Estimation of Above Ground Biomass in Sinharaja Forest Reserve, Using Sentinel Images

L.M.Y.N.Lankadhikara[1#] and A.K.R.N.Ranasinghe[2]

[1] *Department of Remote sensing and GIS, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka,*
[2] *Department of Surveying and Geodesy, Faculty of Geomatics,Sabaragamuwa University of Sri Lanka*
[#] lmyn_lankadhikara@std.geo.sab.ac.lk

Abstract— *This research aimed to explore the potential of remote sensing techniques in estimating Above Ground Biomass (AGB) values over the Sinharaja forest area in Sri Lanka. Sentinel-1&2 satellite images were used to extract AGB values, and the accuracy was validated using field measurements. Statistical analysis including correlation and regression analysis were employed to investigate the relationship between the estimated AGB values and field measurements. The results revealed a strong positive correlation between Sentinel-1 Estimated AGB and field-calculated AGB, while the correlation between Sentinel-2 Estimated AGB and field-calculated AGB was relatively weak. Non-linear regression analysis was also conducted to explore the relationship between the AGB values, which revealed a quadratic relationship between Sentinel-2 Estimated AGB and field-calculated AGB. Non-linear regression analysis was not conducted between sentinel-1 and field-calculated AGB data. Because there was strong positive correlation. This study conducted an annual analysis of above-ground biomass (AGB) along Neluwa, Lankagama, and Deniyaya roads within Sinharaja Forest. By comparing AGB values from 2018 to 2022, significant decreases were observed in 2019, indicating a critical year for deforestation activity. These findings provide valuable insights for conservation efforts and measures to mitigate further forest degradation and protect the ecosystem. The study suggests that remote sensing techniques can be used as a reliable and cost-effective method to estimate AGB values in dense forest areas, particularly when field measurements are difficult to obtain. However, higher resolution multispectral satellite images or advanced techniques can be used for more accurate results. Overall, the study provides valuable insights for forest management and conservation practices*

Keywords- **AGB, multispectral, Sentinel, Sinharaja, Neluwa, Lankagama, Deniyaya, Sri Lanka**

I. INTRODUCTION

Accurate estimation of above-ground biomass (AGB) is crucial for evaluating forest ecosystems' carbon sequestration and balance capacity. AGB estimation is an important aspect of studying the carbon cycle and understanding the dynamics of forest biomass. Foreign researchers have extensively investigated AGB estimations, including the use of RADAR data.

To evaluate the potential of C-band SAR data from the Sentinel-1/2 instruments and machine learning algorithms for the estimation of forest above ground forest biomass (AGB) in a high-biomass trop-ical ecosystem (Debastiani et al, 2019).

The Sudanian Savanna (SS) of West Africa is characterized by tropical savannas and woodlands. Accurate estimation of AGB and carbon stocks in this biome is important for addressing sustainable development goals as the information can aid natural resource management at varied spatial scales. Previous AGB mapping efforts focused on humid forests, with little attention on savannas. This study explored the use of annual monthly timeseries of Senitinel-1 (S-1) and Sentinel-2 (S-2) data to map AGB in the SS. Backscatter, spectral reflectance, and derivatives (vegetation indices and biophysical parameters) were combined with field inventory data in a Random Forest regression to map AGB (Forkuor et al., 2020).

However, there is a lack of research focusing on AGB development in Sri Lanka. To date, no articles have been discovered regarding the creation of a forest canopy density model based on AGB in Sri Lanka (Brown, Gillespie and Lugo, 1989).

Biomass serves as an ecological and management indicator, providing insights into species dominance and the energy potential of a site's vegetation. It is an essential tool for rangeland management, helping evaluate carrying capacity and adjust stocking rates based on forage availability. Forest biomass dynamics also play a vital role in national greenhouse gas inventories and understanding the impact of forest management on climate change. However, it is important to note that while above-ground biomass is examined extensively, below-ground biomass, which accounts for a significant portion of forest biomass, remains challenging to collect and quantify (Lu, 2005).

