Estimating forest aboveground biomass and carbon stocks using satellite imagery: A case study of Luot Mountain, Vietnam National University of Forestry

Tran Thi Thom[1], Le Hung Chien[1*], Ngo Thi Dinh[1], Nguyen Thi Oanh[1], Nguyen Khac Linh[2]
[1]*Vietnam National University of Forestry*
[2]*Hanoi University of Natural Resources and Environment*

Xây dựng mô hình ước tính sinh khối, trữ lượng các-bon rừng từ tư liệu ảnh vệ tinh: Trường hợp nghiên cứu tại Núi Luốt, Trường Đại học Lâm nghiệp

Trần Thị Thơm[1], Lê Hùng Chiến[1*], Ngô Thị Dinh[1], Nguyễn Thị Oanh[1], Nguyễn Khắc Lĩnh[2]
[1]*Trường Đại học Lâm nghiệp*
[2]*Trường Đại học Tài nguyên và Môi trường Hà Nội*
**Corresponding author: chienlh@vnuf.edu.vn*

https://doi.org/10.55250/jo.vnuf.11.2.2026.082-090

Article info:
Received: 04/03/2026
Revised: 07/05/2026
Accepted: 15/06/2026

Keywords:
Aboveground Biomass, Carbon stocks, Luot Mountain, Sentinel-2, Vegetation indices, VNUF

ABSTRACT

This study aimed to develop a model for estimating aboveground forest biomass and carbon stocks in the Luot mountain area of Vietnam National University of Forestry (VNUF) using Sentinel-2 satellite imagery. The results demonstrate the effectiveness of integrating remote sensing technology with Geographic Information Systems (GIS) for estimating forest biomass and carbon stocks. The study employed a multivariate regression model incorporating vegetation indices, vegetation biophysical variables, and field-measured biomass data. The resulting model was used to generate a forest biomass distribution map for the Luot mountain area of VNUF. Forest biomass exhibited substantial spatial variation, with higher biomass concentrations in the central part of Luot mountain, particularly in the elevated terrain surrounding Peak 133 m, where favorable ecological conditions and limited anthropogenic disturbance prevail. Based on the forest biomass map and an appropriate biomass-to-carbon conversion factor, the study estimated aboveground carbon stocks and generated a forest carbon stock distribution map, with values ranging from 0 to approximately 3,310 ton of carbon per hectare (t C/ha). The spatial distribution of carbon stocks closely corresponded to that of forest biomass, with higher carbon stocks in areas of greater forest cover and lower stocks in areas affected by logging or occupied by young, regenerating forests.

Từ khóa:
Các chỉ số thực vật, Đại học Lâm nghiệp, Núi Luốt, Sentinel-2, Sinh khối, trữ lượng các-bon.

TÓM TẮT

Nghiên cứu xây dựng mô hình ước tính sinh khối và trữ lượng các-bon rừng trên mặt đất cho khu vực Núi Luốt, Trường Đại học Lâm nghiệp dựa trên dữ liệu vệ tinh Sentinel-2. Kết quả nghiên cứu cho thấy việc ứng dụng công nghệ viễn thám kết hợp với hệ thống thông tin địa lý (GIS) trong nghiên cứu sinh khối và trữ lượng các-bon rừng mang lại hiệu quả rõ rệt. Nghiên cứu đã sử dụng mô hình hồi quy đa biến giữa các chỉ thực vật, biến sinh lý thực vật và sinh khối thực đo từ ngoài thực địa. Kết quả nghiên cứu đã xây dựng được bản đồ phân bố sinh khối rừng trên khu vực Núi Luốt, Trường Đại học Lâm nghiệp. Phân bố sinh khối có sự chênh lệch rõ rệt giữa các khu vực, với sinh khối cao tập trung trung tâm Núi Luốt, nơi địa hình cao xung quanh đỉnh 133 m, điều kiện sinh thái thuận lợi và ít bị tác động bởi con người. Từ bản đồ sinh khối rừng và hệ số chuyển đổi phù hợp, nghiên cứu đã xác định được trữ lượng cacbon trên mặt đất và xây dựng bản đồ trữ lượng các-bon rừng với giá trị dao động từ 0 đến khoảng 3.310 tấn C/ha. Trữ lượng các-bon phân bố tương đồng với sinh khối, cao hơn ở những khu vực có độ che phủ rừng lớn và thấp hơn tại các vùng có hoạt động khai thác hoặc rừng non mới phục hồi.

