CARBON ABSORPTION ANALYSIS THROUGH ORGANIC-C CONTENT IN SEDIMENT AT AMPEKALE MANGROVE ECOSYSTEM, MAROS REGENCY

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Submitted: April 29, 2025   Accapted: July 28, 2025

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ABSTRACT

Global warming represents a significant challenge, primarily driven by the escalating concentrations of greenhouse gases in the atmosphere, notably carbon dioxide (CO_2). Mangrove ecosystems are integral to climate change mitigation due to their capacity to sequester and store carbon within their biomass and sediment. This study sought to evaluate carbon sequestration through the analysis of organic carbon content in the sediments of mangrove ecosystems located in Ampekale, Maros Regency. Sampling was executed using a purposive sampling method across nine sites, employing a 50 × 5 cm corer. Each sediment sample was sectioned into five depth intervals (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and 40-50 cm). The organic carbon content was assessed using the loss on ignition (LOI) method, with parameters measured including bulk density, sediment organic carbon concentration, carbon storage, and carbon uptake in sediments. Statistical analyses were conducted utilizing one-way and two-way ANOVA tests. The findings indicated that the mangrove ecosystem in Ampekale exhibited a total carbon storage in sediments of 731.72 tons/ha, with a total carbon uptake of 2685.42 tons/ha. The greatest carbon storage and uptake were observed at the 40-50 cm depth, with values of 342.056 tons/ha and 1255.34 tons/ha, respectively.

Keywords: Mangroves, organic carbon, carbon uptake, carbon storage, sediments.

INTRODUCTION

Global warming represents a significant global challenge, as evidenced by the rise in Earth's surface temperature, which is attributable to elevated levels of greenhouse gas accumulation. The primary driver of global warming is the escalation of greenhouse gas emissions, notably carbon dioxide (CO_2) and methane (CH_4), which are predominantly generated by industrial activities, transportation, and agricultural and livestock operations (Rahmadania, 2022). The increase in carbon dioxide (CO_2) emissions contributes to global warming, leading to temperature increases in the atmosphere, oceans, and terrestrial environments (Nasprianto et al., 2016). A viable strategy to mitigate atmospheric CO_2 levels is the implementation of carbon sequestration techniques, which involve capturing carbon from the atmosphere and storing it in vegetation (Kusuma et al., 2024).

Mangrove forests constitute tropical coastal vegetation communities predominantly composed of mangrove tree species that flourish in tidal-influenced muddy regions (Farhaby, 2017). Physically, mangroves serve as sediment traps, offer protection to the land from storms and floods, and contribute to the stabilization of the coastline's geomorphology.Mangroves serve as critical habitats for a diverse array of flora and fauna and contribute significantly to pollution control. Additionally, they provide essential habitats for commercial fisheries (Barbier2017). Mangrove ecosystems provide essential livelihoods for local communities by yielding a variety of economically valuable resources, such as timber, fish, shrimp, crabs, and shellfish. Additionally, mangrove forests serve as sites for recreation, ecotourism, and educational activities (Sialagan et al., 2021).

The mangrove ecosystems along the Indonesian coastline were estimated to cover an area of 3.36 million hectares in 2021 (KLHK, 2021). These ecosystems exhibit a superior capacity for carbon sequestration compared to other forest types, with the majority of carbon being sequestered in sediment. Microorganisms decompose fallen mangrove leaves and twigs, resulting in the production of organic matter, which serves as a primary carbon source in mangrove sediments.(Kauffman & Donato, 2012; Suryono et al., 2018). Mangroves sequester carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis, subsequently storing it within their trunks, branches, leaves, and sediments (Azizah et al., 2024).

Despite their essential roles in mitigating climate change, mangrove ecosystems face various threats that can lead to their degradation and deforestation. Land conversion for fishponds, tourism, logging, reclamation, and abrasion are the main factors that reduce mangrove forest area (Yaqin et al., 2022). In addition, the degradation of mangrove ecosystems can release carbon stored in sediments into the atmosphere, thereby increasing greenhouse gas emissions (Ketaren & Kimars 2023). Therefore, conserving mangrove ecosystems is becoming increasingly important, considering the high rate of mangrove loss due to human activities and environmental changes (Hamilton & Casey, 2016). Mangroves have a large carbon storage capacity; therefore, it is essential to calculate

the percentage of carbon stored, particularly in mangrove sediments (Verisandria et al., 2018). The Ampekale mangrove ecosystem in Maros Regency has excellent potential as a research subject.

