri *et al*., 2017). For e.g. the amount of carbon dioxide in the atmosphere has been remove CO_2 from the atmosphere through absorption. Forests, soils, oceans and atmosphere are agents for storage of carbon

(Giri *et al*., 2017).

Carbon sequestration through forests is estimated at 2-4 gigatons of carbon annually. Almost about 60% of sequestered carbon is returned to the atmosphere by the process of deforestation. Such studies are needed for studying and predicting long-term behavior of carbon sequestration as a part of the global and climate change scenarios (Issa *et al*., 2020).

Types of Carbon Sequestration

Any reservoirs or stores of carbon are called carbon pools. Storing of CO_2 occurs at three levels (Dahy *et al*., 2020):

1. Terrestrial (plants and soil),
2. Geological (underground) and
3. Ocean (deep in oceans)

1. Terrestrial Sequestration:

Terrestrial or biologic sequestration is the process of storing atmospheric CO_2 as carbon in the stems, roots of plants and soil. Photosynthesis is the process of converting CO_2 in the atmosphere to biomass stored in plants (Dahy *et al*., 2020). It is a set of land management practices that maximizes the amount of carbon that remains stored in the soil and plant material for the long term. Wetland management, rangeland management, and reforestation are examples of terrestrial sequestration (Giri *et al*., 2017).

2. Geological Sequestration:

Geologic sequestration is long term storage CO_2 in geologic zones deep underground. Geologic sequestration is the method of storage that is generally considered for carbon capture and storage (CCS) projects. CO_2 is injected into deep underground rock formations, at depths of one km or more (Giri *et al*., 2017).

3. Ocean Sequestration:

Carbon Sequestration by direct injection into the deep ocean involves the capture, separation, transport and injection of CO_2. The ocean represents a large potential sink for sequestration of anthropogenic CO_2 emissions. Currently, the ocean actively takes up one-third of our anthropogenic CO_2 emissions annually. On a time scale of 1000 years, about 90 percent of today's anthropogenic emissions of CO_2 will be transferred to the ocean. Ocean sequestration strategies attempt to speed up this process to reduce both atmospheric CO_2 concentrations and their rate of increase (Giri *et al*., 2017).

3. Advantages of Carbon Sequestration

- Forested areas are large carbon sinks because enormous amounts of carbon dioxide are naturally stored in the soil, a result of photosynthesis.
- By absorbing extra carbon dioxide from the atmosphere, carbon sequestration prevents the occurrence of climate change.
- Deep injection of carbon dioxide improves the extraction of fuels like oil and methane from their reserves in addition to removing excess pollutants from the air.
- Renewable energy sources like solar and wind are unlikely to replace coal in the near future, but carbon sequestration could potentially reduce emissions by 80% to 85%.
- As CO2 in the air is reduced, it can have positive impacts on public health and well-being.

4. Methods for Estimating Terrestrial Carbon Sequestration

There are five carbon pools of terrestrial ecosystem involving biomass, namely the aboveground biomass (AGB), below-ground biomass (BGB), dead mass of litter, woody debris and soil Organic Matter (SOM). The carbon dioxide predominant in plants during photosynthesis is transferred across the different carbon pools. The above-ground biomass of a tree constitutes the major portion of the carbon pool. It is the most important and visible carbon pool of the terrestrial forest ecosystem. Any changes in the land use system like forest degradation and deforestation has a direct impact on this component of the carbon pool (Giri *et al*., 2017).

The below ground biomass which constitutes all the live roots plays an important role in the carbon cycle by transferring and storing carbon in the soil. The dead mass of litter and woody debris are not a major carbon pool as they contribute merely a small fraction to the carbon stocks of forests.

Forest biomass can be estimated through field measurement and Remote sensing & GIS methods. There are two methods for estimating the AGB i.e., destructive method and non-destructive method (Giri *et al*., 2017).

1. Destructive method:

The destructive method is also known as the harvest method. It is the most direct method for estimation of above ground biomass and the carbon stocks stored in the forest ecosystems. This 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, branches and measuring the weight of these components after they are oven dried. This method of biomass estimation is limited to a small area or small tree sample sizes (Giri *et al*., 2017).

