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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

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Abstract

Importance of the work: Remote sensing techniques can help to estimate forest carbon sequestration, especially for large areas.

Objectives: To compare satellite image data from two different satellites for estimating above-ground carbon (AGC) sequestration.

Materials & Methods: Tree data were collected and allometric equations were used to calculate the AGC sequestration. The relationship between the AGC sequestration and each of six vegetation indices (VIs) from satellite data was determined based on linear regression. The model having the highest coefficient of determination (R^2) was chosen.

Results: The Sentinel-2 data had greater potential to estimate the AGC sequestration than the Landsat 9 data. The relationship between the ratio vegetation index (RVI) and the amount of AGC sequestration had the highest R^2 value (0.71). The model with the form y = - 79.56 + 63.88x was created, which was significant at the 95% confidence level. Furthermore, the estimated AGC sequestration from the model and the AGC sequestration from the allometric equation were not significantly different at the 95% confidence level.

Main finding: Although Landsat 9 is a new satellite, the relationship between AGC sequestration and VIs using its data was poorer than for the Sentinel-2 data. Therefore, the spatial resolution may have affected the estimation of AGC sequestration.

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Introduction

Climate change that results in many natural disasters, such as floods, droughts, wildfires and storms, is an important issue, with the levels of greenhouse gas (GHG) emissions on the rise, mainly caused by burning of fossil fuels, deforestation and forest degradation (Department of National Park, Wildlife and Plant Conservation, 2014). The Reducing Emissions from Deforestation and Forest Degradation (REDD) framework is an initiative to reduce deforestation, forest degradation and carbon emissions from forest ecosystems in developing countries (Department of National Park, Wildlife and Plant Conservation, 2014). REDD requires that GHG emissions and removals are benchmarked against a reference level to estimate their impact in units of tonnes CO_2 equivalent via biennial update reports (Herold et al., 2019). Forests play an important role in countering climate change as they absorb carbon dioxide (CO_2) gas from the atmosphere through photosynthesis, a process referred to as a "carbon pool", especially as above-ground biomass (AGB), which can be calculated in terms of the above-ground carbon (AGC) sequestration (Intergovernmental Panel on Climate Change, 2003).

Field measurements provide the most reliable estimates of forest carbon sequestration (Tomppo et al., 2010) but they take time and are labor-intensive and expensive, especially for large areas. Over the last few decades, remote sensing techniques have developed rapidly; thus satellite image data represent a more cost-efficient and promising data source for the estimation of AGB. Studies of estimating AGB sequestration using various VIs from optical sensor data are widely available (Sibanda et al., 2015; Topaloğlu et al., 2016; Xue and Su, 2017; Ali et al., 2018; Astola et al., 2019; Puliti et al., 2021). There are some satellite image data freely available, such as from Landsat 9 and Sentinel-2, which were used in the current study. Landsat data have provided one of the most valuable datasets for monitoring the Earth's surface over the past 50 years (Topaloğlu et al., 2016). Landsat 9, the newest satellite in this project, was launched on 27 September 2021 and has a higher radiometric resolution than Landsat 8. Furthermore, the Sentinel-2 mission provides continuity for the current Landsat missions but with better spatial resolution (Topaloğlu et al., 2016). Thus, comparing the performance of different satellite image data could make the data analysis as reliable as analyzing data from field measurements.

It has been estimated that Thailand emitted approximately 354,400 Gg CO_2eq in 2016, with the largest proportion of GHG emissions from grid-connected electricity and heat production at 108,240 Gg CO_2eq or 42.84% of the energy sector (Office of Natural Resources and Environmental Policy and Planning, 2020). The Mae Moh mine in Lampang province, the largest open pit mine in Southeast Asia (Electricity Generating Authority of Thailand, 2016), is responsible for producing lignite to be used as fuel for power generation. The mining operation severely disrupts the environment. Therefore, measures are needed to minimize the impact of mining on the environment. The objective for the end-use of 93% of the land involved in the mining is reforestation as stated in the reclamation master plan, which resulted in the commencement of reforestation in 1982 (Revision of Mine Master Plan Committee, 2020). The objective of the current study was to estimate the AGC sequestration for the reforestation site of Mae Moh mine based on a comparative analysis of the relationship between the AGC sequestration and several VIs using Landsat 9 and Sentinel-2 data. This study should play an important role in monitoring the CO_2 sequestration in Lampang province, Thailand.

