

CREATION OF TECHNIQUE FOR ASSESSING ABOVE GROUND BIOMASS AND CARBON SEQUESTRATION USING UNMANNED AERIAL VEHICLES

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ABSTRACT

This study aims to develop a method for assessing above ground biomass and carbon sequestration using data obtained from unmanned aerial vehicle (UAV) imagery. The research focuses on analyzing above ground biomass and estimating carbon storage by examining the correlation between carbon sequestration and vegetation indices through regression analysis. Field survey data revealed a total of 336 trees and 22 plant species. The total above ground biomass in the study area was found to be 86.214 tons, with a corresponding carbon sequestration of 40.520 tons of carbon. Vegetation index (VI) analysis employed three modeling approaches—NDVI_FC, SAVI_FC, and MSAVI2_FC—using an area block method. The estimated carbon sequestration values were 6.90388, 6.90388, and 6.83419 tons, respectively. Using the grid block method, the carbon sequestration values derived from NDVI_FC, SAVI_FC, and MSAVI2_FC were 32.47310, 32.48533, and 34.17078 tons, respectively. This study demonstrates the effectiveness of UAV imagery in estimating carbon sequestration, which can be effectively applied in natural resource management and environmental planning.

Key-words: UAV imagery, Above Ground Biomass, Carbon Sequestration, Vegetation Index.

1. INTRODUCTION

Carbon is a fundamental element of all living organisms and plays a crucial role in maintaining balance within ecosystems. It is stored in various environmental components and circulates through the carbon cycle (Earthobservatory, 2025). In nature, carbon exists in different forms depending on the storage reservoirs, including terrestrial, aquatic, atmospheric, and biological systems. It can be found in solid, liquid, and gaseous states, with the majority of natural carbon stored in plants as hydrocarbon compounds that form part of plant tissues (Ngthai, 2025). Human activities have increasingly contributed to the release of carbon from natural reservoirs into the atmosphere in large quantities. These activities include the combustion of fossil fuels, transportation, and industrial production (Laosuwan et al., 2023; Laosuwan et al., 2025). Moreover, human-induced destruction of carbon sinks, such as deforestation, has diminished the natural capacity to absorb atmospheric carbon dioxide. This reduction weakens the effectiveness of the carbon removal process and leads to higher concentrations of carbon dioxide in the atmosphere, which contributes to the greenhouse effect—a phenomenon that increases the Earth's average temperature, known as global warming (Liu & Liang, 2017; Saengpradit et al., 2024; Vattanavongsiri et al., 2024). Carbon dioxide absorbs heat radiation from both the sun and the Earth's surface, intensifying this warming effect. A sustainable approach to mitigating global warming is to convert atmospheric carbon into carbon stored within living organisms, particularly through tree planting.

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Trees play a vital role as carbon sinks by absorbing carbon dioxide during photosynthesis. This carbon is then stored in various parts of the tree—such as the stem, branches, and leaves—in the form of biomass. Therefore, tree planting is an effective method for reducing atmospheric carbon and addressing the challenges of global warming (Lewis et al., 2009; Pandey et al., 2014; Yadav et al., 2017; Uttaruk & Laosuwan 2019; Lal & Singh, 2020). Typically, the amount of carbon sequestered in trees is directly related to biomass, which represents the total mass of all tree components, including the stem, branches, leaves, roots, and others (Chopra et al., 2023; Uttaruk et al., 2024). Therefore, anatomical characteristics of trees—such as height, trunk diameter, and crown width—can be used to estimate the amount of carbon stored in trees through the application of allometric equations. These equations describe the relationship between biomass and tree structural attributes. Such structural data can be obtained through field surveys (Uttaruk & Laosuwan 2020; Huynh et al., 2022; Oumasst et al., 2024). Although field surveys provide highly accurate data on tree structure and form, they require skilled personnel and can be time-consuming and costly. In densely vegetated or remote areas, field data collection can be inconvenient and prone to error (Uttaruk et al., 2024). As a result, remote sensing technology has been increasingly applied for large-scale spatial studies to reduce survey time (Auntarin et al., 2021; Jomsrekrayom et al., 2021; Ounrit et al., 2022; Samdaengchai et al., 2022; Nakapan & Hongthong, 2022; Uttaruk et al., 2022; Hongthong & Nakapan, 2023; Jumadi et al., 2024).

While satellite imagery is already available, its limitations in terms of resolution, area coverage, or cost may prevent it from being suitable for detailed carbon estimation. Currently, there is a growing demand for high-resolution data for site-specific studies, leading to the adoption of unmanned aerial vehicle (UAV) imagery. UAVs offer several advantages, including affordability, environmental friendliness, and high-resolution data acquisition, making them widely applicable in various fields (Mendes et al., 2023; Angkahad et al., 2024). However, a review of related literature indicates that the use of UAVs specifically for estimating above-ground biomass carbon sequestration remains limited. Most UAV applications focus on broader spatial analyses, such as land cover classification and land use change detection (Pepe et al., 2021; Lu et al., 2023; Alfio, 2024). This study aims to develop a method for surveying above-ground carbon sequestration using UAV imagery, with a case study conducted at SC1 and SC2 buildings of Mahasarakham University.