1. INTRODUCTION

Climate change remains a critical global challenge, with its multifaceted impacts becoming increasingly evident across the globe. A wide array of ecological issues has emerged, including sea-level rise [1], glacial melting [2-4], extreme weather events [5, 6], reduced food security [7], species extinction and adverse effects on human health [8], Forest ecosystems sequester more carbon than any other terrestrial ecosystem, acting as a pivotal factor in climate change mitigation [9], Conversely, when forests are cleared or degraded, significant amounts of carbon are

released into the atmosphere as CO_2 [10]. Forest degradation not only emits vast quantities of greenhouse gases but also destroys critical global carbon sinks, profoundly impacting future climate stability. Therefore, the accurate estimation of forest biomass is essential for assessing carbon sequestration capacity and carbon balance, particularly in large-scale carbon cycle research. Forest aboveground biomass (AGB) reflects complex nutrient cycling relationships and serves as a vital indicator of an ecosystem's carbon sequestration potential [11, 12]. Within the context of climate change, estimating forest AGB provides a scientific foundation for managing and monitoring carbon fluctuations, supporting Payment for Forest Environmental Services (PFES) regarding carbon sequestration. Rapid and accurate forest AGB estimation remains a persistent challenge in forestry research [13, 14]. Generally, estimation methods are categorized into: field-based measurements, remote sensing-based approaches, and ecological modeling [15, 16]. While field measurements are labor-intensive and costly, they remain the most accurate method for collecting reference biomass data [17, 18], The estimate AGB across extensive or inaccessible areas, researchers integrate remote sensing indices with ground-plot inventory data. Common data sources include optical satellite imagery, microwave (SAR) data, and LiDAR, each possessing distinct advantages and limitations. Nevertheless, remote sensing is projected to play an increasingly vital role in providing the theoretical basis for carbon cycle studies and forest monitoring. The Vietnam National University of Forestry (VNUF) manages 105.80 hectares of land and forest at its main campus in Xuan Mai, comprising administrative areas and the Luot Mountain forest. In 1984, the area consisted of barren hills and scrubland. Since then, the university has implemented reforestation programs using fast-growing species such as Pinus, Acacia, and Eucalyptus. Subsequently, supported by national programs and projects—such as Program 327 (1993–2000), Project 661 (1998–2010), and various scientific initiatives (2003–2013)—these plantations were progressively thinned to underplant native species and non-timber forest products (NTFPs). These efforts aim to conserve rare genetic resources, restore biodiversity, and facilitate academic research. Consequently, researching biomass and carbon stocks has become imperative to quantify the effectiveness of these long-term programs. Quantifying greenhouse gas sequestration provides clear evidence of the forest's environmental value and its role in climate change adaptation. Furthermore, as a practical training site for students, these data serve as essential teaching and research materials, contributing to the development of high-quality human resources in the forestry sector.

2. RESEARCH METHODS

2.1. Study area

The Luot Mountain forest, managed by the VNUF, is situated approximately 40 km southeast of Hanoi's city center. The geographical coordinates are approximately 20°50’30‘‘N; 105°30’45‘‘E. The study area is bordered to the West and Northwest by Luong Son commune, Phu Tho province. To the south, it adjoins Xuan Mai town and National Highway 6, while the Eastern boundary is defined by National Highway 21A (Figure 1). The Northern perimeter is adjacent to Team 6 of the Cuu Long Tea Farm.

The Luot Mountain forest is situated in a transition zone between the Eastern plains and the Western mountainous region, resulting in a relatively simple and uniform topography. The terrain consists of two contiguous hills forming a continuous ridge, with the highest elevation reaching 133 m above sea level. The average slope of the area is approximately 15°. According to hydrological data from the VNUF, the Xuan Mai area is located within climatic sub-region 3 of Northern Vietnam, characterized by two distinct seasons. The rainy season spans from mid-April to October, while the dry season lasts from November to March of the following year, during which evaporation rates typically exceed precipitation. Research conducted by the Department of Soil Science at VNUF indicates that the soil in the Luot Mountain area is derived from nearly homogeneous parent material. The geological substrate is predominantly Porphyrite (intermediate igneous rock), with a negligible proportion of

Quartz Porphyry. Under the influence of a hot and humid tropical monsoon climate with high rainfall, the Porphyrite is highly susceptible to weathering. This is evidenced by a thick and friable C horizon (parent material layer). Rock outcrops are primarily concentrated on the peak and upper slopes of the 133 m summit, while being rarely encountered on the 90 m hill. Overall, the soil in the Luot Mountain area exhibits high uniformity, having developed from the same parent rock and evolved under similar geological and environmental conditions.

