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Geo-Spatial Approach for Estimating Carbon Stock in Context of Siwalik Forests of Arunachal Pradesh, India: A Review

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Abstract

Climate change has been identified as a global issue that must be controlled at every possible step. Arunachal Pradesh is considered a biodiversity hotspot that needs to be conserved. Carbon stock assessment of an area, especially forests, has emerged as an important aspect of understanding the carbon storage capacities of trees of that forest, helping to mitigate climate change along with promoting sustainable conservation of biodiversity. Siwalik refers to the foothill part of the Himalayas comprising of small hillocks. It is characterised by rugged and undulating topography. Due to increasing anthropogenic activities, this region is growing fragile and needs to be conserved. This review article presents various aspects of carbon stock assessment, highlighting the benefits and the challenges that hinder the process of carbon stock estimation. Various articles based upon assessing forest biomass and carbon stock of Arunachal Pradesh were reviewed. To provide insights about associated opportunities, futuristic tendencies, and challenges in carbon stock assessment using geospatial technology, the present article was planned. Reach to understand the preferred method of estimating forest biomass and related carbon stock. Also to get to know about the obstacles that was confronted during the assessment of the carbon potential of forests. The article will review and highlight the use of field-based data inventory in combination with Remote Sensing technology for carbon stock assessment of an area along with the challenges, benefits, and futuristic scope related to them.

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Introduction

Growing industrialization and anthropogenic pressures on the environment are enhancing the amount of atmospheric carbon dioxide (CO_2) causing an unusual warming of the atmosphere and cause climate change. Deforestation is one of the major reasons behind it because forests are considered as the natural sponges that sequester atmospheric carbon dioxide (Baral, 2011). The process of capturing and storing atmospheric CO_2 by plants and trees as biomass through photosynthesis is called terrestrial carbon sequestration (EPA, 2011). There are three types of carbon dioxide sequestration (1) Ocean Sequestration (occurring in deep oceans), (2) Terrestrial Sequestration (occurring in plants and soil), and (3) Geological Sequestration (occurring underground) (Issa *et al.*, 2020). As compared to other types of carbon sequestration, the terrestrial method is preferred as it is environmentally friendly and requires less labor. The need to accurately estimate the carbon stock available in trees is gaining importance to understand their extent and contribution to mitigating climate change and global warming (Choudhary *et al.*, 2014). The rapid reduction of forest cover decreases their ability to sequester the carbon present in nature (Das *et al.,* 2021). So, it is imperative to sustainably manage these forests.

The geospatial technology (remote sensing) has emerged and proved itself to be a faster alternative for biomass assessment than the traditional method (measuring the tree parameters lying under the sample plots like diameter at breast height, tree height, frequency, density, etc.) as it can cover a larger area in a go with suitable precision. The advantages of using the remote sensing approach (characterised by microwave and optical data) are the ability to gather data for inaccessible areas, repetitiveness in data acquisition, cost-effectiveness in vegetation analysis, and the accessibility of historical datasets (DeFries, 2008). The commonly followed method of mapping the forest biomass includes the integration of both techniques remote sensing and traditional field-based inventory (Figure 1).

Arunachal Pradesh is the largest among the eight states in north-east India that have diverse ecosystems and is an important part of the Himalayas characterized by features like rich biodiversity, diverse tribal communities, and beautiful environmental features like mountains, vast forests, rivers, etc. The reasons for this diversified nature are (1) the location of the state at a coinciding junction of three biogeographical realms, (2) high rainfall patterns, and (3) a wider altitudinal gradient (Page *et al.*, 2022). Hence, the forests of Arunachal Pradesh must timely and accurately be assessed in terms of biomass. This review article presents various aspects of carbon stock assessment, highlighting the benefits and the challenges that hinder the process of carbon stock estimation.

Review of Literatures

In a study of the East Siang district of Arunachal, Dabi *et al.* (2021) combined ground-based data with remote sensing technology to spatially model the biomass along with carbon sequestration capacities of three plantations namely *Areca catechu*, *Citrus sinensis*, and *Hevea brasiliensis*. Of the three, the biomass of *Hevea brasiliensis* was found to be the highest (43.10 t/ha) followed by *Areca catechu* (36.48 t/ha) and the least was of *Citrus sinensis* (13.37 t/ha). Kashung *et al.* (2023) focussed on the effectiveness of bamboo (*Bambusa vulgaris*) in mitigating the concentration of CO_2 present in the atmosphere.