Ampekale Village is geographically one of eight villages located on the west coast of the Bontoa District, Maros Regency, with an area of approximately ±15.75 km². The presence of mangroves in this area has various potentials, including as a location for mangrove ecotourism activities and coastal environmental conservation programs, primarily due to the stunning beauty of the mangrove ecosystem, which spans approximately 15 hectares, as well as the attraction of river and sea tourism (Ahdan et al., 2024). Imburi et al. (2024) highlighted that mangrove ecosystems can capture carbon within their sediments, thereby aiding climate change mitigation and preserving coastal ecosystems.

Mangrove ecosystems are celebrated for their high productivity and remarkable ability to capture and retain organic carbon in sediments (Hickmah et al., 2021). According to Pangestika et al. (2023), carbon storage estimates in mangrove sediments in Ayah District, Kebumen Regency, showed varying values, with station MA2 having the highest carbon storage of 8.86 tons/ha. This study revealed that environmental conditions and sediment texture characteristics significantly impact carbon storage values and influence CO_2 absorption by the mangrove ecosystem.

Sediment acts as a growth medium and a place to accumulate various components, including carbon (Irawati et al., 2021). Aldiano et al. (2023) state that sediment can store carbon in coastal ecosystems exceeding 50%. Research conducted by Nwankwo et al. (2023) in the Eastern Niger Delta, Nigeria, showed that mangrove sediments not only serve as carbon storage but also have significant potential for carbon sequestration, which can play a role in alleviating climate change effects. This research underscores the significance of mangrove ecosystems in managing carbon and stresses the urgent need for habitat conservation to maximize their role in mitigating climate change.

Studies on organic carbon in mangrove sediments have been carried out by Tahir et al. (2023) in the mangrove habitat of Rua Village, Kota District, South Ternate, resulting in an overall sediment organic carbon stock of 224.36 tons/ha and research conducted by Susilowati et al. (2020), located in the mangrove ecosystem of Tambakbulusan Village, Demak, Central Jawa with sediment organic carbon absorption of 211.89 tons/ha. In addition, Azzahra (2020) found that mangrove sediment in Bedono Village, Sayung, Demak, has a carbon content of 480.608 tons/ha, which shows the ability of the mangrove ecosystem to store organic carbon significantly. This demonstrates the high ability of sediment in the mangrove ecosystem to absorb carbon. Therefore, this study aimed to analyze carbon absorption through the organic carbon content in the sediment of the Ampekale mangrove ecosystem in Maros Regency. Thus, this study is expected to play a significant role in developing strategies for mitigating climate change, especially in reducing greenhouse gas emissions, which can reduce the impact of global warming.

MATERIAL AND METHODS

Research Location

This study was conducted in the coastal mangrove ecosystem of Ampekale Village, Maros Regency, Indonesia. The research locations are illustrated in Figure 1.
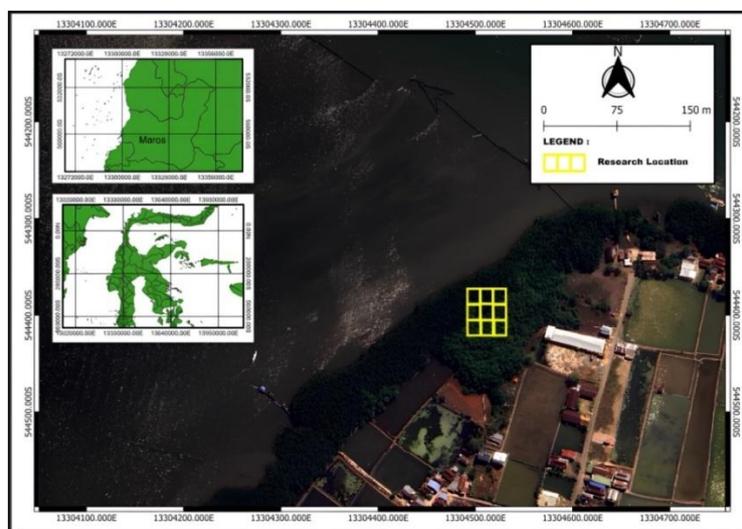

Figure 1. Map of the study Location

The tools and materials used for sampling in the field included measuring ropes, wooden stakes, cameras, core samplers or corers (50 cm × 5 cm), and stationery.