Example: The use of destructive method for predicting biomass and carbon stock in a planted Eucalyptus Forest. Scaling was performed on 21 trees. For methodology 1, a control sample was harvested, sectioned, weighted in the field, and the carbon stock calculated based on these data. Methodology 2 was also destructive, as trees were harvested, scaled and the carbon stock predicted based on these data. The average carbon stock obtained using methodology 1 was 0.0438 ± 0.0308 MgC, a value similar to those found using methodologies 2 (0.0470 ± 0.0343 MgC) (Schettini *et al.*, 2022).

2. Non-destructive method:

This method estimates the biomass of a tree without felling. The non-destructive method is applicable for those ecosystems with rare or protected tree species were harvesting of such species is not very practical or feasible. The biomass of the individual tree was estimated by taking into account the tree shape, physical samples of different components of the trees like branches and leaves and dendrometric measurements, volume and bulk density of the different components. This method also takes into consideration diameter at breast height, height of the tree, volume of the tree and wood density and calculate the biomass using algometric equation (Giri *et al.*, 2017).

Example: Tree biomass in tropical dry deciduous forest (DDF) and tropical mixed deciduous forest (MDF) was estimated using a non-destructive method in 0.1 ha permanent plots that were constructed at seven sites each in seven districts of Madhya Pradesh in Central India. A site-specific volume equation and species-specific gravity, the biomass of each species was determined. The average above ground biomass of both DDF and MDF of all sites were 31.8 t $ha^{-1}$and 20.7 t ha^{-1} respectively (Salunkhe *et al.*, 2016)

Table 1: Techniques for Above -Ground Biomass Estimation

Name of category	**Type of method**	**Data used**
Field measurement-based methods	Destructive sampling	Sample trees (Individual trees)
	Allometric equations	Sample trees (Individual trees)
Remote sensing-based methods	Fine spatial resolution data	Aerial photo-graphs, IKONOS (Per- pixel level)
	Medium spatial resolution data	Landsat TM/ETM+, SPOT (Per-pixel level)
	Coarse spatial resolution data	AVHRR (Per-pixel level)
	Radar data	RADAR, LIDAR (Per-pixel level)
GIS-based methods	Ancillary data	Elevation, soil, precipitation, etc. (Per-pixel level or per field level)

The traditional assessment methods are more accurate as they are based on field measurements. However., they are intensive labor time consuming, costly and difficult to implement on geographical areas. Remote sensing (RS) integrated with Geographic Information Systems (GIS) techniques are widely applied to different natural resources applications and biomass assessment.RS is capable of accurately and timely, sensing and recording forest variables over large areas and at relatively very low cost. Also, the modelling RS data within a GIS environment will increases the advantages of both technologies, permitting for the use of a wide range of ancillary and field data to the analysis, hence increasing the accuracy of the estimated AGB. Land use and land cover (LULC), forest, and biomass mapping using Landsat satellite data have all been successfully improved by using an integrated classification approach in conjunction with GIS analysis. Results show that an integration of RS and spatial analysis functions in GIS improves the overall classification result from 50.12% to 74.38% (Issa *et al*., 2020).

5. Managing and monitoring of carbon sequestration with integration of RS-GIS

The strength of integrated RS-GIS rests on its ability to perform advanced spatial and/or temporal analysis on multiple layers of high-resolution information. This helps with research aimed at controlling the global carbon cycle, mostly by offering knowledge with added value and supporting methods for implementation. For CS management and monitoring, integrated RS-GIS can function as a Decision Support System (DSS) tool. Long-term cost and time savings are anticipated from the use of RS-GIS because of its capacity to identify uncertainties, enhance observational accuracy, and nondestructive data collection across a large geographic area. RS tools such as Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR) and satellite sensors such as Landsat, SPOT and IKONOS have been used to map carbon stocks. Regional- scale GIS has been used as the operating platform in the development of C-Lock, a new system that standardizes estimation of agricultural carbon sequestration credits. In forestry sector, utilizing an integrated assessment method based on RS-GIS to assess the complexity of a region’s afforestation and reforestation initiatives and aimed to improve Raising CS and enhancing biodiversity. In the USA, Landsat imagery integrated into a GIS was used to identify hotspots (i.e., high Carbon Sequestration capacity locations) for afforestation programs. This approach enabled the prediction of potential CS capacity as a result of afforestation for 20-50 years (Jeyanny *et al*., 2011).

