Hue University Journal of Science: Agriculture and Rural Development
pISSN: 2588-1191; eISSN: 2615-9708
Vol. 131, No. 3C, 2022, P. 65–82, DOI: 10.26459/hueunijard.v131i3C.6992

ENVIRONMENTAL EFFICIENCY OF DIPTEROCARP FOREST LAND MANAGEMENT AT YOK DON NATIONAL PARK

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(*Received: November 8, 2022; Accepted: November 22, 2022*)

Abstract. The dipterocarp forest is a featured ecological forest in the Central Highlands of Vietnam. However, humans and nature are disrupting the ecological balance structure of the forest. This study was conducted to evaluate the environmental efficiency of land management activities of the dipterocarp forest at Yok Don National Park by altering the dipterocarp forest ecosystem and soil organic carbon (SOC) stock for 2001–2020. The results show that the area of the forest converted to other ecosystems (such as meadow, shrub land, construction land, etc.) is 8,284.51 ha. Notably, there was a decrease of 6,107.3 ha in the last 10-year studying period. In Yok Don National Park, SOC varies from 14.3 to 246.8 tons/ha. The total SOC stock is estimated at 7,644,080.493 tons. The average SOC content in the dipterocarp forest in Yok Don National Park is higher than that in other dry dipterocarp forest land.

Keywords: environmental efficiency, Yok Don National Park, dipterocarp forest, SOC

1 Introduction

The dipterocarp forest ecosystem is a unique ecosystem in the world. This kind of dipterocarp forest remains in Southeast Asia, including Vietnam. The dipterocarp forest ecosystems in Southeast Asia are diverse, uneven, and multi-layered, growing all year round in places with high-warm temperatures, high rainfall, and poor nutrient soils [1]. Southeast Asia's dipterocarp forest is one of the most threatened tropical ecosystems in the world, and only about 16% of the total area remains as primary forest [2].

Realizing the essential role of the dipterocarp forest ecosystem in nature, the Ministry of Forestry of Vietnam established Yok Don National Park under Decision No. 301/TCLD dated June 24, 1992. Yok Don National Park, with an area of 58,200 ha, is a typical site for the dipterocarp tree. Until 2002, at Decision No. 39/2002/QD-TTG, dated March 18, 2002, of the Prime Minister, the total area of Yok Don National Park was expanded based on merging Dang Phok Forest Enterprise and Ban Don Forest Enterprise. Therefore, the area of this park increased to 115,545 ha of the special-use forest located in Dak Lak and Dak Nong provinces. Yok Don National Park conserves the dipterocarp forest ecosystem's plant and animal genetic resources, facilitating research and international cooperation and combining the expansion of ecotourism services and environmental education.

Yok Don is a unique national park in Vietnam that manages and protects the dipterocarp forest ecosystem. However, the Park is facing a decline in wood stocks due to limitations in management policies and the illegal exploitation of forest resources [3]. This situation entails environmental effects such as loss of conservation value and reduction of carbon stocks stored in plant biomass and forest soils, an essential carbon sink of nature [4–6]. Mitigating climate change in forest ecosystems provides opportunities for forest conservation, biodiversity, and forest management worldwide, especially in the dipterocarp region [1].

Humans have seriously affected the environment and the sustainable use of resources. Studying the reduction of environmental degradation and monitoring the progress of sustainable development are necessary to acquire indicators of the current state of the environment [7]. These indicators are also a useful tool for assessing the effectiveness of policies designed to protect the environment and warning against unsustainable activities [8, 9]. In this study, the assessment of environmental impacts concerning the management of dipterocarp forest land was carried out through two environmental indicators, namely the change in ecosystem and the organic carbon stock in dipterocarp forest soil in Yok Don National Park from 2001 to 2020.

2 Methods

2.1 Overview of the study area

Yok Don National Park is located in Dak Lak and Dak Nong provinces in Vietnam, with a total area of 115,545 ha. The strict protection subdivision is 80,947 ha; the ecological restoration subdivision is 30,426 ha; the administrative service subdivision is 4,172 ha. The Park's buffer zone is 133,890 ha. Yok Don is the largest national park in Vietnam. According to previous research and additional investigation, Yok Don National Park consists of natural forest, grassland, shrubs, water surface, village, and agricultural ecosystems [10].

