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Original Research

Estimation of Forest Biomass and Absorbed CO_2 by Remote Sensing in Can Gio, Vietnam

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Abstract

In recent years, the Can Gio district in Vietnam has faced escalating challenges linked to climate change, including deforestation, urbanization, and rising carbon emissions. This study employs remote sensing techniques to estimate critical forest metrics, particularly aboveground biomass (AGB) and carbon sequestration potential in the region. Through meticulous data collection and analysis, this research establishes strong correlations between vegetation indices derived from remote sensing data and AGB, as well as CO_2 absorption. Our results reveal that the Can Gio mangrove forest boasts an impressive AGB ranging from 200 to 500 tons/ha and demonstrates significant variations in carbon sequestration potential across different sub-zones. These findings not only contribute to efficient AGB estimation methods but also facilitate sustainable forest management and climate change mitigation strategies, vital for the Can Gio district and regions globally grappling with similar challenges.

Keywords: aboveground biomass, CO_2, estimate, GHG, remote sensing

Introduction

In recent years, the global community has grappled with the pressing challenges of climate change and escalating global warming [1, 2]. These phenomena, resulting primarily from human activities, have led to the release of a multitude of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NOx), chlorofluorocarbons (CFCs), and sulfur hexafluoride (SF6), profoundly amplifying the greenhouse effect [3]. Among these gases, CO_2 emerges as a major protagonist, playing a pivotal role in the ongoing greenhouse effect [4]. Consequently, the Can Gio district, located in Vietnam, confronts a multifaceted threat encompassing deforestation, land-use alterations, and escalating carbon emissions due to rapid urbanization and industrialization [5].

Within this intricate ecological and climatic backdrop, the forests situated in the Can Gio district emerge as invaluable assets, intricately interwoven with the mitigation of climate change impacts. These forests, beyond their intrinsic ecological significance, function as pivotal carbon sinks, effectively sequestering substantial volumes of atmospheric CO_2. As such, their preservation and judicious management assume paramount importance, not only in the context of carbon

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sequestration but also for the overarching sustainable development of the region [6].

In the broader international arena, global initiatives such as the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program underscore the need for precise estimation of crucial forest metrics. These metrics, notably encompassing aboveground biomass (AGB) and forest carbon stocks, constitute the cornerstone for evaluating the Can Gio forest's carbon sequestration potential, ascertaining carbon credits for emissions mitigation, and assessing the quantifiable benefits arising from its CO_2 sequestration services [7]. Regrettably, conventional methodologies employed for monitoring AGB in the Can Gio district are inherently labor-intensive, costly, and constrained in scope [8]. While field-based inventories offer commendable accuracy, their implementation is marked by substantial time requirements and frequently poses challenges in the context of large-scale assessments. Consequently, a significant research void exists, underscoring the compelling necessity to explore and implement efficient, cost-effective methodologies for AGB estimation within this specific geographic domain.

Amidst this backdrop, remote sensing techniques emerge as a promising avenue to bridge this research lacuna. Leveraging data acquired from satellites and airborne sensors, remote sensing methodologies empower comprehensive, repeatable measurements over expansive geographical extents [9]. These techniques offer the capacity to indirectly estimate forest AGB by scrutinizing spectral data and vegetation indices intrinsically linked to biomass [8]. However, despite numerous endeavors dedicated to remote sensing-based AGB estimation in diverse global contexts, limited research has centered on the unique challenges posed by the Can Gio district's specific context.

Consequently, this study assumes the crucial task of filling this research lacuna by methodically scrutinizing and synthesizing a spectrum of AGB estimation approaches predicated on remotely sensed data, with a specific focus on the Can Gio district. The primary objectives are twofold: firstly, to quantify the magnitude of CO_2 absorption and biomass accumulation within the forested expanses of the Can Gio district, utilizing Over-The-Counter (OTC) plants as a comparative reference. This entails the development of an equation encapsulating the intricate relationship between biomass, CO_2 absorption and the vegetation index derived from remote sensing data. Secondly, the study aims to engender a spatial map delineating dry biomass distribution and CO_2 uptake across the Can Gio district's forest plantations. These objectives align within the broader context of advancing our understanding of the region's carbon dynamics, thereby facilitating informed, ecologically responsible management practices and contributing to the global discourse on climate change mitigation.

