

# Mangrove Cover Dynamics and Carbon Storage Estimation at Cemara Beach, West Lombok Regency

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**Abstract:** Mangrove ecosystems play an essential role in carbon sequestration and coastal protection. This study analyzes changes in mangrove cover and associated carbon storage at Cemara Beach, West Lombok Regency, using Sentinel-2 satellite imagery from 2019 and 2024. Supervised classification with the CART algorithm was applied through Google Earth Engine, supported by field verification and stakeholder interviews for management assessment. Results indicate an expansion of mangrove cover from 66,6 ha in 2019 to 71,63 ha in 2024, an increase of 4,97 ha (7,46%). Correspondingly, carbon stocks rose from 14.728,26 tons C to 16.252,45 tons C, with mangroves contributing the largest portion (over 62%). SWOT analysis showed strong ecological potential and supportive policies but highlighted challenges such as limited funding, land-use pressure, and low community awareness. Strengthening multi-stakeholder collaboration, environmental education, and sustainable rehabilitation programs is recommended to enhance ecological resilience and maximize blue carbon benefits.

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## INTRODUCTION

Mangroves are coastal vegetation commonly found in tropical and subtropical estuarine environments. Ecologically, mangrove ecosystems function as coastal protection against abrasion and seawater intrusion while providing habitat for aquatic organisms (1). Mangroves also play an important role in nutrient and carbon cycling within coastal ecosystems (2).

In the context of climate change mitigation, mangroves function as significant blue carbon sinks capable of storing atmospheric carbon in biomass and sediments over long periods (3). Their carbon storage capacity is higher than that of many terrestrial forests due to long-term sediment carbon accumulation (4).

Mangrove carbon stocks can be estimated using remote sensing techniques through vegetation index analysis derived from satellite imagery (5). This approach enables spatial and temporal monitoring of mangrove cover dynamics to support sustainable coastal management.

Cemara Beach, located in Lembar Selatan Village, West Lombok Regency, possesses significant mangrove ecosystem potential dominated by *Rhizophora* sp. Mangroves in this area contribute to coastal protection and support marine ecological processes (1). However, limited spatial information regarding mangrove cover and carbon stocks remains a constraint for effective ecosystem management.

Therefore, this study aims to: (1) analyze mangrove cover conditions in 2019 and 2024; (2) estimate mangrove contributions to carbon storage; and (3) formulate sustainable mangrove management strategies for Cemara Beach.

## RESEARCH METHOD

This study employed a mixed-method approach involving field observation, satellite image analysis, and stakeholder interviews. Mangrove cover changes between 2019 and 2024 were analyzed using Google Earth Engine (GEE), while SWOT analysis was used to formulate sustainable mangrove management strategies based on internal and external conditions.

The study utilized both secondary and primary data. Secondary data included Sentinel-2 imagery, Google Earth imagery, administrative shapefiles, and mangrove land cover maps. Primary data were obtained through field verification using GPS coordinates and interviews with stakeholders, including government agencies, local tourism groups (Pokdarwis), and environmental NGOs..

### Data Analysis

#### Satellite Image Processing

Satellite image processing consisted of four stages [6]:

1. Collection of Sentinel-2 imagery from 2019 and 2024;
2. Median composite processing to reduce cloud cover and reflectance noise;
3. Collection of training samples using RGB 432 composites; and
4. Land cover classification using the Classification and Regression Trees (CART) algorithm within the GEE platform.

#### Supervised Classification

Supervised classification was performed using the CART machine learning algorithm, which is effective for land cover classification in satellite imagery. Training samples were selected based on spectral characteristics to represent each land cover class [7]. The classification process referred to the United States Geological Survey (USGS) land cover classification system before applying the CART algorithm.

Table 1. Land cover classification

| No | Classification   | Value |
|----|------------------|-------|
| 1  | Agriculture land | 0     |
| 2  | Mangrove         | 1     |
| 3  | Water            | 2     |
| 4  | Built-up land    | 3     |
| 5  | Barren land      | 4     |

#### Accuracy Test

Classification accuracy was assessed using a confusion matrix to calculate Overall Accuracy (OA) and the Kappa Coefficient. The analysis included user accuracy, producer accuracy, and Kappa statistics to evaluate classification reliability [8]. An OA value above 70% indicates acceptable classification accuracy for land cover analysis [9]. The Kappa Coefficient was used to measure agreement between classified and reference data while considering chance agreement..