They mentioned that Bamboo grows faster in nature which increases its ability to store more amount of carbon. In other studies for assessing the carbon sequestration potential of ten important agroforestry tree species, Choudhary *et al.* (2014) found highest above and below-ground biomass in *Pinus kesiya* species with a carbon storage capacity of 252.82 kg/tree. The second and third positions were acquired by *Pinus wallichiana* and *Cinnamomum camphora* respectively.

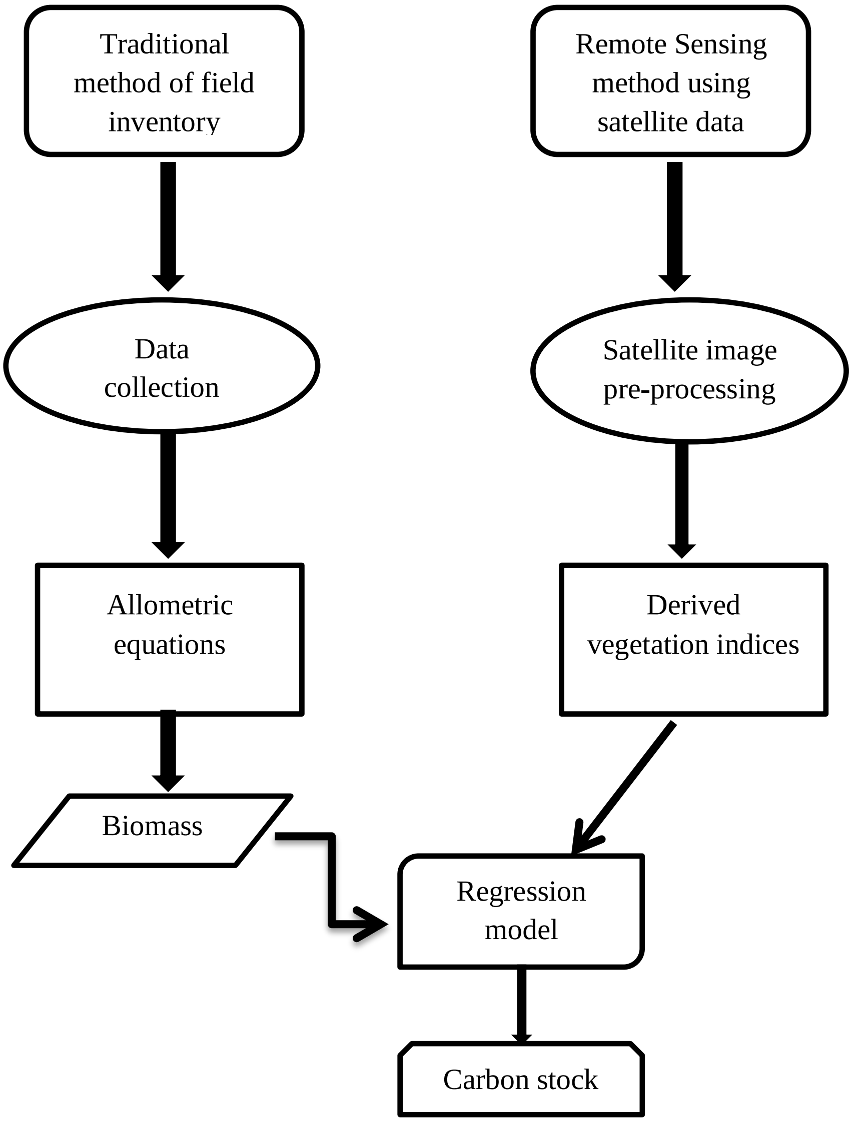

Figure 1. Integrated approach for field inventory and geo-spatial method for assessment of carbon stock