Methodology

Study Area

The data is collected in Can Gio District, Ho Chi Minh city, the characteristics of the area could be found in our previous study [5].

Biomass and CO_2 Uptake Calculation

The methodology employed for estimating biomass and CO_2 uptake adopted a comprehensive and rigorous approach called standard plotting method, comprising several steps. Initially, the study area was meticulously selected, focusing on the representative Can Gio plantation forest. To collect individual tree data, standardized Overstory Tree Crowns (OTCs) were thoughtfully established at strategic locations along the Rung Sac route. Within each OTC, precise measurements of trunk diameters were conducted at 1.3 meters above the ground, using a standardized 1.5-meter tape measure to ensure meticulous accuracy. The collected data were then utilized to estimate the Soil Carbon (SC) of trees within each OTC, with subsequent application of carbon sequestration coefficients to determine CO_2 uptake in the sample plots.

Table 1. Correlation formula for each plant species' absorbed CO_2 and dry biomass.

No.	Type of tree	Dry biomass	CO_2 absorbed	Height (cm)
1	*Rhizophora apiculata*	$W = 0.3482\times D_{1.3}^{2.2965}$	$CO_2 = 0.6171 \times D_{1.3}^{2.2896}$	$3.2<D_{1.3}<30.3$
2	*Ceriops tagal (Perr) C. B. Rob.)*	$W = 1.56426 \times 1.42198^{D1.3}$	$CO_2 = 0.5 \times W \times \frac{44}{12}$	$1.9<D_{1.3}<9.4$
3	*Ceriops decandra*	$W = 0.20792 \times D_{1.3}^{2.40729}$	$CO_2= 0.372325\times D_{1.3}^{2.37829}$	$1.27<D_{1.3}<7.48$
4	*Sonneratia coseolaris (L.) Engler.*	$W = 0.251x\ 0.340\ x\ D_{1.3}^{2.46}$	$CO_2 = CF \times W \times \frac{44}{12}$	$5<D_{1.3}<49$
5	*Xylo- carpus grana-tum Koen*	$W = 0.251\ x\ 0.528 \times D_{1.3}^{2.46}$	$CO_2 = CF \times W \times \frac{44}{12}$	$5<D_{1.3}<49$
6	*Lumnitzera racemosa Willd*	$W = 0.17446 \times D_{1.3}^{2.3263}$	$CO2 = 0.275788\times D_{1.3}^{2.37829}$	$1.8<D_{1.3}<12.2$
7	*Avicenniaalba Bl*	$W = 0.251\ x\ 0.506 \times D_{1.3}^{2.46}$	$CO_2 = CF \times W \times \frac{44}{12}$	$5<D_{1.3}<49$
8	*Phoenix paludosa Roxb*	$W =(-1.5857 + 1.6962 \times \sqrt{D_{1.3}})^2$	$CO_2 =(-2.2223+2.2965 \times \sqrt{D_{1.3}})^2$	$2.55<D_{1.3}<8.28$

Biomass and Absorbed CO_2 Calculation

The tree conservation approach was employed to compute the above-ground biomass and the CO_2 uptake by the plants in the sample plot. This estimation was based on the growth correlation equation specific to each tree species listed in Table 1, incorporating the following parameters:

- D1,3: trunk diameter at a height of 1.3 meters.
- W: Dry biomass (in kilograms).
- CF: Conversion factor (CF = 0.5) as per the IPCC guidelines of 2003.