Forest biomass estimation has implications for policy formulation and environmental management. It offers valuable information for decision-making in forest ecosystem management and the implementation of climate policies. Understanding the carbon-sequestering ability and energy recharge rate of vegetative ecosystems is crucial for assessing the carbon cycle and its impact on global climate and environmental change. Therefore, accurate estimation of above-ground biomass (AGB) in forests becomes essential (Herold et al., 2018).

Assessing forest fire risk and preserving the Sinharaja Rainforest Reserve in Sri Lanka require accurate estimation of above-ground biomass (AGB). Mapping fire risk zones and understanding forest composition and structure can mitigate wildfire damage. AGB calculation aids in evaluating deforestation impact on the reserve's

World Heritage Site status (Estimating Deforestation and Forest Degradation in Sri Lanka).

The objective of this study is to estimate the above-ground biomass (AGB) in Sinharaja forest reserve, Sri Lanka, by utilizing Sentinel-2 optical images. The study aims to extract relevant spectral and spatial information from the images and develop methodologies or models to estimate AGB based on this data. Additionally, it intends to incorporate data from both Sentinel-1A radar and Sentinel-2 optical imagery to create a comprehensive AGB map. By comparing AGB maps derived from radar and optical imagery, the study aims to assess the strengths and limitations of each approach. The analysis will contribute to understanding the capabilities of Sentinel imagery for AGB estimation.

II. METHODOLOGY

A. Study Area

Sinharaja Rainforest is a world-renowned tropical rainforest in Sri Lanka, situated in the southwest of the island. Figure 1 displays the map of Sinharaja Forest Reserve.

Figure 1: Sinharaja forest Reserve

As a result of its location in a wet zone, the annual rainfall in the area is approximately 3000 to 6000 mm, and the mean annual temperature is around 23-25 Celsius. The Sinharaja Rainforest Reserve covers an area of approximately 18,900 hectares and is one of the largest remaining rainforests in Sri Lanka. The reserve is situated between Latitudes 60 21' and 60 26' N and Longitudes 800 21' and 800 34' E. The elevation of the rainforest varies from 300 meters to 1170 meters above sea level. The terrain is steep, and the area is marked by numerous ridges and valleys.

B. Field Base AGB Estimation

In order to estimate the above-ground biomass (AGB) in Sinharaja forest, a field-based AGB estimation method was employed. The field surveys were conducted in designated plots within the forest. The plots were carefully selected to represent different vegetation types and biomass variations in the forest. Prior to conducting the surveys, the forest area was thoroughly studied to identify suitable locations for the plots. The plots were established with proper spacing and random placement to ensure unbiased representation. Within each plot, measurements were taken of the diameter and height of selected trees (Aranha, Viana and Rodrigues, 2008)

$$\mathbf{AGB = a*(DBH)^{b}} \quad (1)$$

a, b values determined by the type of the trees.

C. Sentinels-1 AGB Estimation

The backscattering coefficient formula calculates the strength of the radar signal reflected back to the satellite. It is represented by the symbol σ (sigma) and is typically expressed in units of square meters per square meter (m^2/m^2) or decibels (dB). The backscattering coefficient can be calculated using the following formula (Omar, Misman and Kassim, 2017).

$$\mathbf{Backscatter=10*(log10\ (VV*VV) - log10(0.01))} \quad (2)$$

VV- vertical transmit & vertical receive backscatter coefficients

The Backscatter-based AGB Index (BAI) is a widely used index for estimating Above-Ground Biomass (AGB) using Sentinel-1 Synthetic Aperture Radar (SAR) imagery. The BAI is calculated as the ratio of the difference between the VH (vertical transmit and horizontal receive) and VV (vertical transmit and vertical receive) backscatter coefficients to their sum ((Rodríguez-Veiga et al., 2019). This index captures the sensitivity of backscatter to forest biomass and structure, providing valuable information for AGB estimation.

$$\mathbf{AGB=0.0556*(Backscatter)^{0.9478}} \quad (3)$$

D. Sentinels-2 AGB Estimation

The NDVI, obtained from remote sensing (satellite) data, and widely used around the world to monitor drought, estimate agricultural productivity, and aid in the forecasting of fire zones and desert offensive maps (Earth Observing System, 2019). So, it is a significant vegetation index that is commonly used in worldwide environmental and climate change research studies. NDVI is calculated as the ratio difference between measured canopy reflectance in the red and NIR bands (Khan et al., 2018).

