EVALUATION OF TREE BIOMASS AND CARBON SEQUESTRATION THROUGH REMOTE SENSING AND FIELD METHODS

***Teerawong LAOSUWAN** [1,4], **Yannawut UTTARUK** [2], **Supachai NAKAPAN** [3], **Jumpol ITSARAWISUT** [1,4], **Chaiphat PLYBOUR** [1,4*]*

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ABSTRACT

Among other greenhouse gases, Carbon dioxide (CO_2) is a gas that generates the most accumulated heat energy in the atmosphere and it is the main factor to causes the greenhouse effect by humans. However, aboveground biomass (AGB) can be converted to carbon sequestration by multiplying the constant according to Intergovernmental Panel on Climate Change (IPCC) instructions where the estimation of biomass or carbon sequestration is still an interesting issue. This article presents the method for estimating aboveground biomass of dry deciduous dipterocarp forest with data from the Sentinel-2A satellite. Summary procedures are 1) conduct field survey by creating 24 sample plots size 20x20 m and measure the size and height of the trees to calculate for aboveground biomass, 2) analyze data from Sentinel-2A satellite by using MSAVI2 and FVC Model, and 3) figure out the relationship between the analysis results from Sentinel-2A satellite and field survey data by using a statistical method and carbon sequestration in the study area. The study result finds a relationship equation $y = 4.9358^{0.038x}$ and finds that the study area of dry deciduous dipterocarp forest has aboveground biomass of 2,135.57 tons, which equals 187.407 tC, 3,680.31 tCO_2eq, and 26.77 ha.

***Key-words**: Remote Sensing; Carbon dioxide; Carbon sequestration; Biomass; Dry deciduous dipterocarp forest.*

1. INTRODUCTION

Fossil fuel combustion and deforestation are human activities that emit the most greenhouse gases into the atmosphere and are major factors to cause global climate change. In 2000, all kinds of activities around the world produced greenhouse gas emission 41,755 $MtCO_2eq$ which consists of carbon dioxide (CO_2) 77%, methane (CH_4) 14%, nitrous oxide (N_2O) 8%, and hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) total is 1% (Laosuwan & Uttaruk, 2023). Global climate change known as global warming is a major problem that impacts the global ecosystem and human habitation. Melting arctic ice and sea level rise lead to the loss of creature habitation and ecosystem change as well as emerging diseases that cause lots of human death (Uttaruk, & Laosuwan, 2019; Rotjanakusol & Laosuwan, 2020; Uttaruk et al., 2024). The increasing global temperature arises from greenhouse gases: GHGs emissions, especially CO_2 from human activities such as fuel combustion in various industries, transportation, agriculture, forest burning, and so on (Liu & Liang, 2017; Laosuwan et al., 2023; Uttaruk et al., 2024).

[1]*Department of Physics, Faculty of Science, Mahasarakham University, Maha Sarakham, Thailand, teerawong@msu.ac.th, drjumpol.i@gmail.com, chaiphat.p@msu.ac.th*
[2]*Department of Biology, Faculty of Science, Mahasarakham University, Maha Sarakham, Thailand, yannawut.u@msu.ac.th*
[3]*Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Thailand, supachai.n@cmu.ac.th*
[4]*Space Technology and Geo-Informatics Research Unit, Faculty of Science, Mahasarakham University, Maha Sarakham, Thailand*
**Corresponding author*

Currently all over the world have tried to solve and reduce CO_2 which is a major factor of greenhouse effect such as forcing by price mechanism to eliminate greenhouse gas and so on (Anagnostou et al., 2016; Meena & Laosuwan, 2021).