Image Preprocessing

Pham et al. (2019) [10] noted that terrestrial radiation from cosmic carriers can be affected by diffraction due to various factors such as tilt angle, sun height and atmospheric optical conditions like absorption and scattering. Hadjimitsis et al. (2010) [11] highlighted the significant impact of the atmosphere on the blackbody surface irradiance value. To address this, radiation correction was carried out during the image preprocessing stage, converting Digital Number (DN) values to actual values of radiation (B) with units of $Wm^{-2}m^{-1}$. This conversion was done using the provided default values of M_L (unit conversion factor) and A_L (deviation) from the metadata file of the Landsat 8 image product. To convert the numerical values of DN to surface reflectance values for Landsat 8 images, the following formula provided by the USGS was employed as Eq. (1).

$$P_\lambda = \frac{M\rho \times Qcal \times A\rho}{\sin\theta SE} \tag{1}$$

This formula involves the unit conversion factor M_ρ, numeric data of each pixel cell Q_{cal}, reflection data deviation A_ρ, and the sun elevation angle θ_{SE}.

Vegetation Index Calculation

To accurately estimate biomass and CO_2 absorption, it is crucial to establish a robust correlation between the vegetation index derived from remote sensing imagery and the actual plant biomass obtained through ground-based survey measurements [12]. Our study employs two distinct methods for biomass calculation and estimation, which are elaborated below.

Normalized Difference Vegetation Index (NDVI), the NDVI is computed using the formula:

$$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{2}$$

Where: RED denotes the reflectance value in the red spectrum channel; NIR represents the reflectance value in the near-infrared spectral channel.

The NDVI value ranges from -1 to +1, with higher values indicating denser vegetation cover, such as forests with a high density of trees and a closed canopy [13]. Mean NDVI values falling within the range of 0.2 to 0.3 are indicative of shrubs and lawns, while urban areas, bare land and water typically exhibit very low NDVI values (NDVI<0.1).

Ratio Vegetation Index (RVI):

The RVI index inversely correlates with vegetation density, with lower RVI ratios indicating higher vegetation cover [14]. The RVI is calculated using the formula:

$$RVI = \frac{\text{NIR}}{\text{RED}} \tag{3}$$

By integrating both the NDVI and RVI methods, we can effectively account for regional variations and achieve more accurate estimations of biomass and CO_2 absorption across diverse vegetation types and regions [12].

Table 2. Correlation between soil carbon (SC), vegetative index and CO_2 absorption.

Type of correlation	Equations	Regression	R^2 value (%)	P-value
SC vs. vegetative index	SC = -1277.7 + 2484.3 × NDVI	Linear	71.90	0.000
	SC = 7006 – 24731.5 × NDVI + 22241.5 × NDVI²	Quadratic	79.26	0.000
	SC = 662 – 1565.3×RVI	Linear	29.47	0.013
	SC = 2096.7 – 13052.2 × RVI + 22337.6 × RVI²	Quadratic	41.22	0.011
CO_2 absorption vs. vegetative index	CO_2 = -2209.9 + 4302.4 × NDVI	Linear	71.83	0.000
	CO_2 = 12188.2 – 43001.7 × NDVI + 38658.2 × NDVI²	Quadratic	79.24	0.000
	CO_2 = 1148 – 2704.8 × RVI	Linear	29.31	0.014
	CO_2 = 3646.7 – 22710.3 × RVI + 38902.9 × RVI²	Quadratic	41.18	0.011

Correlation Equations for Biomass, CO_2 Absorption and Vegetation Index

Regression functions are constructed in Excel, utilizing vegetation index and SC values (representing CO_2 absorption) obtained from field surveys within the OTCs [15].