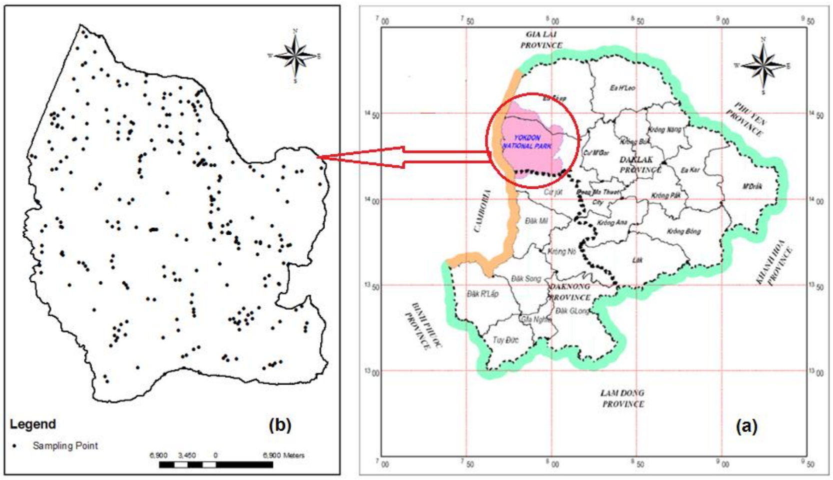


Fig. 1. Location of Yok Don National Park (a) and soil sampling points (b)

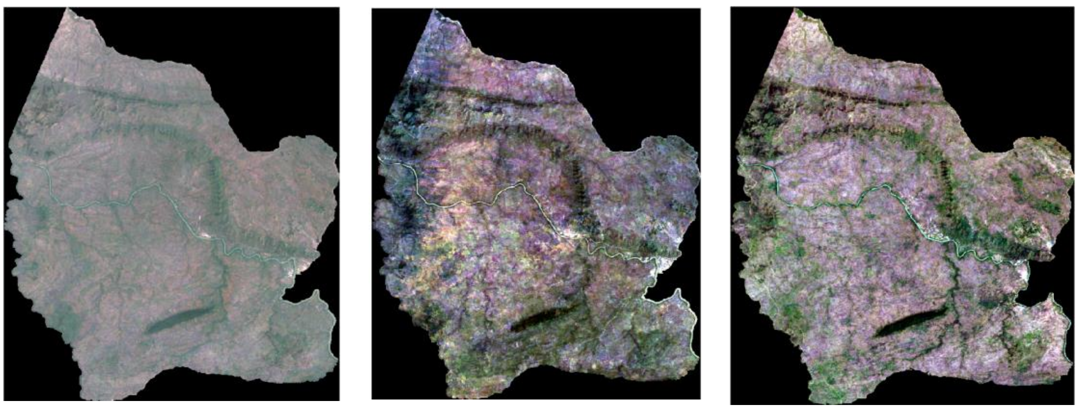
This area has an eroded and flattened-surface terrain and gently undulating hills with an average elevation of 250 m. The terrain slopes decrease gradually from the East (400–500 m) to the West (about 140 m) with an average slope of 17.5°. The Srepok River in the Park flows to Cambodia. Because of the low-lying terrain surrounded by highlands, the climate of the Park is very dry and hot compared with that of other areas. The region's climate is characterized by tropical monsoons with two distinct seasons: rainy and dry seasons [10].

2.2 Data collection

The Landsat 5 Tier 1 of the years 2001 and 2010 Satellite Imagery (resolution of 30 × 30 m) and the Landsat 8 Collection 1 Tier 1 Satellite Image TOA Reflection (resolution of 30 × 30 m) of 2020 at the researched area were downloaded, and the cloud from the images were removed with the Google Earth Engine (GEE). A serial image from 2000 to 2020 (Table 1) was used to match the seasonal deciduous nature of the dipterocarp forest ecosystem. In this study, the normalized difference vegetation index (NDVI) of dry and rainy seasons was calculated. The NDVI was derived from the red: near-infrared reflectance ratio [NDVI = (NIR – RED)/(NIR + RED), where NIR and RED are the amounts of near-infrared and red light reflected by the vegetation and captured by the sensor of the satellite]. The formula is based on the fact that chlorophyll absorbs RED, whereas the mesophyll leaf structure scatters NIR. The NDVI values thus range from –1 to +1, where negative values correspond to an absence of vegetation [11]. The Digital Elevation Model (DEM) was used for slope calculation based on slope analysis in the ArcGIS software. The images were projected to the WGS84_UTM_Zone 48N coordinate system.