$$OA = \frac{\text{number of correct predictions}}{\text{prediction total}}$$

$$Kappa = \frac{((Po - Pe))}{(1 - Pe)}$$

Po = Total rows X column

Pe = Total prediction

Tabel 2. Kappa Classification

| Nilai Kappa | Interpretasi   |
|-------------|----------------|
| 0,00 – 0,20 | Low            |
| 0,21 – 0,40 | Balanced       |
| 0,41 – 0,60 | Moderate       |
| 0,61 – 0,80 | Substantial    |
| 0,81 – 1,00 | Almost perfect |

Source : data analysis [9]

### Groundcheck Research Area

Ground verification was conducted using GPS-based land cover sample points at selected locations to validate satellite image classification results [9]. Sampling applied purposive random sampling by prioritizing accessible areas, land cover changes, and representative mangrove distribution.

### Stock Carbon Analysis

Carbon stock estimation was calculated by multiplying land cover area by the corresponding carbon stock constant (tons C/ha) [9]. Mangrove carbon stock was calculated using the following equation:

$$C = \text{Carbon Constant} \times \text{mangrove cover area (year)}$$

### SWOT Analysis of Mangrove Area Management

SWOT analysis was used to formulate sustainable mangrove management strategies based on stakeholder interviews. Internal factors were evaluated using the Internal Factor Evaluation (IFE) matrix, while external factors were analyzed using the External Factor Evaluation (EFE) matrix to identify strengths, weaknesses, opportunities, and threats [10].

Table 3. Score weight

| No | Weight | Description |
|----|--------|-------------|
| 1  | 1      | Very low    |
| 2  | 2      | Low         |
| 3  | 3      | High        |
| 4  | 4      | Very High   |

Source: Data analysis [8]

The weight as follows [11]:

0,00-0,05 = Minor impact

0,06-0,10 = Moderate impact

0,11-0,15 = Significant impact

0,16-0,25 = Very Significant impact

Each factor was assigned a weight and rating according to its level of importance. Weighted scores were subsequently calculated to determine the strategic position of mangrove management within the Internal-External (IE) Matrix framework.

IFE and EFE scores below 2.5 indicate weak strategic conditions, whereas scores above 2.5 indicate strong strategic conditions [8]. The resulting strategic position was used as the basis for formulating mangrove ecosystem management strategies in the Cemara Beach area.

## RESULTS AND DISCUSSION

### Mangrove cover conditions 2019 and 2024

#### a) Mangrove Cover in 2019

The 2019 Sentinel-2 imagery analysis showed that mangrove cover at Cemara Beach reached 66.6 ha. The ecosystem was dominated by *Rhizophora mucronata*, *Rhizophora apiculata*, *Sonneratia alba*, and *Avicennia alba*, which were mainly distributed along the western and central coastline areas. During this period, mangrove cover remained relatively stable and represented baseline conditions prior to rehabilitation activities.

The mangrove ecosystem in 2019 exhibited relatively dense vegetation with NDVI values ranging from -0.09 to 0.60. NDVI analysis using Google Earth Engine classified vegetation density into five canopy classes, from very sparse to very dense. Overall, the ecosystem condition was relatively well preserved, although several areas experienced pressure from land conversion for ponds and settlements. Human activities are recognized as a major factor affecting mangrove degradation in Southeast Asia, including Indonesia [12].

