Validating Carbon Stock Estimation Using Photogrammetry and the GLOBE Tree Application in Krabi

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Abstract

Efforts to manage mixed deciduous forests around the world have the potential to contribute to global sustainability significantly. This study focuses on the carbon stock assessment, comparing the GLOBE-based method with the Drone-based method in managing mixed deciduous forests in Krabi province, Thailand. Field data were gathered from a 40x40 m^2 two-sample plot within the Krabi province's mixed deciduous forests, and the carbon stock of standing trees was determined using allometric equations. The drone-based technique for estimating tree height was compared with the GLOBE-based method. Results revealed an average carbon storage of 6604.73 kg and 6181.39 kg for the drone-based and GLOBE-based methods, respectively in site 1 (Wat Kaew Korawaram), and an average carbon storage of 12817.87 kg and 10342.04 kg for the drone-based and GLOBE-based methods in site 2 (Thara Park). The notable difference in carbon storage estimates between the techniques may be attributed to potential human errors, including inaccuracies in measuring the diameter at breast height (DBH) and variations in the steps taken by different individuals. Future projects will involve planning adjustments to the measurement methods to enhance precision and reliability. Nonetheless, it can be inferred that managing mixed deciduous forests in Krabi province shows promise in climate change mitigation. This aligns with broader objectives such as addressing climate change, promoting sustainable land management, conserving biodiversity, supporting carbon trading initiatives, formulating legislation, advancing research, and educating the public on the significance of maintaining healthy ecosystems.

keywords: Carbon stock, Above-ground biomass, GLOBE tree, Drone.

1. Introduction

Krabi Province is located on the western part of the Thai-Malay Peninsula, at the uppermost part of the Strait of Malacca, opposite Sumatra Island in Indonesia. To the east, it is adjacent to Phang Nga Province; to the south, it borders Trang Province; and to the west, it faces the Andaman Sea. The province has an area of approximately 4,710 square kilometers, is characterized by its coastal location, and is known for its stunning coastal landscapes. The province is divided into eight districts, with 51 sub-districts and 389 villages. There are a total of 127,540 households in the province. Additionally, Krabi Province has one municipal area and nine sub-district municipalities. The total land area is 2,942,820 rai, with 548,648.33 rai designated as fertile agricultural land, accounting for 18.64% of the total area. The province's coastal regions cover approximately 221,900 rai and include the districts of Mueang Krabi, Ao Luek, Nuea Khlong, and Ko Lanta. Nevertheless, it has been disturbed by anthropogenic activities, such as land-use changes (Wilcove et al., 2013). This might lead to CO_2 emissions. Data on biomass is necessary to assess the ability to store carbon in the forest ecosystem. Anyway, there needs to be more data on both biomass and carbon stock on the MDF in the forest; the collection of its biomass (such as aboveground biomass) is required.

Krabi province has lush forest areas in a region with heavy rainfall. It is rich in essential types of wood such as Yang, Takian, Ngerngai, Tamsao, and Rubberwood. Additionally, it has mangrove forests with species like Mangrove Apple, Kongkang, and Lime Wood. Wood products, especially charcoal from Mangrove wood, are significant exports to foreign countries. Currently, the forested areas are decreasing due to the expansion of agricultural land, illegal logging, and encroachment into protected areas. The forests in Krabi province are classified into three types: (1) Evergreen Forest, characterized by high humidity, dense vegetation, and large-sized trees at the top, medium-sized trees in the middle, and small and densely packed trees at the bottom; (2) Deciduous Forest: Comprising low-height shrubs with scattered large trees, generally not exceeding 20 meters in height. This type of forest is found throughout Krabi province, and (3) Mangrove Forest: Krabi is a rich source of mangrove forests, with diverse plant life growing in complex ecosystems along the coastline and river mouths. This includes various species of mangrove plants and other natural occurrences, dependent on the specific mangrove zone and river estuary. The plant species include those like Kongkang and Sam.

The conventional approach to measuring biomass involves destructive sampling methods that necessitate crop harvesting, weighing, and recording. However, these methods are time-consuming and challenging for large-scale and long-term assessments (Gnyp et al., 2014). In contrast, remote sensing has emerged as a superior technical tool for biomass monitoring and estimation, facilitated by platforms and sensors (Han et al., 2019). Various remote sensing techniques, such as unmanned aerial vehicles (UAVs) and satellite imagery, have been developed for evaluating forest biomass and carbon. Among these platforms, UAV-based data gathering offers enhanced operational flexibility in terms of cost, time, platforms, location, and repeatability compared to satellite-based methods (Stocker et al., 2017). Additionally, UAVs provide high geographical and temporal resolution data, contributing to more accurate measurements of Aboveground Biomass (AGB) and carbon stock (Fritz et al., 2013).