Materials and Methods

Study area

The Mae Moh mine is an open pit lignite mine, located in Lampang province, northern Thailand (Fig. 1), covering 1,969.28 ha. Its topography is determined by a plain between mountains at about 320–400 m above sea level. Its geographical coordinates are 18°17'–18° 22' N and 99°40'–99°46' E. There are three seasons in this region: summer (March–May), rainy (May–October) and winter (November–February). The original forest type was mixed deciduous forests (TEAM Consulting Engineering and Management Public Co. Ltd., 2017)

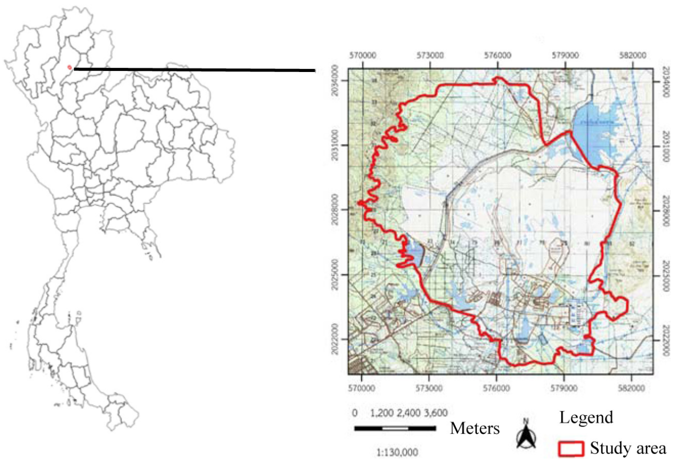

Fig. 1 Study area location in northern Thailand

Data preparation from remote sensing

Landsat 9 satellite data

Data were used from Landsat 9 OLI-2, level 1, path 130, row 47, dated 6 January 2022. The mosaic contained bands 2, 3, 4 and 5 (30 m spatial resolution). The data were converted from digital numbers (DN) to top-of-atmosphere (TOA) reflectance to reduce errors associated with energy reflecting from objects on Earth to the sensor, based on the current environmental conditions, including weather, landscape, temperature and angle of incidence, using Equations 1 and 2. (Khunrattanasiri, 2020; Anderson, 2021):

$$\rho_\lambda' = M_\rho Q_{cal} + A_\rho \tag{1}$$

$$\rho_\lambda = \frac{\rho_\lambda'}{sin(\theta_{SE})} \tag{2}$$

where ρ_λ' is the TOA planetary reflectance without correction for solar angle, M_ρ is the band-specific multiplicative rescaling factor, Q_{cal} is the quantized and calibrated standard product pixel values (DN), A_ρ is the band-specific additive rescaling factor, ρ_λ is the TOA planetary reflectance and θ_{SE} is the local sun elevation angle.

Geometric correction was applied to correct the satellite image data.

Sentinel-2 satellite data

Data were chosen from Sentinel-2 MSI, level 1C, 47QNA, dated 8 February 2022. The mosaic contained bands 2, 3, 4 and 8 (10 m spatial resolution) and were acquired in geometrically corrected format (European Space Agency, 2015).