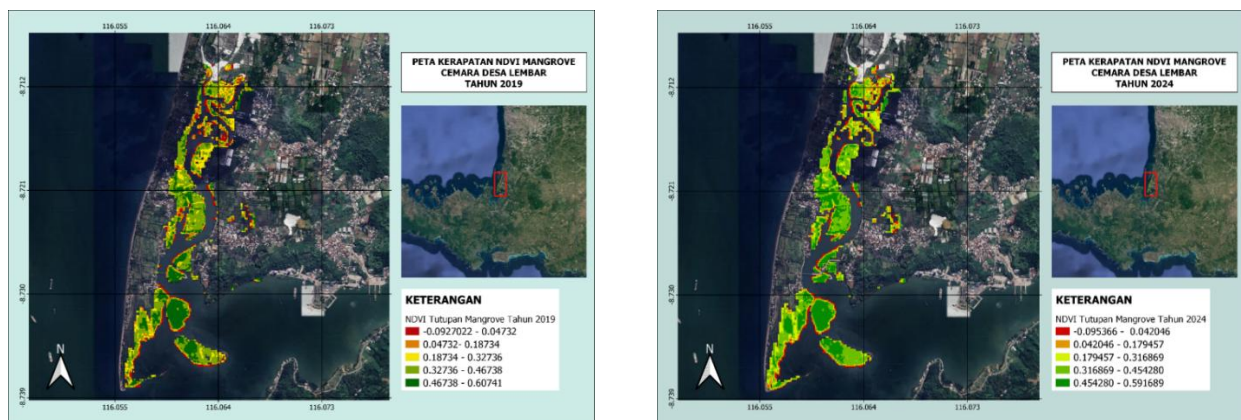


Figure 1. NDVI density map of mangroves in 2019 and 2024

#### b) Mangrove Cover in 2024

Interpretation of Sentinel-2 imagery in 2024 showed that mangrove cover increased to 71.63 ha, representing an expansion of 4.97 ha compared to 2019. This increase indicates ecosystem recovery driven by natural regeneration and community-based rehabilitation programs. Similar trends in mangrove expansion have been reported in Indonesian coastal areas due to increasing public awareness and rehabilitation activities [13]. At Cemara Beach, rehabilitation efforts were supported by local communities and the Cemara Beach Tourism Group.

According to the village chief, the development of mangrove cover to its current condition cannot be separated from the role of the mangrove ecosystem itself in natural accumulation, supported by the *Rhizophora* spp species, which is known to grow rapidly using only fallen seeds..

The NDVI value results are -0,0927022- 0,60741. Vegetation index classification analysis. The NDVI method results are the level of vegetation greenness classified into 5 classes, namely: 1) Canopy density very rare ( $0, -0,09 \leq \text{NDVI} \leq 0,04$ ); 2) Low canopy density ( $0,04 \leq \text{NDVI} \leq 0,17$ ); 3) Medium canopy density ( $0,17 \leq \text{NDVI} \leq 0,31$ ); 4) Dense canopy ( $0,31 \leq \text{NDVI} \leq 0,45$ ); and 5) Very dense canopy ( $0,45 \leq \text{NDVI} \leq 0,59$ ),

Spatial analysis of Sentinel-2 satellite imagery and land cover classification shows changes in mangrove cover between 2019 and 2024. Based on the results of image interpretation and field verification, the mangrove area data in table 4. is as follows:

Table 4. Mangrove cover change in Cemara Coastal

| Year | Mangrove Cover Total (Ha) | Mangrove Change (Ha) | Percentage (%) |
|------|---------------------------|----------------------|----------------|
| 2019 | 66,6                      | -                    |                |
| 2024 | 71,6                      | +4,97                | 7,46%          |

Mangrove cover increased by 4.97 ha (7.46%) from 66.6 ha in 2019 to 71.63 ha in 2024, indicating positive ecosystem recovery and increased carbon storage potential. This increase reflects natural regeneration and reduced anthropogenic pressure under favorable environmental conditions [14]. Lembar Selatan Village contained the largest mangrove area, covering approximately 80.08 ha (71%), followed by Eyat Mayang Village with 27.48 ha (24%) and Labuan Tereng Village with 5.65 ha (5%) [15].

Classification accuracy was evaluated using a confusion matrix. The 2019 classification produced an Overall Accuracy (OA) of 94.64% and a Kappa Coefficient of 0.9203, indicating very high classification reliability and an “almost perfect agreement” level [16]. Most classified pixels were located along the confusion matrix diagonal, reflecting high agreement between classified and reference data. Minor misclassification occurred in several classes due to spectral similarity and transition areas. Nevertheless, the classification accuracy was considered highly reliable for mangrove cover change analysis.

Table 5. Calculation of OA for 2019

| Class  | Prediction |     |     |    |    | Number of Correct | Total |
|--------|------------|-----|-----|----|----|-------------------|-------|
|        | 0          | 1   | 2   | 3  | 4  |                   |       |
| 0      | 25         | 0   | 1   | 1  | 3  | 25                | 30    |
| 1      | 0          | 103 | 1   | 0  | 2  | 103               | 106   |
| 2      | 3          | 0   | 139 | 0  | 0  | 139               | 142   |
| 3      | 2          | 0   | 0   | 18 | 1  | 18                | 21    |
| 4      | 0          | 0   | 1   | 2  | 15 | 15                | 18    |
| Jumlah |            |     |     |    |    | 300               | 317   |

Based on the test results, an Overall Accuracy value of 93,15% was obtained. This value indicates that the pixels in the classification image have been classified correctly according to the reference data. Meanwhile, the Kappa Coefficient value reached 0.8988, which indicates a very high level of conformity between the classification and the reference data after reducing the probability of random conformity (chance agreement).