Table 2: Sensors used for estimating the Above Ground Biomass (AGB)

Sensors	**Resolutions**	**Advantages**	**Constraints**	**References**
Optical sensors	Coarse spatial resolution Ex: MODIS, AVHRR, and METEOSAT	Estimation and mapping of AGB at continental and global scale, and cloud-free data	Mismatch between the size of field plots, field measurements and pixel size (mixed pixels) and Predictive error of 42%	Issa *et al*., 2020
	Medium spatial resolution Ex: TM Landsat, ETM+ and SPOT	Small to large-scale mapping Cost-effective (Free)	No reliable indicators of biomass in closed canopy structure and predictive error of 32%	Issa *et al*., 2020
	Fine spatial resolution Ex: IKONOS and Quickbird	Estimate tree crown size Validation at localized scale	High cost, and more costly when it applies on large areas and predictive error of 27%	Issa *et al*., 2020
	Hyperspectral Ex: ALOS and AISA Eagle	Potential for the future of RS-based biomass estimation models	Cloud cover, High cost and suffers from band redundancy	Issa *et al*., 2020
RADAR Sensors	Ex: Microwave/radar (ALOS PALSAR and ERS-1)	A promising strategy is to integrate RADAR with many data sources, such as optical, microwave, and GIS modeling approaches	Inaccurate for species-level AGB assessment due to low spatial resolution, Polarization (e.g., HV and VV) problems and predictive error of 25%.	Dahy *et al*., 2019
LiDAR Sensors	Ex: Carbon 3D	It estimating AGB with great accuracy, Potential for satellite- based system to estimate global forest carbon stock	Requires extensive field data calibration Highly expensive and predictive error of 14%	Dahy *et al*., 2019

6. Biomass and Carbon Stock Estimation

For estimation of tree biomass species-specific allometric equations for many species was developed by FRI (1996), but there is a lack of allometric equations for many native species of the region.

Table 3: Species specific allometric equation

Name of Species	**Allometric Equation**	**No of samples harvested**	**Biomass / Carbon stock**	**Criteria Based**	**References**
Azadirachta indica	$AGB=0.016H^{4.862}$	9	338.8 t/ha	Basal diameter classes (0-10, 10-20, 20-30cm)	Mohamed *et al*., 2018
Tectona grandis	$AGB=0.4989D^2–0.202D-21.971$	33	73.2 mg ha^{-1} (at 30year age)	Age-series (1,5,11,18,24 &30	Jha *et al*., 2015

				years	
Acacia auriculiformis	$\ln AGB = -1.974 + 0.827 \ln D^2H$	165	AGB at 7 and 5 year is 183.54 and 140.5 Mg ha^{-1}	Silvipastoral experiment both at 7and5 year age	Kumar *et al.*, 1998
Casuarina equisetifolia	$AGB = -0.378 + 0.033D^2H$	127	AGB at 7 and 5 year is 33.68 and 35.9 Mg ha^{-1}	Silvipastoral experiment both at 7and5 year age	Kumar *et al.*,1998
Leucaena leucocephala	$\ln AGB = -1.543 + 2.248 \ln D$	147	AGB at 7 and 5 year is 63.51 and 65.8 Mg ha^{-1}	Silvipastoral experiment both at 7and5 year age	Kumar *et al.*, 1998

Note: AGB- Aboveground Biomass, D- Diameter at breast height of tree, H- Tree/culm height

Belowground biomass (BGB) was estimated by using conversion factor for the tropical moist deciduous forest. The conversion of carbon stock (CS) from biomass for the different land uses was estimated by using the default conversion factor of 47% of the total biomass. i.e.