Vegetation index synthesis

The two satellite image datasets were used to calculate VIs, consisting of the Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Renormalized Difference Vegetation Index (RDVI) and Green Normalized Difference Vegetation Index (GNDVI), using Equations 3–8, respectively (Xue and Su, 2017; Khunrattanasiri, 2020):

$$RVI = \frac{NIR}{R} \tag{3}$$

$$DVI = NIR - R \tag{4}$$

$$NDVI = \frac{NIR - R}{NIR + R} \tag{5}$$

$$SAVI = \frac{(NIR - R)}{(NIR + R + L)} \tag{6}$$

$$RDVI = \frac{NIR - R}{\sqrt{NIR + R}} \tag{7}$$

$$GNDVI = \frac{NIR - G}{NIR + G} \tag{8}$$

where NIR is the near infrared band, R is the red band, L is the soil conditioning index and G is the green band.

Then, the VI values were extracted from both sets of satellite image data corresponding with the plot center coordinates of the permanent plots used for the fieldwork data collection.

Field work

In total, 34 permanent plots (each 40 m × 40 m) were chosen from the reforestation site. Tree data were collected consisting of the diameter at breast height over bark (DBH) and tree height (H) of trees with a DBH ≥ 4.5 cm and all trees were identified to the species level. The sample plots were divided into two sets, with one for data analysis and the other for validation, according to Katong (2018).

Data analysis

The allometric equations (Equations 9–12) for plants growing in the mixed deciduous forest of Thailand (Ogawa et al., 1965; Viriyabuncha, 2020) were used to calculate the amount of AGB in each plot.

$$W_s = 0.0396(D^2H)^{0.9326} \quad (9)$$
$$W_b = 0.003487(D^2H)^{1.027} \quad (10)$$
$$W_l = (28/(W_s + W_b) + 0.025)^{-1} \quad (11)$$
$$AGB = W_s + W_b + W_l \quad (12)$$

where W_s is the biomass of stems, W_b is the biomass of branches, W_l is the biomass of leaves and AGB is the above-ground biomass.

The AGB was used to calculate AGC sequestration and CO_2 absorption (Intergovernmental Panel on Climate Change, 2003). Then, estimates were determined for AGC sequestration using the Landsat 9 and Sentinel-2 data as follows: 1) linear regression analysis was performed between AGC sequestration and the VIs; 2) the coefficient of determination (R^2) was calculated for each model; 3) sample plots for validation were used to estimate AGC sequestration using the model with the highest R^2 value and the difference was compared to that from the AGC sequestration from the allometric equation as a percentage; 4) the differences were analyzed using a t test at the 95% confidence level and the model with the highest R^2 value was selected as the most appropriate equation to estimate AGC sequestration for the reforestation site of the Mae Moh mine.

Results and Discussion

Field data analysis

The AGB was calculated using the DBH and H of the trees on the 34 plots based on the allometric equations and multiplied by the carbon fraction (Thailand Greenhouse Gas Management Organization, 2016) to calculate the AGC sequestration. The average AGB was 69.54 Mg/ha and the average AGC sequestration was 32.68 Mg/ha. (Table 1)

Analysis of relationship between above-ground carbon sequestration and vegetation indices

The different VIs were assessed based on their relationship with AGC sequestration. The resulting linear regression models for each index derived from the two sets of satellite data are listed in Table 2. For the Sentinel-2 data, the RVI had the highest R^2 value (0.71), followed by SAVI and NDVI (0.63 and 0.63 respectively). For the Landsat 9 data, the NDVI had the highest R^2 value (0.11), with all indices based on the Landsat

Table 1 Average above-ground biomass (AGB) and above-ground carbon (AGC) sequestered, estimated using allometric equation

Plot	AGB sequestration (Mg/ha)	AGC sequestration (Mg/ha)
1982–1986	140.59	66.08
1987–1991	86.88	40.83
1992–1996	82.96	38.99
1997–2001	79.11	37.18
2002–2006	48.62	22.85
2007–2012	30.46	14.32
2013–2017	21.60	10.15
Average	69.54	32.68