$$\mathbf{NDVI=[NIR_{(B8)}-RED_{(B3)}]/[\ NIR_{(B8)}+RED_{(B3)}]} \quad (3)$$

The Sentinel 2 AGB (Above-Ground Biomass) index is calculated based on the NDVI (Normalized Difference Vegetation Index) value. The equation for calculating the AGB index using the NDVI is as follows (Aranha, Viana and Rodrigues, 2008).

$$\mathbf{AGB=0.9478*(NDVI)^{\ 0.0556}} \quad (4)$$

E. Statistical Analysis

The analysis was based on the Above Ground Biomass index derived from Sentinel-1 and Sentinel-2 satellite imageries. Various data sources were used to validate the results obtained from the above ground biomass index. The data preprocessing steps flow chart is presented in Figure 2 below. The methodology describes the process of acquiring the required data, such as satellite imageries and ground truth data. The data preprocessing steps, such as image enhancement, filtering, and segmentation, are also described in detail. Furthermore, the methodology outlines the steps taken to derive the above ground biomass index, including the use of image rationing and the conversion of backscatter coefficients to biomass. Finally, the methodology explains the statistical analysis techniques used to validate the results obtained from the above ground biomass index.

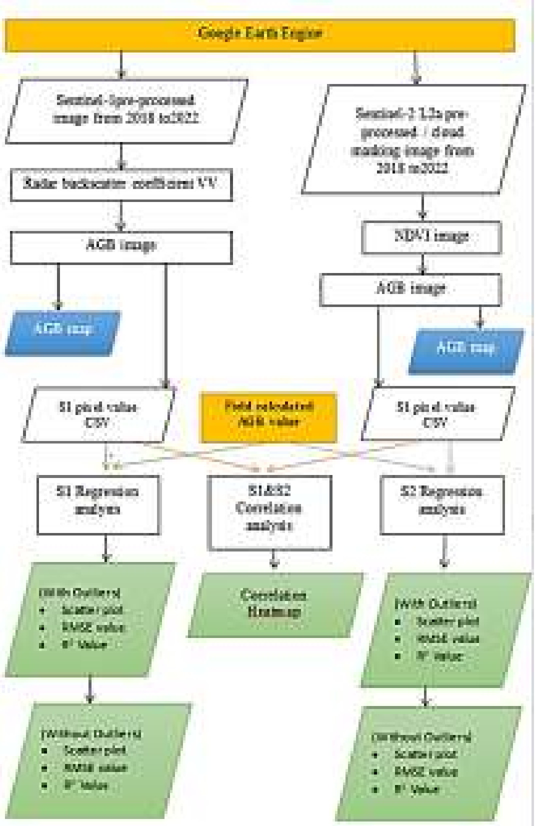

Figure 2: Flow Chart of Research Methodology

III. RESULTS AND DISCUSSION

A. Sentinel-1 AGB estimation results

To estimate the above ground biomass (AGB) in this study, preprocessed Sentinel 1 Synthetic Aperture Radar (SAR) image bands were utilized with the help of Google Earth Engine (GEE). Various band equations proposed by different researchers in the past were implemented to derive the AGB values. Maps of AGB were created for 2018, 2019, 2020, 2021 and 2022. Maps are shown in the Figure 3 below