However, the reduction of CO_2 emission into the atmosphere has many ways such as clean production technology development, using clean energy, and using carbon capture and sequestration technology (European Commission, 2024; UCDAVIS, 2024). Carbon capture and sequestration are regarded as one method to control the emission of CO_2 not floating to the atmosphere and the best sequestration, economical and natural way is sequestration in the trees and wooden products as trees will absorb CO_2 from the atmosphere through photosynthesis and store it in the form of biomass both aboveground biomass, namely stem, branch and leaf and Below Ground Biomass, namely any underground part of the tree, mostly are roots (Lewis et al., 2009; Pandey et al., 2014; Yadav et al., 2017; Lal & Singh, 2020; Chopra et al., 2023), then carbon will be detained in the tree until it is cut. If it has more photosynthesis then more CO_2 has been used and accumulated (Boston University, 2024). Tree anatomical characteristics can be used to evaluate the biomass of the tree using the allometric equation which is the relationship between biomass and tree structure (Tkemaladze & Makhashvili, 2016). Tree structure measures from field surveys but this method requires a field specialist as well and it is time-consuming and costly (Chaiyo et al., 2011; Poorte et al., 2012; Fernando et al., 2020; Nowak & Crane, 2021; Pati et al., 2022).

Currently, geoinformatics technology, especially remote sensing technology has been widely used as a main tool to study various spatial phenomena by using data from natural resource survey satellites as a tool to continuously and efficiently record the area condition (Rotjanakusol & Laosuwan, 2019a; Nakapan, & Hongthong, 2022; Hongthong, & Nakapan, 2023). It can explore natural resources on land surface, water surface and sub-surface, covering a wide area (Lolli, 2023). In addition, remote sensing technology is recognized as an up-to-date and efficient technology, it can monitor and detect any phenomenon on earth's surface rapidly and with timeliness (Rotjanakusol & Laosuwan, 2019b; Prohmdirek et al., 2020; Jomsrekrayom et al., 2021). Regarding the study of relevant research and documents in the analysis and evaluation of aboveground biomass and carbon sequestration in the forest and agriculture areas found that various researchers have studied this matter (Chaiyo et al., 2012; Thammanu et al., 2021; Chen et al., 2023; Duangsathaporn et al., 2023), but Thailand has not found such research for dry deciduous dipterocarp forest with data from Sentinel-2A satellite and use Modified Soil Adjusted Vegetation Index (MSAVI2) and Fractional Vegetation Cover (FVC) model. For this reason, a researcher has the objective to evaluation of tree biomass and carbon sequestration through remote sensing and field methods of dry deciduous dipterocarp forest which is located at the Nature Education Center at Mahasarakham University with satellite imagery data of Sentinel-2A and uses MSAVI2 and FVC model.

2. MATERIALS AND METHODS

2.1. Study Area

The area of dry deciduous dipterocarp forest is located at the Nature Education Center at Mahasarakham University and has an area of 21.99 ha (**Fig. 1**). Maha Sarakham Province is located in the middle of northeastern Thailand at an elevation of 153 m. General geography is plateau but no mountains, northern and southern parts are highland and lowland alternately and gradually slope to the plain on the eastern part. Regarding the weather conditions in Thailand, the seasons in Maha Sarakham are divided into three seasons: winter starts from mid-October to mid-February, summer starts from mid-February to mid-May, and rainy starts from mid-May to mid-October.

2.2. Data Collecting

Sentinel-2A is a natural resources observation satellite that operates under the supervision of the European Space Agency (ESA). Currently, Sentinel-2 has two satellites, namely Sentinel-2A and Sentinel-2B, it orbits at the height of 785 kilometres from the Earth's surface and records approximately the same data at the same location every five days. Data recorded by the satellite will cover three wavelengths, namely Visible light, Near Infrared, and Short-Wave Infrared. Sentinel-2 satellite has spatial resolution in three types which are 10, 20, and 60 meters.