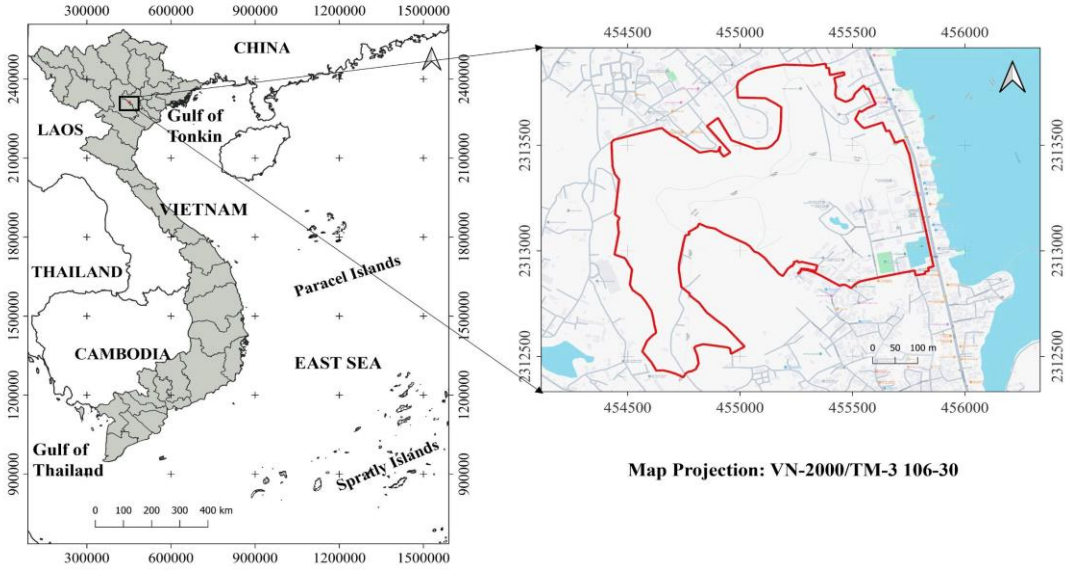


Figure 1. Study area

2.2. Method and materials

2.2.1. Data Collection method

For forest inventory, a typical plot sampling method was employed to ensure representation across various forest ages, growth stages, and distribution patterns. The selection and establishment of Sample Plots (SPs) were based on existing forest status maps, satellite imagery, and preliminary field reconnaissance. These plots were strategically located to represent diverse stand ages, maintaining a minimum distance of 100 meters between adjacent plots to ensure spatial independence.The precise locations of the SPs were determined using Global Positioning System (GPS) devices. The coordinates of these plots were pre-defined based on satellite data and forest maps, then verified through ground surveys. To investigate AGB, the study utilized 15 existing sample plots, each measuring 20 m x 20 m (400 m^2), distributed across the study area (Table 1).

Table 1. Geographic coordinates and estimated AGB of the study plots

No.	Plot ID	X (m)	Y(m)	AGB (kg)
1	NuiLuot_OTC_1	558578	2313269	72.1528
2	NuiLuot_OTC_2	558620	2313444	98.040099
3	NuiLuot_OTC_3	558745	2313381	101.57377
4	NuiLuot_OTC_4	558879	2313243	136.59678
5	NuiLuot_OTC_5	559300	2313389	159.64385
6	NuiLuot_OTC_6	558876	2313192	126.89501
7	NuiLuot_OTC_7	559209	2313457	120.45747
8	NuiLuot_OTC_8	559335	2313669	141.57721
9	NuiLuot_OTC_9	558886	2313465	133.402
10	NuiLuot_OTC_10	558880	2313316	114.1278
11	NuiLuot_OTC_11	559092	2313392	129.76596
12	NuiLuot_OTC_12	559071	2313387	169.24805
13	NuiLuot_OTC_13	558694	2312909	62.5103
14	NuiLuot_OTC_14	558740	2313217	74.0997
15	NuiLuot_OTC_15	558724	2313075	114.2224

In this study, the Sentinel-2 satellite imagery covering the research area was obtained from the United States Geological Survey (USGS) via the EarthExplorer portal (https://earthexplorer.usgs.gov/). The specific image used is identified by the ID: S2A_MSIL2A_20240427T032521_N0510_R018_T48QWJ_20240427T090350.SAFE captured on April 27, 2024. The data was acquired at a spatial resolution of 20 meters.

2.2.2. Remote sensing image processing

The study calculated key vegetation indices to enhance the ability to discriminate forest states, estimate biomass, and assess forest cover in areas of sparse forest, regenerating forest, or bare land. Traditional reflectance indices, such as NDVI (used to assess vegetation greenness and development), GNDVI (a variant of NDVI designed to be more sensitive to changes in canopy chlorophyll content), and SAVI (a vegetation index adjusted to minimize the influence of soil surface reflectance during vegetation analysis, particularly in areas with low to moderate vegetation cover), were used to reduce soil background effects. The Red-edge index group, including IRECI (developed to enhance the estimation of chlorophyll concentration and vegetation biomass), NDVI45 (a variant of NDVI to improve sensitivity to moisture and biomass structure), and TNDVI (an index that improves sensitivity to dense vegetation), was employed to overcome the "saturation" phenomenon in dense forest areas and provide higher sensitivity to vegetation density, thereby supporting forest biomass estimation research more effectively. Additionally, a group of ecological and structural indices was utilized, such as LAI (representing the leaf area per unit of ground surface and serving as a critical ecological parameter reflecting the plants' capacity for photosynthesis, transpiration, and biomass accumulation), FPAR (reflecting the fraction of solar radiation in the 400–700 nm wavelength range—photosynthetically active radiation—absorbed by vegetation for photosynthesis), FCOVER (representing the proportion of ground area covered by green vegetation canopy when observed vertically), and CAB (representing the total content of chlorophyll pigments a and b—a key factor in plant photosynthesis). These were used to assess forest canopy density, vegetation cover, light absorption efficiency, and biological productivity on a large scale with low cost and high coverage, reflecting the physiological condition and health of the trees. The integration of these indices into forest biomass estimation models helps improve the accuracy of carbon stock assessments. The indices were calculated according to the formulas in Table 2. After processing the remote sensing imagery, including steps such as geometric correction, atmospheric correction, and cloud removal, the vegetation indices were calculated and analyzed (Table 2).