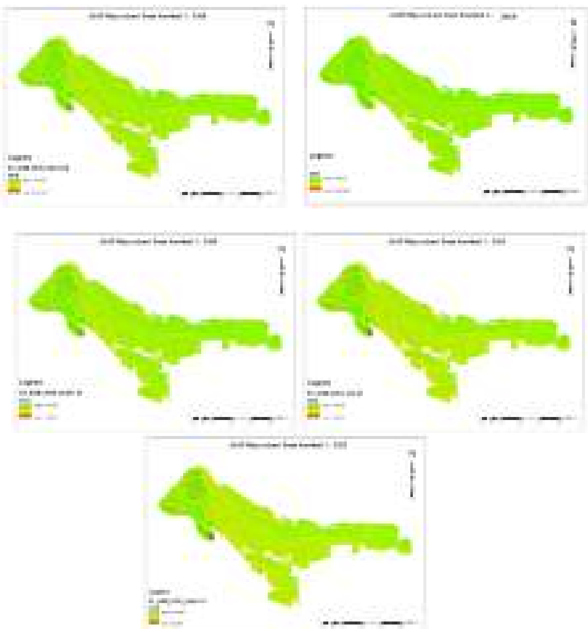

Figure 3: AGB maps, extract from sentinel-1

B. Sentinel-2 AGB estimation results

In this study, the above ground biomass (AGB) estimation was carried out by utilizing preprocessed Sentinel 2 multispectral image bands with the assistance of Google Earth Engine (GEE). A range of band equations proposed by researchers in the past were implemented to derive the AGB values. Maps of AGB were created for 2018, 2019, 2020, 2021 and 2022. Maps is shown in the Figures 4 below.

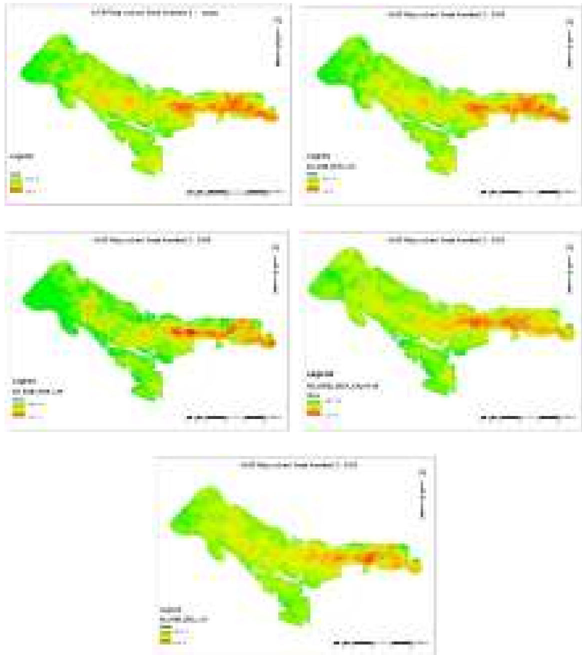

Figure 4: AGB map, extract from sentinel-2

C. Calculated Year Wise Changes of the Biomass

Calculating year-wise changes in biomass in Sinharaja forest reserve is important for several reasons. Firstly, it helps monitor the health and dynamics of the forest ecosystem over time. By analyzing the fluctuations in biomass, researchers can assess the impact of natural disturbances, climate change, or human activities on the forest's structure and productivity. Secondly, understanding the year-wise changes in biomass provides valuable insights into the carbon sequestration potential of the forest, aiding in climate change mitigation strategies. Additionally, it helps inform conservation and management efforts by identifying areas of high biomass loss or gain, enabling targeted interventions for sustainable forest management and biodiversity conservation. The graph depicting the year-wise changes of the biomass is presented in Figure 5 below.

Figure 3: Calculated Year Wise Changes of the Biomass

Huge value gap occur between two data sets. But same pattern. But in 2022 Sentinel-1 AGB value deviate from pattern. Reason is 2018 shows highest value and it decreasing annualy. In 2022, there has been a noticeable decrease in foliage density, resulting in lower AGB (Above-Ground Biomass) values as observed by the Sentinel-2 optical sensors in comparison to the AGB values captured by the Sentinel-1 sensors. Farther analysis was done to check what was correct from two data sets.

D. *Regression analysis for S1 & S2 data sets*

Regression analysis was conducted to examine the relationship between AGB values obtained from Sentinel-1 and Sentinel-2 data for the years 2018-2022. plot is shown in the Figure 6 below. The analysis involved fitting a regression model to the data, allowing for the estimation of the slope and intercept coefficients that quantify the linear relationship between the variables. The regression analysis provided insights into the strength and direction of the relationship, enabling predictions of AGB values based on the values obtained from either Sentinel sensor.