They stated in general 50% of tree carbon is stored in the trunk whereas 30% of it is stored in branches and stems. Das *et al.* (2021) followed an integrated approach of ground inventory and remote sensing to assess the carbon stock for major land use in Arunachal Pradesh and their associated potential to sequester carbon. The considered land uses were forests (dense, moderately dense, open, and plantations) and jhum cultivated land (>5 years, <5 years, and current) of which the highest above-ground biomass (332.28 t/ha) was of dense forest and least (16.84 t/ha) was of the current jhum cultivation. Among the five vegetation indices, were DVI: Difference Vegetation Index, NDVI: Normalized Difference Vegetation Index, SAVI: Soil Adjusted Vegetation Index, ARVI: Atmospheric Resistant Vegetation Index and EVI: Enhanced Vegetation Index, ARVI was found to be the best followed by the SAVI to develop the AGB prediction model.

Bordoloi *et al.* (2022) conducted a study to assess the above-ground biomass and derived carbon stock of various land uses in northeastern India along with their capacities for carbon storage. They used the integrated approach of vegetation indices (ARVI, NDVI, and SAVI) and field inventory to spatially model the above-ground biomass and the carbon stock. The average values of predicted AGB were found to be 148.78 mg/ha with a range of 14.32-185.95 mg/ha. The futuristic trend of carbon stock for the considered land uses and their carbon sequestering potentials were simulated using the CO_2FIX empirical model. In a similar study, Das et al. (2022) collected the forest data of four western districts of Arunachal Pradesh viz. West Kameng, East Kameng, Papum pare, and Lower Subansiri to estimate the above-ground biomass (AGB) of these forests. They developed a multilinear regression model that incorporates the Landsat image-derived spectral data, soil moisture, and land surface temperature. The findings of the study included an AGB estimated range of 2.64 t /ha to 534.21 t /ha. Carbon stock was derived from AGB using the conversion factor of 0.55. Das *et al.* (2022) mentioned that to understand the carbon cycle and forest dynamics on a global scale forest AGB mapping of various forest types is very important. Nath *et al.* (2019) followed the harvest method for gaining data of trees for different forest types like evergreen, tropical, and pine forests to prepare generalized models for biomass estimation (BEMs) in North East India (NEI). They compared their models with the models developed by Chambers *et al.* (2001), Brown *et al.* (1989), and Chave *et al.* (2005; 2014). Out of four, two of the developed generic models were found to fit best for the forests of NEI which were: AGB = $0.32(D^2H\delta)^{0.75}*1.34$ and AGB = $0.18D^{2.16}*1.32$. They proposed that these developed biomass estimation models will serve best for various climate change mitigation projects. In a study of biomass estimation of forests of Papum Pare district, Das *et al.* (2017) followed the combined approach of field-based data and geospatial technique. Among all vegetation indexes, SAVI was declared to be a highly correlated index with AGB, and hence was included in the AGB prediction model. With an average value of 172.36 t/ha, the plot-wise AGB range was between 29 and 588.8 t/ha, whereas the basal area ranged between 9.1 to 114.7m^2/ha. They provided the average values of AGB predicted for different land uses as mixed dense forest (191.16 t/ha), plantation (157.61 t/ha) and of degraded forest (96.76 t/ha). Kumar et al. (2019) did a relevant study in the West Kameng and Tawang districts of Arunachal Pradesh to better understand the effect of altitudinal variations on tree diversity and above-ground biomass (AGB). They stated that AGB follows an increasing trend up to the temperate zone and thereafter starts decreasing, but tree diversity showed an indirect proportionality with increasing altitudes. They reported the highest AGB value at a height of 1700-2800 m and concluded that L band PALSAR backscatter information proves to be a reliable source for estimating the AGB in alpine and sub-tropical regions in the Eastern Himalayas. Table 1 represents the vegetation indexes used in the reviewed articles.