Table 2 Mathematical forms of linear regression equations and coefficient of determination (R^2) values for various indices derived from Sentinel-2 and Landsat 9 data

Index	Sentinel-2		Landsat 9	
	Equation	R^2	Equation	R^2
RVI	y = - 79.56 + 63.88x	0.71	y = 3.20 + 10.69x	0.10
DVI	y = - 15.76 + 0.04x	0.55	y = 38.52 - 29.23x	0.003
NDVI	y = - 27.52 + 226.32x	0.63	y = 0.10 + 72.54x	0.11
SAVI	y = - 27.52 + 150.89x	0.63	y = 26.68 + 28.30x	0.01
RDVI	y = - 22.51 + 2.99x	0.61	y = 22.08 + 46.69x	0.02
GNDVI	y = - 17.69 + 215.80x	0.44	y = 21.89 + 29.80x	0.02

RVI = Ratio Vegetation Index; DVI = Difference Vegetation Index; NDVI = Normalized Difference Vegetation Index; SAVI = Soil Adjusted Vegetation Index; RDVI = Renormalized Difference Vegetation Index; GNDVI = Green Normalized Difference Vegetation Index; x = parameter based on the respective index in first column.

9 data having R^2 values that were lower than their Sentinel-2 counterparts. Scatterplots for all the indices based on the Landsat 9 and Sentinel-2 datasets and their models are shown in Fig. 2 and Fig. 3, respectively. These results were consistent with the study by Katong (2018), which found that NDVI had the highest R^2 value based on Landsat 8 data and RVI had the highest R^2 value based on the Sentinel-2 data, as well as the indices based on the Sentinel-2 data being more accurate in estimating the AGC sequestration compared to the same indices based on the Landsat 8 data in the same study area.

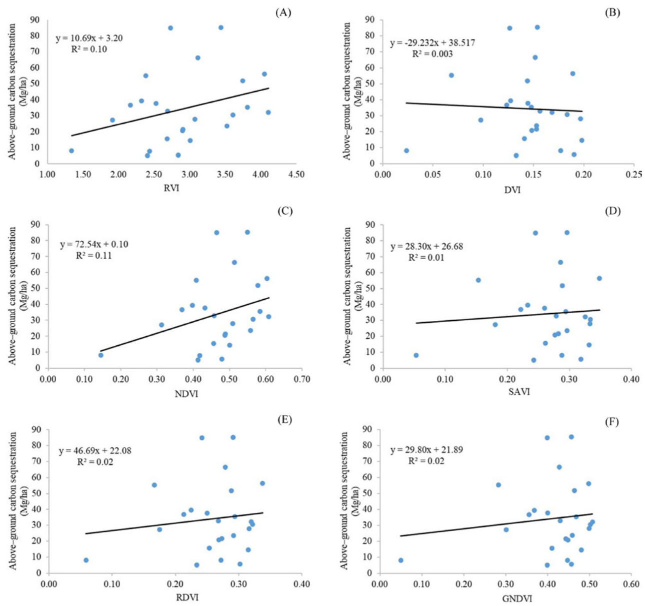

Fig. 2 Distribution of data (A–F) between above-ground carbon sequestration and values for different vegetation indices based on Landsat 9 data, where R^2 = coefficient of determination, black line indicates linear equation provided in each subfigure, RVI = Ratio Vegetation Index, DVI = Difference Vegetation Index, NDVI = Normalized Difference Vegetation Index, SAVI = Soil Adjusted Vegetation Index, RDVI = Renormalized Difference Vegetation Index and GNDVI = Green Normalized Difference Vegetation Index