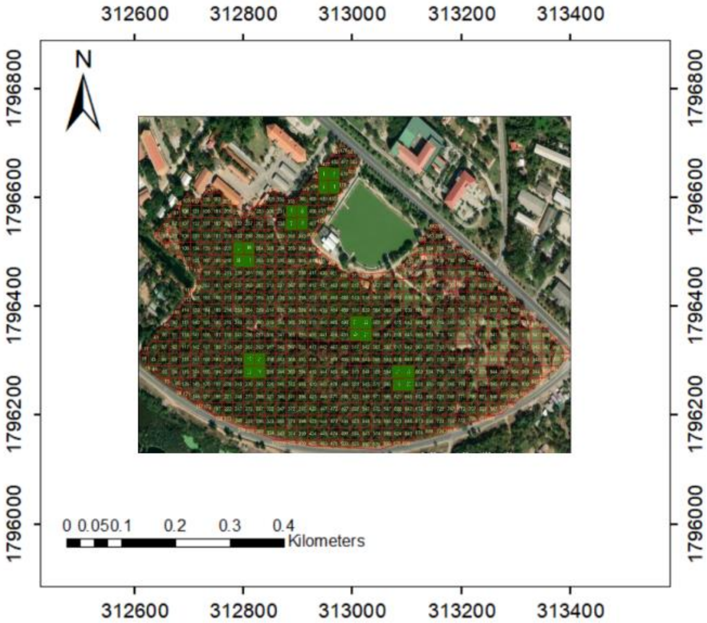

Fig. 1. Study area.

2.3. Operation

The operation in this study will state in each step as follows below.

2.3.1. Field data collecting

This study conducted 24 sample plots size 20x20 m to represent the Nature Education Centre at Mahasarakham University (see in **Fig. 1**) and records the geographic coordinate system by using Global Positioning System (GPS) as shown in **Table 1**. In these sample plots, all individual trees with diameter at breast height (130 cm aboveground) more than 4.5 cm were measured using diameter tape and the total height of the tree was measured using a laser meter (Nikon Forest ProII).

Table 1.

24 sample plots size 20x20 m.

No.	ID	Latitude	Longitude	No.	ID	Latitude	Longitude
1	1MSU01	312951	1796674	13	2MSU04	312811	1796374
2	1MSU02	312951	1796654	14	2MSU05	312811	1796354
3	1MSU03	312971	1796674	15	2MSU06	312831	1796374
4	1MSU04	312971	1796654	16	2MSU07	312831	1796354
5	1MSU05	312892	1796614	17	2MSU08	313095	1796354
6	1MSU06	312892	1796594	18	2MSU09	313094	1796334
7	1MSU07	312912	1796614	19	2MSU10	313115	1796357
8	1MSU08	312912	1796594	20	2MSU11	313115	1796337
9	1MSU09	312791	1796554	21	2MSU12	313011	1796439
10	2MSU01	312791	1796534	22	2MSU13	313011	1796419
11	2MSU02	312811	1796554	23	2MSU14	313031	1796441
12	2MSU03	312811	1796534	24	2MSU15	313031	1796421

2.3.2. Carbon storage estimation

An allometric equation for Mixed deciduous and dry deciduous dipterocarp forest by (Ogawa et al., 1965) (allometric equation see in **Table 2**) was used to estimate aboveground biomass in tree level. Then calculated belowground biomass of each tree by multiplying with default value shoot and root ratio 0.27 for tropical forest by IPCC (IPCC, 2006). To convert biomass to carbon was multiplied biomass values by carbon fraction 0.47. The carbon in plot level was calculated by sum of all tree carbon in each plot by kilogram then converted to tone. The calculated carbon density of the sample area by sum all carbon in plot level and divided by sampling plot area $tC \cdot ha^{-1}$.

Table 2.

Equation for analysis of biomass.

Forest Type	**Equation**	**Source**
Deciduous dipterocarp forest	$Ws = 0.0396\ D^2H\ 0.9326$ $Wb = 0.003487\ D^2H\ 1.0270$ $Wl = (28.0/wtc+0.025)^{-1}$	Deciduous dipterocarp forest (Ogawa et al., 1965)

2.3.3. Data analysis from Sentinel-2 satellite

Pre-processing: Satellite imagery data of Sentinel-2 is the data that has radiometric correction but needs to have geometric correction by referring to UTM zone 48N WGS1984 mapping control. The correction method will refer to the accurate coordinate from the image that needs to be corrected to the image that has a coordinate system that refers to the image to image by using Second Order Polynomials correction and determining Root Mean Square Error not exceeding 1 pixel and selecting conversion method to Nearest Neighbor Resampling.