The following Sentinel-2 spectral bands were utilized in the calculation of the indices:

Band 3 (Green): Green radiation band with a central wavelength of 559.8μm

Band 4 (Red): Visible red-light band with a central wavelength of 664.6μm.

Band 5 (Red-edge 1): A specific band in the vegetation red-edge transition zone with a central wavelength of 704.1μm

Band 6 (Red-edge 2): An additional red-edge band providing higher sensitivity to chlorophyll, with a central wavelength of 740.5μm

Band 8 (NIR): Near-Infrared radiation band with a central wavelength of 832.8μm

The forest biomass map was developed by integrating remote sensing data with field based biomass measurements to estimate large-scale spatial distribution. This approach relies on extracting various vegetation indices from satellite imagery—including NDVI, SAVI, EVI, LAI, FCOVER, FPAR, and CAB—which reflect the physiological and ecological characteristics of the vegetation to infer AGB [21, 22]. Hese indices were subsequently evaluated for their correlation with biomass data collected from the field sample plots. Field data, including diameter at breast height ($D_{1.3}$), tree height, and stand density, were converted into biomass using species-specific or dominant species group allometric equations.

Table 2. Summary of vegetation indices and biophysical parameters used in the study

Index/Parameter	Formula	
Normalized Difference Vegetation Index (NDVI) [19]	$NDVI = \frac{NIR - RED}{NIR + RED} = \frac{Band\ 8 - Band\ 4}{Band\ 8 + Band\ 4}$	(1)
Inverted Red-Edge Chlorophyll Index (IRECI) [19]	$IRECI = \frac{NIR - RED}{\frac{RedEdge1}{RedEdge2}} = \frac{Band\ 8 - Band\ 4}{\frac{Band\ 5}{Band\ 6}}$	(2)
NDVI Variant 45 (NDVI45) [19]	$NDVI45 = \frac{RedEdge1 - RED}{RED + RedEdge1} = \frac{Band\ 5 - Band\ 4}{Band\ 4 + Band\ 5}$	(3)
Transformed NDVI (TNDVI) [19]	$TNDVI = \left(\frac{NIR - RedEdge1}{NIR + RedEdge1} + 0.5\right)^{0.5} = \left(\frac{Band\ 8 - Band\ 5}{Band\ 8 + Band\ 5} + 0.5\right)^{0.5}$	(4)
Soil Adjusted Vegetation Index (SAVI) [19]	$SAVI = \left(\frac{NIR - RED}{NIR + RED + 0.5}\right)^{1.5} = \left(\frac{Band\ 8 - Band\ 4}{Band\ 8 + Band\ 4 + 0.5}\right)^{1.5}$	(5)
Leaf Area Index (LAI) [20]	$\mathrm{LAI} = 22.273 + 83.169 * \mathrm{NDVI}$	(6)
Fraction of Absorbed Photosynthetically Active Radiation (FPAR) [20]	$\mathrm{FPAR} = -0.08 + 1.075 * \mathrm{NDVI}$ [26]	(7)
Fractional Vegetation Cover (FCOVER) [19]	$\mathrm{FCOVER} = 0.004 * \exp(6.18 * \mathrm{gNDVI}) + 1.075 * \mathrm{NDVI}$ $gNDVI = \frac{NIR - GREEN}{NIR + GREEN} = = \frac{Band\ 8 - Band\ 3}{Band\ 8 + Band\ 3}$	(8)

Based on the vegetation indices and field data, regression models were established to simulate the relationship between spectral indices and biomass. Common methods employed include linear, non-linear, and multivariate regression, as well as machine learning algorithms such as Random Forest (RF) or Artificial Neural Networks (ANN) [23, 24]. The models were calibrated and validated using an independent dataset to select the most accurate model based on statistical indicators: the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE). Once the optimal model was selected, it was applied to the entire satellite scene to estimate the biomass for each pixel. The resulting data is displayed as a raster map, representing the spatial distribution of forest biomass.