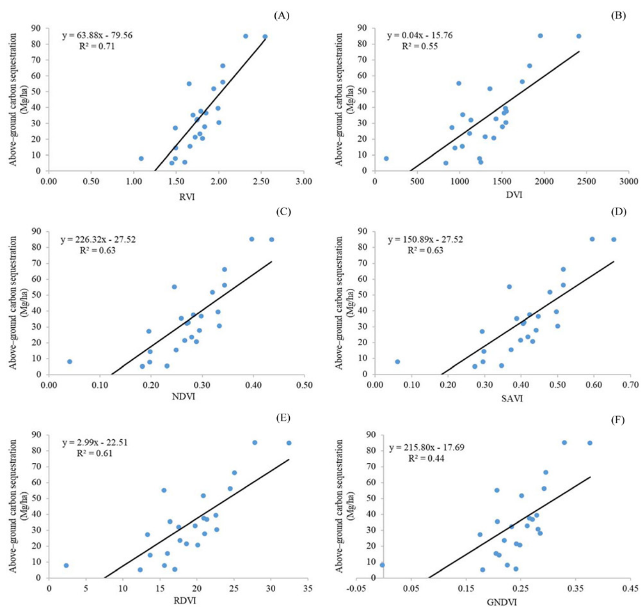

Fig. 3 Distribution of data (A–F) between above-ground carbon sequestration and values for different vegetation indices based on Sentinel-2 data, where R^2 = coefficient of determination, black line indicates linear equation provided in each subfigure, RVI = Ratio Vegetation Index, DVI = Difference Vegetation Index, NDVI = Normalized Difference Vegetation Index, SAVI = Soil Adjusted Vegetation Index, RDVI = Renormalized Difference Vegetation Index and GNDVI = Green Normalized Difference Vegetation Index

Analysis of suitable equations for estimating above-ground carbon sequestration

Based on the coefficients of determination, the AGC sequestration calculated using the allometric equations was most correlated with RVI from the Sentinel-2 data based on analysis, with the F test statistic equal to 54.24, which was greater than the critical value ($F_{0.05(1,23)} = 4.28$), confirming there was a significant relationship at the 95% confidence level, as shown in Table 3. This was consistent with the study by Katong (2018) that reported the equation from Sentinel-2 data as being the optimal one, as in the current case for estimating the AGC sequestration of reforestation for the Mae Moh mine site.

Table 3 Analysis of variance statistics for Ratio Vegetation Index based on Sentinel-2 data to estimate above-ground biomass sequestration

	df	SS	MS	F	Significance F
Regression	1	8425.031115	8425.031	54.24139	0.00*
Residual	22	3417.144794	155.3248		
Total	23	11842.17591			

df = degrees of freedom; SS = sum of squares; MS = mean square.
* = significant difference at $p < 0.05$.

In addition, studies by Sibanda et al. (2015), Topaloğlu et al. (2016), Ali et al. (2018), Astola et al. (2019) and Puliti et al. (2021) reported that Sentinel-2 data produced more precise estimates of AGB than Landsat data; however, the advantage of using Landsat data was that it allowed retrospective estimations of AGB using previous collected Landsat data, which is not possible with the more recent Sentinel-2 data (Puliti et al., 2021)

The sample plots for validation were used to check the accuracy of the AGC sequestration estimation calculated based on the RVI model and to analyze the difference between data from the allometric equation and the model using a t test. The t test value was -1.28, which was in the critical range ($t_{0.05(1,9)} = \pm 2.26$), as shown in Table 4, indicating that the estimated AGC sequestration based on the RVI model using the Sentinel-2 data and the AGC sequestration based on the allometric equation were not significantly different at the 95% confidence level. The average AGC sequestration using the allometric equation was 288.95 Mg/ha while the average AGC sequestration based on the RVI model using the Sentinel-2 data was 332.23 Mg/ha (a difference of 14.98%).