Analysis of MSAVI2 (Qi et al., 1994) and FVC (Zhang et al., 2019): MSAVI2 is a vegetation index that attempts to reduce the influence of electromagnetic radiation reflection from the ground with few vegetations and MSAVI2 analysis is shown in Equation 1. The analysis of the FVC model from the Modified Soil Adjusted Vegetation Index (MSAVI2) is shown in Equation 2. In addition, a researcher has analyzed carbon sequestration amount which is the analysis of actual greenhouse gas sequestration from a reservoir. In this study, a researcher uses stratified sampling to create a sample plot methodically between the planting area and the non-planting area. However, the analysis of biomass and carbon sequestration amount is shown in Equations 3 to 8 and **Table 2**. (1)

$$MSAVI2 = 1/2 \times ((2 \times (NIR+1)) - (((2 \times NIR)+1)2 - 8(NIR-red))1/2) \qquad (1)$$

where:
MSAVI is the vegetation index
NIR is the Near Infrared band reflectance and
RED is the red band reflectance

$$FVC = \frac{(VI - VI_{open})}{(VI_{canopy} - VI_{open})} \qquad (2)$$

where:
FVC is the tree canopy fractional cover
VI is the vegetation index
VIopen is the vegetation index of open areas and
VIcanopy is the vegetation index of tree canopy

$$AGB = Ws + Wb + Wl \qquad (3)$$

$$BGB = ABG \times R \qquad (4)$$

$$CTree = (AGB + BGB) \times 0.47 \qquad (5)$$

where:
C_{tree} is carbon cost quantification in tree biomass
ABG is Aboveground biomass
BGB is Belowground biomass and
R is the shoot and root ratio (IPCC, 2006).

$$\text{Cdensity} = \frac{\sum \text{Ctree}}{\text{Sampling area}} \tag{7}$$

$$\text{Ctotal} = \text{Cdensity}' \ \text{Forest\_area}) \tag{8}$$

$$\text{CO2eq} = \text{Ctotal} \times \frac{44}{12} \tag{9}$$

3. RESULTS AND DISCUSSION

3.1. Amount of Aboveground Biomass

The analysis result found that aboveground biomass from measuring the tree in a sample plot with a girth from 14.5 cm at the breast height (130 cm) by using diameter tape and measuring the tree height in meters by using a laser meter and using allometric equation to calculate tree biomass. The result detailed in **Table 3**, found that the area of dry deciduous dipterocarp forest locates at the Nature Education Center at Mahasarakham University has total above ground biomass of sampling plots was 88.081 tons which carbon density equals 187.410 tC. The total carbon stock in forest area 34.646 tCO_2/ha and 4,769.27 tCO_2e.

Table 3.

Analysis of biomass from field survey.

	tC	**tCO_2e**	**tCO_2/ha**
Field survey	187.410	4,769.27	34.646

3.2. Analysis of MSAVI2 and FVC

The analysis result of MSAVI2 and FVC for Dry Deciduous Dipterocarp Forest at the Nature Education Center at Mahasarakham University is shown in **Fig. 2** and **Fig. 3**.

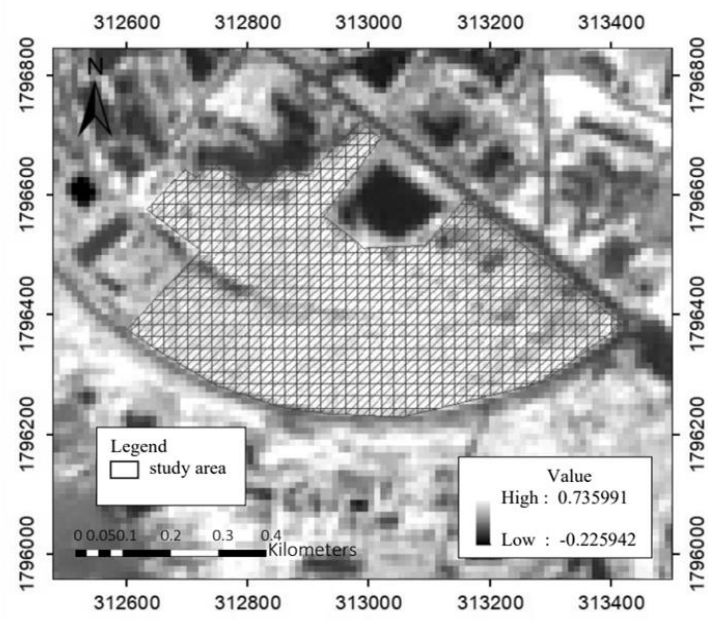

Fig. 2. Analysis result of MSAVI2.