This study aimed to estimate aboveground carbon stock in Krabi, Thailand, utilizing the GLOBE- and drone-based methods. Accurate measurement of forest carbon stock is vital for addressing global warming challenges and implementing strategies to reduce CO_2 emissions (Egusa et al., 2020). The carbon stock assessment is critical in addressing climate change, advocating for sustainable land management, preserving biodiversity, supporting carbon trading initiatives, shaping policy decisions, advancing research efforts, and educating the public about maintaining healthy ecosystems.

Research questions

1. Compared with the conventional method, can aerial imagery (drone) be applied to measure the carbon stock in a mixed-deciduous forest?
2. To calculate the above-ground carbon stock of the tree using field measurements compared with drone-based data.
3. To evaluate whether the diversity of plant species and their abundance affects carbon credit or not.

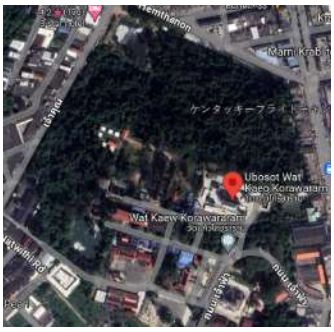
2. Materials and Methods

A. Study Area Description

The province of Krabi is located on the southern part of the western coast of Thailand (Latitude 8.08605, Longitude 98.90551). It covers an approximate area of 4,624 km^2. Krabi is a province situated along the sea, and its temperature remains constant throughout the year. It experiences heavy rainfall during the rainy season due to its location on the windward side, influenced by the southwestern monsoon. The average temperature throughout the year is around 27.0°C, with an average maximum temperature of 32.4°C and an average minimum temperature of 22.4°C. We conducted our study at two study sites: (1) Wat Kaew Korawararam and (2) Thara Park.

(a)

(b)



(c)

(d)

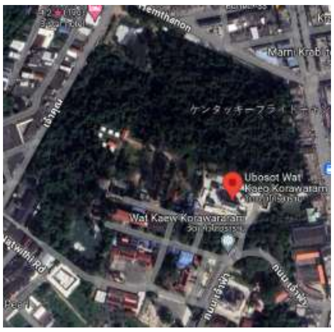
(e)

(f)

Figure 1. (a) Map of Thailand, (b) Krabi Province, South Thailand, (c, d) Wat Kaew Korawararam and (e, f) Thara Park

B. Plot Set Up

The study site is located in mixed deciduous forest (MDF), the 40 m × 40 m^2 plot was set up in two plots (Fig. 2).



(a) (b)

(a)

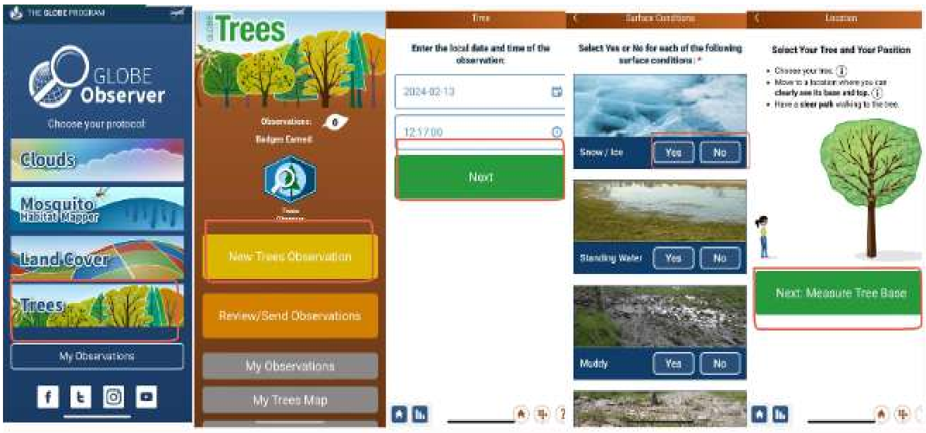
(b)

Figure 2. The study area of this study is (a)Wat Kaew Kowaram and (b) Thara Park.