Laboratory testing used ovens, digital scales, aluminum cups, porcelain crucibles, beakers, mortars, pestles, and furnaces. The materials used for organic carbon

analysis included plastic samples, tissue rolls, and sediments.

Location Determination

The research site was selected using purposive sampling. The sampling process utilized a survey methodology, referring to the research of Verisandria et al. (2018), by conducting observations and taking samples directly at the location. Samples were collected at nine predetermined points to analyze carbon absorption through the organic carbon content in the soil or sediment of the mangrove ecosystem.

Data collection

The data collection for this study encompassed two categories: primary and secondary. Original data were gathered through direct field identification, which involved observations and sediment sampling for organic carbon analysis. Secondary data were sourced from the existing literature, including previous research findings.

Sampling sediment

Sediment sampling was performed using a 50 cm × 5 cm core. The corer was pressed into the sediment at each sampling point and was carefully lifted. The collected sediment was divided into five distinct layers according to depth: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and 40-50 cm. The samples were placed in labeled plastic containers and then analyzed for organic carbon content at the Chemical Oceanography Laboratory, Faculty of Marine Sciences and Fisheries, Hasanuddin University.

C-organic analysis

Sediment C-organic analyses were performed using the loss on ignition (LOI) method. The LOI method was used to measure the organic content in the sediment by weighing the samples before and after combustion (Suryono et al., 2018). According to Howard et al. (2017), the analysis stages are as follows:

The sediment samples were transferred to aluminum cups and dried in an oven at 60°C for 48 h.

Once dried, the sample was crushed using a mortar until it reached a uniform consistency, after which the finely ground sample was placed in a zipper bag or a plastic container.

The sample weighed 3 g and was placed in a porcelain crucible. The sample was then placed in a muffle furnace and incinerated at 450°C for 4 h, after which it was reweighed and the results were documented.

Data analysis

The organic carbon data in the sediment were analyzed using the ashing method in a muffle furnace. The organic carbon content was calculated using the following formula, according to Agus et al. (2011) and Yaqin et al. (2022):

$$BOrganic\ matter\ content = Dry\ matter\ content\ (\%) - Ash\ content(\%)$$

The organic carbon percentage was determined through calculations based on the following formula:

$$Organic\ carbon\ (\%) = BO(\%)\ x\ 0{,}58$$

Where:
%C = Organic carbon contained in sediment
%BO = Percentage of organic matter in sediment
0,58 = Constant to convert %BO to %C

Soil density analysis (bulk density) was performed by calculating the specific gravity of the soil using the following formula, according to SNI 7724 (2011):

$$BD(g/cm^3) = (Oven\text{-}dry\ mass)/(Sample\ volume)$$

Where:
Oven-dry mass = Weight of dried sample (g)
Sample volume = Sample volume (cm^3)

Carbon storage was determined using the equation provided by Ariani et al. (2016) as follows:

$$Ct(g/cm^2) = Kd\ x\ \rho\ x\ \%C\text{-}organic$$

Where:
$Ct(g/cm^2)$ = Soil carbon content (g/cm^2)
Kd = Depth of the soil sample (cm)
ρ = Bulk density (g/cm^3)
% C-Organik = Percentage value of carbon content

SNI 7724:2011 states that the standard unit for calculating carbon storage is tons/ha. Therefore, the conversion of carbon storage in the sediment can be determined using the following formula:

$$BCarbon\ storage\ (ton/ha) = Ct\ (g/cm^2)\ x\ 100$$

Where:
BCarbon storage (ton/ha) = Organic carbon storage in sediment per hectare (ton/ha);
$Ct(g/cm^2)$ = Soil carbon content (g/cm^2)
100 = Conversion factor from g/cm^2 to tons/ha.