The conversion to a carbon stock map was performed using specific conversion factors between biomass and carbon content. These factors reflect the biological relationship between total forest biomass and the carbon sequestered in woody tissues, typically determined by species, forest type, and regional ecological conditions. This methodology is widely used in studies assessing carbon stocks, forest ecosystem sequestration, REDD+ potential, and climate change mitigation [25, 26]. The fundamental formula for estimating carbon stocks from biomass is as follows (9):

$$\mathrm{C} = \mathrm{AGB} * 0.47 \quad (9)$$

where:

C is Aboveground Carbon stock;

AGB is Aboveground Biomass.

3. RESULTS AND DISCUSSION

3.1. Spatial distribution of vegetation indices and biophysical variables

The analysis of Sentinel-2 spectral indices, including NDVI, IRECI, NDVI45, TNDVI, and SAVI, reveals significant spatial differentiation in vegetation health and structure across Luot Mountain (Figure 2). NDVI values (ranging from -0.16 to 0.62) indicate that nearly 80% of the area is covered by dense vegetation (NDVI > 0.3), primarily within central special-use forests and plantations. These results demonstrate that the NDVI distribution map not only reflects the status of forest cover but also serves as a critical database for subsequent stages, such as forest biomass and carbon stock estimation . Similarly, high values of IRECI, TNDVI (0.10–0.54), and SAVI (0.19–1.19) are concentrated around Peak 133 and the Southwest/Northeast sectors, denoting vigorous photosynthetic activity and high leaf density. Conversely, lower values across all indices consistently correspond to non-vegetated surfaces, such as

administrative buildings, lecture halls, and the Luot Mountain cemetery. Notably, TNDVI and IRECI proved highly effective in highlighting stratified canopy layers and biological stress, providing a robust baseline for biomass estimation.