2. MATERIALS AND METHODS

2.1 Study Area

The study area includes the SC1 and SC2 buildings of the Faculty of Science, Mahasarakham University, located in Kham Riang Subdistrict, Kantharawichai District, Maha Sarakham Province, Thailand. The total area of the study site is 21,392.4198 square meters, as shown in **Fig. 1**.

2.2. Tree Physical Data Collection

In this study, the researcher measured the circumference of all trees with a minimum circumference of 4.5 centimeters at a height of 130 centimeters above ground level (approximately breast height). Tree height, measured from the ground to the top of the canopy, was recorded using a laser range finder.

2.3. UAV-Based Multispectral Image Acquisition

UAV-based imagery was collected using a multispectral camera system that captured data across multiple spectral bands, including Green, Red, Red Edge (RE), and Near Infrared (NIR). The collected data were used to calculate three types of Vegetation Indices (VIs): the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979), the Soil-Adjusted Vegetation Index (SAVI) (Huete, 1988), and the Modified Soil-Adjusted Vegetation Index (MSAVI2) (Qi et al., 1994), as shown in Equations 1 to 3.

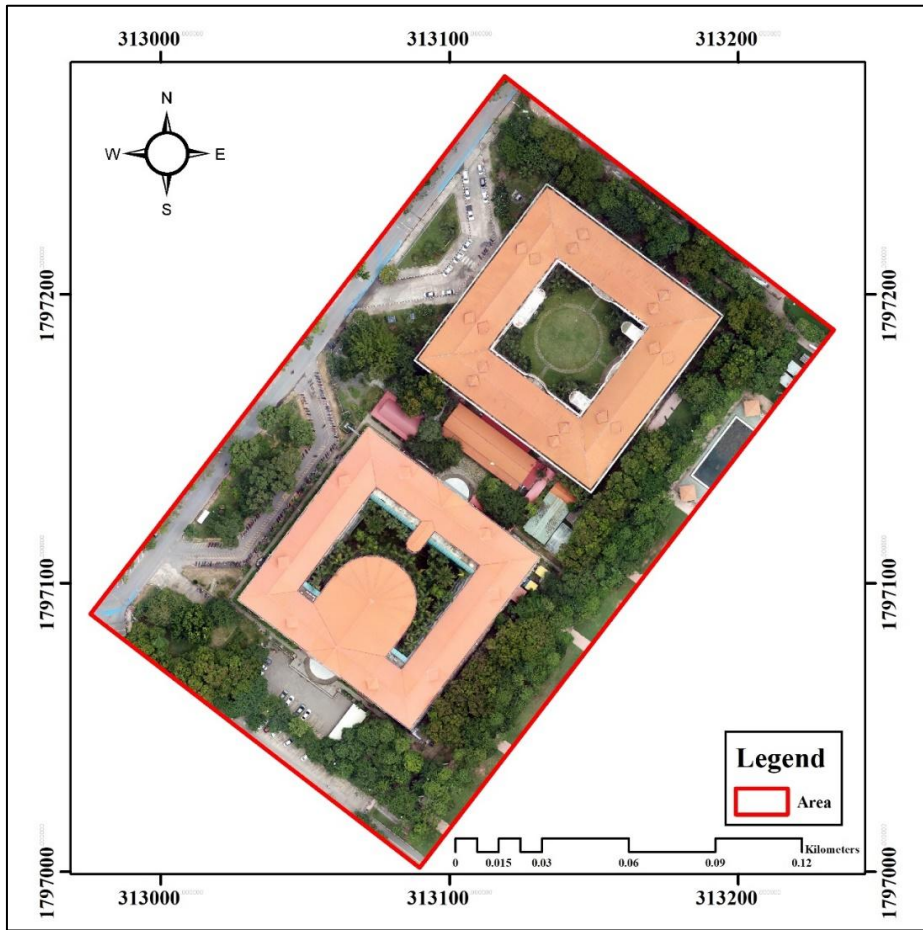


Fig. 1 Study area.

These indices were subsequently used to analyze the Fractional Green Vegetation Cover (FC), as shown in Equation 4.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

VIS and NIR refer to the spectral reflectance measurements obtained in the visible red and near-infrared regions, respectively.

$$SAVI = \frac{(L + 1) \times (NIR - RED)}{NIR + RED + L} \quad (2)$$

NIR and Red denote the bands linked to their respective wavelengths. The L value fluctuates based on the extent of green vegetative cover present. Typically, in regions devoid of green vegetation, L is equal to 1; in areas with moderate green cover, L is 0.5; and in regions with dense vegetation, L reaches 0, which aligns with the NDVI method. This index produces values ranging from -1.0 to 1.0.

$$MSAVI2 = \frac{(2NIR + 1) - \sqrt{(2NIR + 1)^2 - 8(NIR - RED)}}{2} \quad (3)$$

The Modified Soil Adjusted Vegetation Index 2 (MSAVI2) improves the dynamic range of vegetation signals and more effectively mitigates the influence of soil background effects compared to the Soil Adjusted Vegetation Index (SAVI). This characteristic is especially advantageous in areas with limited vegetation. VIS and NIR denote the spectral reflectance measurements captured in the visible red and near-infrared wavelengths, respectively.