Results and Discussion

Nexus between Vegetation Indices with Biomass and CO_2 Absorption

Regarding the correlation equation results (Table 2), the quadratic equations consistently exhibit higher correlation values for both NDVI and RVI compared to linear equations. Specifically, the NDVI index shows a very high correlation with the biomass of planted forests (R^2 value of 79.26%), while the RVI index exhibits a relatively lower correlation (R^2 value of 41.22%). As a result, the Eq. (4) is selected as the biomass estimation equation for planted forests in Can Gio.

$$\text{Biomas (ton/ha)} = 22241.5 \times NDVI^2 + 24731.5 \times NDVI + 7008 \quad (4)$$

Similarly, the correlation between absorbed CO_2 and plant indices (NDVI and RVI) also demonstrates significant associations (Table 2). Quadratic equations show higher correlation values, especially for the NDVI index (R^2 value of 79.24%) corresponding to Eq. (5).

$$CO_2\text{ (ton/ha)} = 38658.2 \times NDVI^2 + 430001.7 \times NDVI + 12188.2 \quad (5)$$

Mapping Biomass and CO_2 Sequestration in the Forests

Utilizing the established correlation equation between biomass and NDVI, we generated a comprehensive biomass map covering all sub-zones within the Can Gio mangrove forest (Fig. 1). The map illustrates the distribution of biomass in different sub-zones, with varying density levels observed. Sub-zones 10B and 10C predominantly exhibit biomass levels ranging from 200 to 400 tons/ha, while Sub-area 10A showcases higher biomass density, ranging from 400 to 500 tons/ha, with certain locations exceeding 500 tons/ha. Notably, lower biomass levels are observed near the forest edge and roads, while biomass concentration is evident in the interior regions, particularly along water sources like canals (Fig. 2).

Furthermore, Fig. 3 displays the CO_2 absorption levels across the sub-zones. Sub-zones 10B and 10C

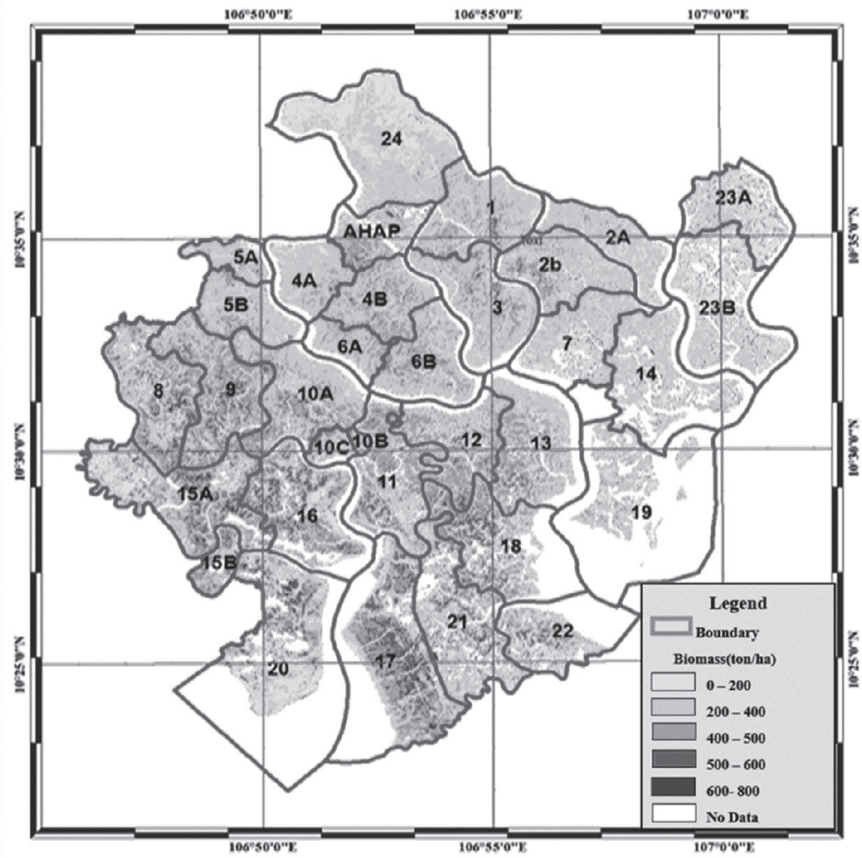

Fig. 1. Biomass Mapping of Planted Forests in Can Gio Mangrove Forest.

