Environment and Natural Resources Journal

Volume 22
Issue 6
2024

Carbon Sequestration Assessment Using Satellite Data and GIS at Chiang Mai Rajabhat University

Ratchaphon Samphutthanont[1,2*], Worawit Suppawimut[1,2], Phathranit Kitthitinan[1,3], and Kitisak Promsopha[2]

[1]*Department of Geography and Geoinformatics, Faculty of Humanities and Social Sciences, Chiang Mai Rajabhat University, Thailand*
[2]*Asian Air Quality Operations Center by Space Technology, Geoinformatics and Environmental Engineering (AiroTEC), Chiang Mai Rajabhat University, Thailand*
[3]*Department of Business Administration, Faculty of Management Sciences, Chiang Mai Rajabhat University, Thailand*

ARTICLE INFO

Received: 27 Jun 2024
Received in revised: 25 Sep 2024
Accepted: 4 Oct 2024
Published online: 6 Nov 2024
DOI: 10.32526/ennrj/22/20240183

Keywords:
Carbon sequestration/ NDVI vegetation index/ Sentinel-2/ Geographic Information Systems (GIS)

*** Corresponding author:**
E-mail: ratchaphon_sam@cmru.ac.th

ABSTRACT

This study conducted a project to assess carbon sequestration in the forest area of Chiang Mai Rajabhat University, Mae Rim Campus, covering a total area of approximately 5,600 rai, with about 75% consisting of dry dipterocarp forest. The Sentinel-2 satellite data from 2019 to 2023 were used to analyze and classify forest density using the Normalized Difference Vegetation Index (NDVI). It was classified into four NDVI levels: highest, high, moderate, and low. Then, eight sample plots were distributed across all density levels to collect field data on tree species, number of trees, height, and diameter. The biomass and carbon sequestration in the sample plots showed a strong correlation with vegetation density, with the highest average correlation in February, particularly on February 13, 2023, showing the highest correlation coefficient of 0.817. This relationship is described by the equation y=78.601x–25.726, indicating that this model is effective for estimating carbon sequestration. The analysis revealed that the area with the highest NDVI level of dry dipterocarp forest had the highest above-ground carbon sequestration rate of 16.25 tons per rai, whereas the forest with the lowest NDVI level had an above-ground carbon sequestration rate of 0.21 tons per rai. In total, the above-ground carbon sequestration for the trees amounted to 50,907.35 tons. This preliminary assessment serves as a promising foundation for future efforts the conservation and restoration of the university's forest area, contributing to sustainable strategies for mitigating global warming.

1. INTRODUCTION

Currently, we are facing the problem of global warming, scientifically believed to be caused by greenhouse gases released from human activities. In general, greenhouse gases are essential for maintaining the Earth's temperature by enveloping the atmosphere (TMD, 2024). However, excessive amounts of these gases can increase global temperatures, affecting ecosystems and living organisms. Carbon dioxide (CO_2), in particular, is the most abundant greenhouse gas in the atmosphere, primarily resulting from human activities (ISDNRE, 2020). Major sources of emissions are from electricity production, industrial operations, transportation, and agricultural activities, which are challenging to control (Manee-in, 2022). Nevertheless, the increase in CO_2 can be managed by expanding green areas with trees which use CO_2 to produce biomass for the stems, branches, leaves, and roots (Forest Learning, 2020), thereby sequestering carbon in various parts of the tree (Tripattanasuwan et al., 2010). As is obvious that forests can, thus, act as significant carbon sinks, storing CO_2 in above-ground biomass (IPCC, 2003; Brown, 1996; Mousiew et al., 2019). Restoring the remaining natural forest areas can provide a means of carbon sequestration to mitigate greenhouse gas issues

Citation: Samphutthanont R, Suppawimut W, Kitthitinan P, Promsopha K. Carbon sequestration assessment using satellite data and GIS at Chiang Mai Rajabhat University. Environ. Nat. Resour. J. 2024;22(6):574-584. (https://doi.org/10.32526/ennrj/22/20240183)

and reduce global warming (Mousiew et al., 2019). Therefore, assessing the carbon sequestration capacity of forest areas is beneficial for understanding the current status to strategically plan for effective forest restoration, conservation, and reforestation.

According to the guidelines issued by the Thailand Greenhouse Gas Management Organization (Public Organization) or TGO, remote sensing technology has been proposed as an option for assessing carbon sequestration of trees (TGO, 2023) since it provides rapid, reliable data and is economical. Currently, satellite imagery is widely applied in forest carbon sequestration assessments, using various satellites such as Landsat 5 (Boonsang and Arunpraparat, 2011), Landsat 7 (Chai-udom et al., 2016), Landsat 8 (Pannual et al., 2015; Lolupiman et al., 2016; Uttaruk et al., 2018; Sukarna et al., 2021), Landsat 9 (Khunrattanasiri et al., 2024), and the high-resolution Sentinel-2 (Kesornbua et al., 2022; Khunrattanasiri et al., 2023). These assessments involve classifying forest areas and using the Normalized Difference Vegetation Index (NDVI) alongside field survey data and allometric equations (Thongmee et al., 2019). The timing of satellite data collection can impact the accuracy of biomass assessment models due to forest phenology and leaf shedding (Theerakultomorn et al., 2022), whereas the biomass of natural forests varies based on forest type, tree species composition, forest density, terrain, and environmental factors (Faculty of Forestry Kasetsart University, 2011; Kavinpholasa, 2023). Accurate forest classification combined with field surveys can thus enhance the precision of tree biomass carbon sequestration assessments.

Chiang Mai Rajabhat University has a plan to achieve carbon neutrality as part of its social responsibility. Therefore, it has supported preliminary surveys and assessments to determine the spatial capability of trees for carbon sequestration, as no such project has previously been conducted. The objective of this study is to survey the area and apply satellite and geographic information systems (GIS) data to assess carbon sequestration in the natural forest area within Chiang Mai Rajabhat University, Mae Rim Campus. The study aims to estimate the amount of carbon stored as biomass in trees using an above-ground biomass assessment model and multiple linear regression analysis from Sentinel-2A satellite data, selecting the most reliable time frames. The findings will provide crucial information for conserving and restoring forest areas to enhance the capacity for CO_2 absorption, raise awareness of the loss of forest areas and support organizational projects to reduce, absorb, or offset CO_2, thereby contributing to ongoing global warming mitigation efforts.