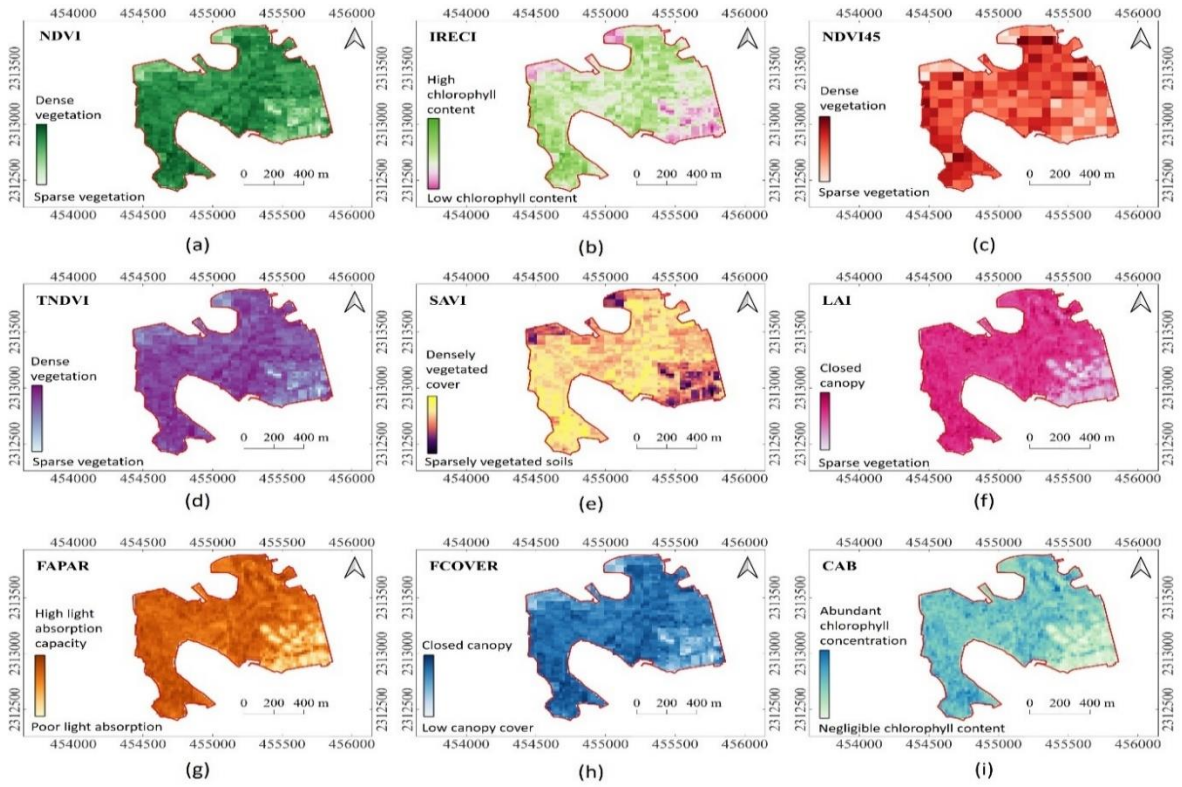


Figure 2. Spatial distribution maps of vegetation indices

(a) NDVI, (b) IRECI, (c) NDVI45, (d) TNDVI, (e) SAVI, (f) LAI, (g) FAPAR, (h) FCOVER, (i) CAB

In addition to spectral indices, biophysical parameters provide a quantitative assessment of the forest's physiological productivity. The Leaf Area Index (LAI), ranging from -0.21 to 2.66, identifies undisturbed forest cores (LAI > 1.0) as critical zones for carbon sequestration. This is supported by FPAR (0.01–0.76) and FCOVER (0.16–0.62) data, where values exceeding 0.4 characterize areas with high canopy closure and light absorption efficiency. Furthermore, Chlorophyll content (CAB) concentrations (15–145 µg/cm²) highlight the superior vitality of well-established forest stands (CAB > 60 µg/cm²) compared to nurseries or degraded fallow plots. These parameters collectively illustrate the high carbon storage potential of the dense vegetation zones in the central study area.

The spatial distribution of these indices reflects a clear correlation between forest health and anthropogenic impact. While the central high-elevation zones exhibit optimal biophysical characteristics, the Eastern and Northeastern regions show lower values due to residential infrastructure and higher human activity. The consistent performance of these multiple variables across diverse land-cover classes confirms the reliability of the dataset. Consequently, this comprehensive spectral and physiological profile serves as the foundational input for the subsequent multivariate regression modeling, ensuring high precision in the estimation of AGB and total carbon stocks for the VNUF region.

3.2. Development and evaluation of Aboveground Biomass regression models

The multivariate linear regression model was established using six independent variables: FAPAR, NDVI, LAI, FCOVER, SAVI, and CAB. The results indicate that the model possesses a strong capability to explain the variation in field-measured biomass, with a coefficient of determination R^2=0.80, RMSE=13.76 (Figure 3). The unstandardized linear regression equation (10) was constructed as follows:

$$\boldsymbol{AGB} = 231{,}434 - 59{,}954 * LAI - 29{,}647 * SAVI - 298{,}899 * NDVI - 0{,}115 * CAB - 16{,}508 * FCOVER + 307{,}536 * FPAR \quad (10)$$

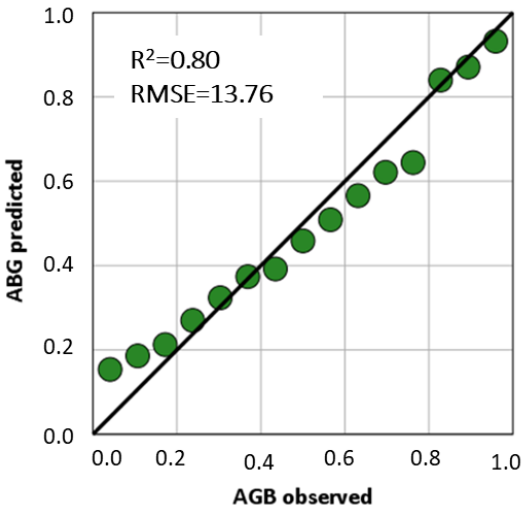


Figure 3. Scatter plot showing the correlation between measured and predicted AGB using the multivariate regression model

3.3. Establishment of Forest Biomass and Carbon Stock Maps for the Luot Mountain area, Vietnam National University of Forestry

The forest biomass map for the Luot Mountain area was constructed by applying the multivariate linear regression model to Sentinel-2 satellite data. The results clearly reflect the spatial differentiation of biomass, with values represented through a color scale from white to dark green, corresponding to a range from 23.79 to approximately 281.75 tons/pixel (per area of over 400 m²). Overall, the forest biomass in the study area exhibits non-uniform spatial distribution, significantly influenced by topographical features and the extent of human impact. Approximately 35% of the area possesses high biomass values (above 200 tons/pixel), primarily concentrated at the mountain peaks and the Western slopes. These are regions with steep terrain and difficult access, which provide favorable conditions for natural biomass accumulation and strict conservation of the study plots. Conversely, about 45% of the area has low biomass values (below 100 tons/pixel), mainly located to the East and along the foothills, including the lecture hall areas of the VNUF. In these locations, high anthropogenic impact has limited the developmental capacity of the forest vegetation. The variation in biomass levels clearly reflects the differing land use and experimental management statuses across various zones. The application of the linear regression model combined with remote sensing and GIS technologies has enabled a detailed forest biomass assessment down to the pixel level. This facilitates the monitoring of research sample plots and the formulation of appropriate management and conservation plans.