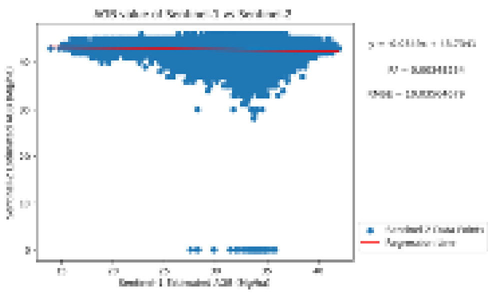

Figure 4 : Regression analysis between Sentinel-1 & Sentinel-2

In the conducted regression analysis, an R^2 value of zero indicates that there is no linear relationship between the AGB values obtained from Sentinel-1 and Sentinel-2 data. This means that the variation in one variable cannot be explained by the other variable using a linear model. Additionally, a non-zero root mean square error (RMSE) value suggests that there is a significant deviation between the predicted AGB values based on the regression model and the actual observed values, indicating a poor fit of the model to the data.

E. *Correlation analysis for S1 & S2 data sets*

A heatmap generated using Python visually displayed the correlation between AGB values of Sentinel-1 and Sentinel-2 for 2018-2022. Heatmap is shown in the Figure 6 below. The heatmap revealed a consistent positive correlation, with weekly positive correlations in 2018 and 2019. This supported the findings of the scatterplot analysis, providing valuable insights into the relationship between the two datasets.

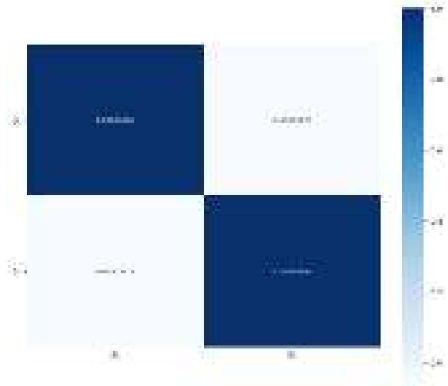

Figure 5 : Correlation analysis between Sentinel-1 & Sentinel-2

A correlation analysis was performed to assess the relationship between AGB values derived from Sentinel-1 and Sentinel-2 data for the years 2018-2022. When the correlation value is equal to zero, it indicates no linear relationship between the two sets of data. This suggests that there is no consistent or predictable association between the AGB values obtained from Sentinel-1 and Sentinel-2 during the specified time period.

F. *Regression analysis for S1,S2 & field calculated AGB data sets*

Regression analysis was conducted to examine the relationship between Sentinel-1 and Sentinel-2 AGB data and field AGB data for the year 2021. Regression analysis Graph is shown in the Figure 8 below. The Python platform was utilized to perform the analysis, and the resulting scatterplots indicated a positive linear relationship between each set of data. Increases in Sentinel-1 AGB values were accompanied by increases in field AGB values, as well as increases in Sentinel-2 AGB values

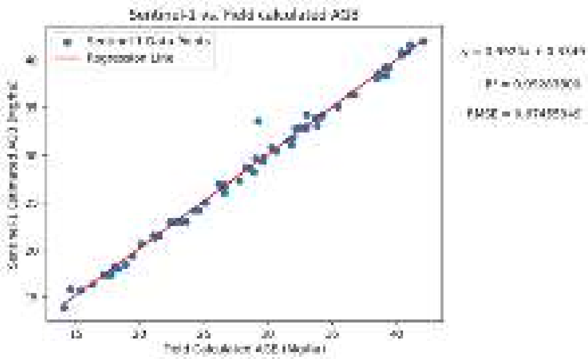

Figure 6 : Relationships between actual AGB & Sentinel-1 data

In the regression analysis comparing Sentinel-1 data with field calculate AGB data, if the R^2 value is equal to 1, it indicates a perfect fit between the two datasets. This means that all the variability in the field calculate AGB data can be explained by the Sentinel-1 data, resulting in a strong and precise relationship. Additionally, if the RMSE value is zero, it implies that there is no difference or error between the predicted values from the regression model and the actual field calculate AGB data, indicating an exact match.