2. METHODOLOGY

2.1 Study area

The study area is Chiang Mai Rajabhat University, Mae Rim Campus, located in Mae Rim District, Chiang Mai Province. It covers an area of 5,625.90 rai (Engineering and Architecture Division, Building and Grounds Department, Chiang Mai Rajabhat University, 2023) with geographical coordinates ranging from 19.009° N to 19.045° N latitude and 98.902° E to 98.945° E longitude. The forest type found in this area is the Dry Dipterocarp Forest, including tree species such as *Shorea obtusa* Wall. ex Blume, *Shorea siamensis* Miq, *Dipterocarpus obtusifolius* Teijsm ex Miq, *Dipterocarpus tuberculatus* Roxb, *Canarium subulatum* Guillaumin and *Memecylon edule* Roxb (Rattanachuchok, 2017). The predominant soil type in the Dry Dipterocarp Forest is sandy loam or lateritic soil, which retains little water (Woodland Campus Park, 2021). The terrain is characterized as flatlands and hills, with elevations ranging from 300 to 410 meters above sea level (m.a.s.l.). The average maximum and minimum temperatures occur in April and January, 36.5 and 14.9 degrees Celsius, respectively. The highest and lowest average rainfall amounts are recorded in August and January, totaling 216.9 and 4.2 millimeters, respectively (based on a 30-year standard from the Meteorological Department, 2010). Average annual rainfall in this area is 1,130.6 millimeters per year (RID, 2024).

2.2 Data and methods

2.2.1 Classification of land use within Chiang Mai Rajabhat University, Mae Rim Campus

Land use classification was conducted using visual interpretation methods with aerial photographs from the U.S. public domain and satellite images from Keyhole, Inc., available in Google Earth software (Intapiw, 2017). This was performed on April 19, 2023, categorizing into five types; forest, water bodies, open land, built-up areas, and agricultural areas.

2.2.2 Forest type classification

2.2.2.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is calculated to assess vegetation health using near-infrared and red wavelength reflections. NDVI values range from -1 to 1 (Jensen, 2015; Theerakultomorn et al., 2022). Negative NDVI values indicate water bodies. Values approaching 0 indicate sparse vegetation, and values approaching +1 indicate dense green vegetation (Mongkonsawat et al., 2009; Theerapon, 2018). Equation (1) is used for general NDVI calculations, while Equation (2) adapts NDVI for Sentinel-2 satellite data:

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

$$\text{NDVI}_{\text{Sentinel-2}} = \frac{\text{B8} - \text{B4}}{\text{B8} + \text{B4}} \quad (2)$$

Regarding Sentinel-2 satellite data from the HARMONIZED collection, the European Space Agency (ESA) adjusted the processing baseline on January 26, 2022, which resulted in negative digital number (DN) values. This differs from the previous data. To ensure a smooth analysis of these changes, the Sentinel-2 HARMONIZED collection dataset was used (Sentinelhub, 2021; Samphutthanont, 2024).

2.2.2.2 Forest NDVI classification

To assess aboveground carbon sequestration in trees, forest conditions are classified based on completeness of vegetation using satellite imagery (Pannual et al., 2015). The ISO Cluster Unsupervised Classification method is employed using the ISO Cluster and Maximum Likelihood Classification tools, classifying 2 lowest data clusters. Each cluster should have an adequate signature file. For example, to classify forest areas within a specific boundary, the forest area should constitute a substantial percentage (ArcGIS Pro 3.1, 2023). The classification divides the forest into four density levels: Low NDVI levels, Moderate NDVI levels, High NDVI levels, and Highest NDVI levels. In this context, the average NDVI data over 5 years from Sentinel-2 satellite imagery for the period 2019-2023 is used to represent the study area.

2.2.3 Survey of biodiversityd in forest areas

Field surveys were conducted from April to May 2024, collecting data by placing 2 sampling plots size 20 × 20 meters, 2 plots per forest density, totaling 8 plots to study all types of perennial tree species. The sampling method was purposive, ensuring spatial distribution across all areas with varying NDVI density. The trees, distributed throughout the study area, were selected for the DBH of 4.5 cm or more and the height greater than 1.3 m.

2.2.4 Calculation of biomass and carbon sequestration of sample plots

Field data were used to calculate the biomass of trees, separated into the components of stems, branches, and leaves, based on the allometric equations for dry dipterocarp forest by Ogawa et al. (1965), who studied the biomass of dry dipterocarp forest in Ping Khong District, Chiang Mai Province, Thailand as presented in Equations (3)-(5).

$$\text{Stem } (W_S) = 0.0396(D^2H)^{0.9326} \quad (3)$$

$$\text{Branch } (W_B) = 0.003487(D^2H)^{1.027} \quad (4)$$

$$\text{Leaf } (W_L) = \frac{22.5}{W_S + 0.025} \quad (5)$$

Where; W_S=Biomass of stem (kg); W_B=Biomass of branches (kg); W_L=Biomass of leaves (kg); D=diameter at breast height (cm); H=Height of tree (m).

It is calculated from the average carbon content in plant tissues, including stems, branches, and leaves, with carbon fractions (CF) specified as 49.9%, 48.7%, and 48.3% respectively (Tsutsumi et al., 1983; Mousiew et al., 2019). Meanwhile, roots have a carbon fraction of 47.0% (IPCC, 2006; Mousiew et al., 2019).

2.2.5 Analysis of relationship between carbon sequestration and NDVI

The study analyzed the correlation between carbon sequestration and NDVI across 52 data sets, using a 1-square-meter grid on each 400-square-meter sample plot in order to obtain an average that is most appropriate for the area in which the sample plot boundaries overlap the Sentinel-2 data points, and to analyze the average NDVI index values and the time period that has the greatest carbon sequestration. Regression Analysis, the relationship between the dependent variable (Y) or carbon sequestration and the primary variable (X) or the NDVI index value in the sample plot area, shows the regression equation y=a+bx to explain the relationship between two variables from the R-Squared (R^2) value (Charoenhirunyingyos, 2018).

2.2.6 Carbon sequestration calculation by forest density

Carbon sequestration was estimated based on NDVI values during the peak correlation period, evaluating carbon stored within trees-stem, branch, and leaf and above-ground biomass.