Subsequently, utilize the results from the analysis of the three Index methods to evaluate the Fractional Green Vegetation Cover (FC) using Equation 4.

$$FC = \frac{VI - VI_{soil}}{VI_{forest} - VI_{soil}} \quad (4)$$

VI_{soil} represents the VI value of a pixel with 0% vegetation cover, while VI_{veg} denotes the VI value of a pixel with 100% vegetation cover.

2.4. Field Survey for Tree Physical Measurement

2.4.1. Tree Physical Data Collection

Field data collection involved measuring the diameter at breast height (DBH) at 130 centimeters above ground level, with a minimum DBH of 4.5 centimeters. Tree height (H) was also measured. The geographic coordinates (X, Y) of each tree were recorded using GPS. Additional information including species name, trunk circumference (in centimeters), and tree height (in meters) was documented using a data recording form. Data were collected for all trees within the study area. In this study, data collection was conducted in the vicinity of the SC1 and SC2 buildings without defining sample plots; thus, all standing trees within the area were measured.

2.4.2. Above Ground Biomass and Carbon Sequestration

Once data such as height (H) and diameter at breast height (DBH) were collected from the field survey, these values were substituted into the allometric equation developed by Ogawa (Ogawa et al., 1965) (Equation 5), which is commonly used for dry dipterocarp and mixed deciduous forests, to estimate above ground biomass. The resulting biomass values were then used to calculate carbon sequestration using Equation 6 .

$$\begin{aligned} W_s &= 0.0396 D^2 H^{0.9326} \\ W_b &= 0.003487 D^2 H^{1.0270} \\ W_l &= (28.0 / w_{tc} + 0.025)^{-1} \\ W_{tc} &= W_s + W_b \end{aligned} \quad (5)$$

where:

W_s represents the biomass of the trunk (in kilograms), W_b denotes the biomass of the branches (in kilograms), W_l indicates the biomass of the leaves (in kilograms), W_{tc} refers to the combined biomass of the trunk and branches (in kilograms), D signifies the diameter measured at a height of approximately 130 centimeters, and H represents the height of the tree up to the crown (in meters).

$$CS = AGB * 0.47 \quad (6)$$

In this context, CS represents the carbon stock measured in tonnes, above ground biomass denotes the above-ground biomass, and 0.47 (IPCC, 2006) serves as the conversion factor or the carbon fraction found in above ground biomass.

2.5. UAV Data Analysis Methods

In this research, three methods were employed for UAV data analysis: Crown Cover Generation, Area Block Generation, and Grid Block Generation, as illustrated in **Fig. 2**.

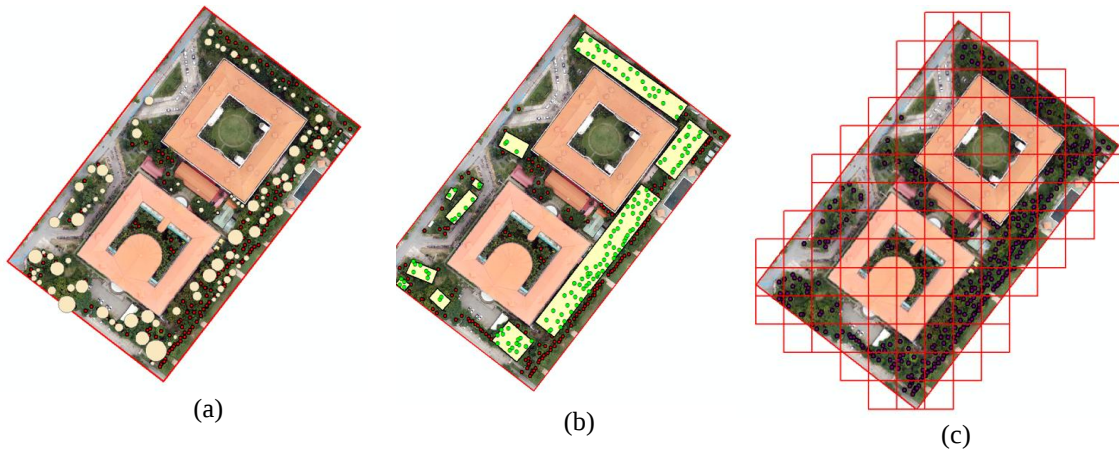


Fig. 2 (a) Crown Cover Generation, (b) Area Block Generation and (c) Grid Block Generation.