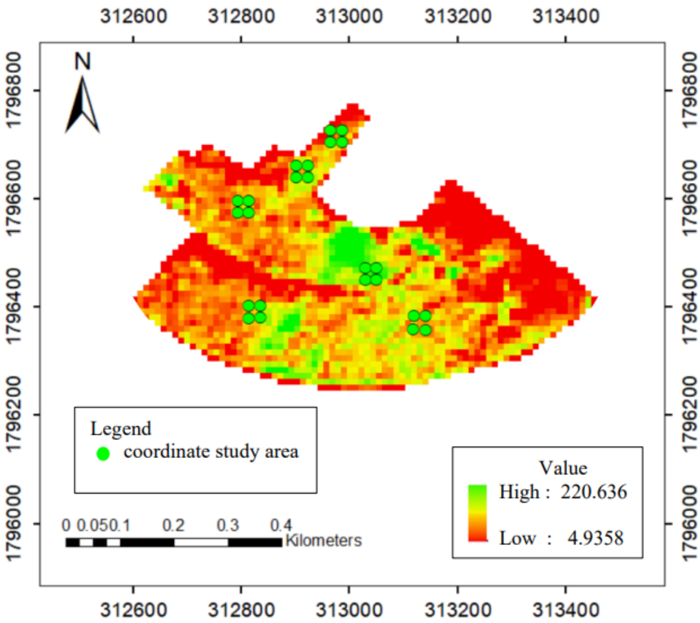

Fig. 3. Analysis result of FVC.

In **Fig. 2** using MSAVI2, the analysis result found the maximum value is 0.735 and the minimum value is 0.2225, and in **Fig. 3** using the FVC model, the result found the maximum value is 220.636 and the minimum value is 4.935.

3.3. Analysis of the statistical relationship

This study presents the analysis result from the Sentinel-2A satellite by using the FVC model and field survey to figure out the statistical relationship (shown in **Table 4**).

Table 4.

Analysis of biomass from the Sentinel-2A satellite by using the FVC model.

	tC	tCO_2e	tCO_2/ha
FVC model	187.407	3,680.31	26.766

The analysis result of the statistical relationship is shown in **Fig. 4**; an equation of the statistical relationship is $y = 4.9358^{0.038x}$ and coefficient of determination where X is the analysis result from the FVC model and Y is a carbon (ton). Regarding the statistical relationship representing carbon in the dry deciduous dipterocarp forest at the Nature Education Center at Mahasarakham University, the obvious result is the red area shows less carbon and it can be anticipated that there are fewer trees or wastelands while the orange area has more carbon than the red area as there are fewer trees but not plenty of it as well as the forest has been disturbed and tree space is far enough.

In addition, the yellow area found more carbon than the orange area and the green area had the most carbon (**Fig. 5**). It also found that the study area has a total aboveground biomass of 2,135.574 tons, which equals 187.407 tC, 3,680.31 tCO_2e, and 26.766 tCO_2/ha. Further, a researcher has tested the statistical accuracy by using a Pair Sample T-test with the SPSS program between analyzed data from Sentinel-2A satellite and data from field survey found that Sig value is less than significant value ($0.001 < 0.05$) and it has statistically significant difference at 95% of reliability level.