3. RESULTS AND DISCUSSION

3.1 Land use

At Chiang Mai Rajabhat University, Mae Rim Campus, the predominant land use type was found to be Forest, occupying the largest area at 4,273.60 rai, accounting for 75.96%. This was followed by Building and Road, Miscellaneous, Bare soil, road, Agricultural, and Water, covering areas of 305.5 rai, 304.2 rai, 243.6 rai, 209.7 rai, 171.1 rai, and 118.2 rai, respectively, representing percentages of 5.43%, 5.41%, 4.33%, 3.73%, 3.04%, and 2.10%. This information is summarized in Table 1 and illustrated in Figure 1, indicating that the majority of the area is covered by forests.

Table 1. Current land use within Chiang Mai Rajabhat University, Mae Rim Campus

Landuse types	Area (rai)	Percentage (%)
Forest	4,273.60	75.96
Building and road	305.50	5.43
Miscellaneous	304.20	5.41
Bare soil	243.60	4.33
road	209.70	3.73
Agricultural	171.10	3.04
Water	118.20	2.10
Total	5,625.90	100.00

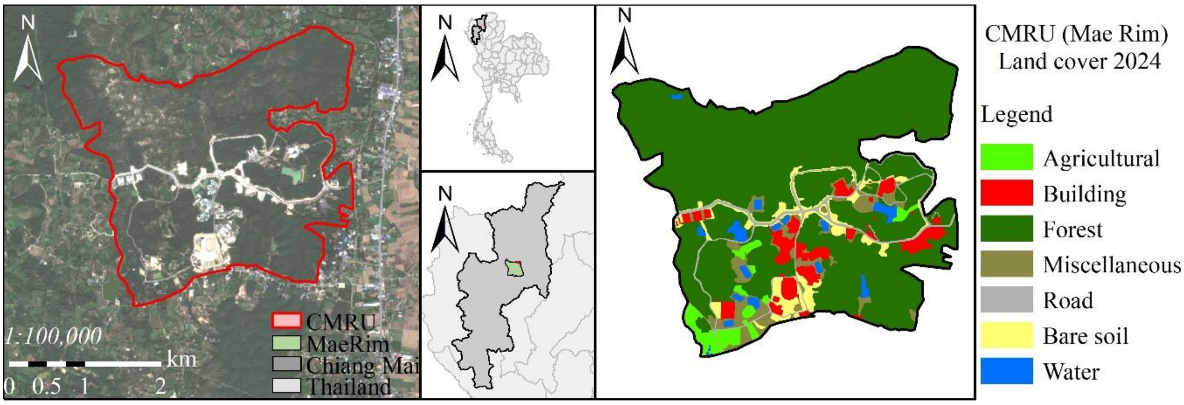

Figure 1. Map of Chiang Mai Rajabhat University, Mae Rim Campus (left) and Land Use (right)

3.2 Forest NDVI classification

3.2.1 Monthly NDVI values from 2019 to 2023

Within the study area, the highest average monthly NDVI value was observed in September, with a value of 0.688, due to high Vegetation Density in rainy season. Following this, October and November had NDVI values of 0.687 and 0.667, respectively. March was recorded the lowest average monthly NDVI value at 0.367, as it is the hottest month of the year, leading to dry conditions and dipterocarp forests. April and February had NDVI values of 0.430 and 0.449, respectively. The average NDVI value over the 5-year period was 0.579, as shown in Figure 2 and Table 2.

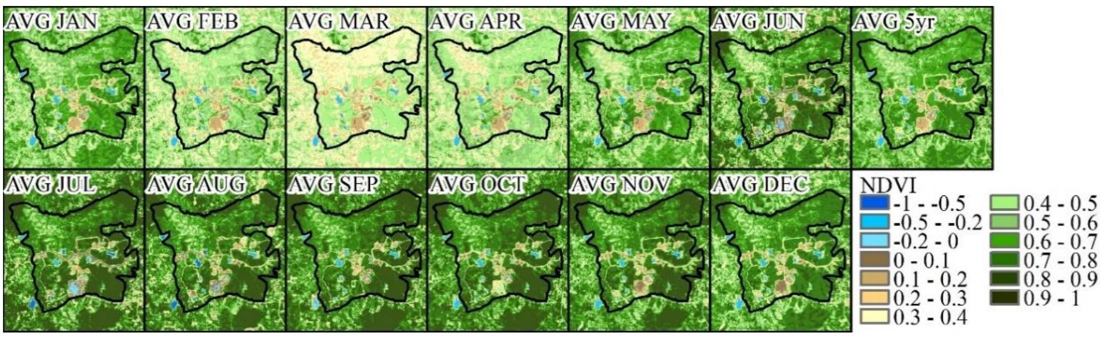

Figure 2. Monthly average NDVI from 2019-2023 and 5-year average NDVI

3.2.2 Classification of forest types based on NDVI density

Within the study area, forested areas were categorized into 4 types based on the 5-year average NDVI values using Unsupervised Classification. The largest area was classified as Highest NDVI levels, covering 2,107.30 rai, accounting for 49.75%. This was followed by areas classified as High NDVI levels, Moderate NDVI levels, and Low NDVI levels, which covered 1,536.30 rai, 550.2 rai, and 41.8 rai, respectively, accounting for 36.27%, 12.99%, and 0.99%, respectively. Therefore, the majority of the area is considered to have high forest density.

Regarding the monthly average NDVI values of forested areas, the values were arranged from lowest to highest for each month. The month with the lowest average NDVI was March, while the highest average NDVI was observed in September, as presented in Table 2 and Figure 3 and Figure 4.