Estimation of above-ground carbon sequestration for reforestation site at Mae Moh mine, Lampang province

Substituting the VI values of each plot into the AGC sequestration estimation equation from the Sentinel-2 data, for the total area of 1,969.28 ha, the estimated average AGC sequestration was 33.96 Mg/ha, which was an increase from the earlier study by Katong (2018) that estimated an average AGC sequestration of 25.76 Mg/ha for the same area. The current study results indicated that the total amount of AGC sequestration was 66,879.23 Mg and the average CO_2 absorption was 124.64 Mg/ha. In addition, the total amount of CO_2 absorbed was 245,446.78 Mg, which was similar to the estimate of 34.26 Mg/ha by Nuanurai (2005) for the average AGC sequestration of mixed deciduous forests in the Kaeng Krachan National Park. Boonsang (2011) reported that the average AGC sequestration of mixed deciduous forests in the Mae Tuen Wildlife Sanctuary was 80.16 Mg/ha. The current study results indicated that the AGC sequestration for the reforestation site at the Mae Moh mine in Lampang province had increased to be closer to the AGC sequestration of mixed deciduous forest, which was characteristic of the original forest on the site before mining commenced.

In conclusion, the reforestation site at the Mae Moh mine, Lampang province can play an important role in reducing the severity of climate change because it has a large area on which suitable revegetation can absorb CO_2 from the atmosphere. Nowadays, remote sensing monitoring of reforestation projects is more important than in the past

Table 4 Statistical results for the Ratio Vegetation Index based on Sentinel-2 data for estimation of above-ground biomass sequestration

	Allometric equation	Satellite image data
Mean	28.90	33.22
Variance	717.61	775.48
Observations	10	10
Pearson correlation	0.93	
Hypothesized mean difference	0	
df	9	
t Stat	-1.28	
P(T<=t) one-tail	0.12	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.23	
t Critical two-tail	2.26	

because of the increased interest in combatting increasing CO_2 emissions and global warming. The current study has provided an early example of using Landsat 9 data to estimate AGC sequestration. Furthermore, the results indicated that the Sentinel-2 data were more closely related to AGC sequestration than the Landsat 9 data in terms of root mean square error and coefficient of determination. The RVI based on the Sentinel-2 data was the most appropriate: - 79.56 + 63.88x (R^2 = 0.71), with the estimated average AGC sequestration for the reforestation site being 33.96 Mg/ha. In addition, the total amount of AGC sequestration was 66,879.23 Mg, the average CO_2 absorption was 124.64 Mg/ha and the total amount of CO_2 absorbed was 245,446.78 Mg. The results showed that although the Landsat 9 data were more recent than the Sentinel-2 data, the coefficient of determination values for all the VIs based on the Sentinel-2 data in the current study were higher than for their Landsat-9 data counterparts. Thus, it could be assumed that different spatial resolutions could affect the accuracy of estimates.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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References

Ali, A., Ullah, S., Bushra, S., Ahmad, N., Ali, A., Khan, M.A. 2018. Quantifying forest carbon stocks by integrating satellite images and forest inventory data. Austrian J. For. Sci. 135: 93–117.

Anderson, C. 2021. Landsat 8-9 Calibration and Validation (Cal/Val) Algorithm Description Document (ADD). Department of the Interior U.S. Geological Survey. Sioux Falls, SD, USA.

Astola, H., Häme, T., Sirro, L., Molinier, M., Kilpi, J. 2019. Comparison of Sentinel-2 and Landsat 8 imagery for forest variable prediction in boreal region. Remote Sens. Environ. 223: 257–273. doi.org/10.1016/j.rse.2019.01.019

Boonsang, S. 2011. Estimation of Above-ground Carbon Sequestration of Forest Area by Using Remote Sensing Techniques at Mae Tuen Wildlife Sanctuary, Tak Province. M.S. thesis, Faculty of Forestry, Kasetsart University. Bangkok, Thailand. [in Thai]

Department of National Park, Wildlife and Plant Conservation. 2014. Survey and Assessment of Carbon Sequestration in Forest Areas. The Agricultural Co-operative Federation of Thailand. Bangkok, Thailand. [in Thai]

Electricity Generating Authority of Thailand. 2016. Measures to prevent and correct environmental impacts from mining. https://mmmenv.egat.co.th/egatmmm/web/management.php, 27 February 2023. [in Thai]

European Space Agency. 2015. Sentinel-2 User Handbook. https://sentinels.copernicus.eu/web/sentinel/user-guides/document-library/-/asset_publisher/xlslt4309D5h/content/sentinel-2-user-handbook, 25 November 2021.

