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Research article

Estimation of carbon sequestration capacity of the Wilpattu National Park, Sri Lanka: A remote sensing based non-destructive approach

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ABSTRACT

Tropical forests play a critical role in capturing and storing significant amounts of carbon, thereby contributing substantially to the reduction of emissions caused by human activities. Wilpattu National Park (WNP) is the largest national park in Sri Lanka and consists of dense and sparsely covered forest ecosystems and Villu ecosystems. The main goal of this study was to estimate forest biomass and evaluate carbon sequestration for the year 2019 using advanced remote sensing methods and Sentinel 2 satellite images. A Geographic Information System (GIS) module was developed to compute and map key parameters including Normalize Difference Vegetation Index (NDVI), Above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Accumulated Biomass (TAB), Total Carbon Stock (TCS), and Amount of Carbon Sequestration (ACS) for WNP. The accuracy of the model has been verified through the use of the calculated kappa coefficient for the NDVI. The average values for the AGB, BGB, TCB, TCS and ACS were 72.73 - tons per hectare (ton ha^{-1}), 14.99 -ton ha^{-1}, 86.72-ton ha^{-1}, 40.76 - ton Carbon Per hectare (ton C ha^{-1}) and 149.57 -ton C ha^{-1}, correspondingly in WNP for the year 2019. The kappa coefficient accuracy of NDVI was found 92%. Evaluation of these findings points out that GIS modeling is a powerful method for assessing carbon sequestration and it is evident that tropical forests are indispensable in the storage of carbon on earth and help to mitigate the air pollution and climatic change.

1. Introduction

Global warming is probably the biggest challenge that humanity is facing today. According to the Changes in the year 2007, the evidence is extremely probable that increase of worldwide averaged temperatures in the last mid-20th century could be attributed to the increase in human activity in greenhouse gas concentration. The result is warming in the surface and lower atmosphere of Earth. All those gases absorb outgoing infrared radiation; as a result, they increase the temperature. Such gases are water vapor, carbon dioxide (CO_2), methane, and others, and among these gases, CO_2 is more responsible for greenhouse effect mainly because of its significant part as the foremost anthropogenic greenhouse gas, which is corroborated by Change (2007). According to Giri and Mandla (2017), Hastuti et al. (2017), and Vicharnakorn et al. (2014), high increases in greenhouse gases concentration are due to the human activities, like the burning of fossil fuels for energy, industrial activities, deforestation and forest degradation, as well as changes in land use, such as those which clear forests by combustion. Forests contribute immensely to resilience and robustness concerning their biotic elements and also act in conjunction with the future of ecosystem services in carbon sequestration (Sedjo and Sohngen, 2012). Sierra et al. (2012), stated that tropical forests are extremely important to the global system by storing very high amounts of carbon and avoiding carbon emissions.

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Change (2014), claimed that forests are among the key ecosystems for carbon storage and sequestration, comprising contributions from significant above-and below ground components. Among the major pools of carbon are plant biomass, understory vegetation, litter and soil organic carbon. In Sri Lanka, a network of 189 tropical forest plots is present to monitor and study such dynamics (Ali et al., 2022). Wilpattu National Park (WNP), the largest and one of the oldest National Parks in Sri Lanka, occupies an area of 131667.1 hectare (Sandamali and Welikanna, 2018). There is no significant published literature on carbon sequestration analysis of WNP. Therefore, the study plans to estimate a few parameters including Above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Accumulated Biomass (TAB), Total Carbon Stock (TCS), and Amount of Carbon Sequestration (ACS) within WNP during the year 2019. Although, field data measurements yield the most reliable results, they have a limited practicability for a wide-scale assessment. However, like any other data acquisition method, Remote Sensing techniques provide many other benefits; the cost-effective data capture for large areas, from remote and inaccessible areas (Kumar and Mutanga, 2017). Thus, this study used Remote Sensing data for carbon sequestration estimation within WNP for the year 2019. Further, a GIS model was developed to analyze the satellite imagery and to generate maps and calculations to support the research objectives.

2. Methodology

2.1 Study area

WNP was selected as the study area considering its vast forest area. Study area map was developed through ArcGIS software and Sentinel-2 images collected from Google Earth Engine and represented in Fig. 1.