C: GLOBE Observer: Trees

The GLOBE Observer: Trees App was employed to gather tree data at the five study sites. This application, part of the GLOBE Program, facilitates environmental observations that supplement NASA satellite data, supporting scientists studying Earth and the global environment (Figure 3a-c).

(a)



(b)

(c)

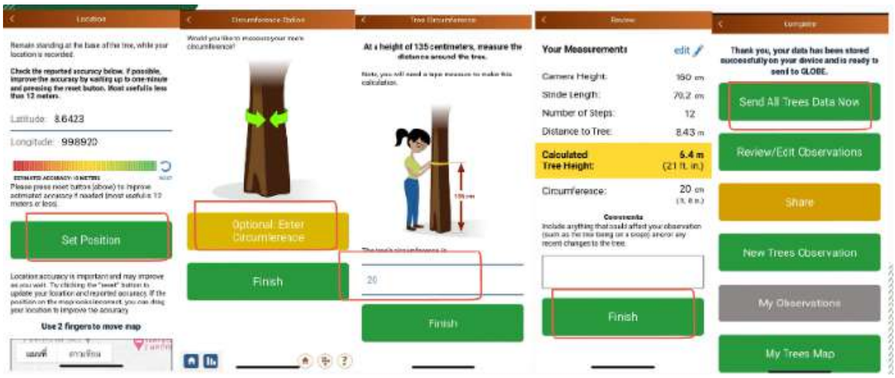


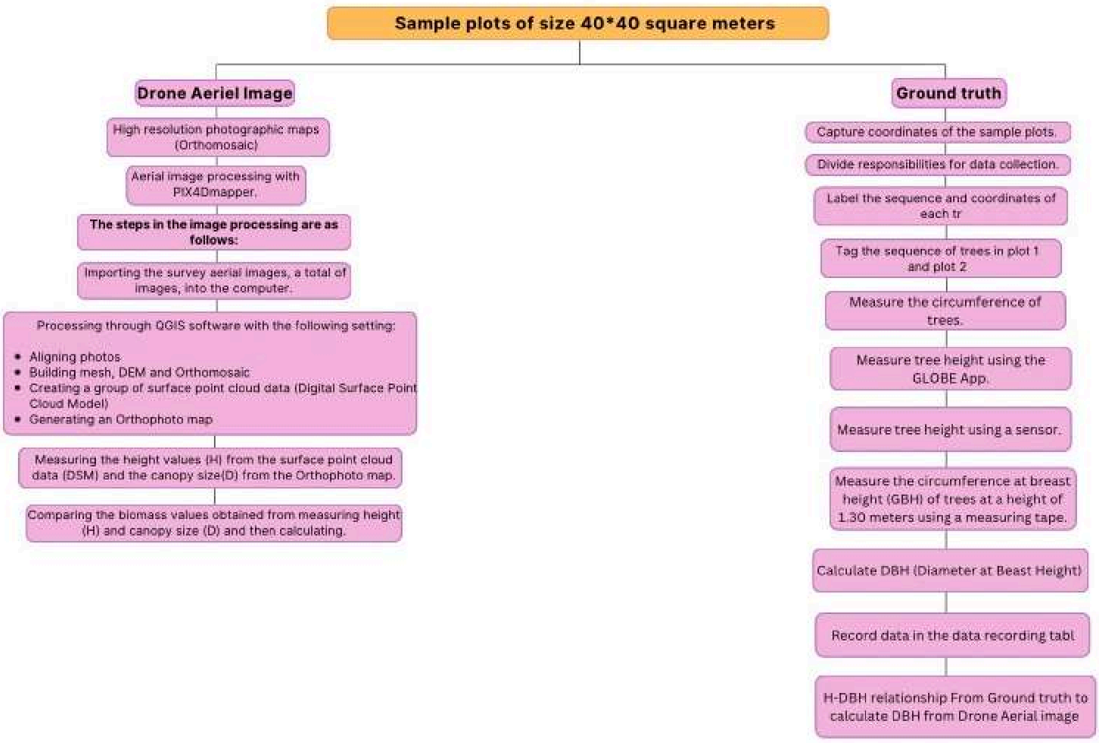
Figure 3. The GLOBE Observer: Trees App. (a) Choose Protocol: Trees >> New Trees Observation >> Choose the date, time, latitude & longitude and select the following surface conditions. (b)Take a photo: choose your tree and your positions while counting your steps (c) Set position >> Measure your tree circumference >> Finish and send your tree measurement to the GLOBE App.