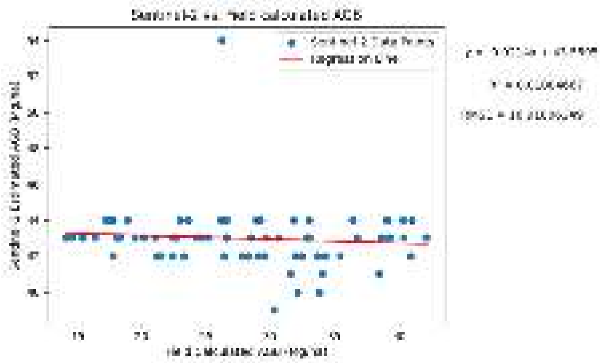

Figure 7 : Relationships between actual AGB & Sentinel-2 data

Comparing Sentinel-2 data with field calculate AGB data, if the R^2 value is 0.0100 (equal to 0), .it suggests that there is no linear relationship or correlation between the two datasets. Figure 9 shows the regression analysis graph depicting the relationship between the variables. The absence of a significant relationship means that the Sentinel-2 data does not explain or predict the variability in the field calculate AGB data. Furthermore, if the RMSE value deviates from zero, it indicates that there is a difference or error between the predicted values from the regression model and the actual ground truth values, suggesting a lack of accuracy in the prediction.
Then sentinel-1 data set was taken for farther analyses.

G. Change detection map

A change detection map can be useful to identify areas with significant changes in AGB over time. By comparing the AGB values from 2018 and 2022, we can identify areas that have experienced significant decreases or increases in AGB. Change detection map is shown in the Figure 10 below.
In this case, the red color areas represent the locations where the AGB values have decreased significantly from 2018 to 2022, indicating a potential loss of biomass. These areas could be of particular interest for further investigation and management, as they may be experiencing environmental stress or disturbance.

Figure 8 : Change detection map

H. Neluwa-Lankagama Road project problem

To collect the sum of above-ground biomass (AGB) pixel values along the Neluwa, Lankagama, and Deniyaya roads located within the border of Sinharaja Forest, an annual analysis was conducted. The aim was to identify the temporal patterns of deforestation occurring specifically along these roads. By analyzing the AGB pixel values, which represent the biomass density, for each year, Sum of AGB pixel graph is shown in the Figure 11 below. it becomes possible to observe changes in vegetation cover over time. Significant decreases in AGB pixel values along these roads would indicate areas of deforestation. This analysis helps to pinpoint the specific time periods when deforestation activities occurred along the roads, providing valuable information for understanding the impact of road construction and associated human activities on the forest ecosystem.

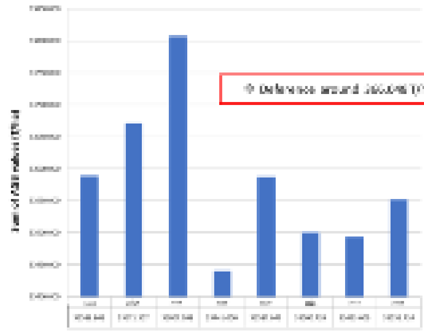

Figure 9: Sum of AGB pixel values along the Neluwa, Lankagama, and Deniyaya roads

In the annual analysis of AGB pixel values along the Neluwa, Lankagama, and Deniyaya roads located within the border of Sinharaja Forest, the year 2019 showed the minimum value. This suggests that 2019 had the lowest biomass density or highest deforestation activity along these roads compared to other years. The decrease in AGB pixel values during that specific year indicates a significant loss of vegetation cover, potentially caused by deforestation activities. Understanding the temporal pattern of deforestation, with 2019 standing out as a critical year, provides important insights for addressing conservation efforts and implementing measures to mitigate further forest degradation along these road areas.