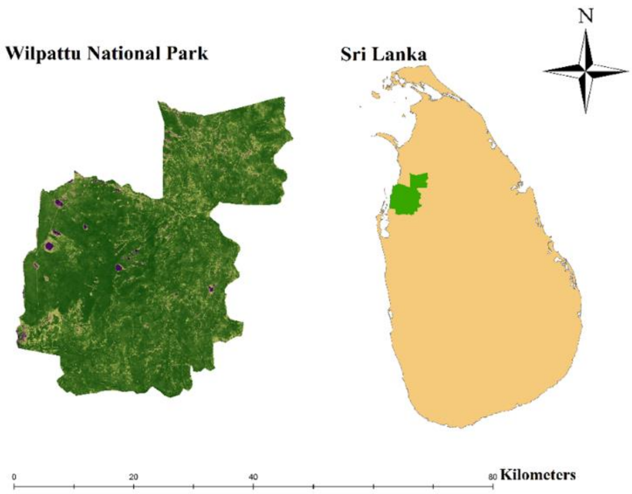

Fig. 1 Map of WNP and Sri Lanka

2.2 Normalized difference vegetation index (NDVI)

One of the frequently employed vegetation indices is the NDVI, as originally defined by Rouse et al. (1974). Healthy vegetation efficiently absorbs specific portions of the electromagnetic spectrum, particularly in the blue (0.4–0.5 µm) and red (0.6–0.7 µm) wavelengths, it happened due to the presence of chlorophyll in the vegetation. Plants tend to absorb light between wavelengths of 0.5 and 0.6 µm ever so accurately, constantly yielding back to an observer-the human eye-green light. Thus, in a general view, the healthy vegetation cabins appear mainly green. Accompanying this property is high plant reflectance in the near-infrared (NIR) domain (0.7-1.3 µm), largely influenced by their inner leaf structure. Reflected light measurement in NIR and absorption in the red spectrum together lay the basis for determining NDVI, which is one of the principal metrics related to the health and density of vegetation (Basnet and Khadka, 2020). While usually NDVI is between -1 to +1, here +1 represents a healthy ground covered by plants at a high density, lower values refer to low plant density, and negative values usually represent surface water resources (Hummadi and Khalaf, 2024; Chauhan et al., 2021). In this study, NDVI images were classified into six major classes according to the threshold values described by Akbar et al. (2019). The five classes were (i) water; (ii) sand and soil; (iii) shrub and grassland; (iv)sparse vegetation; and (v) dense vegetation. An accuracy assessment was done to find the Kappa coefficient for NDVI. The NDVI values were calculated using Eq. 1 for WNP using the equation from satellite imagery as follows:

$$NDVI = (B8 - B4) / (B8 + B4) \qquad (1)$$

In this formula, B8 represents the NIR band and B4 represents the red band.

2.3 Estimation of above ground biomass

Above-ground biomass is one of the major and easily accessible carbon pools for carbon storage and ecological studies (Vashum and Jayakumar, 2012). According to the Kumar and Mutanga (2017), about 70% to 90% of the total biomass in the forest ecosystems is above-ground forest biomass. The AGB was estimated by a correlation approach between NDVI results and the below Eq. 2, as outlined by Hastuti et al. (2017).

$$AGB\ (ton\ ha^{-1}) = 305.9 * NDVI4.864 \qquad (2)$$

2.4 Below ground biomass (BGB) estimation

The total biomass of the all living root system is known as the BGB. When estimation of BGB, fine roots smaller than 2 mm in diameter are frequently excluded. This exclusion arises because fine roots are challenging to distinguish from soil organic matter through empirical methods (Ravindranath and Ostwald, 2008). BGB can be calculated using following Eq.3 which is derived by Cairns et al. (1997):

$$BGB = \{\exp(-1.0587 + 0.8836 * \ln(AGB))\}\ ton\ ha^{-1}. \quad (3)$$

2.5 Total accumulated biomass (TAB)

Total ecosystem biomass according to Vargas et al. (2008), is all above-ground and below-ground components of ecosystem biomass, while total ecosystem carbon is all above-ground carbon and below-ground carbon. TAB was calculated by adding both AGB and BGB using following Eq. 4 :

TAB (ton ha^{-1}) = AGB + BGB (4)

2.6 Total Carbon Stock (TCS) calculation

Eq. 5 derived by Westlake (1963) was used for calculation of TCS.

TCS (ton C ha^{-1}) = TAB * %C Organic (5)

The carbon content percentage (%C) is calculated using a conversion factor of 0.47 or from laboratory results in carbon emissions as cited in popular studies like Hastuti et al. (2017), Pragasan (2022), and Bordoloi et al. (2022). Biomass is then converted into the amount of carbon stock available in the ecosystem.