- Crown Cover Generation: This method involves generating crown covers by expanding the XY coordinates of each tree to create a buffer area representing the tree's canopy. The average vegetation index values within each crown cover area are calculated and used to determine the correlation with carbon sequestration values at the same coordinates. Only trees with clearly visible canopies in the UAV imagery were selected for this analysis.

- Area Block Generation: Area blocks were created to extract vegetation index values from each defined block. These values were then used to analyze their correlation with the total carbon content within each area block. This method provides spatially distributed data.

- Grid Block Generation: Grid blocks were created to extract vegetation index values from each block. These values were used to analyze the correlation with total carbon content per block. Grid blocks offer equal-sized areas and provide higher spatial resolution than the area block method.

2.6. Relationship Between Carbon Sequestration & Vegetation Indices Using the Crown Cover

The average vegetation index values derived from the crown cover method—limited to locations where tree canopies were clearly visible—were analyzed using Microsoft Excel. In this analysis, Y represents the amount of carbon sequestered (in tons of carbon) at coordinates corresponding to the vegetation index values, and X represents the average values of NDVI_FC, SAVI_FC, and MSAVI2_FC from 107 crown cover points.

2.7. Relationship Between Carbon Sequestration and Vegetation Indices Using the Area Block

The Area Block method involves calculating the sum of vegetation index values within each block, which are then used to analyze the correlation with the total carbon content in the corresponding block. In this analysis, Y represents the amount of carbon sequestered (in tons of carbon) in each block, and X represents the total values of NDVI_FC, SAVI_FC, and MSAVI2_FC within each block. A total of 11 Area Blocks (or 11 Area Block IDs) were randomly selected for analysis.

2.8. Relationship Between Carbon Sequestration and Vegetation Indices Using the Grid Block

The Grid Block method involves summing the vegetation index values within each grid block, which are then used to calculate the correlation with the total carbon content per block. In this analysis, Y represents the total carbon sequestered (in tons of carbon) within each grid block, and X represents the total NDVI_FC, SAVI_FC, and MSAVI2_FC values within each respective grid block.

3. RESULTS AND DISCUSSION

In this study, data obtained from unmanned aerial vehicle (UAV) imagery were utilized alongside physical measurements of individual trees surrounding the buildings. These data were used to calculate above-ground biomass and estimate the amount of carbon sequestered by each tree. Remote sensing technology was applied based on the principle of reflectance and absorption of electromagnetic energy at different wavelengths by vegetation. This enabled the calculation of vegetation indices, including NDVI, SAVI, and MSAVI2, as well as the fractional green vegetation cover (FC). The vegetation index values were then analyzed for their correlation with the carbon content of individual trees. The derived regression equations from these correlations were subsequently used to estimate spatial carbon values across the study area. The results of the implementation are presented as follows:

3.1. Above Ground Biomass

Based on the field survey, a total of 336 trees representing 22 different species were identified. The eight most frequently occurring species in the study area were: *Pterocarpus indicus* Willd. (119 trees), *Dalbergia cochinchinensis* Pierre (52 trees), *Cassia fistula* Linn. (38 trees), *Peltophorum pterocarpum* (DC.) K.Heyne (36 trees), *Peltophorum dasyrachis* (Miq.) Kurz (19 trees), *Lagerstroemia speciosa* (L.) Pers. (17 trees), *Sindora siamensis* Teijsm. ex Miq. (15 trees), and *Ficus benjamina* L. (8 trees), along with several other species. The total above ground biomass (AGB) estimated from this research is presented in **Table 1**.

Table 1.
Above Ground Biomass

Weight	Tons
The weight of the stem (Ws)	68.57863323 tons
The weight of the branch section (Wb)	15.56469544 tons
The weight of the leaf section (Wl)	2.07146152 tons
The total above ground biomass (AGB)	86.21479019 tons

Table 1 presents the weights of various components of aboveground biomass, which include the weight of the stem (Ws) at 68.57863323 tons, the weight of the branches (Wb) at 15.56469544 tons, and the weight of the leaves (Wl) at 2.07146152 tons. In total, the aboveground biomass (AGB) amounts to 86.21479019 tons. This data collection is crucial for studying the carbon cycle within ecosystems, as these biomass components can sequester carbon dioxide from the atmosphere through photosynthesis, converting it into organic matter within plants. Assessing biomass quantities enhances our understanding of forests' capacity to store carbon, which is vital for mitigating global warming and climate change. Furthermore, it facilitates more effective management of natural resources. Therefore, studies on biomass play a significant role in developing models and environmental management policies.

3.2. Carbon Sequestration from Field Data

The amount of carbon sequestration was calculated by using the above-ground biomass values to estimate the carbon content. According to the formula for carbon sequestration of trees (C_s) = above-ground biomass $\times$ 0.47, the total amount of carbon sequestered by the trees was 40.52095139 tons of carbon.