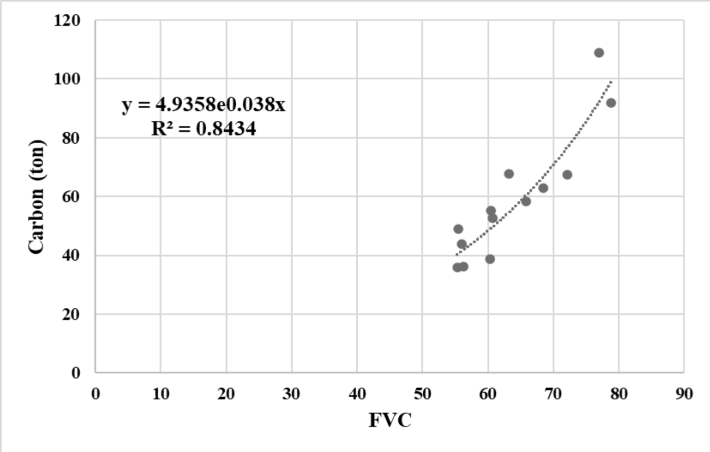

Fig. 4. Statistical relationship from the Sentinel-2A by using the FVC model and field survey.

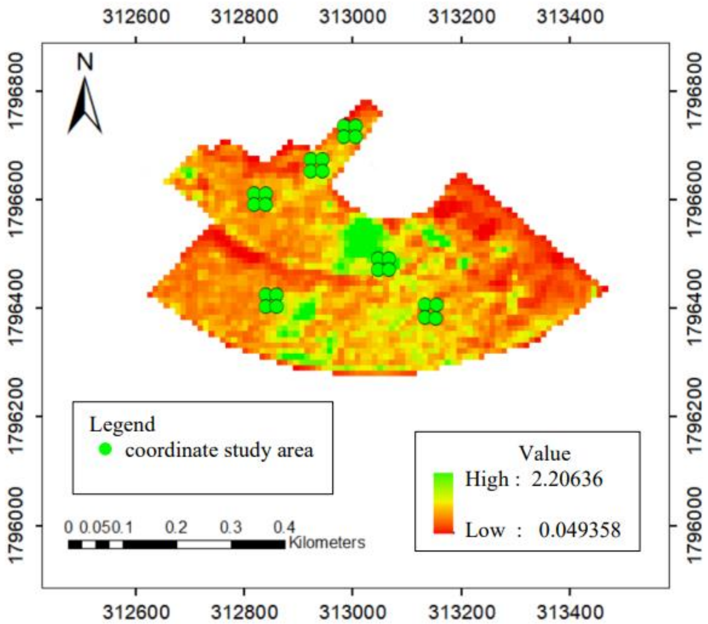

Fig. 5. Carbon sequestration in study area.

This study presents an analysis based on data from the Sentinel-2A satellite, employing the FVC model in conjunction with field surveys to determine statistical correlations. The results revealed a robust statistical association, indicated by an R^2 value of 0.843. The effective performance of this estimation can be attributed to the carefully chosen wavebands of Sentinel-2, which capture a range of leaf characteristics such as chlorophyll concentration, leaf area index, and green biomass. These characteristics are vital for evaluating forest services, including biomass and carbon stock (Dube et al., 2014; Gara et al., 2016; Mngadi et al., 2021). Our results support the hypothesis that the band configuration and settings of the Sentinel-2 sensors are optimal for assessing vegetation metrics and services, particularly biomass and carbon sequestration (Mutanga et al., 2012). Additionally, the near-infrared (NIR) bands of the Sentinel-2 satellite provide accurate spectral reflectance, facilitating precise evaluations of vegetation metrics, including biomass and carbon stock. The NIR band operates within a narrow spectral wavelength range of 850 to 880 nm, exhibiting high sensitivity to the biophysical and biochemical responses of vegetation (Matongera et al., 2017; Bindu et al., 2020). Key biophysical properties, such as leaf area and biomass, along with biochemical characteristics like chlorophyll content, are essential for evaluating the health and productivity of vegetation. Results of this study also showed a strong correlation between the estimated aboveground carbon sequestration and measured carbon sequestration. Such a strong relationship is associated with the consolidation of optimal variables of MSAVI2 selected by process for the final prediction FVC model of carbon sequestration. This could be attributed to the fact that MSAVI2 is an important indicator of green-biomass, which can be effectively used for deriving and monitoring aboveground carbon sequestration (Uttaruk & Laosuwan, 2020).