2.7 Calculation of CO_2 sequestration amount

According to IPCCC (2001), it is to express carbon stock from the biomass in terms of carbon dioxide uptake using the subsequent conversion:
Eq. 6 applied for the calculation of ACS (ton C ha^{-1}) is given as follows:

ACS = 3.67 * TCS (6)

Table 1 Mean ± Standard deviation, Maximum values, and Minimum values of NDVI, AGB, BGB, TAB, TCS, and ACS

	Statistics		
Parameter	**Mean ± SD**	**Max**	**Min**
NDVI (ha)	0.72±0.11	0.86	-0.4
AGB (ton ha^{-1})	72.73±26.57	149.71	0
BGB (ton ha^{-1})	14.99±5.15	28.99	7.18
TAB (ton ha^{-1})	86.72±31.72	178.71	7.79
TCS (ton C ha^{-1})	40.76±14.91	83.99	3.66
ACS (ton C ha^{-1})	149.57±54.71	308.25	1.34

2.8 Model development for carbon sequestration

Producing a GIS module to process and visualize satellite data in terms of NDVI, AGB, BGB, TAB, TCS, and ACS for WNP, using composite Sentinel-2 data average images for the year 2019. Advance remote sensing techniques and Arc GIS software was used for the development of module (Fig. 2). This module enables the precise mapping and analysis of critical ecological parameters to enhance understanding of the forest ecosystem's carbon storage and biomass characteristics.

3. Results and discussion

Through satellite image analysis and the NDVI method, WNP was found to encompass 15480 ha of vegetation area in the year 2019. The NDVI accuracy assessment yielded a Kappa coefficient of 92%, indicating a high degree of precision. The mean NDVI value for the year 2019 was 0.72±0.11 (Table 1).

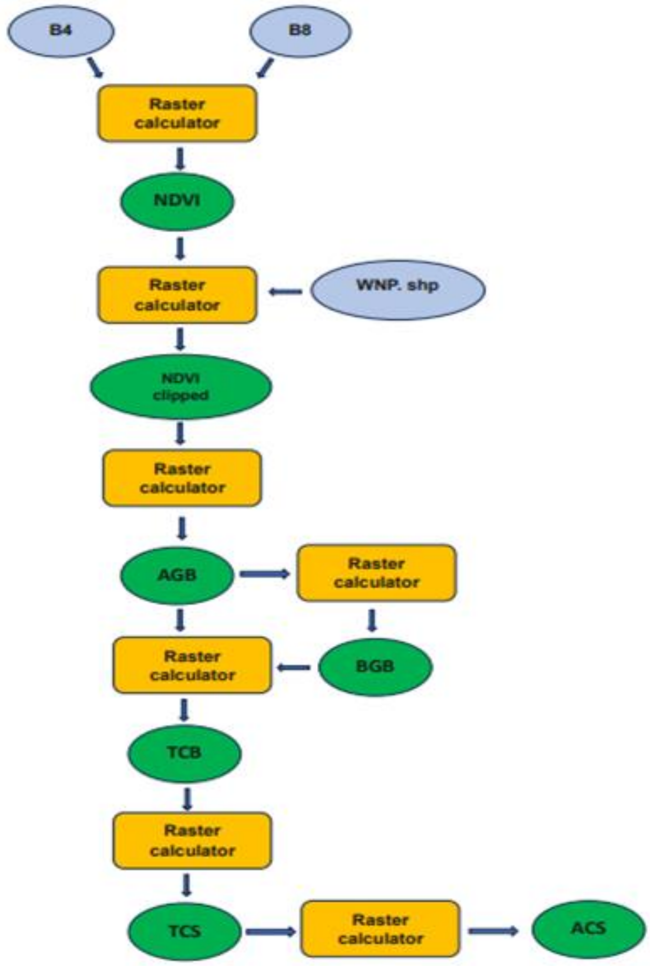

Fig. 2 Model of carbon sequestration (B8 is the band NIR and B4 is the Red band of Sentinel 2 satellite imagery)

It means the average WNP is present with dense vegetation (United States Geological Survey, 2020). As detailed in Table 1, the AGB was quantified at 72.73±26.57 tons per hectare (ton ha-1), while the BGB measured 14.99±5.15 ton ha^{-1}. It is noteworthy that AGB exceeded BGB, aligning with the findings of Kumar and Mutanga (2017), who suggested that AGB typically accounts for 70% to 90% of total forest biomass. In this study, AGB represented 83.87% of the Total TAB, which encompasses the total biomass above and below the soil surface and was calculated at 86.72±31.72 ton ha-1. Hernández et al. (2020), reported that the average AGB values for various types of tropical dry forests were 69.3-, 100.4-, and 127.5 ton ha-1 for deciduous, semi-deciduous, and semi-evergreen forests, correspondingly. Wilson (2014) stated that WNP is a dry deciduous forest with thorny scrub jungle and riparian forests. The result of AGB obtained from this study is located between deciduous and semi-deciduous forests.