3.3 Vegetation Index Analysis Results

UAV imagery was analyzed using NDVI, SAVI, MSAVI2 models, along with the fractional green vegetation cover (FC). The analysis results are as follows:

3.3.1. NDVI Analysis Results

NDVI is a vegetation index derived from the ratio between the reflectance values of near-infrared and red wavelengths, normalized to a scale ranging from -1 to 1. The NDVI analysis results are shown in **Fig. 3** and can be described as follows:

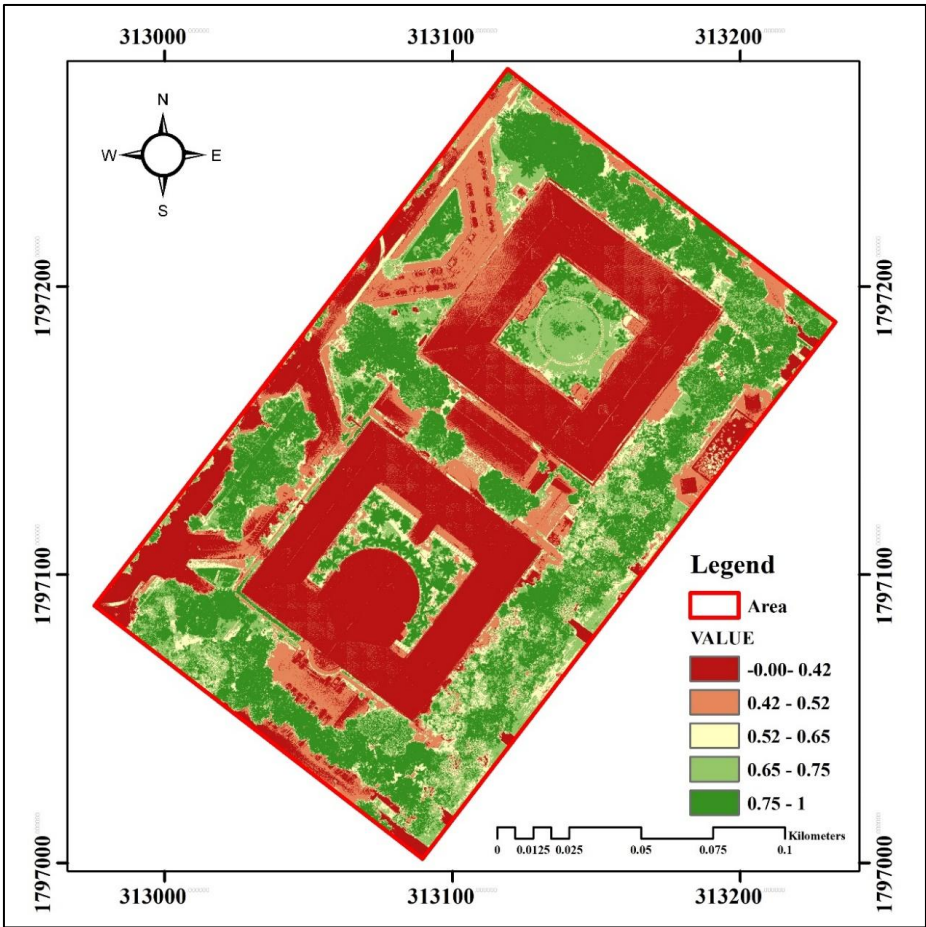


Fig. 3. NDVI Analysis Results.

According to **Fig. 3**, the calculated NDVI_FC value at coordinates 313121 1797057 was the lowest at 0.5147, while the highest NDVI_FC value was 0.8887 at coordinates 313217 1797182. On average, areas shaded in red and orange, with NDVI_FC values ranging from -0 to 0.5215,

represented areas with no vegetation cover, such as academic buildings and paved roads. Yellow to light green areas, with values ranging from 0.5215 to 0.7490, represented areas with moderate vegetation cover, such as grass patches. Dark green areas, with values ranging from 0.7490 to 1.0000, represented areas with dense vegetation cover, typically large trees with clearly visible canopies.

3.3.2. SAVI Analysis Results

SAVI (Soil-Adjusted Vegetation Index) is a vegetation index calculated from the difference in reflectance between near-infrared and red wavelengths, normalized by the sum of the two, with a correction factor applied to minimize the influence of soil brightness—particularly in areas with sparse vegetation. This method is commonly used in arid regions where vegetation cover is low. The SAVI analysis results are shown in **Fig. 4** and can be described as follows:

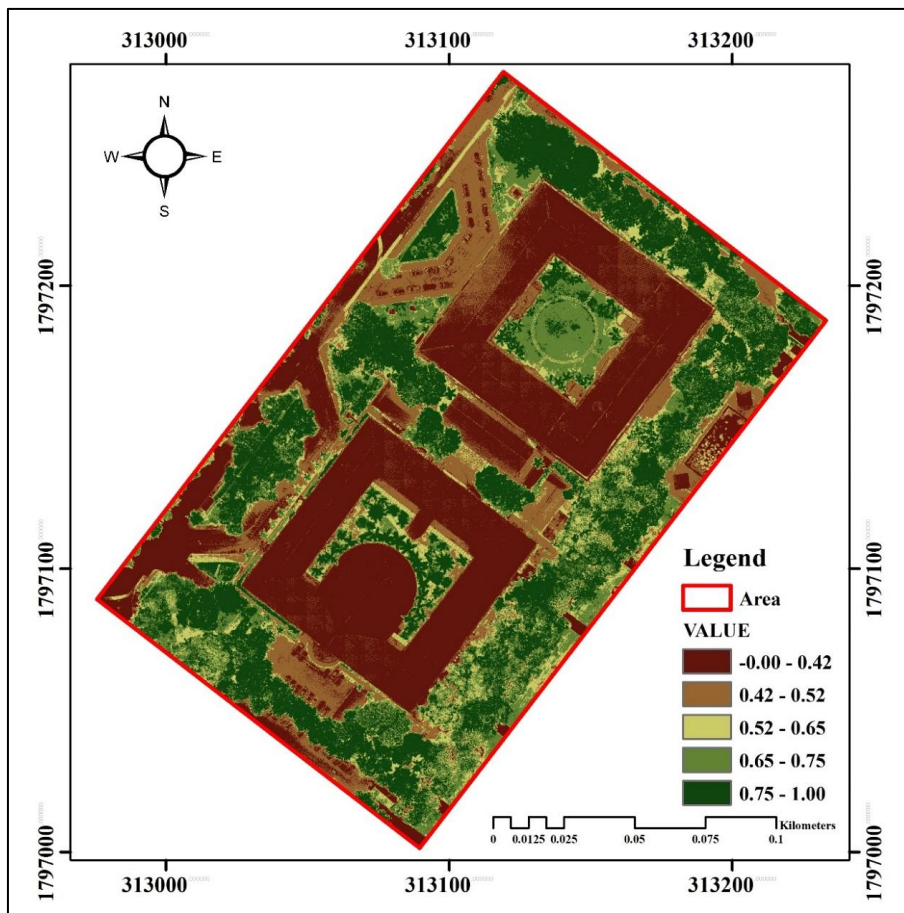


Fig. 4. SAVI Analysis Results.

According to **Fig. 4**, the SAVI_FC value at coordinates 313121 1797057 was the lowest at 0.5147, while the highest SAVI_FC value was 0.8887 at coordinates 313217 1797182. Areas with values between 0 and 0.5215 represent locations with no vegetation cover, such as academic buildings and paved roads. Areas with values between 0.5215 and 0.7490, typically shown in green shades, represent regions with moderate vegetation cover, such as grassy areas. Areas with values between 0.7490 and 1.0000, typically shown in dark green, represent regions with dense vegetation cover or large trees with prominent canopies.

3.3.3. MSAVI2 Analysis Results

MSAVI2 (Modified Soil-Adjusted Vegetation Index) is a vegetation index modified to reduce the influence of soil reflectance in areas with sparse vegetation cover. It incorporates both soil adjustment and vegetation weighting factors. The MSAVI2 analysis results are shown in **Fig. 5**. According to **Fig. 5**, the MSAVI2_FC value at coordinates 313095 1797105 was the lowest at 0.1912, while the highest value of 0.8543 was found at coordinates 313023 1797134. Areas with values between 0 and 0.2392 represent regions with no vegetation cover, such as academic buildings and paved roads. Yellow to orange shaded areas with values from 0.3725 to 0.6039 indicate regions with moderate vegetation cover, such as grass patches. Red shaded areas (excluding buildings and cemented surfaces), with values ranging from 0.6039 to 1.0000, represent areas with dense vegetation cover or large trees with well-defined canopies.