Table 2. Average monthly NDVI of each forest type's density

AVG NDVI/level	Low NDVI levels	Moderate NDVI levels	High NDVI levels	Highest NDVI levels	AVG
January	0.288	0.457	0.592	0.688	0.556
February	0.251	0.372	0.468	0.554	0.449
March	0.239	0.324	0.381	0.434	0.367
April	0.237	0.353	0.453	0.522	0.430
May	0.248	0.414	0.576	0.688	0.546
June	0.288	0.471	0.651	0.789	0.607
July	0.369	0.575	0.731	0.830	0.666
August	0.330	0.546	0.704	0.806	0.653
September	0.343	0.571	0.729	0.818	0.688
October	0.363	0.588	0.741	0.818	0.687
November	0.365	0.578	0.731	0.811	0.667
December	0.337	0.538	0.691	0.775	0.630
AVG NDVI 5 year	0.339	0.490	0.618	0.708	0.579

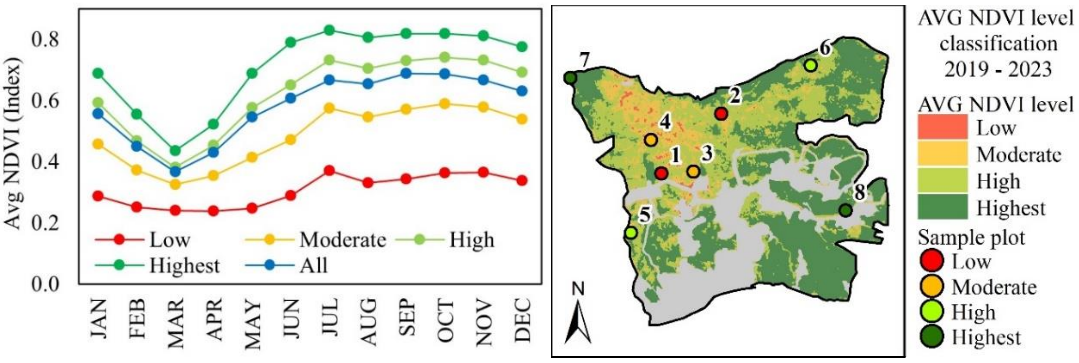

Figure 3. Average monthly NDVI (left) and plot locations (right)

3.3 Tree height and circumference within sample plots

The survey results of the sample plots revealed that the deciduous forest is dominated by species such as *Dipterocarpus obtusifolius* Teijsm. ex Miq, *Shorea obtusa* Wall. ex Blume, *Shorea siamensis* Miq, *Dipterocarpus tuberculatus* Roxb, *Canarium subulatum* Guillaumin, and *Memecylon edule* Roxb. In the areas with the highest NDVI levels, the highest average tree height was found to be 23.22 m in Plot 8, and 14.27 m in Plot 7. In contrast, in Low NDVI level areas, the lowest average tree height was 4.35 m in Plot 1 and 4.96 m in Plot 2. Regarding tree count, the highest number of trees was recorded in Plot 8 with 74 trees. Plot 7 had 33 trees, and the average diameter at breast height (DBH) was the highest at 15.55 cm. Forest areas classified under High, Moderate, and Low NDVI levels showed a decreasing trend in both tree count and DBH, corresponding to the NDVI values, as shown in Table 3.

3.4 Biomass and carbon sequestration of trees within sample plots

The Highest NDVI level areas exhibited the highest biomass quantity, with a value of 50.79 tons/rai, as well as carbon sequestration of 25.08 tons/rai. In contrast, the Low NDVI level areas had the lowest biomass quantity, at 1.04 tons/rai, and carbon sequestration of 0.51 tons/rai (Table 3). Thus, it can be concluded that the total biomass and carbon sequestration are significantly correlated, and when NDVI, indicating vegetation density and health, increases, both biomass and carbon sequestration also increase.

Table 3. Tree count, average DBH, height, biomass, and carbon sequestration of trees within sample plots

Plot	NDVI level	Number of trees	Trees/rai	Avg. DBH (cm)	Avg. H (m)	Biomass (tons/rai)	Carbon sequestration (tons/rai)	Survey date
1	Low	17	68	7.66	4.35	1.04	0.51	24 Apr 24
2	Low	19	76	6.63	4.96	1.14	0.56	1 May 24
3	Moderate	34	136	10.27	7.56	6.04	2.97	24 Apr 24
4	Moderate	36	144	10.90	8.21	6.96	3.43	1 May 24
5	High	50	200	10.70	7.15	8.33	4.11	23 Apr 24
6	High	63	252	10.71	7.39	9.90	4.88	24 Apr 24
7	Highest	33	132	15.55	14.27	22.53	11.13	23 Apr 24
8	Highest	74	296	12.76	23.22	50.79	25.08	25 Apr 24

Figure 4. Sample plots with low vegetation density in plot 1 (left) and highest vegetation density in plot 8 (right)

3.5 Relationship between carbon sequestration and NDVI index

The analysis of the correlation between carbon sequestration within sample plots and the NDVI index across 40 datasets revealed that the highest correlation coefficient (R^2) occurred in February, with a value of 0.717. January and December also showed notable correlation coefficients. Specifically, on February 13, 2023, the correlation coefficient peaked at 0.817. This relationship is expressed by the equation y=78.601x-25.726, indicating a suitable model for estimating carbon sequestration. This model suggests that during February, which typically experiences dry conditions and leaf shedding due to high temperatures and low rainfall, carbon sequestration processes are significantly affected as depicted in Table 4 and Figure 5.

3.6 Carbon sequestration

Analysis reveals that in the deciduous forest areas categorized as Highest NDVI level, the carbon sequestration rate above ground is highest, at 16.25 tons/rai. This is followed by High NDVI level, Moderate NDVI level, and Low NDVI level with rates of 9.38, 3.49, and 0.21 tons/rai, respectively. Within the study area, the average rate of above-ground carbon sequestration is 11.91 tons/rai. The total amount of above-ground carbon sequestration by all trees is calculated to be 50,907.35 tons, as shown in Table 5 and Figure 6.

Table 4. Correlation between carbon sequestration and monthly NDVI index

No.	NDVI	R Square	No.	NDVI	R Square	No.	NDVI	R Square
1	20 Jan 19	0.648	15	25 Mar 23	0.601	29	23 Oct 19	0.553
2	15 Jan 20	0.564	16	20 Apr 19	0.213	30	27 Oct 20	0.409
3	19 Jan 21	0.614	17	19 Apr 20	0.331	31	26 Nov 19	0.490
4	24 Jan 22	0.581	18	19 Apr 21	0.644	32	30 Nov 20	0.486
5	14 Jan 23	0.607	19	14-Apr-22	0.490	33	30 Nov 21	0.487
6	14 Feb 19	0.534	20	19-Apr-23	0.162	34	30 Nov 22	0.585
7	14 Feb 20	0.710	21	21 May 19	0.390	35	25 Nov 23	0.197
8	13 Feb 21	0.749	22	15 May 20	0.512	36	21 Dec 19	0.400
9	13 Feb 22	0.574	23	15 May 21	0.580	37	15 Dec 20	0.490
10	**13 Feb 23***	**0.817**	24	25 May 23	0.505	38	20 Dec 21	0.491
11	26 Mar 19	0.123	25	4 Jun 23	0.598	39	20 Dec 22	0.571
12	30 Mar 20	0.301	26	24 Jul 23	0.561	40	20 Dec 23	0.523
13	25 Mar 21	0.431	27	23 Aug 21	0.524			
14	25 Mar 22	0.279	28	18 Sep 19	0.573			

*On February 13, 2023, the highest correlation value was 0.817.