The map illustrates the spatial variation of forest carbon stocks within the study area, calculated based on the AGB map using a biomass-to-carbon conversion factor of 0.47. Results show that carbon stock values range from 11.18 to approximately 132.42 tons C/pixel (represented by a color scale from white/light blue to dark green)(Figure 4). Given that each pixel covers an area of 400 m² (0.04 ha), this value corresponds to a maximum carbon stock of approximately 3,310 tons C/ha. Accordingly, carbon stocks are unevenly distributed across the region. High carbon stocks (dark green) are clearly concentrated in the Southern and Southwestern regions, as well as small patches in the North. These areas possess high forest cover, corresponding to zones with large AGB, reflecting mature or

well-protected forests. Low carbon stocks (white/light blue) are mainly distributed in the central and Northeastern regions, corresponding to low-biomass areas. These sites may be heavily impacted by human activities or consist of young/regenerating forests. This degree of variation visually demonstrates the link between biomass status and the carbon storage capacity of the forest ecosystem. This map not only provides vital information regarding the forest's carbon accumulation potential but also serves as an essential foundation for research related to climate change, carbon financing mechanisms (such as REDD+), and sustainable local forest resource management.

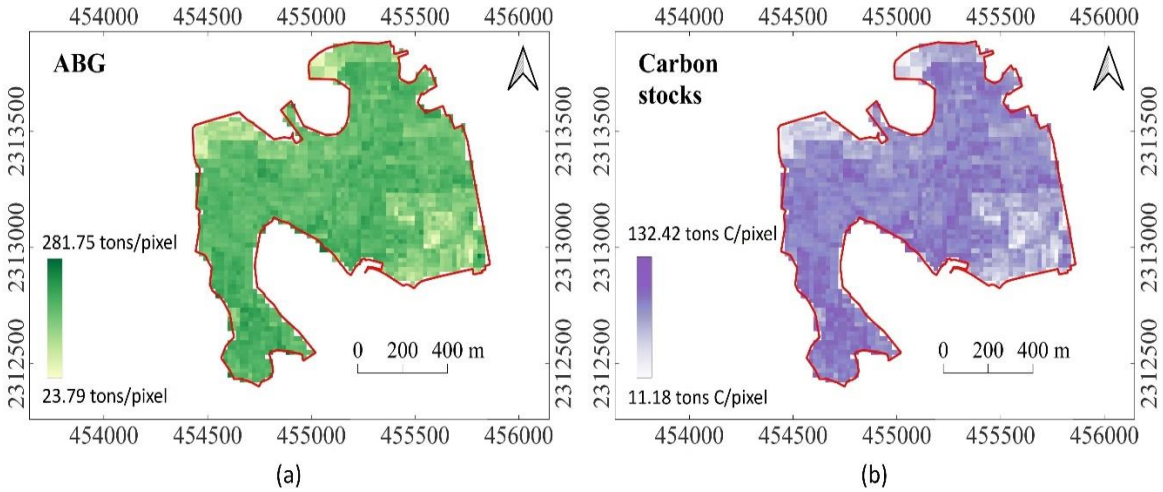


Figure 4. Spatial distribution maps of (a) Aboveground Biomass and (b) Carbon stocks in the Luot Mountain area

4. CONCLUSION

The application of remote sensing technology combined with Geographic Information Systems (GIS) in the study of forest biomass and carbon stocks has demonstrated clear effectiveness. GIS supports the integration, management, spatial analysis, and visualization of data, thereby enhancing assessment capabilities and decision-making support in forest resource management. With remote sensing technology providing broad, continuous, and objective data acquisition, it enables rapid monitoring and updating of forest status, particularly in areas with complex or inaccessible terrain. The research results successfully developed a linear regression model between AGB and six independent variables (FAPAR, NDVI, LAI, FCOVER, SAVI, and CAB), yielding R^2 = 0.80 and RMSE = 13.76. Based on these results, a forest biomass distribution map for the Luot Mountain area was constructed. Biomass distribution shows a marked disparity between regions, with high biomass concentrated in the center of Luot Mountain—specifically the high-elevation areas surrounding Peak 133—where ecological conditions are favorable and human impact is minimal. The study also established a forest carbon stock map with values ranging from 0 to approximately 3,310 tons C/ha. Carbon stocks are distributed unevenly, being higher in areas with extensive forest cover and lower in regions with harvesting activities or newly regenerating young forests. Furthermore, the study proposes the inclusion of additional eco-environmental factors and stand characteristics (such as soil type, elevation, slope, forest type, canopy density, forest age, and litter layer characteristics) into the biomass model to increase reliability and reduce estimation errors. It is also recommended to develop separate biomass models for different ecological zones rather than applying a single general model, which may not accurately reflect the specific eco-silvicultural differences of each area. Cross-validation should be applied to assess the intrinsic errors of the biomass models. Simultaneously, the

applicability of the model should be tested in other ecological regions in Vietnam and tropical areas to determine its stability and generalizability.

REFERENCES

[1]. Karine Vezina, Ferdinand Bonn & Cu Pham Van (2006). Agricultural land-use patterns and soil erosion vulnerability of watershed units in Vietnam's Northern highlands. Landscape Ecology. 21(8): 1311-1325.