Table 1. Image acquisition timelines

No.	Year	Acquisition time	Image type	Number of participating images
1	2001	01/06/2000–31/05/2001	Landsat 5 SR Tier 1	16
2	2010	01/06/2009–31/05/2010	Landsat 5 SR Tier 1	38
3	2020	01/06/2019–31/05/2020	Landsat 8 Tier 1 TOA Reflectance	35



Landsat 5 image in 2001 Landsat 5 image in 2010 Landsat 8 image in 2020

Fig. 2. Satellite images collected and processed at the study area

The set of land-cover samples of the dipterocarp forest classified according to years is shown in Table 2. The forest inventory dataset of Yok Don National Park in 2001 (the time of

Table 2. ROI aggregation (Region of Interest) for the forest cover classification

Cover classification	ROI		
	2001	**2010**	**2020**
Dipterocarp forest:	810	777	810
– Medium and Rich	286	346	286
– Poor	398	305	398
– Impoverished/Very poor	126	126	126
Evergreen forests	115	145	145
Water surface	47	57	57
Other lands	33	44	44
Total	**1,005**	**1,023**	**1,056**

merging Drang Phok and Ban Don Forest Enterprises into the Park) and 2009 and the field data for 2020 were used as references for image classification and interpretation. In addition, spatial and secondary data, such as topographic maps, administrative boundaries, forest owner boundaries, hydrology, traffic, and reports relating to study areas, were also used as supplement resources of information in this study.

One hundred and eighty-seven soil samples were collected randomly in the experimental field. Location tracking was conducted with handheld GPS data. Soil samples were taken to a depth of 30 cm [12]. The samples were collected from five points (North, South, East, West, and centre) inside a circle with a radius of 25 m, and then they were mixed. The soil density and the organic carbon (%OC) were calculated according to Han et al. [13] and Walkley and Black [14], respectively. The organic carbon (SOC) stock in the soil at the 30-cm depth was calculated according to formula (1) [6].

$$SOC \text{ (ton/ha)} = \varrho \times d \times \%OC \times 100 \qquad (1)$$

where ϱ is the soil density ($g \cdot cm^{-3}$); *d* is the thickness of the soil layer calculated (30 cm); %OC is the concentration of organic carbon in the soil.

2.3 Maximum likelihood classification for remote sensing images

We randomly divided the entire sample into sample data for classification (70%) and independent samples for testing (30%) the classification results. In this study, we used the Maximum Likelihood (MLC) method on the Envi application software to classify land cover. The indices for accuracy evaluation of image classification are the overall accuracy (OA), producer's accuracy (PA), user's accuracy and coefficients (UA), and Kappa's coefficient (K) [15, 16].

2.4 Determining factors and variables related to SOC stock

Seven variables were used in this study. Four numeric variables were SOC, NDVI, slope, and elevation. The three categorical variables were soil type, soil mechanical composition, and the status of the dipterocarp forest. Based on the characteristics of the research area and the classification methods of environmental factors in the literature [17–20], we classified the variables and the results are shown in Table 3. To identify the factors causing the primary change of SOC, we used the Factor Analysis of Mixed Data (FAMD) operating on the open-source software R [21]. The FAMD was applied to discard the variables that unsubstantially affect the SOC content and increase the ability to identify the main factors affecting the SOC. The FAMD, a part of the Principal Component Analysis (PCA) method, is appropriate for analyzing the data that contain numeric and categorical variables. The FAMD is also used to test the correlation between the numerical and categorical variables. The FAMD method is a combination of PCA and Multivariate Correspondence Analysis (MCA) [21, 22]. In the analysis, the variables were

Table 3. Description of effect factors

Environmenta l factors	Categories						
	1	2	3	4	5	6	7
Soil type [19]	Clay	Chernozem (Black soils)	Newly transfomed soils	Brown soils	Gray soils	Strongly eroded soils	Red-yellow soils
Soil mechanical composition	Heavy soil mixed with clay	Heavy soil mixed with sand and clay	Heavy soil mixed with sand				
Elevation (m)	0–100	100–200	200–300	300–400	400–491		
Slope (°)	0–3	3–8	8–15	15–20	20–25	25–35	>35
NDVI	(–0.4)–0	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8		
Forest status	Medium and rich	Poor	Impoverished				

normalized, and the numeric variables were divided in the way they have the same ratio of variance. The categorical variables were coded and scaled with MCA. This ensures a balance between the effect of numerical and categorical variables in the analysis [21]. Before estimating the SOC stock, the selected factors were retested and categorized into uniform groups, which served to estimate the SOC stored in the soil.