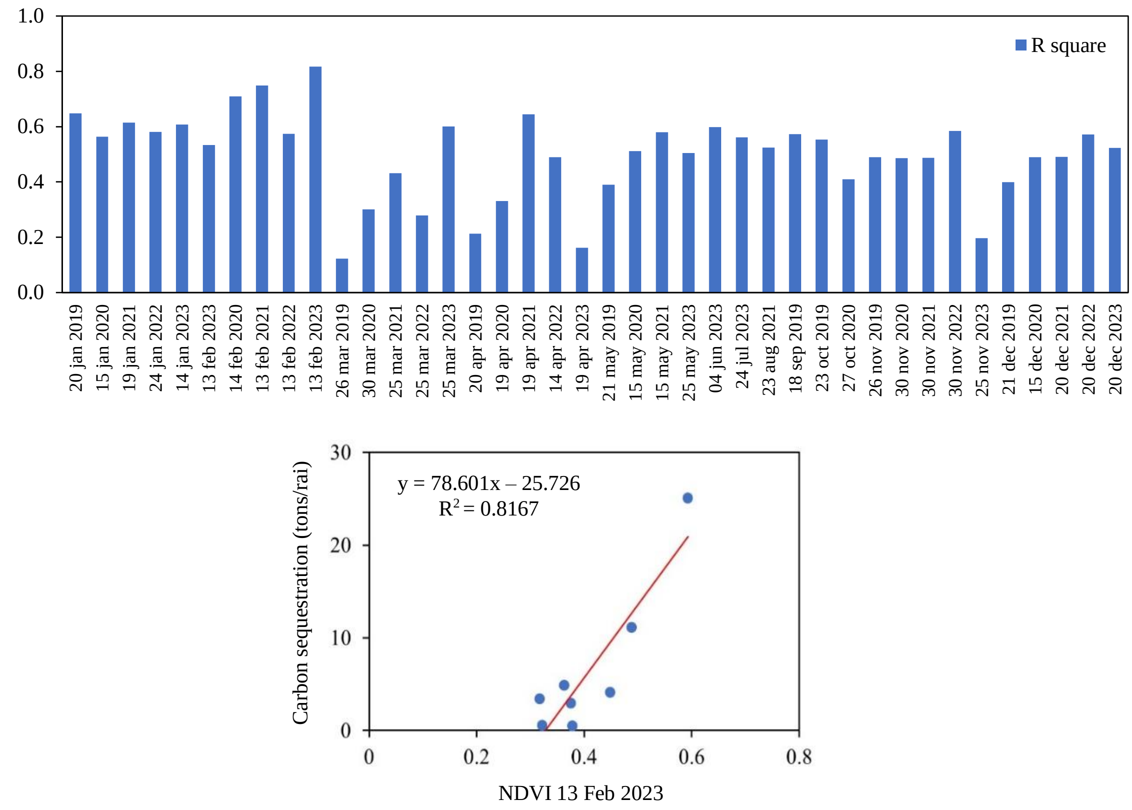

Figure 5. Relationship between carbon sequestration and the monthly NDVI index (top) and the correlation line graph for February 13, 2023 (bottom).

Table 5. Above ground carbon sequestration of trees classified by NDVI level

NDVI level	Area (rai)	Avg. carbon sequestration (tons/rai)	Sum carbon sequestration (tons)
Low	43.50	0.21	9.29
Moderate	562.62	3.49	1,963.24
High	1,551.60	9.38	14,551.39
Highest	2,115.88	16.25	34,383.44
All	4,273.60	11.91	50,907.35

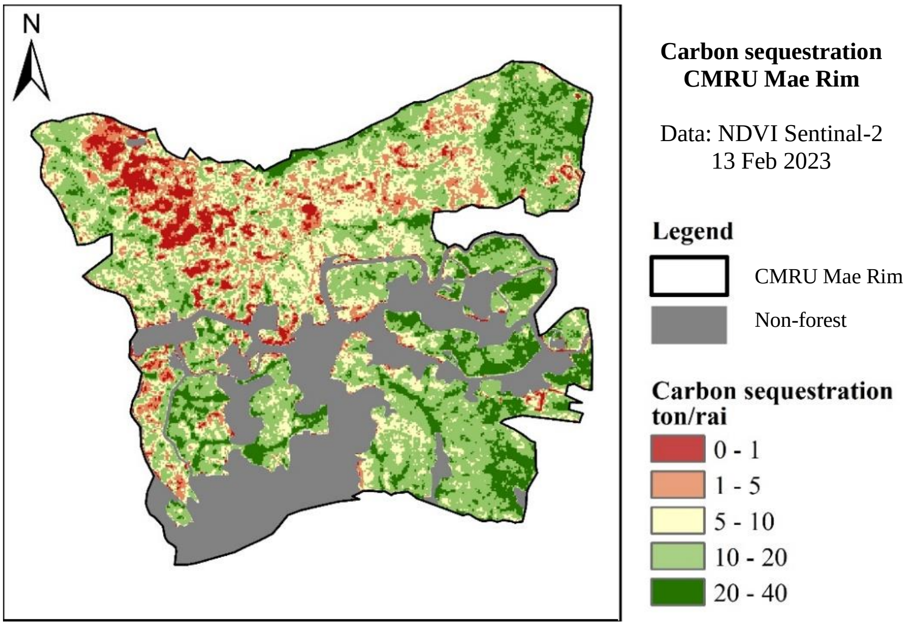

Figure 6. Map showing carbon sequestration in the study area

The study found that the average rate of above-ground carbon sequestration from the model in the dense forest areas categorized as Highest NDVI level is 16.25 tons/rai. Comparatively, a previous study (Theerakultomorn et al., 2022) estimated above-ground carbon sequestration in the deciduous forest area of Nong Rawiang, Rajamangala University of Technology Isan, Mueang Nakhon Ratchasima District, Nakhon Ratchasima Province, using Sentinel-2A satellite imagery captured on April 21, 2020, and carbon sequestration data from 10 sample plots each measuring 100 m^2. It found that the average above-ground carbon sequestration of the forest was 18.38 tons/rai, which is close to the average rate from this model.