[2]. Royston Philip Charles Morgan (2009). Soil erosion and conservation. John Wiley & Sons.

[3]. Jim Ritter & P Eng (2012). Soil erosion–causes and effects. Ontario Ministry of Agriculture and Rural Affairs. 12-105.

[4]. contributors Wikipedia (2026). Soil erosion.

[5]. Quat Nguyen Xuan (1994). Household economy in mountainous areas, sustainable use of sloping land. Agricultural Publishing House, Hanoi.

[6]. Chinh Tran Van (2006). Textbook on Soil Science. Agricultural Publishing House, Hanoi.

[7]. Institute of Agricultural Planning and Design (1984). Project on developing a soil erosion process.

[8]. My Nguyen Quang (2005). Modern soil erosion and prevention measures. Hanoi National University Publishing House, Hanoi.

[9]. Bat Le Thai (2006). Soil erosion and poverty in the northern mountainous provinces: causes and solutions. Annual workshop of social organizations, Hanoi.

[10]. Quang Phan Dang, Chau Thu Dao & Hung Than The (2008). Research results on covering organic woven mats to prevent soil erosion in Tam Nong district, Phu Tho province. Journal of Soil Science. 29: 79-83.

[11]. My Nguyen Quang (1983). Initial research on soil erosion and erosion control experiments in the Central Highlands. Proceedings of scientific conferences on rational use of natural resources and environmental protection. Hanoi.

[12]. Thai Phien and Nguyen Tu Siem (2002). Sustainable land use in mountainous and highland areas of Vietnam. Agricultural Publishing House, Hanoi.

[13]. Duc Chu , My Nguyen Quang & Mai Dinh Yen (1991). Application of systems analysis in erosion research in Vietnam. 2nd Conference on Indochina Geology. Hanoi

[14]. Ha Nguyen Trong (1996). Determining erosion-causing factors and the ability to predict erosion on sloping land. Doctoral dissertation, Water Resources University.

[15]. Tuan Vu Anh (2004). Research on changes in vegetation cover status and its impact on erosion processes in the Tra Khuc river basin using Remote Sensing and Geographic Information Systems. Doctoral dissertation in Geography, Faculty of Natural Sciences, Vietnam National University, Hanoi.

[16]. Vinh Tran Quoc (2012). Research on using Remote Sensing (RS) and Geographic Information Systems (GIS) to assess soil erosion in Tam Nong district, Phu Tho province. Doctoral dissertation, Hanoi University of Agriculture.

[17]. Luong Son district - a gateway region with rich potential. Hoa Binh Newspaper. Accessed from: http://www.baohoabinh.com.vn/12/149651/Huyen-Luong-Son-vung-dat-cua-ngo-giau-tiem-nang.htm.

[18]. Chinh Tran Minh (2021). Research to determine a suitable quantitative soil erosion model for typical agricultural farming systems on sloping land. Doctoral dissertation, Vietnam Institute of Water Resources Science.

[19]. Seid Muhe & Mekuria Argaw (2021). Modeling Forest Carbon Estimation Using Sentinel-2 Derived Indices in Yayu Afro-Montane Forest, South West Ethiopia.

[20]. Ilina Kamenova & Petar Dimitrov (2021). Evaluation of Sentinel-2 vegetation indices for prediction of LAI, fAPAR and fCover of winter wheat in Bulgaria. European Journal of Remote Sensing. 54(sup1): 89-108.

[21]. Xiaoli Zhang, Lu Li, Yanfeng Liu, Yong Wu, Jing Tang, Weiheng Xu, Leiguang Wang & Guanglong Ou (2023). Improving the accuracy of forest aboveground biomass using Landsat 8 OLI images by quantile regression neural network for Pinus densata forests in southwestern China. Frontiers in Forests and Global Change. 6: 1162291.

[22]. Chu Wang, Wangfei Zhang, Yongjie Ji, Armando Marino, Chunmei Li, Lu Wang, Han Zhao & Mengjin Wang (2024). Estimation of aboveground biomass for different forest types using data from Sentinel-1, Sentinel-2, ALOS PALSAR-2, and GEDI. Forests. 15(1): 215.

[23]. L. H. Phuc (1996). Evaluation of growth, development and biomass of three-needle pine plantations. Vietnam National University of Forestry.

[24]. Giap Tran Van Giap & Nguyen Manh Ha (2019). Research on building a model to estimate above-ground biomass of acacia mangium plantations in North Central Vietnam. Journal of Agriculture and Rural Development. 12: 97-104.

[25]. Dengsheng Lu (2006). The potential and challenge of remote sensing-based biomass estimation. International journal of remote sensing. 27(7): 1297-1328.

[26]. Ngoc Tran Tuan & Nga Nguyen Thanh (2014). Application of Radar remote sensing data in determining forest cover biomass in Vietnam. Journal of Surveying and Mapping Science. 19: 39-46.