Table 1. Commonly used vegetation indexes in AGB modelling

Vegetation Indexes	Formulae	References
NDVI	(NIR-R)/(NIR+R)	Rouse et al (1974)
DVI	NIR-R	Jordan (1969)
ARVI	(NIR-RB)/(NIR+RB)	Kaufman and Tanre (1992)
SAVI*	[(NIR-R)/(NIR+R+L)] (1+L)	Huete (1988)
EVI**	G × [(NIR-R)/(NIR+C1R-C2B+L)]	Liu and Huete (1995)

NDVI: Normalized difference vegetation index; DVI: Difference vegetation index; ARVI: Atmospherically resistant vegetation index; SAVI: Soil adjusted vegetation index; EVI: Enhanced vegetation index. *L = correction factor; **G = 2.5; $C_1 = 6$; $C_2 = 7.5$; L = 1.

Rationale of the Article

Arunachal Pradesh is a state of importance characterised by rich biodiversity and long persisting indigenous communities. Although the state is remote along with undulating topography, its role in mitigating climate change cannot be neglected. Hence, the forests of the state need reliable and timely biomass assessment to understand their contribution on carbon sequestration. Hence, this article was planned to review those studies which includes the AGB and carbon stocks assessment of forests within the state.

Methodology

Google Scholar database was used to find important articles related to biomass and carbon stock estimation of forests of Arunachal Pradesh. Out of 36 articles, 12 relevant articles were selected and reviewed to prepare this article. An appropriate explanation of the method of screening and including the articles is well represented by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart which includes three phases of article preference i.e. identification, screening and included phase (Kahale *et al.*, 2021). The PRISMA Flowchart for the current article is as follows:

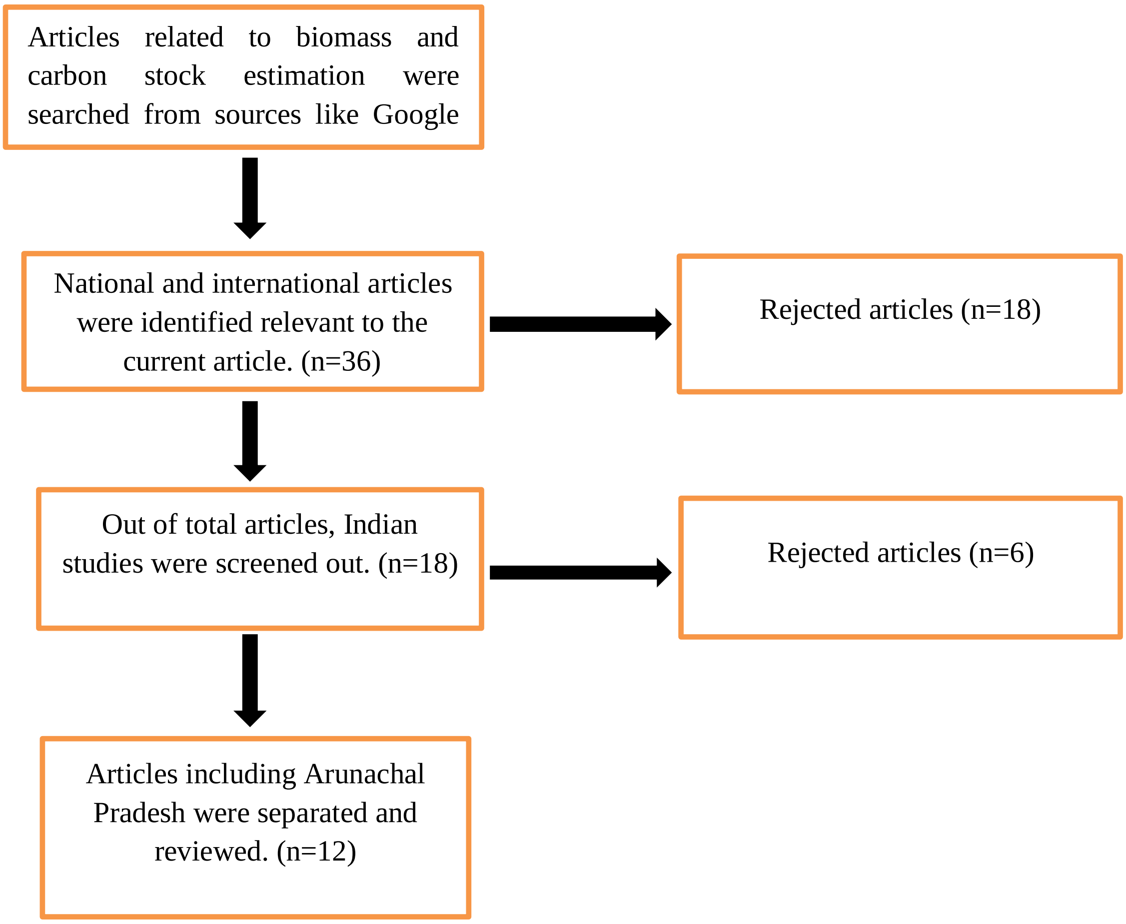

Figure 2. PRISMA flowchart of followed methodology

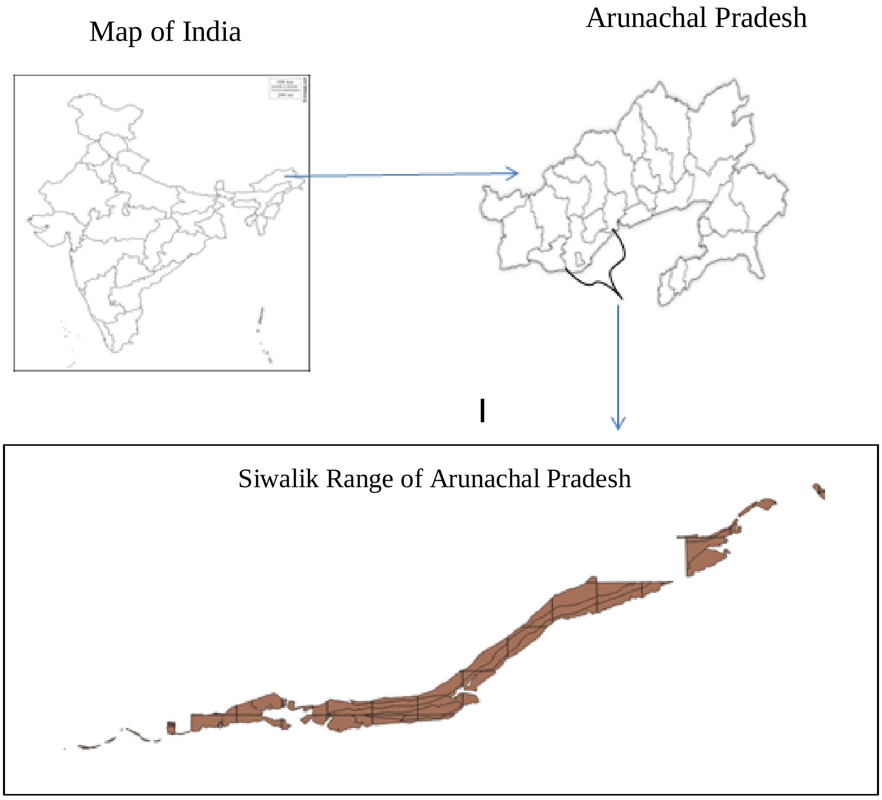

Figure 3. Study area depicting the Shiwalik range of Arunachal Pradesh, India

Benefits and Challenges

The remote sensing method for AGB estimation and mapping is a modern alternative to the traditional estimation method and it is on its way to improvement. The most important benefit of geospatial technology is that it saves time and is labor-efficient but the fact that the above-mentioned method is incomplete without field data cannot also be ignored (Issa *et al.*, 2020). This section highlights the challenges, advantages, and future scope associated with the geospatial technology as follows:

- **Advantages of Remote Sensing**

Firstly, this method provides repetitive coverage of large areas in one go helping in identifying significant features and surveying them. Secondly, the acquired data is available in higher resolutions and scales to meet our requirements like classifying a single tree, evaluating the composition of tree species and estimating various biophysical parameters related to the vegetation (Gougeon and Leckie, 2006). It helps cover and analyse remote areas as well. The extent of analysing a single satellite image is unlimited. Another vital feature is that it obtains information about any earth's feature without disturbing it and maintaining its natural behaviour. It avails both types of sensors active as well as passive so night data is also provided by this technology (Cao *et al.*, 2016).