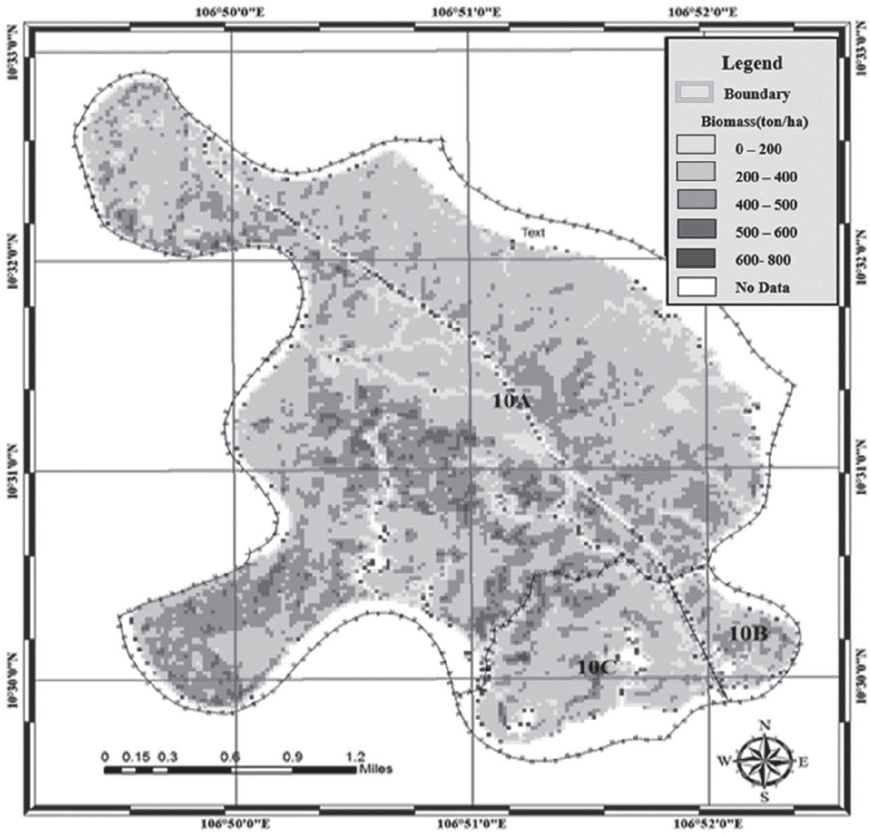

Fig. 2. Forest biological mapping in super-zones 10a, 10b, and 10c of Can gio mangrove forest.