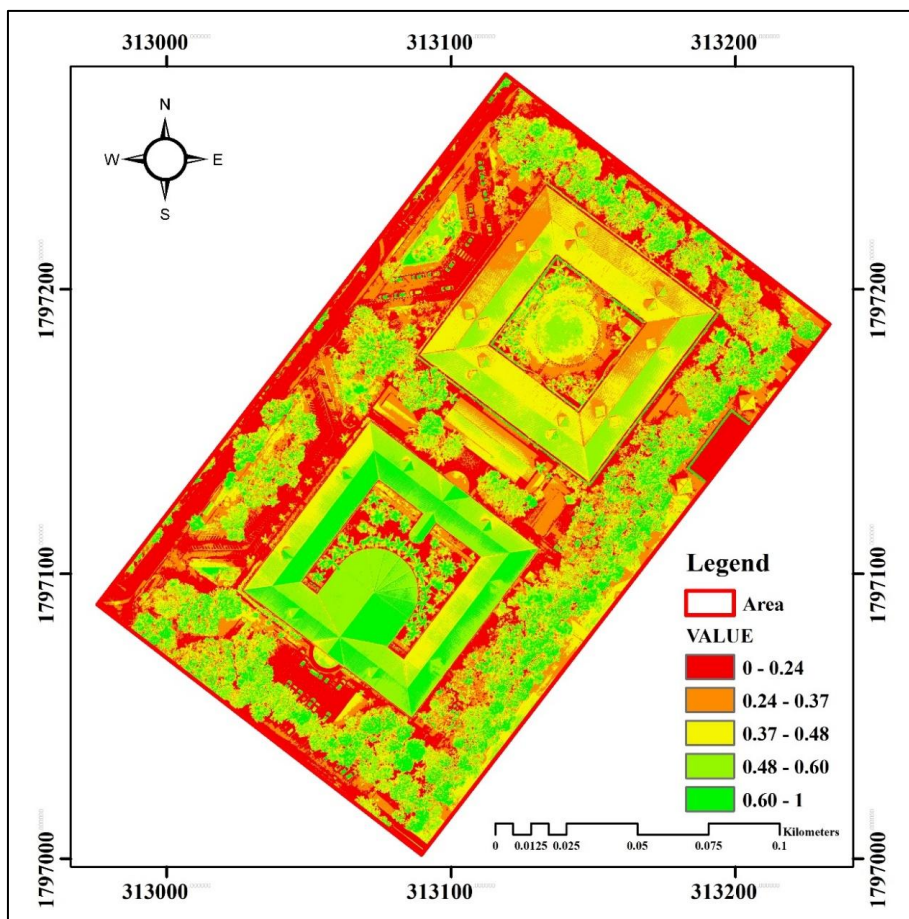


Fig. 5. MSAVI2 Analysis Results.

3.4. Correlation Analysis Results

3.4.1. Correlation Analysis Using the Crown Cover Method

The correlation analysis between carbon sequestration and vegetation indices using the Crown Cover method involved expanding the XY coordinates of each tree to define the radius of the crown cover area. The average vegetation index values within the crown cover were then calculated and paired with the carbon sequestration values of the corresponding trees. NDVI_FC, SAVI_FC, and

MSAVI2_FC values from 107 crown cover points at matching XY coordinates were used to perform regression analysis.

The results are as follows: the coefficient of determination (R^2) values for NDVI_FC, SAVI_FC, and MSAVI2_FC were found to be 0.0721, 0.0635, and 0.0639, respectively. These R^2 values indicate a low level of correlation. Therefore, it can be concluded that NDVI_FC, SAVI_FC, and MSAVI2_FC show weak relationships with carbon sequestration and are not suitable for accurately predicting carbon sequestration using this method, as the strength of the correlation is low.

3.4.2. Correlation Analysis Using the Area Block Method

The correlation analysis between carbon sequestration and vegetation indices using the Area Block method involved defining areas to calculate the total vegetation index values and total carbon sequestration within each Area Block. The carbon sequestration values (in tons of carbon) and the total values of NDVI_FC, SAVI_FC, and MSAVI2_FC within each of the 11 randomly selected Area Blocks (11 Area Block IDs) were used to perform regression analysis.

The results are as follows: from the vegetation indices NDVI_FC, SAVI_FC, and MSAVI2_FC, the derived regression equations were $y = 0.5966e^{0.0667x}$, $y = 0.5966e^{0.0667x}$ and $y = 0.5904e^{0.1068x}$, respectively, and the corresponding R^2 values were 0.8924, 0.8924, and 0.8940, respectively. It can be seen that the coefficient of determination (R^2) values for NDVI_FC, SAVI_FC, and MSAVI2_FC are high, indicating that the relationships between carbon sequestration and vegetation indices can be effectively predicted.

3.4.3. Correlation Analysis Using the Grid Block Method

The correlation analysis between carbon sequestration and vegetation indices using the Grid Block method involved creating areas to calculate the average vegetation index values and the total carbon sequestration within each Grid Block. The carbon sequestration values (in tons of carbon) and the total NDVI_FC, SAVI_FC, and MSAVI2_FC values from all 61 Grid Blocks were used to perform regression analysis.

The results are as follows: from the vegetation indices NDVI_FC, SAVI_FC, and MSAVI2_FC, the derived regression equations were $y = 0.2655e^{0.1847x}$, $y = 0.2656e^{0.1847x}$, and $y = 0.2814e^{0.2534x}$, respectively, and the corresponding R^2 values were 0.8526, 0.8526, and 0.7965, respectively. It can be seen that the R^2 values for the vegetation index models NDVI_FC, SAVI_FC, and MSAVI2_FC are relatively high, indicating that these models can be effectively used to predict the relationship between carbon sequestration and vegetation indices.

3.5. Carbon Estimation Results Using Modeling

3.5.1. Results from the Area Block Modeling Method

The carbon estimation results using the model based on the regression equations between total carbon sequestration and vegetation indices derived from the Area Block method are presented in **Table 2**. Table 2 shows a comparison of carbon values between field survey data and UAV imagery processed using the Area Block method. Among the 11 Area Blocks, differences were observed between carbon estimates obtained from vegetation indices (NDVI_FC, SAVI_FC, and MSAVI2_FC) and those from field data.