D: Data collection

In this study, data collection was divided into two parts: (1) ground truthing (field measurement) and (2) aerial images.

Figure 4. The workflow implemented in this study represents the analysis and output

E: Aboveground Biomass and C-stock Estimation



All trees were measured for Diameter at Breast Height (DBH) and total height. The aboveground tree biomass was estimated using the allometric equation introduced by Ogawa et al. (1965), with the corresponding equations outlined in Table 1. The calculation of aboveground biomass was derived from the allometric equations established by Issaree et al. (1982) and Suwannapinunt et al. (1983).

Table 1 Allometric equations for the estimation of biomass.

Plant / Forest	Equations	Reference
Mixed deciduous forest	$W_S = 0.0396\ (D^2H)^{0.933}$ $W_B = 0.00349\ (D^2H)^{1.030}$ $W_L = (28/(W_S+W_B+0.025))^{-1}$ $W_T=(W_S+W_B+W_L)$	Ogawa et al. (1965)
Calculate carbon storage	Carbon storage = biomass (Wt) ×0.5	IPCC (2006)

Note: DBH = Diameter at breast height (cm), H = Total height of the tree (m)

Where D is the diameter at breast height (centimeter), H is the height of tree stand (meter), W_S is the mass of stem (kilogram), W_B is the mass of branch (kilogram), W_L is the mass of leaf (kilogram),

3. RESULTS AND DISCUSSION

A. Above Ground Biomass of Tree Stand

Within the study plot, the aboveground biomass, encompassing stem, branch, and leaf components, was measured at 2530.19 kg (equivalent to 148834.7 tons/ha) and 8024.8 kg (equivalent to 308646.15 tons/ha) and 1393.2 kg (equivalent to 435373.12 tons/ha) using ground truth and drone-based techniques, respectively (refer to Table 2A). Among the most prevalent trees identified in site 1 (Wat Kaew Korawaram) were Black Afara, Unknown species 1, and Unknown species 2 (tree name species), representing a total of 3 different species (see Figure 5).

Additionally, in site 2 (Thara Park), the aboveground biomass, encompassing stem, branch, and leaf components, was measured at 6280.9 kg (equivalent to 215099.25 tons/ha) and 1431.76 kg (equivalent to 74339.97 tons/ha) using ground truth and drone-based techniques, respectively (refer to Table 2B). Among the most prevalent trees identified in site 2 (Thara Park) were Northern black wattle and Unknown species 3 (tree name species), representing a total of 2 different species (see Figure 5).

Regression analysis indicates a lack of correlations between data obtained from the drone and ground truth data (see Figure 6). The relationship between Diameter at Breast Height (DBH) and total height (H) is notably weak, as evidenced by an R^2 value of 0.383 and 0.845. Conversely, estimating tree height from ground truth and drone-based techniques yields a higher but still modest correlation, with an R^2 value of 0.566 and 0.857.

Several factors contribute to the limited correlations observed in the models. The density of trees can impede drone sensors from adequately penetrating the ground surface (Salim et al., 2020). The dense tree canopy in the study area impacts the Digital Terrain Model (DTM) calculation, resulting in lower accuracy in the Canopy Height Model (CHM). Additionally, the high slope observed in the study plot may influence DTM variation. Furthermore, the difficulty in distinguishing each tree top due to the dense tree cover in the study area introduces human errors in tree height estimation using GLOBE Observer, which relies on trigonometry. Future studies should concentrate on developing methods to mitigate the impact of the dense tree canopy on measurements.

Table 2A The aboveground biomass (AGB) and carbon stock by tree type. These data were collected from Wat Kaew Korawaram (site 1).

No.	Common Name	Av. DBH (cm)		Av. Height (m)		AGB (kg)		C (kg)	
		Drone	Field	Drone	GLOBE app	Drone	Field	Drone	Field
1	Unknown species 1	45.25	41.36	21.30	19.02	3353.42	2618.44	1676.71	1309.22
2	Unknown species 2	52.14	50.96	29.88	29.20	8592.30	8307.07	4296.15	4153.54
3	Black Afara	18.47	18.05	19.81	22.00	1263.75	1437.26	631.87	718.63
Total						13209.47	12362.77	6604.73	6181.39

Table 2B The aboveground biomass (AGB) and carbon stock by tree type. These data were collected from Thara Park (site 2).