Regarding the evaluation of above-ground carbon sequestration in the forest of the conservation area Mae Tuen Wildlife Sanctuary, Tak Province, it was found to be 8.74 tons/rai due to low fertility, low moisture, and frequent wildfires (Boonsang and Arunpraparat, 2011). This finding aligns with a study conducted in the Dipterocarpus forests of Manipur, Northeast India, where the carbon stock values ranged between 9.13 and 10.96 tons C/ha, highlighting the significant impact of environmental factors such as moisture availability and soil fertility on carbon sequestration rates (Debajit et al., 2014). In this study, the density of the mixed deciduous forest in plot 8, classified under the Highest NDVI levels group, is 296 trees/rai, which closely resembles the density of the mixed deciduous forest in the conservation forest area of Nikhom Fak Tha Cooperative, Uttaradit Province, which has 210 trees/rai (Phongthornphruek, 2015). These findings are further supported by research in Southeast Asian tropical forests, where carbon sequestration rates varied significantly depending on disturbance regimes like wildfires and local environmental conditions (Lasco et al., 2006). Comparing with Thammanu et al. (2021), which surveyed the mixed deciduous forest in the community forest of Mae Chieng Rai Lum, Lampang Province, calculated carbon sequestration and average tree density were 4.78 tons/rai and 142.48 trees/rai, respectively. These values are similar to the findings of this study in plot 4, which has a Moderate NDVI level with a tree density of 3.43 tons/rai and 144 trees/rai. Additionally, comparing carbon sequestration studies of three other mixed deciduous forests reveals varying results: Jundang et al. (2010) found an average carbon sequestration of 3.20 tons/rai and an average tree density of 125.28 trees/rai in the mixed deciduous forest of the Manjakiri Forest Garden in Khon Kaen Province, while Duangthip et al. (2022) reported an average carbon sequestration of 5.98 tons/rai and an average tree density of 302 trees/rai in the mixed deciduous forest of community forest in Tha Sala, Chiang Mai Province. Meanwhile, Kamjai et al. (2017) found higher values in the mixed deciduous forest in the community forest area of Ban Nong Yai, Kanchanaburi Province, with an average carbon sequestration of 6.19 tons/rai and an average tree density of 259.36 trees/rai. Therefore, it is evident that carbon sequestration and tree density values vary significantly among different mixed deciduous forest areas studied. These findings are supported by multiple studies across different forest types, indicating that local conditions, forest management practices, and specific environmental factors play crucial roles in determining carbon sequestration potential.

This study's model for assessment carbon sequestration in trees using the NDVI index achieved the highest correlation (R^2) in February, with a value of 0.82. This is comparable to the model study in the Mae Moh Mine Area, Lampang Province, which used satellite data from February and reported a correlation value of 0.70 (Khunrattanasiri et al., 2023). It is also consistent with Boonsang and Arunpraparat (2011) model for estimating carbon sequestration in the mixed deciduous forest in the Mae Tuen Wildlife Sanctuary, Tak Province, which used February satellite data and had a correlation value of 0.75. However, Theerakultomorn et al. (2022) study used NDVI satellite data from April to model carbon sequestration in trees in the mixed deciduous forest area of Nong Rawiang Educational Center, Rajamangala University of Technology Isan, Nakhon Ratchasima Province, and found a correlation of 0.76. Additionally, Malik et al. (2023) studied the carbon sequestration model for trees in agroforestry areas in Rancakalong, Sumedang, Indonesia, using June NDVI data, achieving a correlation (R^2) of 0.80. For the model study on estimating carbon sequestration in a plantation forest using teak as the primary species in Tak Province (Thiteja et al., 2020), December NDVI data was used for the evaluation, resulting in a correlation (R^2) of 0.96. Therefore, it is evident that the correlation between the amount of carbon sequestration in sample plots and the NDVI values varies across different regions. The choice of timing is crucial, as selecting the appropriate period for the study area enhances the accuracy of the tree carbon sequestration assessment.

From the calculation of carbon sequestration, the CO_2 absorption, derived from the amount of above-ground carbon sequestration (TC) multiplied by the proportion between carbon dioxide and carbon (CO_2CF), where carbon dioxide (CO_2) has a molecular mass of 44 and carbon (C) and a molecular mass of 12, the proportion as 44/12, or 3.66, as in Equation (6) (Suthampaeng and Boonyanuphap, 2020). It was found that the forested areas within Chiang Mai Rajabhat University, Mae Rim Campus absorbed 186,320.90 tons of carbon dioxide (tCO_2).

$$CO_2 \text{ absorption} = TC \times CO_2CF \quad (6)$$

4. CONCLUSION

In this study, Dry Dipterocarp Forest within the boundaries of Chiang Mai Rajabhat University, Mae Rim campus, were classified visually, identifying a total area of 4,273.60 rai. Using ISO Cluster Unsupervised Classification with average NDVI data from 2019 to 2023, the Dry Dipterocarp Forest were categorized into four levels: Low NDVI levels, Moderate NDVI levels, High NDVI levels, and Highest NDVI levels, covering 0.99%, 12.99%, 36.27%, and 49.75% of the forest area, respectively.

Field surveys conducted during April to May 2024 gathered data and calculated the biomass and above-ground carbon sequestration of standing trees with a diameter equal to or greater than 4.5 cm and tree height greater than 1.3 m, using the allometric equation of dipterocarp forest, applied to sample plots measuring 20 × 20 m and totaling 8 plots. The plot categorized under Highest NDVI levels exhibited the highest biomass and above-ground carbon sequestration, decreasing with lower NDVI levels.

Analysis of the relationship between carbon sequestration quantity and monthly NDVI indices, averaging 52 data points, revealed that average NDVI decreased with lower NDVI levels, similar to biomass and above-ground carbon sequestration. The highest average NDVI value was observed in February, with the highest correlation coefficient (R^2), likely due to the leaf shedding period, enabling the estimation of above-ground carbon sequestration, averaging 11.91 tons/rai, totaling 50,907.35 tons of carbon sequestration.