According to Kauffman and Donato (2012), the conversion of carbon storage to total CO_2 uptake in sediments can be formulated as:

$$WCO_2 = Carbon\ storage(ton/ha)\ x\ 3{,}67$$

Where:
W = Carbon dioxide absorption.
3.67 = equivalent conversion of element C to CO_2

The obtained data were analyzed descriptively to provide an overview of the C-organic content in the sediments of the Ampekale mangrove ecosystem. Statistical analysis was performed using One-way ANOVA to test for significant differences in bulk density and carbon concentration based on depth. In addition, a Two-way ANOVA was used to test for significant differences in carbon storage and the absorption of CO_2 across different sediment depths. The results of the analysis were significant ($P<0.05$)

and were performed using GraphPad Prism 8. The analysis results are illustrated graphically to highlight the variations in carbon storage and organic carbon absorption at various depths.

RESULTS AND DISCUSSION

Bulk density (BD) (g/cm³)

The analysis results indicated that sediments at different depths across nine distinct locations exhibited a range of bulk density (BD) values. The BD values at each depth are presented in Figure 2. Based on the analysis results, the bulk density (BD) value in the Ampekale mangrove ecosystem ranged from (0.00–0.050) g/cm³, with a distribution pattern that varied at each depth (Figure 2). The maximum bulk density (BD) value was recorded at a depth of 40–50 cm, measuring 0.028 g/cm³, whereas the minimum value was observed at a depth of 20–30 cm, measuring 0.013 g/cm³. However, based on the results obtained from the statistical analysis of the One-Way ANOVA test, the difference in BD values between depths was not significant (P>0.05).
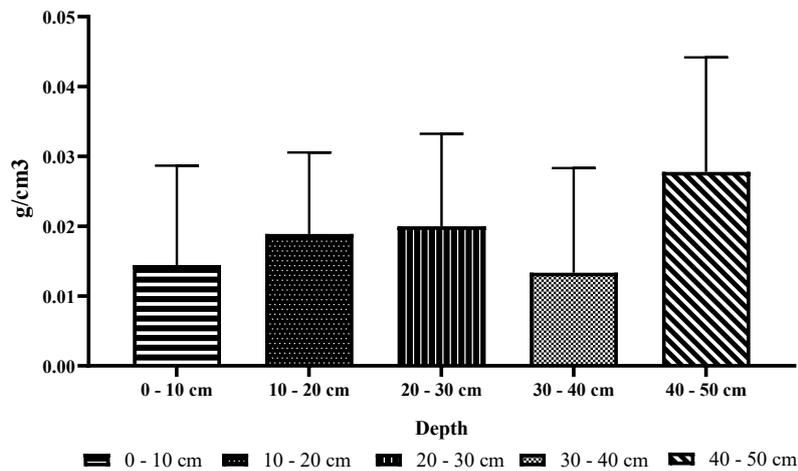

Figure 2. Graph of bulk density by depth level ($\overline{X} \pm SE, N = 9$).

Carbon concentration (%)

The analysis revealed that the carbon concentration in mangrove sediments at Ampekale varied between 1.29% and 3.21%, exhibiting different distributions at each depth (Figure 3). The maximum carbon content was detected at a depth of 40–50 cm, reaching 2.43%.
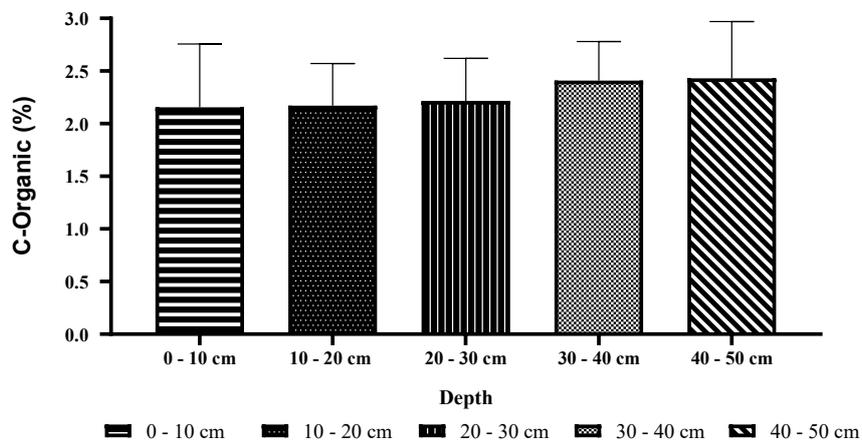