IV. RESULTS AND DISCUSSION

The results showed that R2 of the regression analysis of Sentinel-1 was 0.336, reason is analysis do in outliers. After remove outliers R2 was 0.993 which indicate the relationship between dependent and independent variables and, the value was very good as a model. At the same time RMSE value come 9.0888 to 0.675. The RMSE is not approaching zero, indicating that a best fit model is not there. However, there is no such thing as a universally "good" RMSE value. The range of values in the dataset is affected to the model outputs.
When consider about Sentinel-2 AGB results that R2 of the linear regression analysis of Sentinel-2 was 0.01. Therefore consider non- linear regression, results that R2 of the non-linear regression analysis of Sentinel-2 was 0.04. So, the remote sensing approach is quite promising and improvements were required to have much highly accurate AGB model for sentinel 2. According to that high-resolution satellite images, highly saline study areas, and different approaches to analysis can be implemented

to, improve the current outcome of the study. Based on the results of the linear and non-linear regression analyses of Sentinel-2 AGB values compared to ground sampling truth data, it appears that there is a weak relationship between the two. The R2 values of 0.01 and 0.04 suggest that only a small proportion of the variability in ground AGB values can be explained by Sentinel-2 data.

One possible reason for this weak relationship could be related to the spatial resolution of Sentinel-2 imagery. Sentinel-2 has a relatively coarse resolution of 10-60 meters, which may not capture fine-scale variability in AGB values that can be detected by ground-based measurements. Additionally, Sentinel-2 may not be able to capture certain aspects of vegetation structure and composition that are important for determining AGB.

Another potential reason could be related to the methods used to extract AGB values from Sentinel-2 imagery. Different approaches to image processing and AGB estimation can lead to variability in results, which may affect the strength of the relationship between Sentinel-2 data and ground truth data.

the use of non-linear regression models can be especially useful when working with complex data sets like satellite imagery, where relationships between variables may be non-linear or difficult to capture using traditional linear models (Lopes et al. 2020),. This highlights the importance of carefully selecting appropriate modeling techniques when working with satellite imagery data

A. Recommendations

In dense forest areas like Sinharaja, it can be challenging to obtain ground truth data such as DBH due to the difficult terrain and thick vegetation. In such cases, higher resolution multispectral satellite images can be useful to obtain accurate data. For example, QuickBird images with a resolution of 2.4m x 2.6m can provide more detailed information about the forest canopy and understory, which can aid in estimating AGB values. However, it is important to note that the use of satellite images alone may not always provide accurate results, and it is important to combine them with ground truth data whenever possible to validate and improve the accuracy of the results.

As part of the research process, the SNAP software was used for processing Sentinel-1 and Sentinel-2 images to extract AGB values. However, it was observed that the SNAP software requires a significant amount of processing power and performance to handle the large amount of data involved in the analysis. In this study, an Intel Core i3 laptop was used for the analysis, which had limited processing power and performance compared to a high-performance workstation. If the research were to be conducted on a high-performance workstation with better processing capabilities, it would have resulted in a more efficient and faster analysis process.

Therefore, it is recommended that future studies using the SNAP software for remote sensing analysis should be conducted using high-performance workstations or servers with better processing capabilities to improve the efficiency and accuracy of the analysis. This will help to reduce the processing time and improve the accuracy of the results obtained from the analysis.

Using Sentinel-1 and Sentinel-2 data for AGB estimation provided a cost-effective and efficient method for large-scale forest monitoring. However, the accuracy of the results can be further improved by using more accurate methods such as drone photogrammetry and lidar. These methods can provide higher resolution and more detailed data on forest structure and biomass. Therefore, it is recommended that future research incorporates these methods to obtain more accurate AGB estimates for forest monitoring. However, it should be noted that using drone photogrammetry and lidar can be more expensive and time-consuming compared to using Sentinel data, so it is important to carefully consider the trade-offs between accuracy, cost, and efficiency when choosing a method for forest monitoring

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AUTHOR BIOGRAPHY

Author's Name:	L.M.Y.N.Lankadhikara
Background:	Bachelor of Science **(Hons) in Surveying Sciences in Remote Sensing – 2017 Sabaragamuwa University of Sri Lanka (Second class lower division)**

Expertise:	Remote Sensing
Interests:	Built Environment and Spatial Sciences
Other Relevant Information:	I have been employed as a research assistant at the Geo Tech-Hub, a research center within the Faculty of Geomatics at Sabaragamuwa University of Sri Lanka, since January 2023.