ACKNOWLEDGEMENTS

This project has received funding from the Genetic Conservation Project of the Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG). We extend our gratitude for this support. Additionally, we would like to thank the Institute of Research and Development for facilitating the project, also AiroTEC, CMRU, for providing equipment, personnel, and various data. And finally, the project team would like to thank the administrators of Chiang Mai Rajabhat University for recognizing the importance of the project. This assessment of carbon

sequestration in forest areas of Chiang Mai Rajabhat University, Mae Rim Campus, is hoped to be valuable and a good starting point for future projects aimed at conserving and restoring university forest areas for sustainable global warming mitigation.

REFERENCES

ArcGIS Pro 3.1. Iso Cluster Unsupervised Classification (Spatial Analyst) [Internet]. 2023 [cited 2024 Apr 4]. Available from: https://pro.arcgis.com/en/pro-app/3.1/tool-reference/spatial-analyst/iso-cluster-unsupervised-classification.htm.

Boonsang S, Arunpraparat W. Estimation of above-ground carbon sequestration of forest using remote sensing techniques in Mae Tuen Wildlife Sanctuary, Tak Province. Thai Journal of Forestry 2011;30(3):14-23.

Brown S. Mitigation potential of carbon dioxide emission by management of forests in Asia. Ambio 1996;25(4):272-8.

Chai-Udom K, Karnchanasutham S, Nualchawee K, Sri-ngernyuang K, Sungpalee W. A causal relationship model among above-ground biomass and vegetation index in Lower Montane Forest, Doi Inthanon National Park Chiang Mai, Thailand. Phranakhon Rajabhat Research Journal (Science and Technology) 2016;11(1):27-35 (in Thai).

Charoenhirunyingyos S. Best correlation between vegetation indices and fresh fruit bunch of oil palm yield derived from LANDSAT 8. Srinakharinwirot University Journal of Social Sciences 2018;21(1):235-47 (in Thai).

Debajit R, Nepolion B, Ashesh KD. Assessment of aboveground and soil organic carbon stocks in Dipterocarpus forests of Barak Valley, Assam, Northeast India. International Journal of Ecology and Environmental Sciences 2014;40(1):15-28.

Duangthip N, Anongrak N, Kachina P, Khamyong S. Plant community structure and carbon storage in a dry dipterocarp community forest with using *Dipterocarpus tuberculatus* Roxb. Journal of Thai Forest Ecology 2022;6(1):13-30.

Engineering and Architecture Division, Building and Grounds Department, Chiang Mai Rajabhat University. Survey Report on the Boundaries of Chiang Mai Rajabhat University, Mae Rim Campus. Chiang Mai, Thailand: Chiang Mai Rajabhat University; 2023 (in Thai).

Faculty of Forestry Kasetsart University. Handbook on the Potential of Tree Species for Promotion under the Clean Development Mechanism Project in Forestry. Bangkok: Aksorn Siam Publishing; 2011 (in Thai).

Forest Learning. How is carbon stored in trees and wood products [Internet]. 2020 [cited 2024 Sep 3]. Available from: https://forestlearning.edu.au/images/resources/How%20carbon%20is%20stored%20in%20trees%20and%20wood%20products.pdf.

Intapiw S. Remote Sensing Application for Bypass Street: A Case Study of Nakhon Ratchasima Ringroad South Site Sec 4 [dissertation]. Thammasat University; 2017 (in Thai).

Intergovernment Panel on Climate Change (IPCC). Good Practice Guidance for Land Use, Land-Use Change and Forestry. The Institute for Global Environmental Strategies (IGES) [Internet]. 2003 [cited 2024 Sep 3]. Available from: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_ files /GPG_LULUCF_FULL.pdf.

The Institute for Sustainable Development of Natural Resources and Environment (ISDNRE). 7 Types of Greenhouse Gases: The Main Causes of Global Warming [Internet]. 2020 [cited 2024 Sep 5]. Available from: https://hub.mnre.go.th/th/knowledge/detail/65375.

Jensen JR. Introductory Digital Image Processing: A Remote Sensing Perspective. 4th ed. Glenview, US: Pearson Prentice Hall; 2015.

Jundang W, Puangchit L, Diloksumpun S. Carbon storage of dry dipterocarp forest and eucalypt plantation at Mancha Khiri Plantation, Khon Kaen Province. Kasetsart University Journal of Forestry 2010;29(3):36-44 (in Thai).

Kamjai K, Meunpong P, Diloksumpun S. Dynamics of dry dipterocarp forest and carbon sequestration at Nongyai Community Forest, Kanchanaburi Province. Kasetsart University Journal of Forestry 2017;36(2):55-66 (in Thai).

Kavinpholasa K. Carbon Sequestration in Biomass of Trees in Huay Satang Watershed Management Unit, Nan Province [dissertation]. Maejo University; 2023 (in Thai).

Kesornbua P, Hongkaew A, Salukkham E. Modelling of the predictive carbon storage in Para Rubber Plantation by using Sentinel-2A data. Advanced Science Journal 2022;22(1):61-77.

Khunrattanasiri W, Amarakul A, Rianthakool L, Hutayanon T. Above-ground carbon storage estimation of a reforestation site at Mae Moh Mine, Lampang Province, using Sentinel-2 Satellite data. Thai Journal of Forestry 2023;42(2):113-22.

Khunrattanasiri W, Amarakul A, Rianthakool L, Hutayanon T. Comparative study of Landsat 9 and Sentinel-2 satellite data for above-ground carbon sequestration estimation at Mae Moh mine reforestation site, Lampang Province, Thailand. Agriculture and Natural Resources 2024;58(2):175-82.

Lasco RD, MacDicken KG, Pulhin FB, Guillermo IQ, Sales RF, Cruz RVO. Carbon stock assessment of selectively logged Dipterocarpus forest and wood processing mills in the Philippines. Journal of Tropical Forest Science 2006; 18(4):166-72.

Lolupiman T, Nakhapakorn K, Ussawarujikulchai A. Estimation of above ground carbon stock in Para Rubber Plantation by application of remote sensing, Rayong Province. Journal of Science and Technology 2016;24(6):914-26.

Malik DA, Nasrudin A, Withaningsih S, Parikesit. Vegetation stands biomass and carbon stock estimation using NDVI - Landsat 8 imagery in mixed garden of Rancakalong, Sumedang, Indonesia. In IOP Conference Series: Earth and Environmental Science 2023;1211:Article No. 012015.