3 Results and discussion

3.1 Changes in the ecosystem of dipterocarp forests

To investigate the ecosystem change, we focused on analyzing the area reduction of the dipterocarp forest due to the replacement of other ecosystems, such as grassland, Schizostachyum land, shrubland, bare land, agricultural land, construction land, and evergreen forest ecosystem. After 20 years (2001–2020), the total area of dipterocarp forest decreased significantly by 8,284.51 ha, of which the most decline occurred in the last ten years by 6,107.30 ha (Table 4). This fall was caused by the following reasons.

– The deforestation degraded the forest flora, resulting in the replacement of dipterocarp forests with shrubs or bamboos. From 2010 to 2020, according to the authority's reports, there were seven deforestation incidents: three cases in 2013, 2014, and 2016 with 4,593, 3,643, and 405 m^2, respectively, and four cases in 2018 with 30,908 m^2. The violations in 2016 and 2018 were deforestation for cultivation purposes, and the loggers were responsible for the rest of the cases. In addition, from 2010 to 2020, illegal forest-product exploitation activities were widespread with 816 cases decreasing the area of dipterocarp.

Table 4. Statistics on the area of dipterocarp forest over the years

Unit: ha

Type of forest	Areas			Fluctuations by period (Up +, down –)		
	2001	2010	2020	2001–2010	2010–2020	2001–2020
Impoverished	21,864.31	16,521.43	19,172.15	–5,342.88	2,650.72	–2,692.16
Poor	57,387.97	65,461.84	60,601.61	+8,073.87	–4,860.23	+3,213.64
Medium and rich	24,987.46	20,079.26	16,181.47	–4,908.20	–3,897.79	–8,805.99
Total	**104,239.74**	**102,062.53**	**95,955.23**	**–2,177.21**	**–6,107.30**	**–8,284.51**

– The construction of a traffic system, offices, and ranger stations for the management and protection of Yok Don National Park also reduces the dipterocarp forest area. According to statistics, Yok Don National Park is managing and using more than 92 constructions with an area of around 23,489 m^2, such as working offices (2,918 m^2), dormitories for staff and motels (989 m^2), guest houses (696 m^2), other constructions (9,900 m^2), a ranger district (2,578 m^2), 15 ranger stations and 11 ranger posts (4,400 m^2), and mobile rangers (387 m^2).

– The construction of irrigation works reduced the area of the dipterocarp forest. These constructions are the embankment of the Serepok River through the administrative area of Yok Don National Park, Dak Na Dam, Dak Te Dam, Dak Rlop Dam, Dak Lau and the road over DakKen Bridge, the management road of Drang Phok Lake and the system of in-field canals, Drang Phok Irrigation System (60 ha), Buon Tri Irrigation System (100 ha), the bridge over the Serepok River, etc. Besides, these constructions also change the ecological system surrounding them into grasslands, swamps, and even evergreen forests.

3.2 Soil organic carbon reserves in dipterocarp forests

Selection of factors strongly correlating to soil organic carbon reserves

The soil analysis revealed the average SOC content in dipterocarp forests was 78.6 tons/ha, fluctuating from 14.3 to 246.8 tons/ha with a standard deviation of 47.3 tons/ha. This deviation indicates that the SOC value fluctuation is relatively large. The stock of SOC per hectare of dipterocarp forests has a right-skewed distribution and asymptotically approaches the 95% confidence (Fig. 3).

From multi-factor analysis for mixed data, five dimensions arose, and we selected trend 2 (Dim 2) because it provided the highest volatility of SOC. The contribution of factors and variables to the overall volatility and the relationship with SOC is shown in Fig. 4.