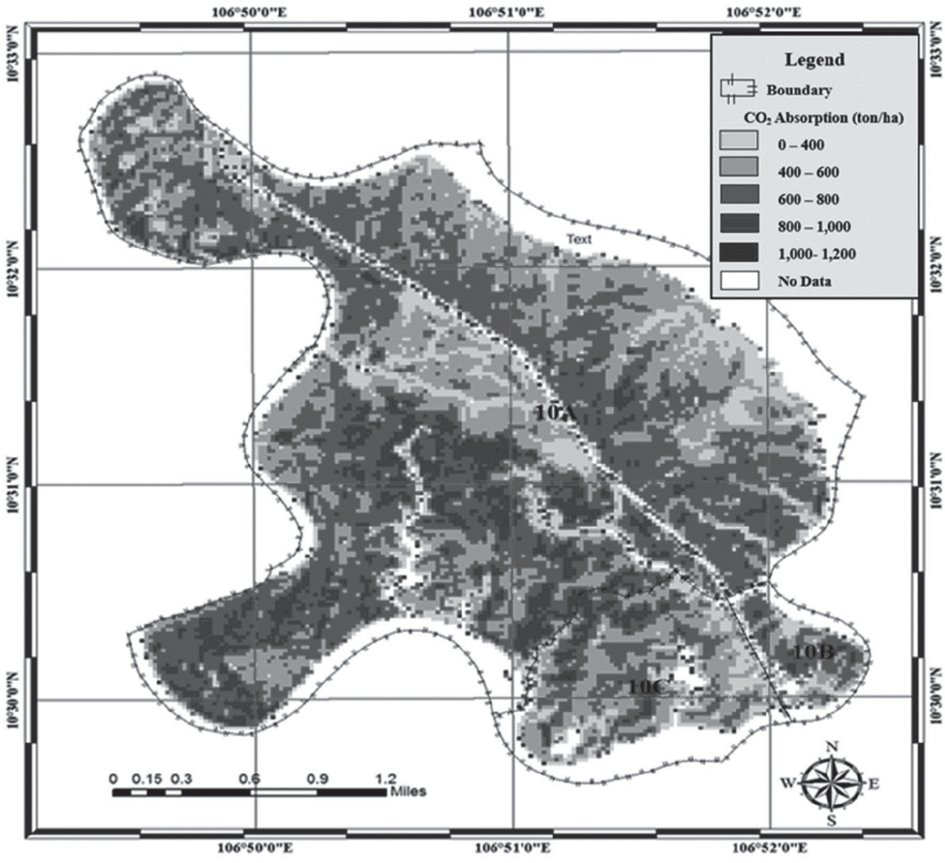

Fig. 3. Cartographic representation of CO_2 absorption in planted forests within sub-zones 10a, 10b, and 10c of Can gio mangrove forest.

demonstrate CO_2 absorption levels below 400 to 600 tons/ha, while sub-zone 10A exhibits multiple areas with CO_2 absorption levels ranging from 600 to 800 tons/ha. As a result, the average CO_2 absorption in sub-zone 10A surpasses that of sub-zones 10B and 10C, indicating variations in the forest's carbon sequestration potential. By considering the average global carbon credit price $5 per metric ton of CO_2 in Vietnam [16] and an exchange rate of 24,395 VND per USD, the estimated value of CO_2 credits in sub-area 10A amounts to approximately 4397 USD/ha or around 110 million VND at the present time (26. 09. 2023), highlighting the economic significance of carbon sequestration in this forest ecosystem. These findings offer valuable insights for forest management strategies and climate change mitigation efforts in the Can Gio mangrove forest.