TCS was estimated by applying a carbon stock percentage of 0.47. Consequently, TCS in WNP for the year 2019 was estimated at 40.76±14.91ton Carbon Per hectare (ton C ha-1). TCS in dry deciduous forests varies by many environmental and chemical factors, including plant diversity, density, soil types, and management practices. The study further determined the ACS in WNP for the year 2019, which amounted to 149.57±54.71 ton C ha-1. These findings are illustrated in Fig. 3, which provides maps depicting NDVI, AGB, BGB, TAC, TCS, and ACS. Chaturvedi (2011) identified that the amount of carbon sequestration on above-ground biomass is between 87 ton C ha-1 and 151ton C ha-1. The amount of carbon sequestration determined for this study is only very slightly below the highest value by Chaturvedi (2011). Here, however, both AGB and BGB were included in the analysis. Carbon sequestration adopted by WNP helps a lot in mitigating the effects of global warming.

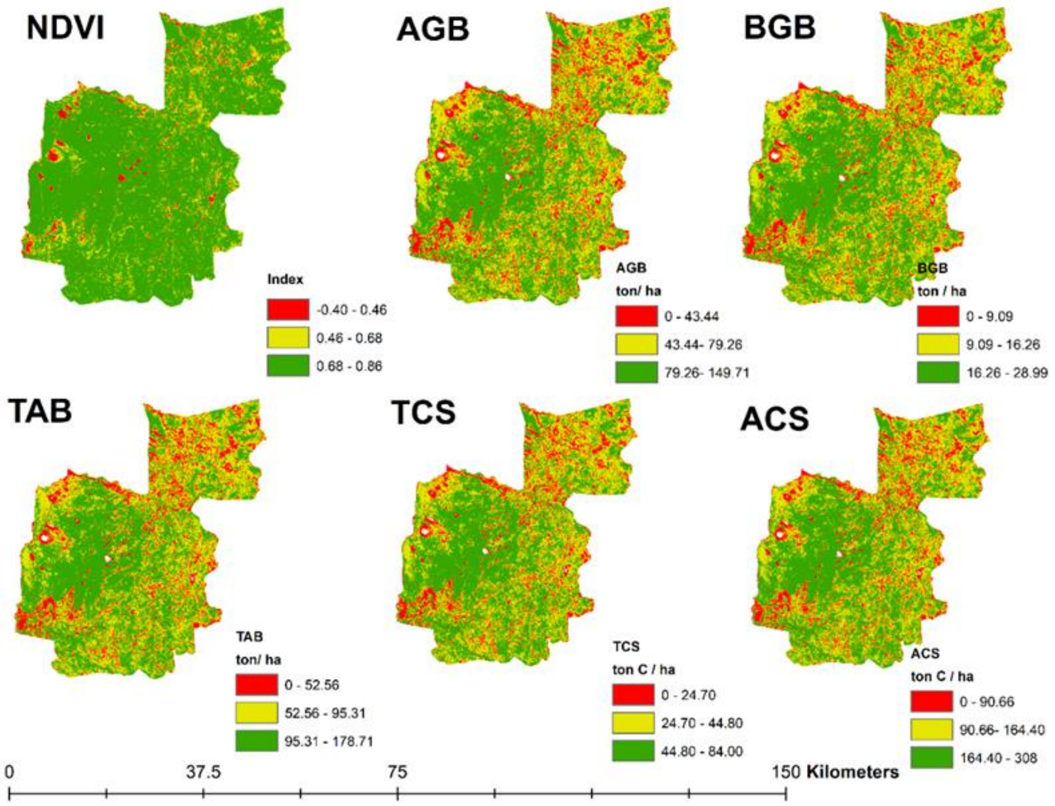

Fig. 3 NDVI, AGB, BGB, TAB, TCS, and ACS maps of WNP in 2019

4. Conclusion

A notably high rate of carbon sequestration was observed within the Wilpattu National Park (WNP) in the year 2019. The results of the present study indicate the effectiveness of GIS modeling as a non-destructive approach for accurately quantifying carbon sequestration. Further, the carbon sequestration capacity assessment of the WNP can be continuously monitored regularly using this approach to understand the impact of variations of the forest cover on the carbon sequestrating capacity over time.

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Author contributions

R.D.T. Rajapaksha: methodology development, Data collection, Data interpretation, and manuscript preparation; D.D.G.L. Dahanayaka: manuscript review, oversight and supervision of the research process; U.K.G.K. Padmalal: manuscript review, oversight and supervision of the research process; W.M.D.N. Wijeyaratne: Manuscript review, oversight and supervision of the research process.

Statement of conflict of interest

The authors declare that they have no conflict of interests when it comes to publishing this manuscript. The authors have no association with any of the Ferae Naturae organizations, nor do they hold any financial or personal interests in anything that might influence or bias their work. The research was conducted independently and with an absolute commitment-free of any commercial or professional pressures-to objectivity.

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