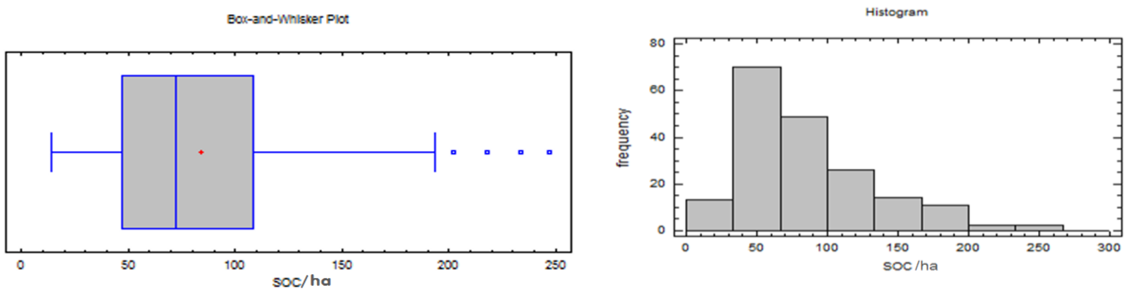
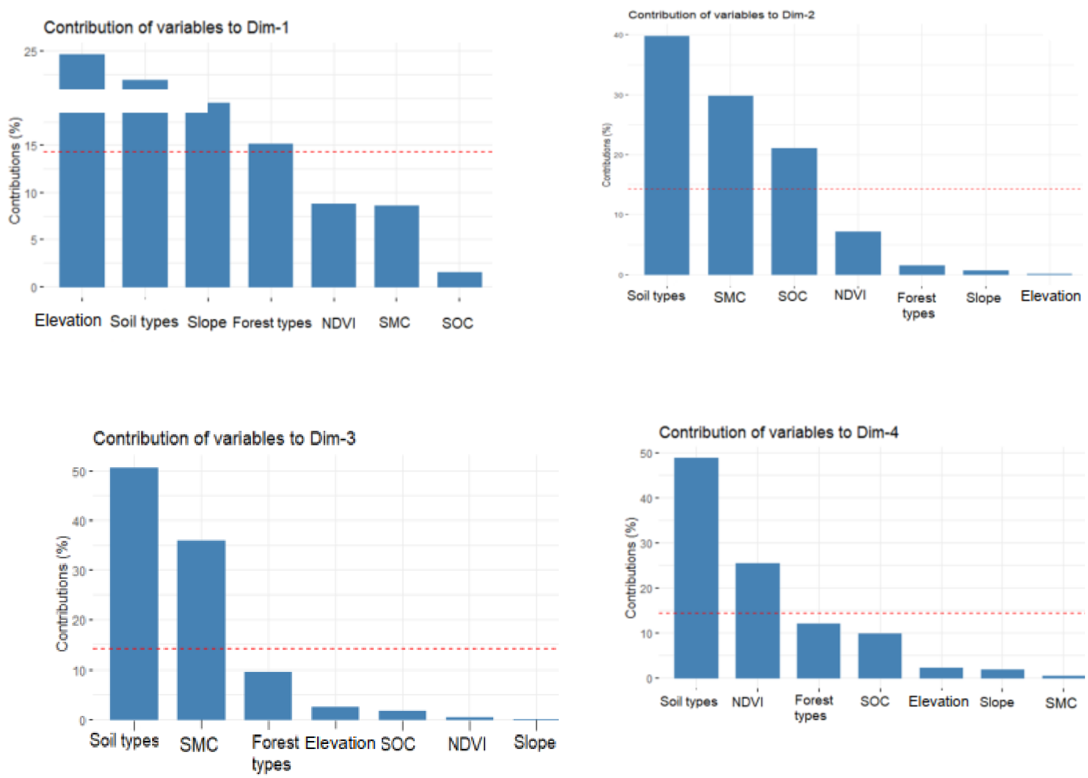


Fig. 3. Soil organic carbon content distribution chart. The red dot on the chart indicates the average soil organic carbon value.



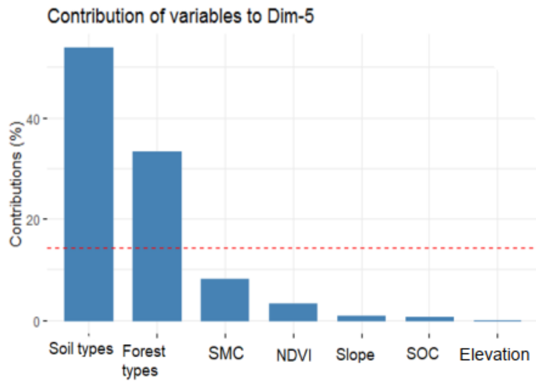


Fig. 4. Contribution of FAMD-influenced factors to trends (dimensions), the red line is the average contribution value of factors

Three variables, including soil type, soil mechanical composition, and SOC, were closely related and contributed more than the average value of the overall variation. The variables that contributed less and weakly related to SOC are NDVI, forest status, slope, and altitude. Therefore, the soil type and mechanical composition were chosen to estimate the total SOC content in the dipterocarp forest of Yok Don National Park.