Conclusions

Among the plant indices used, the Normalized Difference Vegetation Index (NDVI) stands out with a higher correlation (R^2 values of 79.26% for biomass and 79.24% for absorbed CO_2) and meets the required criteria. Conversely, the Ratio Vegetation Index (RVI) exhibits only a moderate correlation with biomass and absorbed CO_2, resulting in relatively lower and unsatisfactory outcomes (highest R-squared values of 41.22% for biomass and 41.18% for absorbed CO_2). Moreover, the study has successfully developed and selected a correlation model between Soil Carbon (SC) and CO_2 absorption using the NDVI vegetative index. The planted forests in the studied sub-zones showcase relatively high average biomass volume and CO_2 absorption, with sub-area 10A being particularly notable, having a biomass volume of 419.87 tons/ha and a CO_2 absorption of 879.4 tons/ha. Taking into account the prevailing global carbon credit prices, the calculated value of CO_2 credits in sub-area 10A approximates 4397 USD per hectare or roughly 110 million VND at the current juncture. These findings carry significant implications for comprehending carbon sequestration dynamics and attributing value to carbon credits within forest ecosystems.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. NGUYEN H.T., NGUYEN S.V., DAU V.-H., LE A.T.H., NGUYEN K.V., NGUYEN D.P., BUI X.-T., BUI H.M. The nexus between greenhouse gases, economic growth, energy and trade openness in Vietnam. Environmental Technology & Innovation, **28** 102912, **2022**.
2. ELSUNOUSI A.A.M., SEVIK H., CETIN M., OZEL H.B., OZEL H.U. Periodical and regional change of particulate matter and CO_2 concentration in Misurata. Environmental Monitoring and Assessment, **193** (11), 707, **2021**.
3. HA MANH B., VAN NGUYEN S., HUYNH A.T., HIEP NGHIA B., NGUYEN H.T.T., PERNG Y.S., BUI X.-T., NGUYEN H.T. Correlation between nitrous oxide emissions and economic growth in Vietnam: An autoregressive distributed lag analysis. Environmental Technology & Innovation, **29** 102989, **2023**.
4. CETIN M. A Change in the Amount of CO_2 at the Center of the Examination Halls: Case Study of Turkey. Studies on Ethno-Medicine, **10** (2), 146, **2016**.
5. TRAN T.B., BUI H.M. Effect of land-use changes resulting from shrimp farming on acid sulfate soils in the Can Gio coastal wetland area (Vietnam). Polish Journal of Soil Science; Vol **51**, No 2 (2018), **2018**.
6. SADIQ M., MOSLEHPOUR M., QIU R., HIEU V.M., DUONG K.D., NGO T.Q. Sharing economy benefits and sustainable development goals: Empirical evidence from the transportation industry of Vietnam. Journal of Innovation & Knowledge, **8** (1), 100290, **2023**.
7. YADAV V.S., YADAV S.S., GUPTA S.R., MEENA R.S., LAL R., SHEORAN N.S., JHARIYA M.K. Carbon sequestration potential and CO_2 fluxes in a tropical forest ecosystem. Ecological Engineering, **176** 106541, **2022**.
8. FAYAD I., BAGHDADI N., GUITET S., BAILLY J.-S., HÉRAULT B., GOND V., EL HAJJ M., TONG MINH D.H. Aboveground biomass mapping in French Guiana by combining remote sensing, forest inventories and environmental data. International Journal of Applied Earth Observation and Geoinformation, **52** 502, **2016**.
9. TUONG T.T.C., TANI H., WANG X., THANG N.Q., BUI H.M. Combination of SAR Polarimetric Parameters for Estimating Tropical Forest Aboveground Biomass. Pol. J. Environ. Stud., **29** (5), 3353, **2020**.
10. PHAM L.T.H., VO T.Q., DANG T.D., NGUYEN U.T.N. Monitoring mangrove association changes in the Can Gio biosphere reserve and implications for management. Remote Sensing Applications: Society and Environment, **13** 298, **2019**.
11. HADJIMITSIS D.G., PAPADAVID G., AGAPIOU A., THEMISTOCLEOUS K., HADJIMITSIS M.G., RETALIS A., MICHAELIDES S., CHRYSOULAKIS N., TOULIOS L., CLAYTON C.R.I. Atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. Nat. Hazards Earth Syst. Sci., **10** (1), 89, **2010**.
12. TRAN T.V., REEF R., ZHU X. A Review of Spectral Indices for Mangrove Remote Sensing. Remote Sensing, **14** (19), 4868, **2022**.
13. LE H.T., TRAN T.V., GYELTSHEN S., NGUYEN C.P.T., TRAN D.X., LUU T.H., DUONG M.B. Characterizing Spatiotemporal Patterns of Mangrove Forests in Can Gio Biosphere Reserve Using Sentinel-2 Imagery. Applied Sciences, **10** (12), 4058, **2020**.

14. DO A.N.T., TRAN H.D., ASHLEY M., NGUYEN A.T. Monitoring landscape fragmentation and aboveground biomass estimation in Can Gio Mangrove Biosphere Reserve over the past 20 years. Ecological Informatics, **70** 101743, **2022**.
15. DASRIZAL, RAHMI, REZKI A., FARIDA, ULNI A.Z.P., SYAFRUDDIN Y.S. Outlook for carbon stock of tropical forest in the context of climate change. IOP Conference Series: Earth and Environmental Science, **299** (1), 012049, **2019**.
16. GLOBAL V. Vietnamese enterprises prepare for carbon credit market: VIETNAMNET; 2023 [cited 2023 26/09]. Available from: https://vietnamnet.vn/en/vietnamese-enterprises-prepare-for-carbon-credit-market-2122063.html.