Figure 3. Graph of carbon concentration by depth level ($\overline{X} \pm SE, N = 9$).

The minimum concentration was observed at a depth of 0–10 cm (2.15 %). The results of the One-Way ANOVA statistical analysis demonstrated that the carbon concentration in sediments remained consistent across different depths, indicating no statistically significant differences (P>0.05).

Soil organic carbon storage and absorption

Based on the analysis results, the highest carbon storage in the sediment was 342,056 tons/ha at a depth of 40-50 cm and the lowest carbon storage was at a depth of 0-10 cm at 37 and 455 tons/ha. Overall, the average total carbon storage was 731.72 tons/ha. The findings revealed by the statistical tests carried out with the two-way analysis revealed that depth significantly influenced carbon storage (P<0.05).

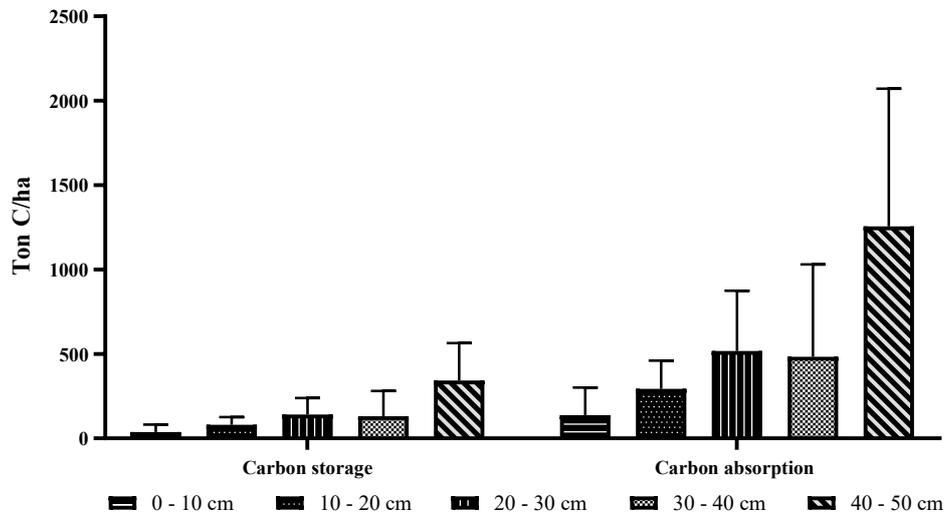Figure 4. Graph of carbon storage and absorption by depth level ($\overline{X} \pm SE, N = 9$).

Carbon absorption in sediment had the highest content, with a value of 1255.34 tons/ha at a depth of 40-50 cm whereas the minimum carbon absorption value recorded was 137.46 tons/ha. The total carbon absorption value in the sediment was 2685.42 tons/ha. Statistical analysis using Two-Way ANOVA showed that depth significantly affected carbon absorption (P <0.05).

Bulk density (BD) (g/cm³)

The bulk density (BD) values varied with depth (Figure 2). The highest average BD was recorded at 0.028 g/cm³, whereas the lowest value was 0.013 g/cm³. This varied BD distribution pattern indicates differences in the sediment characteristics at each depth layer. According to the results of the statistical analysis of the One-Way ANOVA test, the difference in the BD values between depths was not significant, indicating that there was no significant difference in the BD values at various sediment depths

Compared to previous studies, the BD values obtained in this study were lower. Ayu et al. (2022), stated that in the Temmalebba mangrove ecosystem, the average BD value was 1.28 g/cm³ at a depth of 60–100 cm, which indicates a higher level of sediment compaction compared to Ampekale. In addition, research conducted by Ningrum et al. (2024) showed a variation in BD values at various locations. The highest BD value at the Salo Palai location was recorded at 1.15 g/cm³ at a depth of 0–15 cm, while at the MBU location, the BD obtained was 0.63 g/cm³.