BGB=AGB*0.26 (IPCC, 2006)
Carbon stock=Biomass*0.47 (IPCC, 2006)

For destructive approach to the estimation of biomass of forest (shrubby and herbaceous) vegetation. For shrub, two individuals of each species present in each quadrat of (5 m × 5 m) was harvested, and plant parts were separated in to stem, stem barks, branch and twigs and foliage, and fresh weight were weighed separately in laboratory after oven-dry and biomass value was multiplied by the total number of individual present in each quadrat to arrive at quadrat level biomass subsequently converted to per hectare basis. All the herbs present in each quadrat (1 m × 1 m) were harvested, weighed, and dried at 80°C. The total ecosystem carbon (TEC) was calculated as follows (Bordoloi *et al.*, 2022)

TEC = Vegetation carbon + Soil carbon

Soil and Climate Data:

The soil samples were collected from three soil depths (0–15 cm, 15–30 cm and 30–45 cm) using a soil augur two time from all the selected sites as per (IPCC) for estimation of soil organic carbon (SOC) content (%) while soil bulk density (BD) estimated at one time. The BD and SOC content were estimated using the method as described by Robertson and wet oxidation method (Walkley and Black, 1934) respectively. The SOC stocks (Mg ha^{-1}) for each of the three depths were computed separately and summed up to represent SOC stock for 0–45 cm depth (Bordoloi *et al.*, 2022).

SOC stocks (mg/ha) = SOC × ρ × d × 10,000

Where, SOC is the soil organic carbon measured in g g^{-1}; ρ is the soil bulk density (g cm^{-3}), d is the depth of soil layer (m). The value of 10,000 indicates the stock for 1 ha of land.

The climatic variables such as average annual precipitation and annual mean temperature of last 25 years to establish relationship between AGB with climatic variables (Bordoloi *et al*., 2022).

7. Challenges in estimating carbon sequestration using RS and GIS

- Significant challenge in arid lands, with unique challenges like low signal-to-noise ratios, high soil background reflectance, biological soil crusts, spatial heterogeneity, and irregular growing seasons.
- The fact that large parts of area (arid or desert) lack of photosynthesis and dominated by woody matter resulting in low photosynthetic signal, low in biomass.
- There are still issues with sensors acquisition costs, area coverage (swath width), and restricted availability for AGB estimation.
- Due to the limitation of spatial resolution, using Landsat images for mapping at the species level is challenging, especially in a heterogeneous environment.
- To overcome these challenges: novel combinations of sensors and techniques (e.g., solar-induced fluorescence, thermal, microwave, hyperspectral, and LiDAR) across a range of spatiotemporal scales have to be explored. Developing algorithms that are specifically designed to meet conditions and coupling remote sensing observations with process-based models to improve for long-term projections.

8. Prospects for carbon sequestration in the future

- There is a great deal of potential for improved carbon sequestration through the preservation and restoration of natural carbon sinks including forests, wetlands, and oceans.
- Technologies called direct air capture, which extract carbon dioxide from the atmosphere directly, have the potential to be both effective and scalable in sequestering carbon.
- The technology for carbon capture and underground storage (CCUS) systems, which seize carbon emissions from industrial operations, continue to advance. Technological advancements, in conjunction with supportive policies and investment, can faster the wider-scale implementation of CCUS.
- The implementation of supportive policies, such as carbon pricing and regulations, can incentivize carbon sequestration initiatives. Financial incentives, such as carbon offset markets and investment mechanisms, can encourage the adoption of carbon sequestration practices.

  The term "blue carbon" describes the carbon held in coastal ecosystems, including seagrass beds and mangroves, because these environments have the capacity to carbon sequestration, as well as exploring other ocean-based approaches, can contribute to climate change mitigation efforts.

9. Conclusions

RS and GIS Technologies proved to be workable, practicable, and sufficiently validated for use in AGB assessment monitoring, modeling, and carbon sequestration management.