These results are consistent with those from previous publications. Studying carbon stocks in dry dipterocarp forests in Northern Thailand, Intanil et al. reported the effects of SMC on soil organic carbon [23]. A relationship between the clay content and organic matter in tropical soils was also reported [24, 25]. In another study, Baldock et al. concluded that soil texture was one of the factors affecting the decomposition of SOC [26]. Pham et al. also noted the influence of soil texture on SOC stock in Central Vietnam [20]. In the study of the sequestration of SOC, Stockmann et al. proposed a critical curve and a nominal saturation curve of SOC accumulation as a function of soil texture, which depends on the ratio of sand and clay mixture [27]. The SOC content in clay soil was higher than that in heavy and sandy soil. It was because carbohydrates attached tightly to clay colloids and humic substances [28, 29].

Effect of selected factors on soil organic carbon

The influence level of soil type and soil mechanical composition on SOC is shown in Table 5.

Among the seven types of tested soil, the highest SOC content was recorded in newly transformed soil, with 143.3 tons/ha, and black soil, with 108.968 tons/ha. The gray soil, red soil, and clay were categorized as a medium groups of SOC content with 90.08, 85.4, and 81.1 tons/ha, respectively. Conversely, the low SOC content was found in brown soil with 70.75 tons/ha and in strongly eroded soil with 66.03 tons/ha. When studying soil organic matter in Australia, Spain et al. indicated that some soils played an essential role in dryland farming, such as reddish brown,

Table 5. Variance, ANOVA and Kruskal-Wallis tests between two selected factors according to soil organic carbon (tons/ha)

Factor	Variance according to Levene's standards	*p*-Value according to ANOVA	*p*-Value according to Kruskal-Wallis Test standards
Soil type	0.0522293	0.0056	–
SMC	0.0398777	–	0.00413467

brown and grey clay, brown and red soil with low carbon content, while other important agricultural soils, such as black soil and humus soil in high mountains, stored a greater carbon content [30]. Dengiz et al. recorded the profound influence of soil type on SOC stock in the Mandendere Basin, Turkey [31]. In Australia, a study on the ratio between N and C in soil exhibited that different soil types differred in the organic matter [32]. Differences in the physicochemical properties of soils can be considered a cause for the difference in SOC [30].

Estimated total soil organic carbon stock in the dipterocarp forest in Yok Don National Park

In our study, we used the homogeneous grouping method for soil type and soil mechanical composition to consider their impact on SOC. The results indicate that two groups of soil type and two groups of soil mechanical composition have similar variations when considering the relationship with SOC (Fig. 5).

– Soil type group 1: strongly eroded soil, brown soil, soil with tight clay layer, red-yellow soil (lower SOC)

– Soil type group 2: grey soil, black soil, newly transformed soil (higher SOC)

– SMC group 1: heavy soil mixed with clay and sand, heavy soil mixed with sand (lower SOC)

– SMC group 2: heavy soil mixed with clay (higher SOC)

We created four combinations by incorporating two groups of soil type with two groups of soil mechanical composition (Table 6) and then analyzed the effect of these four combinations on SOC.

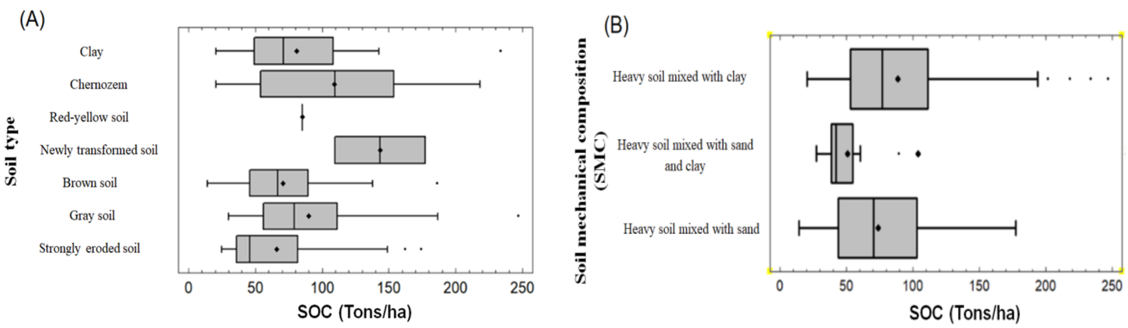


Fig. 5. The Box-whisker chart represents the mean (dot in the box) and fluctuation (boxed frame) of the SOC by soil types (A) and soil mechanical compositions (B) with confidence at 95%