We can opt for a false colour composite for satellite image data to better identify features which we were unable to do in the original data, marking another benefit. Proper mapping of disaster-prone areas like forest fires, earthquakes, floods etc. can help in rescue operations and vigilance. Remote sensing and GIS promote sustainable development planning and protect the cultural and natural heritage of the environment. Decision-makers, environment stakeholders, and policymakers rely upon this technology for achieving the goal of sustainability (Goyal *et al.*, 2020).

Remote sensing proves to be a promising approach for mapping the soil salinity using Synthetic Aperture Radar (SAR) data (Hoa *et al.*, 2019) Salinity is highly correlated with soil moisture content and the latter can easily be measured using the microwave sensors to map the soil salinization (Sahbeni *et al.,* 2023). A newer application of RS is in Urban Building Energy Modelling (UBEM). Input data sources include Unmanned Aerial Vehicles (UAVs), high-resolution satellite image data and LiDAR, of which UAVs reflect more prominence due to higher flexibility in the image acquisition process (Anand and Deb, 2023). So these are some of the most prominent positive points regarding remote sensing.

- **Challenges In Remote Sensing**

A major drawback of geospatial technology is that various remote sensing-derived maps and reports blindly depend upon LU/LC classifications which are prone to errors arising from misclassifications (Goetz and Dubayah, 2011). The technology is very expensive as its maintenance requires a lot of money. Also, skilled professionals are required to study and analyse the spatial data for which training becomes costly (Issa *et al.,* 2020).

Vegetation indexes are influenced when derived for undulating terrain which restricts AGB and carbon stock estimation of forests marking another drawback of remote sensing technology (Das *et al.,* 2021). Clouds and rainfall can badly affect image acquisition creating unclear and blurred data. Multiple sources for data of the same area can create confusion in interpretation. If the relative motion of satellite and sensors is not synchronized, there will be distortions in images (Jacobsen, 2006).

One major drawback related to hyperspectral images is that they require large storage and a heavy operating configuration creating a hurdle in digital image processing (Sajjad and Kumar, 2019). Creating models for mapping any earth feature requires model validation to check the accuracy of the model which marks a challenging task. These were some of the disadvantages related to the remote sensing.

- **Opportunities**

Despite the challenges mentioned above, the RS technology has a great scope in the field of agricultural studies (food security, disease population, etc.), geology (rock and soil studies, earthquakes), meteorology, oceanography (floods, detection of oil spills etc.) and other dynamic fields like rural-urban human settlements, archaeological evidence and many others. It is effective in identifying, obtaining, processing, and storing the heavy spatial data (Chi *et al.,* 2016). Important applications include intelligence, military for defence, economic-commercial fields and human welfare planning (Cracknell, 2007). The technology is gaining advancement through increase in a number of earth observing satellites which will provide us with more processing tools and huge data amounts for new advanced applications. Hyperspectral RS data characterised by higher spectral resolution will be a promising solution for future challenges in the remote sensing approach (Sajjad and Kumar, 2019). Hence, the future scope includes evaluating the performance and reliability of geospatial data based on improved sensors and more earth observing (EO) satellites.

Conclusions

Our earth is full of natural features like forests, mountains, rivers, etc. and these hide many unrevealed secrets in them. These natural ecosystems need to be analysed to understand their role in energy balance on earth. Remote sensing is an emerging field that follows data acquisition of these features, especially the forests, without being in contact with them proving its effectiveness. Covering the largest proportion in the world, tropical forests play a vital role in the global carbon cycle. Deforestation is the major cause leading to climate change as it reduces the carbon storage capacities of the trees in forests. Arunachal Pradesh, the largest in area among the other northeast Indian states, is a significant part of biodiversity hotspots and needs to be conserved. As compared to optical data, SAR and LiDAR data are more advantageous to predict AGB as they are capable of determining the structural parameters of forests. Vegetation indices, although affected due to the topography, are considered as good presenters of the greenness of vegetation canopy so these are utilised for AGB modeling. After reviewing the articles, it can be concluded that although remote sensing is an excellent approach for spatially mapping the tree biomass and carbon stock, there is still a need for improvement in terms of reliability and accessibility.

Conflict of Interest

There is no conflict of interest as declared by the authors regarding the publication of this manuscript.

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