No.	Common Name	Av. DBH (cm)		Av. Height (m)		AGB (kg)		C (kg)	
		Drone	Field	Drone	GLOBE app	Drone	Field	Drone	Field
1	Northern black wattle	46.73	54.62	21.16	47.12	18402.4	14399.29	9201.2	3142.4
2	Unknown species 3	56.34	44.61	46.58	19.14	7233.35	6284.8	3616.67	7199.64
Total						25635.74	20684.09	12817.87	10342.04

SITE			
1	Black Afara 	Unknown species 1 	Unknown species 2 
2	Northern black wattle 	Unknown species 3 	

Figure 5. The tree species occurred in the study plot.

B. Carbon Stock of Above-Ground Biomass

By IPCC guidelines from 2006, where carbon stock is considered to be 50 percent of biomass, the computed carbon stock within the study plot (site 1) amounted to 4,159,520 kg (equivalent to 4,159.520 tons/ha) and 19,986,840 kg (equivalent to 19,986.840 tons/ha) using ground truth and drone-based techniques, respectively (see Table 2A). Furthermore, the computed carbon stock within the study plot (site 2) amounted to 992,510 kg (equivalent to 992.510 tons/ha) and 39,099,140 kg (equivalent to 39,099.14 tons/ha) using ground truth and drone-based techniques (see Table 2B). The limited correlations observed in the regression analysis (refer to Figure 6) contribute to the inadequacy in the accuracy of carbon stock estimation, primarily due to a high variation in aboveground biomass. As a result, comparing the results of this study with those of other studies becomes challenging. Furthermore, factors such as stand structure and composition, topography, altitude, and disturbances (Teshoma, 2019) can influence the variability in aboveground carbon stock.