An Overall Accuracy value above 90% indicates that the classification method used has a very good level of reliability in mapping land cover. Accuracy value above 85% is considered adequate for ecological studies and land cover mapping [16]. In addition, a Kappa value close to

1 indicates a very strong agreement between the classification results and the actual conditions [17]. Furthermore, the classification accuracy level is seen from the Kappa coefficient, with a coefficient value range of table 6.

The main cause of misclassification appears to originate from classes 4 and 5, which show several prediction values that deviate from the actual class. This can occur due to similar reflectance spectra between certain classes, especially between dense and moderate vegetation, or between vegetation and other transitional areas. However, the number of misclassifications is very small compared to the amount of correctly classified data [18].

Table 6. Calculation of OA for 2024

| Class  | Prediction |    |     |    |    | Number of Correct | Total |
|--------|------------|----|-----|----|----|-------------------|-------|
|        | 0          | 1  | 2   | 3  | 4  |                   |       |
| 0      | 14         | 0  | 0   | 0  | 1  | 14                | 15    |
| 1      | 0          | 91 | 0   | 0  | 0  | 91                | 91    |
| 2      | 2          | 0  | 158 | 0  | 1  | 158               | 161   |
| 3      | 1          | 0  | 0   | 26 | 8  | 26                | 35    |
| 4      | 5          | 2  | 1   | 2  | 24 | 24                | 34    |
| Jumlah |            |    |     |    |    | 313               | 336   |

### *Estimation of Carbon Stocks in Mangrove Cover in Lembar Selatan Village*

Based on data on the land cover area of Cemara Beach from 2019 and 2024, the conversion was carried out using the carbon stock constants in Table 7. The highest carbon stock constant is for mangrove land cover. Carbon stock estimates were made using the average carbon reserve value for mangrove ecosystems of 142,6 tons C/ha [19]. In 2019, the carbon stock absorbed by mangrove land was 9.505,64 tons C, while in 2024, it increased to 10.214,2 tons C. This increase was influenced by changes in mangrove area land cover. Carbon stock calculations are presented in table 7 below:

Table 7. Carbon Stock Conversion Based on Land Cover (2019 and 2024)

| Class    | Total (ha) |      | Conversion Factor | Carbon Stock (tons C) |          |
|----------|------------|------|-------------------|-----------------------|----------|
|          | 2019       | 2024 |                   | 2019                  | 2024     |
| Mangrove | 66,6       | 71,6 | 142,6             | 9.505,6               | 10.214,2 |

Land cover change contributes to increased greenhouse gas emissions and influences ecosystem sustainability in coastal areas [20]. Carbon emissions originate not only from land conversion but also from human activities. Although conservation initiatives such as mangrove rehabilitation and reforestation have been implemented by governments, communities, academics, and NGOs, many programs remain limited in long-term monitoring and management. Sustainable conservation is therefore necessary to strengthen the resilience of small islands against climate change impacts.

Increasing carbon stocks may also be achieved through community-based reforestation on private and coastal lands [21]. In Cemara Beach, rehabilitation activities have involved universities, NGOs, and local communities, reflecting relatively strong stakeholder participation in mangrove conservation.

Land cover change analysis between 2019 and 2024 was conducted using supervised Sentinel-2 image classification. Besides mangroves, the study area consisted of agricultural land, water bodies, built-up areas, and barren land. Mangrove cover increased from 66,6 ha in 2019 to 71,63 ha in 2024, indicating ecosystem recovery through rehabilitation and natural regeneration processes [22].

Total carbon stocks increased from 14.728,26 tons C in 2019 to 16.252,45 tons C in 2024. Mangroves remained the dominant carbon contributor, accounting for 9,505.64 tons C (64,56%) in 2019 and 10.214,28 tons C (62,85%) in 2024. Plantation areas contributed 33,66% and 35,57% of total carbon stocks, while built-up and barren land contributed less than 1%. Water bodies showed negligible carbon storage capacity due to zero carbon conversion values.