Two vegetation indices—NDVI_FC and SAVI_FC—produced identical carbon sequestration estimates: 6.90388 tC, 25.31424 tCO₂e, and 0.00432 tCO₂/m². In contrast, MSAVI2_FC estimated carbon sequestration at 6.83419 tC, 25.05868 tCO₂e, and 0.00427 tCO₂/m². When compared to the field survey data, which reported significantly higher values of 23.7047 tC and 86.91723 tCO₂e with a carbon per square meter ratio of 0.01482 tCO₂/m², clearly highlighting the discrepancy between carbon measurement using vegetation indices and field-based data. It can be concluded that estimating carbon sequestration using vegetation indices through the Area Block method tends to yield significantly lower results compared to field measurements.

Table 2.**Results from the Area Block Modeling Method.**

Carbon volume	Area sq.m. (m²)	Tons of carbon (tC)	Tons of carbon dioxide equivalent (tCO₂)	Tons of carbon dioxide/sq.m. (tCO₂/m²)
RS_NDVI_FC	5,864.17956	6.90388	25.31424	0.00432
RS_SAVI_FC	5,864.17956	6.90388	25.31424	0.00432
RS_MSAVI2_FC	5,864.17956	6.83419	25.05868	0.00427
Field data	5,864.17956	23.7047	86.91723	0.01482

3.5.2. Results from the Grid Block Modeling Method

The carbon estimation results using the model based on the regression equations between total carbon sequestration and vegetation indices from the Grid Block method are presented in **Table 3**. Table 3 provides a comparison of carbon values obtained using the Grid Block method, highlighting differences in the amount of carbon measured through various techniques, including NDVI_FC, SAVI_FC, MSAVI2_FC, and field-based data collection. This comparison focuses on an area of 33,853.16369 square meters, with varying results in terms of total carbon (tC) and carbon dioxide equivalent (tCO₂). According to the data in **Table 3**, RS_NDVI_FC and RS_SAVI_FC produced similar results in terms of total carbon and carbon dioxide equivalents. RS_NDVI_FC yielded 32.47310 tC and 119.06804 tCO₂e, while RS_SAVI_FC recorded 32.48533 tC and 119.11288 tCO₂e. Both methods resulted in the same average carbon dioxide per square meter, at 0.00352 tCO₂/m². In contrast, RS_MSAVI2_FC produced slightly higher values, with 34.17078 tC and 125.29286 tCO₂e, resulting in a higher average carbon dioxide per square meter of 0.00370 tCO₂/m². When compared with field data, a clear difference is observed. The field survey reported the highest carbon value at 40.52095 tC and 148.57682 tCO₂e, resulting in the highest average carbon dioxide per square meter of 0.00439 tCO₂/m². From this comparison, it can be concluded that carbon estimation using various Grid Block techniques yields differing results, with variation in the level of accuracy and spatial detail. While field data remains the most accurate source, the use of emerging techniques may offer greater convenience and efficiency for future carbon assessments.

Table 3.**Results from the Grid Block Modeling Method.**

Carbon volume	Area sq.m. (m²)	Tons of carbon (tC)	Tons of carbon dioxide equivalent (tCO₂)	Tons of carbon dioxide/sq.m. (tCO₂/m²)
RS_NDVI_FC	33853.16369	32.47310	119.06804	0.00352
RS_SAVI_FC	33853.16369	32.48533	119.11288	0.00352
RS_MSAVI2_FC	33853.16369	34.17078	125.29286	0.00370
Field data	33853.17307	40.52095	148.57682	0.00439

4. CONCLUSION

This research studied the relationship between carbon sequestration and vegetation indices using various spatial analysis methods. In the Crown Cover method, the R² values representing the relationship between carbon sequestration and vegetation indices were found to be low. Specifically,

the R^2 values for NDVI_FC, SAVI_FC, and MSAVI2_FC were approximately 0.0721, 0.0635, and 0.0639, respectively, indicating a weak predictive capability. In contrast, the Area Block method demonstrated stronger correlations, with R^2 values for NDVI_FC, SAVI_FC, and MSAVI2_FC reaching 0.8924, 0.8924, and 0.8940, respectively. These results indicate that the relationship between carbon sequestration and vegetation indices can be effectively predicted. The regression equations obtained from this study can be applied to spatial carbon analysis. For the Grid Block method, the R^2 values for NDVI_FC, SAVI_FC, and MSAVI2_FC were 0.8526, 0.8526, and 0.7965, respectively, which also demonstrate a good level of correlation and predictive capability. Regarding the carbon estimation results using the models, it was found that both the Area Block and Grid Block methods produced significantly different results compared to field data. Carbon estimation using vegetation indices with the Area Block method tended to yield lower values than field measurements. In contrast, the Grid Block method produced values closer to those obtained from field data, although differences still remained. Field data continues to serve as the most accurate reference. However, the application of new techniques such as Area Block and Grid Block methods may offer increased efficiency and convenience in carbon assessment in the future. These methods represent promising approaches that can be further developed and refined to enhance accuracy and practical value in carbon estimation across various areas.

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