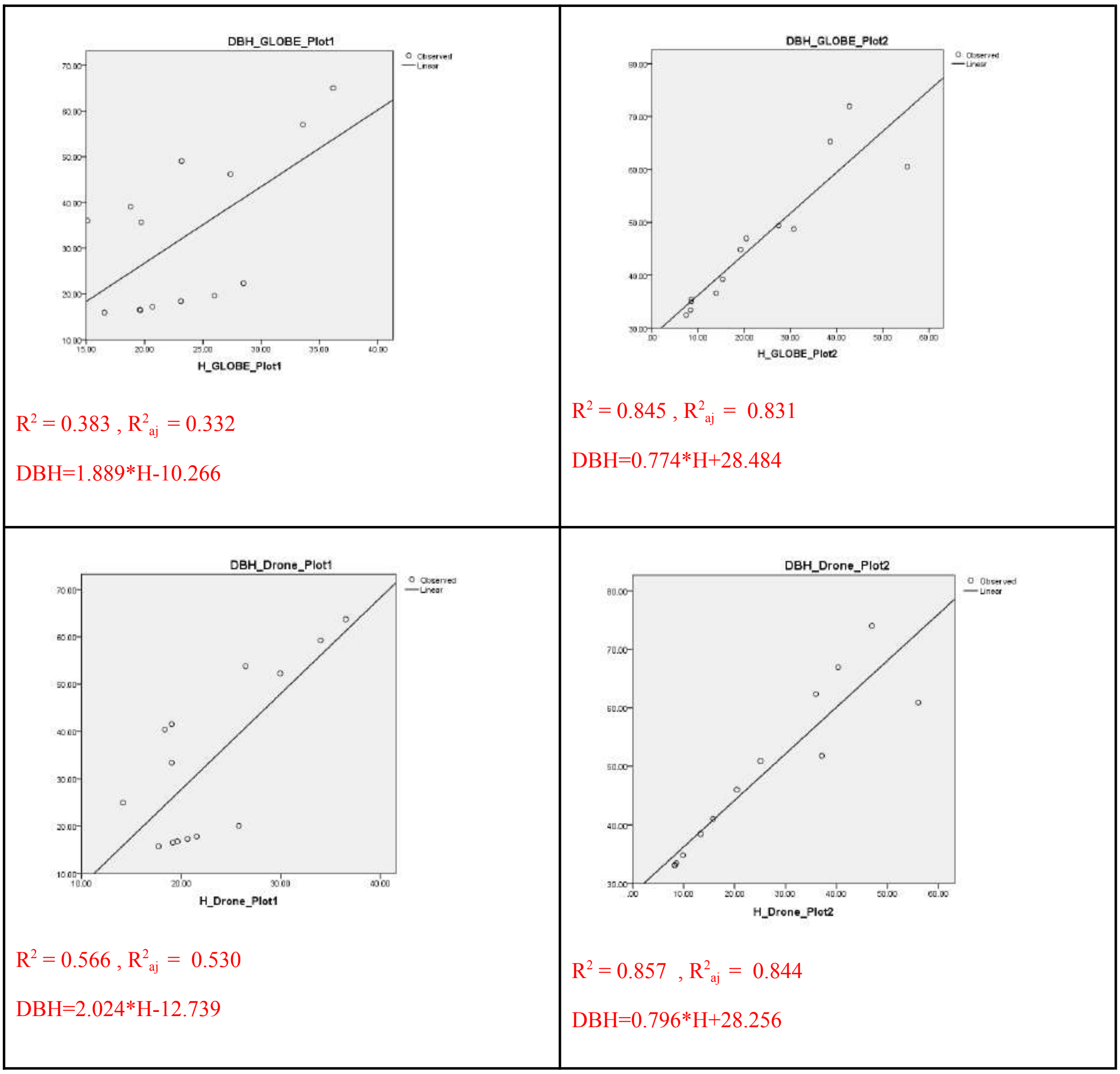


Figure 6. Linear regression models show the relationship between 1) DBH and tree height derived from ground truth (above) and 2) tree height estimated from the ground truth and drone-based (below).

4. CONCLUSION

Since photogrammetry/UAV technology is widely accessible, it's a great time to use this platform to validate carbon stock estimation and better understand forest health. Using UAV data in combination with other data sources and testing various methodologies may yield fascinating results and bring us closer to effective and accessible monitoring of forest carbon and health via remote sensing. However, drones have limitations, and they stem from insufficient research on plant factors connected to allometric equations. Drone ortho-mosaic imaging can directly measure a tree's height, except for DBH. To estimate biomass from drones, we employed second-order estimations of DBH based on regression analysis. According to Jones et al. (2020), using second-order estimates of tree diameter can lead to ambiguity in plant biomass predictions.

With the second platform, the Globe Observer App, an error occurred when collecting the tree height data in the fieldwork. The program necessitates counting the steps taken by observers to the observed tree, which makes it more challenging to regulate step distances. We used a sensor to measure the distance between each observer and verified their step distance and the observed tree. Next, the number of steps needed to complete the GLOBE Observer program was converted from the distance from the sensor—the plot with dense canopy cover made observers misidentify each treetop.

According to the results, the total AGB value of the second study site is significantly more than that of the first site, with a difference of 12,426.27 kg when using the aerial imagery technique and 8,321.32 when using conventional methods. At the same time, the Carbon storage of the second area also notably skyrocketed to the first one, as the difference between both data is 213.14 when using drones and 4,160.65 for the standard procedures. Concerning the data, the carbon storage is directly variable to the AGB value. This means that the trees in the second area will inevitably have a higher Carbon storage than in the first field, as the AGB value of the second study field is higher than in the first. Therefore, the diversity of plant species and their abundance affects carbon credit.

I would like to claim badges.

1. I make an impact.

   The report effectively establishes the connection between a local issue and the research questions, illustrating the links between local and global impacts. To showcase the positive impact on the community, it is essential for students to explicitly detail how the research findings have led to actionable recommendations or concrete steps. This study reveals that Wat Kaew Korawararam and Thara Park contribute to generating carbon credits for the global market, contributing to global warming mitigation by reducing greenhouse gas emissions.

2. I am a STEM professional.

   The report effectively outlines the collaboration with a STEM professional, detailing how this collaboration enhanced research methods, improved precision, and facilitated more sophisticated analyses and interpretations of results. In this study, regression analysis is employed to analyze the findings. Additionally, the results highlight discrepancies between field measurements and drone-based data processing, indicating the potential for refining a quicker method for measuring carbon credits in the future.

3. I am a data scientist.

   The report incorporates a thorough examination of both the students' collected data and data from other sources. Students critically evaluate the limitations of these datasets, draw inferences about past, present, or future events, and utilize the data to address questions or solve problems within the system under study. This includes considering data from other schools or databases. Specifically, this study's regression analysis between field measurements and drone-acquired data assesses the validation of carbon credits calculated from drone data. The limitations of drones and a comparison to findings from other studies are discussed in the later part of the report.

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