Table 6. Combinations by groups of factors

Factor groups	Soil type group 1	Soil type group 2
SMC group 1	Soil type group 1 and SMC group 1	Soil type group 2 and SMC group 1
SMC group 2	Soil type group 1 and SMC group 2	Soil type group 2 and SMC group 2

Table 7. ANOVA analysis of four combinations of factors affecting soil organic carbon

Source	Sum of Squares	*Df*	Mean Square	*F*-Ratio	*p*-Value
Between groups	36417.4	3	12139.1	5.84	0.0008
Within groups	380582	183	2079.68		
Total (Corr.)	416999	186			

The ANOVA analysis shows that the combinations between two soil type groups and two SMC groups significantly affected SOC reserves (p = 0.0008 (<<0.05)) (Table 7). Depending on the combination, the SOC stock varied from 59.24 to 98.57 tons/ha (Table 8). The result indicates that the combination of soil type group 2 and SMC group 2 provided the largest SOC reserve; the combination of soil type group 2 and SMC group 1 and soil type group 1 and SMC group 2 had a lower SOC stock. The combination of soil type group 1 and SMC group 1 exhibited the lowest SOC stock.

The least significant difference (LSD) test was used in the context of analyzing the variance with a significance level at 0.05. Categorizing the combinations based on the significant difference of SOC (Table 8 and Fig. 6) results in the formation of two homogenous combinations:

– Group 1 of the homogeneous combination: Soil type group 1 and SMC group 1; Soil type group 1 and SMC group 2.

Table 8. Grouping of four combinations affecting SOC

Method: 95% LSD

Combination	Amount	Average	Homogeneous groups
Soil type group 1 and SMC group 1	26	59.2408	X
Soil type group 1 and SMC group 2	66	77.0382	X
Soil type group 2 and SMC group 1	15	79.5874	XX
Soil type group 2 and SMC group 2	80	98.5723	X

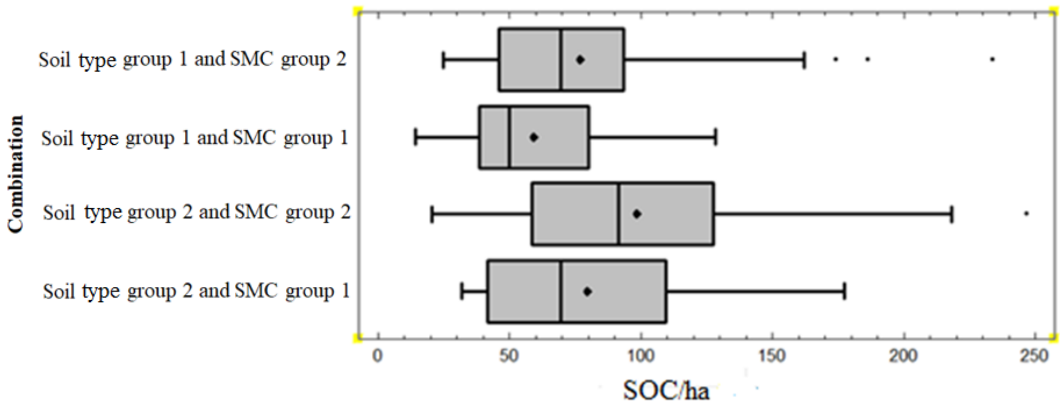


Fig. 6. The Box-whisker chart represents the mean (dot in the box) and fluctuation (boxed frame) of the soil organic carbon in four combinations of soil type group and soil mechanical composition group with 95% confidence

– Group 2 of the homogeneous combination: Soil type group 2 and SMC group 1; Soil type group 2 and SMC group 2.

The average SOC of two homogenous combinations and the total SOC stock in the dipterocarp forest are presented in Table 9 and Table 10. A map of SOC stock distribution in Yok Don National Park was also created based on the SOC content and characteristic of soil type groups and SMC groups (Fig. 7).