Herold, M., Carter, S., Avitabile, V., et al. 2019. The role and need for space-based forest biomass-related measurements in environmental management and policy. Surv. Geophys. 40: 757–778. doi.org/10.1007/s10712-019-09510-6

Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. The Institute for Global Environmental Strategies. Hayama, Japan.

Katong, R. 2018. Comparative study of Landsat 8 and Sentinel-2 data for above ground carbon sequestration estimation at reforestation site of Mae Moh mine, Lampang province. M.Sc. thesis, Faculty of Forestry, Kasetsart University. Bangkok, Thailand. [in Thai]

Khunrattanasiri, W. 2020. Satellite Imagery for Forest Resource Survey. Kasetsart University. Bangkok, Thailand. [in Thai]

Nuanurai, N. 2005. Comparison of leaf area index, above-ground biomass and carbon sequestration of forest ecosystems by forest inventory and remote sensing at Kaeng Krachan National Park, Thailand. M.Sc. thesis, Faculty of Science, Chulalongkorn University. Bangkok, Thailand. [in Thai]

Office of Natural Resources and Environmental Policy and Planning. 2020. Thailand Third Biennial Update Report. Bangkok, Thailand. [in Thai]

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

Puliti, S., Breidenbach, J., Schumacher, J., Hauglin, M., Klingenberg, T.F., Astrup, R. 2021. Above-ground biomass change estimation using national forest inventory data with Sentinel-2 and Landsat. Remote Sens. Environ. 265: 112644. doi.org/10.1016/j.rse.2021.112644

Revision of Mine Master Plan Committee. 2020. Review Mae Moh Mine Master Plan. Electricity Generating Authority of Thailand. Nonthaburi, Thailand. [in Thai]

Sibanda, M., Mutanga, O., Rouget, M. 2015. Examining the potential of Sentinel-2 MSI spectral resolution in quantifying above ground biomass across different fertilizer treatments. ISPRS J. Photogramm. 110: 55–65. doi.org/10.1016/j.isprsjprs.2015.10.005

TEAM Consulting Engineering and Management Public Co. Ltd. 2017. Environmental Health Impact Assessment: Project to Expand the Power Plant for Replacement Power Plants in Mae Moh Machine 4–7. TEAM Consulting Engineering and Management Public Co. Ltd. Bangkok, Thailand. [in Thai]

Thailand Greenhouse Gas Management Organization. 2016. Thailand Voluntary Emission Reduction Program Reference Manual: Forestry and Agriculture Sector. Thailand Greenhouse Gas Management Organization. Bangkok, Thailand. [in Thai]

Tomppo, E., Gschwantner, T., Lawrence, M., McRoberts, R.E. 2010. National Forest Inventories: Pathways for Common Reporting. Springer. Berlin, Germany.

Topaloğlu, R.H., Sertel, E., Musaoğlu, N. 2016. Assessment of classification accuracies of Sentinel-2 and Landsat-8 data for land cover/use mapping. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLI-B8: 1055–1059. doi: 10.5194/isprsarchives-XLI-B8-1055-2016

Viriyabuncha, C. 2020. A Guide to Studying Carbon Stocks Source in Natural Forests. Department of National Park, Wildlife and Plant Conservation. Bangkok, Thailand. [in Thai]

Xue, J., Su, B. 2017. Significant remote sensing vegetation indices: A review of developments and applications. J. Sensors 2017: 1353691. doi.org/10.1155/2017/1353691