Manee-in K. Chapter 4 Global Carbon Dioxide Sources in the United States and Thailand [Internet]. 2022 [cited 2024 Sep 5]. Available from: https://tiche.org/.

Meteorological Department. 30-year Standard Values (1981-2010) [Internet]. 2010 [cited 2024 Jun 15]. Available from: https://www.tmd.go.th/weather/province/last30years-1981-2010/ chiang-mai/2/327501.

Mongkonsawat C, Wattanakit N, Kachai T, Mongkonsawat K, Chuayakhai D. Guidelines for analyzing drought in Northeastern Thailand using Satellite data indices. Proceedings of the Theos Satellite Technology for the Development of Thai Geoinformatics; 2009 September 8-9; Nusa Playa Hotel and Spa, Banglamung District, Chonburi; 2009.

Mousiew K, Thanacharoenchonpas K, Boonyanupap C. Valuation of carbon stock in undisturbed natural forest and mixed fruit tree-based agroforestry system by landslide and under natural succession. Thai Journal of Forestry 2019;38(1):81-95.

Ogawa H, Yoda K, Ogino K, Kira T. Comparative ecological studies on three main types of forest vegetation in Thailand, II. Plant Biomass. Nature and Life in Southeast Asia 1965;4:49-80.

Pannual W, Chuchip K, Jintana V. Above-ground carbon stock assessment of Khuan Khaeng Swamp Forest after severe Burning in 2012 using Satellite imagery. Thai Journal of Forestry 2015;34(1):16-28.

Phongthornphruek S. The biodiversity and plant association structure of dry Dipterocarp Forest in conservative forest of Fak Tha Land Settlement Cooperative, Fak Tha District, Uttaradit Province. Proceedings in the 4th National Forest Ecology Network Conference; 2015 January 22-23; Faculty of Agriculture, Naresuan University, Phitsanulok; 2015 (in Thai).

Rattanachuchok P. Survey and Collection for the Development of the Database System for the Biodiversity of Dry Dipterocarp Forest Plants in the Mae Rim Center, Chiang Mai Rajabhat University, Saluang-Keelek Campus: Research Report. Chiang Mai, Thailand: Chiang Mai Rajabhat University; 2017 (in Thai).

Royal Irrigation Department (RID). Average rainfall over a period of 30 years, Chiang Mai [Internet]. 2024 [cited 2024 Sep 3]. Available from: https://water.rid.go.th/hwm/wmoc/planing /wet/ management2567.pdf.

Samphutthanont R. Assessing agricultural burned areas using dNBR index from Sentinel-2 Satellite data in Chiang Mai, Thailand, from 2019 to 2023. Geographia Technica 2024; 19(2)46-56.

Sentinelhub. Sentinel-2 processing baseline changes and harmonize Values [Internet]. 2021 [cited 2024 Sep 5]. Available from: https://forum.sentinel-hub.com/t/sentinel-2-processing-baseline-changes-and-harmonizevalues/4635.

Sukarna RM, Birawa C, Junaedi A. Mapping above-ground carbon stock of secondary peat swamp forest using forest canopy density model Landsat 8 OLI-TIRS: A case study in Central Kalimantan Indonesia. Environment and Natural Resources Journal 2021;19(2):165-75.

Suthampaeng T, Boonyanuphap J. Assessment of carbon stock in green area of Naresuan University and carbon-credit trading guidelines. Agricultural Science Journal 2020;51(1):80-5 (in Thai).

Thailand Greenhouse Gas Management Organization (TGO). T-VER-TOOL-FOR/AGR-01 (Calculation for Carbon Sequestration) [Internet]. 2023 [cited 2024 Apr 12]. Available from: https://ghgreduction.tgo.or.th/th/tver-method/tver-tool/for-agr/download/4490/245/27.html.

Thammanu S, Han H, Marod D, Srichaichana J, Chung J. Above-ground carbon stock and REDD+ opportunities of community-managed forests in northern Thailand. PLoS ONE 2021; 16(8):e0256005.

Theerakultomorn T, Kamphala A, Prasomsub W, Tiyawongsuwan S, Khamwilai T. Above ground biomass assessment from Sentinel-2A data using multiple linear regression analysis. Proceedings of the 27th National Convention on Civil Engineering; 2022 August 24-26; Chiang Rai, Thailand; 2022.

Theerapon T. Calculation of Drought and Vegetation Indices from Surface Temperature of Landsat 8 Satellite Data and Comparison with Rice Yield in Ubon Ratchathani Province [dissertation]. Chulalongkorn University; 2018 (in Thai).

Thiteja S, Khamyong S, Boontun A, Charoenpanyanet A, Huttagosol P. Using normalized difference vegetation index (NDVI) to assess carbon storage of plantation forests in zinc-mined Mae Tao Watershed, Mae Sod District, Tak Province. Journal of Burapha Science 2020;25(1):51-63 (in Thai).

Thongmee T, Somart C, Chitsukha W. Evaluation of above-ground carbon sequestration of forest in Mahasarakham University using remote Sensing data. Journal of Science and Technology MSU 2019;38(6):586-97.

Thai Meteorological Department (TMD). Greenhouse effect [Internet]. 2024 [cited 2024 Sep 5]. Available from: http://climate.tmd.go.th/content/article/10.

Tripattanasuwan P, Diloksumpun S, Sataporn D, Rattanakaew J. Carbon Sequestration in the Biomass of Certain Plant Species Planted at the Phu Phan Royal Development Study Center, Sakon Nakhon Province. Thailand: Forest and Plant Conservation Research Office, Department of National Parks, Wildlife and Plant Conservation; 2010.

Tsutsumi T, Yoda K, Sahunalu P, Dhanmanonda P, Prachaiyo B. Forest: Felling, Burning and Regeneration, Shifting cultivation. Tokyo University: Japan; 1983.

Uttaruk Y, Rotjanakusol T, Laosuwan, T. Above ground carbon biomass assessment using satellite remote sensing reflection values. Food Agricultural Sciences and Technology 2018; 4(1):41-6.

Woodland Campus Park. Dry Dipterocarp Forest [Internet]. 2021 [cited 2024 Apr 4]. Available from: https://woodland.csc.ku.ac.th/?p=7084.