Based on research conducted in the Mahakam Delta by Diana et al. (2023), the BD value in this study was much lower than that in the Mahakam Delta. The maximum bulk density (BD) value recorded was 8.64 g/cm³, observed in the coastal wetland restoration area of the Mahakam Delta. In natural mangroves, the BD value reached 7.67 g/cm³, whereas in the mangrove area of former pond land, the BD value was 7.16 g/cm³. An elevated bulk density (BD) indicates that the sediment is denser than usual. This density is likely caused by the natural compaction process and the influence of anthropogenic activities that increase the pressure on the sediment layer (Kepel et al., 2018).

Carbon concentration (%)

Organic carbon present in sediments plays a crucial role as a primary element of organic compounds in aquatic environments. The concentration of organic carbon obtained (Figure 3) ranged from 1.29% to 3.21 %, which was almost the same as the research results. Sakmiana et al. (2023) reported that organic carbon in seagrass sediments in Selangan Village, East Kalimantan, ranged from 1.70% to 4.90%, with an average of 2.72 ± 0.20%. The carbon concentration in the sediment increased with the depth of the layer. This is supported by Razaan et al. (2024), who found that the concentration of organic carbon tended to increase in deeper layers. According to Rahman et al. (2024), this is attributed to the accumulation of organic matter, including living biomass and microorganisms, that have been buried for an extended period in the deepest layers. In addition, a higher compaction pressure at greater depths increases the activity of decomposing

organisms in breaking down stored organic carbon.

The statistical analysis results indicated no notable differences in organic carbon concentrations across the sediment layers. In addition, research conducted by Aldiano et al. (2023) stated that although organic carbon stocks at various sediment depths varied, the differences were not always statistically significant. This shows that the distribution of organic carbon in mangrove sediments can vary, but the differences between depths are not always significant.

Soil organic carbon storage and absorption

Carbon uptake in sediment is directly proportional to carbon storage, which increases with depth (Figure 4). This increase indicates that more carbon accumulates in deeper sediment layers, likely due to the long-term organic deposition process and slower decomposition rates compared to the surface layer (Kusuma et al., 2024). Susilowati et al. (2020) indicated that as the bulk density increased, the capacity of the sediment to store carbon also increased with increasing density, as it slowed down the decomposition of organic matter by limiting oxygen availability in the sediment pores. Research conducted by Yaqin et al. (2022) also showed that the organic carbon content in sediment is more stable in deeper layers because of the minimal disturbance from biological and physical activities that can accelerate the decomposition process.

Compared with previous research, the results of this study are higher than those of Marbun et al. (2020), who reported carbon storage of 398.82 tons/ha. However, the value obtained was still lower than that reported by Sumarni et al. (2024), who reported a value of 5224.70 tons/ha. This difference is likely caused by variations in environmental characteristics, ecosystem types, and hydrodynamic factors at each research location.

Based on the results shown in (Figure 4), sediment depth significantly affected carbon storage and absorption in mangrove ecosystems. Statistical analysis showed a significant difference between depths, with a significance value ($P < 0.05$), indicating that carbon accumulation and absorption in sediments tended to increase with increasing depth. The carbon absorption value in mangrove sediments results from the conversion of sediment carbon storage into CO_2 absorption. Therefore, an increase in the carbon stock within the sediment results in a higher level of CO_2 absorption (Tahir et al., 2023).

CONCLUSION

Based on the results of this study, it can be concluded that the mangrove ecosystem in Ampekale, Maros Regency, has a total carbon storage in the sediment of 731.72 tons/ha, with a total carbon absorption of 2685.42 tons/ha. Therefore, sustainable management efforts and expansion of the mangrove area must be conducted to optimize its role in absorbing and storing carbon.

ACKNOWLEDGEMENT

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