Table 9. Average soil organic carbon stock of two homogeneous combinations

Combination		SOC (tons/ha)
Soil type group 1 and SMC group 1	Soil type group 1 and SMC group 2	68.1
Soil type group 2 and SMC group 1	Soil type group 2 and SMC group 2	89.1

Table 10. Soil organic carbon reserves stored in the soil of dipterocarp forests in Yok Don National Park

Combination	Area (ha)	SOC average (Tons/ha)	Total SOC reserves (tons)
Soil type group 1 and SMC group 1	40,177.96	68.1	2,736,119.076
Soil type group 1 and SMC group 2	2,942.54	68.1	200,386.974
Soil type group 2 and SMC group 1	52,834.73	89.1	4,707,574.443
Total	**95,955.23**		**7,644,080.493**

The global organic carbon stock in forest soils is estimated at 1,576 Pg [5], of which 40% is stored in forest ecosystems [33]. At Yok Don National Park, the average SOC content stored in the soil of dipterocarp forest ranges from 68.1 to 89.1 tons/ha, and the total SOC reserve stored in forest land at a soil depth of 0 to 30 cm is 7,644,080.493 tons (Table 10). Our average SOC value is higher than that of other studies (Table 11). This high SOC content could be the result of the following reasons:

1) The diversity and density of plant species are maintained and enhanced by the effective protection and management policy of the National Park. Numerous previously published papers also reported the relationship between the soil carbon reserve and the tree density and vegetation characteristics [34–36].

2) The slope is low and little volatile [35, 37].

3) There is a diversity of soil types and SMC in Yok Don National Park [27].

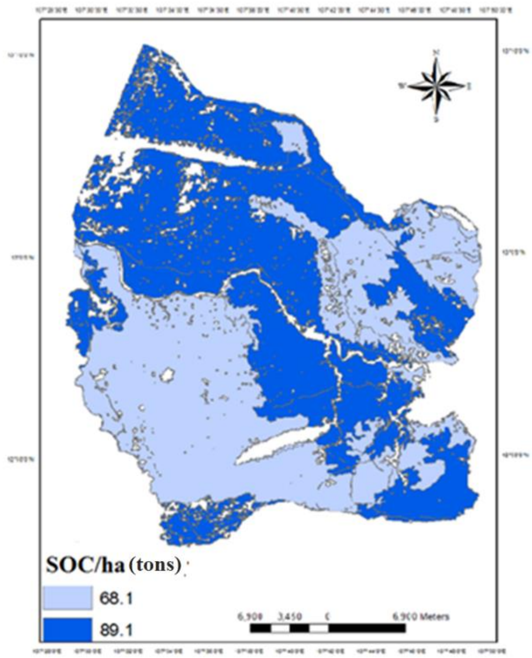


Fig. 7. Map of soil organic carbon distribution in the soil of dipterocarp forests in Yok Don National Park

Table 11. Statistics on soil carbon content in some types of forests and ecoregions

Forest type/region	SOC content (tons/ha)	Reference
Tropical deciduous dry forests, India (50 cm)		
1) Haldwani	39.7–85.5	
2) Bijnor	17.6–84.1	
3) Indo Gangentic Plains	7.7–29.8	[38]
4) Mednipore	8.8–34.1	
5) Midnapore-	26.1–55.7	
6) Betul, Chhindwara	63.4–68.3	
Tropical deciduous dry forests, Himachal Pradesh (30 cm)	36.04	[39]
Yok Don National Park, Vietnam (30 cm)	78.6	This study

4 Conclusions

Yok Don National Park experienced a relatively large change in the area of the dipterocarp forest to other land-use types, such as grassland, agricultural land, shrubland, and evergreen forest, from 2001 to 2020. The primary causes of this decline were the illegal logging of forest products and the construction of infrastructure for the management of the park, irrigation systems, and patrol roads.

The total soil organic carbon reserve in the forest land is high at 7,644,080.493 tons, higher than that in other dry dipterocarp forests worldwide.

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Abbreviation:

DEM: Digital Elevation Model

FAMD: Factor Analysis for Mixed Data

LSD: Least Significant Difference

MCA: Multiple Correspondence Analysis

MLC: Maximum Likelihood Classification

NDVI: Normalised Difference Vegetation Index

PCA: Principal Component Analysis

ROI: Region of Interest

SMC: Soil Mechanical Composition

SOC: Soil Organic Carbon