The findings of this research align with the work of Laosuwan and Uttaruk (Laosuwan & Uttaruk, 2014), who assessed aboveground carbon storage in forested regions through the application of MSAVI2 and FVC methodologies. In a related investigation, Mshelia et al. (Mshelia et al., 2020), assessed the carbon stock of a forest reserve using MSAVI2. The impressive predictive capability of MSAVI2 in estimating carbon stock can be attributed to the sensitivity of the NIR spectrum to the internal leaf mesophyll, a key indicator of vegetation health that significantly influences maximum biomass productivity (Rafique et al., 2016). MSAVI2 encompasses strong spectral data obtained from the Red and NIR bands, which are particularly effective in assessing vegetation health and productivity, serving as important indicators of carbon accumulation. As noted by Laosuwan and Uttaruk (Laosuwan & Uttaruk, 2014). Additionally, the findings regarding carbon stock in this research indicate a variation in carbon stock throughout the study area, which diminishes as canopy density decreases. The differences in carbon stock observed within the study area can be linked to the diverse topographic features of the landscape, which play a crucial role in determining vegetation density and productivity. Research indicates that factors such as slope, elevation, and aspect can have a substantial impact on the spatial distribution of carbon stock in forest ecosystems (Zhu et al., 2019). Additionally, variations may arise from the composition of forest species, which differ in their biophysical attributes (such as leaf area, stomatal characteristics, and canopy structure) and biochemical properties (including leaf pigments, lignin content, and carotenoids) (Waring et al., 1998; Liu et al., 2018). An example of the dry deciduous dipterocarp forest in this study, which includes species such as *Shorea obtusa Wall. ex*-Blume, *Shorea siamensis* Miq. *Dipterocarpus obtusifolius* Teijsm., and *Xylia xylocarpa* (Roxb.) Taub. These forests are characterized by large leaf stomatal properties that enhance plant productivity and carbon storage. In contrast, shrub trees like *Cycas circinalis* L. exhibit limited structural geometry, along with reduced stem and leaf biomass, resulting in a lower carbon stock.

4. CONCLUSIONS

This research conducted at the Nature Education Center of Mahasarakham University aimed to evaluate the aboveground biomass and carbon stock of a dry deciduous dipterocarp forest. The study involved measuring the girth and height of trees within designated sample plots, employing allometric equations to derive biomass estimates. The results indicated a total aboveground biomass of 88.081 tons, which corresponds to a carbon density of 187.410 tC. The carbon stock was assessed at 34.646 tCO_2e/ha, totaling 4,769.27 tCO_2e. To analyze the forest area, the Modified Soil Adjusted Vegetation Index (MSAVI2) and Fractional Vegetation Cover (FVC) were utilized. The MSAVI2 values ranged from 0.2225 to 0.735, reflecting variations in vegetation health and coverage. The FVC analysis yielded values between 4.935 and 220.636, aiding in the understanding of vegetation density and distribution. Utilizing Sentinel-2A satellite data, the study explored the statistical correlation between FVC model outputs and carbon content. This relationship was expressed by the equation y = 4.93580.038x, where (x) denotes FVC results and (y) signifies carbon in tons. The analysis highlighted areas with differing carbon content, revealing that regions with lower carbon levels (indicated by red and orange areas) had fewer trees or were disturbed, while areas with higher carbon levels (represented by yellow and green areas) exhibited greater biomass. The total aboveground biomass calculated was 2,135.574 tons, equivalent to 187.407 tC and 3,680. tCO_2e, with a carbon density of 26.766 tCO_2e /ha. The statistical validity of these findings was affirmed through a Pair Sample T-test, which demonstrated a significant difference between satellite and field survey data, with a p-value of less than 0.001, indicating a high level of reliability at a 95% confidence interval. The insights derived from this study are crucial for developing management strategies aimed at enhancing carbon storage in dry dipterocarp forests, thereby contributing to efforts to mitigate future climate change.

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