- The statement describes the use of Remote Sensing (RS) and Geographic Information Systems (GIS) technologies for assessing, monitoring, modeling, and managing carbon sequestration and aboveground biomass (AGB).
- Allometric equations are mathematical models that relate tree measurements such as diameter at breast height (DBH), height, and other tree characteristics to estimate biomass. These equations are critical for accurately assessing forest biomass. These equations can be combined with RS data (e.g., canopy height, vegetation indices) to improve the accuracy of AGB estimates. This integration helps to bridge the gap between field measurements and remotely sensed data.
- Combining RS and GIS data with on-the-ground measurements leads to more accurate and reliable assessments of forest biomass and carbon stocks. Ground truthing is essential to validate remotely sensed data and ensure the accuracy of biomass estimations. This approach involves using field measurements to calibrate and validate remote sensing models, ensuring that the remotely sensed data is reflective of actual conditions on the ground.
- The Normalized Difference Vegetation Index (NDVI) is a common index derived from RS data. Other vegetation indices (e.g., Enhanced Vegetation Index or EVI) can also provide insights into plant growth, vigor, and biomass. These indices help monitor biophysical conditions such as vegetation cover and productivity.
- The combination of biomass models and NDVI data allows for efficient estimation of carbon stocks in forest areas. This approach can simplify the process by using remote sensing data to infer carbon storage and sequestration in forests. By linking spectral data with biomass and carbon models, researchers and environmental managers can assess the impact of land-use changes and forestry practices on carbon sequestration.

References

Bordoloi, R., Das, B., Tripathi, O.P., Sahoo, U.K., Nath, A.J., Deb, S., Das, D.J., Gupta, A., Devi, N.B., Charturvedi, S.S and Tiwari, B.K. 2022. Satellite based integrated approaches to modelling spatial carbon stock and carbon sequestration potential of different land uses of Northeast India. *Environmental and Sustainability Indicators*.13: 100166.

Dahy, B., Issa, S., Ksiksi, T and Saleous, N. 2020, July. Geospatial technology methods for carbon stock assessment: A comprehensive review. In *IOP Conference Series: Earth and Environmental Science*.540(1): 012036. IOP Publishing.

Giri, R.K.K.V and Madla, V.R. 2017. Study and Evaluation of Carbon Sequestration using Remote Sending and GIS: A Review on Various Techniques. *International Journal of Civil*

Engineering and Technology. *8*(4): 287-300.

Issa, S., Dahy, B., Ksiksi, T and Saleous, N. 2020. A review of terrestrial carbon assessment methods using geo-spatial technologies with emphasis on arid lands. *Remote Sensing*. 12(12): 2008.

Jha, K.K. 2015. Carbon storage and sequestration rate assessment and allometric model development in young teak plantations of tropical moist deciduous forest, India. *Journal of Forestry Research*. 26: 589-604.

Jeyanny, V., Balasundram, S.K and Husni, M.H.A. 2011. Geo-spatial technologies for Carbon Sequestration monitoring and management. *American Journal of Environmental Sciences*. 7(5): 456-462.

Kumar, B.M., George, S.J., Jamaludheen, V and Suresh, T.K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in woodlot and silvopastoral experiments in Kerala, India. *Forest Ecology and Management*. 112(1-2): 145-163.

Rao, G.R., Keerthika, A., Gupta, D.K and Shukla, A.K. 2018. Allometric relationships for biomass and carbon estimation of neem (*Azadirachta indica A. Juss*) plantations in dryland of Hyderabad, Telangana. *International Journal of Bio-resource and Stress Management*. 9(1): 037-043.

Ramachandran, A., Jayakumar, S., Haroon, R.M., Bhaskaran, A and Arockiasamy, D.I. 2007. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. *Current Science*.323-331.

Schettini, B.L.S., Jacovine, L.A.G., Torres, C.M.M.E., Carneiro, A.D.C.O., Castro, R.V.O., Villanova, P.H., Rocha, S.J.S.S.D., Rufino, M.P.M.X., Oliveira, S.N.D and Morais, V.T.M.D. 2022. Use of destructive and non-Destructive methodologies to estimate stem biomass accumulation and carbon Stock in an Eucalyptus forest. *Revista Árvore*. 46: 4611.

Salunkhe, O., Khare, P.K., Sahu, T.R and Singh, S. 2016. Estimation of tree biomass reserves in tropical deciduous forests of Central India by non-destructive approach. *Tropical Ecology*. 57(2): 153-161.