Table 8. Contribution of land cover in the mangrove area to carbon sequestration

| No | Land Cover    | Area (Ha) |        | Constant<br>(Ton C/Ha) | Carbon Stock<br>(Ton C/Ha) | Contribution (%) |       |
|----|---------------|-----------|--------|------------------------|----------------------------|------------------|-------|
|    |               | 2019      | 2024   |                        |                            | 2019             | 2024  |
| 1  | Mangrove      | 66,66     | 71,63  | 142,6                  | 10214,28                   | 64,56            | 62,85 |
| 2  | Agriculture   | 78,72     | 91,75  | 63                     | 5780,56                    | 33,66            | 35,57 |
| 3  | Water         | 212,45    | 197,12 | 0                      | 0                          | 0                | 0     |
| 4  | Built-up Land | 24,92     | 29,52  | 4,1                    | 121,02                     | 0,69             | 0,74  |
| 5  | Barren Land   | 47,44     | 40,17  | 3,4                    | 136,59                     | 1,1              | 0,84  |

Although mangrove cover increased from 66,6 ha in 2019 to 71,63 ha in 2024, its relative contribution to total carbon stocks declined due to increased carbon contributions from other land cover types, particularly plantations. This indicates that total carbon dynamics are influenced not only by mangrove expansion but also by changes in overall land cover composition. Ecologically, mangrove rehabilitation and coastal vegetation conservation contributed positively to carbon stock enhancement. Mangroves remain the dominant carbon sink due to their high carbon density of 142,6 tons C/ha, which is higher than other land cover types [19].

Land cover change may increase greenhouse gas emissions and affect coastal ecosystem sustainability. Although rehabilitation and reforestation programs have been implemented by governments, communities, academics, and NGOs, long-term conservation management remains limited. Sustainable rehabilitation is therefore necessary to strengthen coastal resilience against climate change impacts. Community-based reforestation on private and coastal land may further increase carbon stocks [21]. In Cemara Beach, rehabilitation activities involving local communities, universities, and NGOs indicate strong stakeholder participation in mangrove conservation and ecosystem restoration.

## SWOT Analysis of Mangrove Area Management Strategi in Cemara Beach

### a. IFAS (internal Analysis Strategy)

The IFAS matrix needs to be understood and evaluated within the company's internal environment. These internal factors relate to the strengths and weaknesses of mangrove management. The results of the matrix can be seen in the table below.

Table 9. Strengths and Weaknesses Analysis

| No | Strength                                                                                        | Bobot | Rating | Skor |
|----|-------------------------------------------------------------------------------------------------|-------|--------|------|
| 1  | Mangrove areas have high biodiversity                                                           | 0,12  | 3      | 0,39 |
| 2  | The current condition of the mangrove ecosystem is still well maintained naturally.             | 0,11  | 3      | 0,30 |
| 3  | Local communities have local wisdom in preserving mangroves                                     | 0,12  | 3      | 0,39 |
| 4  | Mangroves have the potential to be developed as educational tourism or ecotourism destinations. | 0,14  | 4      | 0,49 |

|                    |                                                                                               |      |   |             |
|--------------------|-----------------------------------------------------------------------------------------------|------|---|-------------|
| 5                  | The existence of regulatory support or government policies that benefit mangrove conservation | 0,14 | 4 | 0,49        |
| <b>Total</b>       |                                                                                               |      |   | <b>2,07</b> |
| <b>No Weakness</b> |                                                                                               |      |   |             |
| 1                  | The existence of damage or degradation of mangrove forests                                    | 0,06 | 2 | 0,10        |
| 2                  | The local community has a good understanding of the importance of mangroves                   | 0,11 | 3 | 0,30        |
| 3                  | There is overlapping land ownership                                                           | 0,10 | 3 | 0,26        |
| 4                  | There are funding constraints for mangrove rehabilitation programs                            | 0,11 | 3 | 0,30        |
| <b>Total</b>       |                                                                                               |      |   | <b>0,95</b> |

In Table 9 above, it can be seen that the strength matrix value is 2.07 and the weakness matrix value is 0.95. Thus, the total value of the strength and weakness matrix is 3.02, which means that strength is higher than weakness in determining the mangrove area management strategy.

#### b. EFAS (External Analysis Strategy)

The EFAS matrix needs to be understood and evaluated in relation to the company's external environment. These external factors relate to opportunities and threats in mangrove management. The results of the matrix can be seen in the table below.

Table 10. Opportunities and Threats Analysis

| No           | Opportunity                                                                                                        | Weight | Ratings | Score       |
|--------------|--------------------------------------------------------------------------------------------------------------------|--------|---------|-------------|
| 1            | Government, NGO, or international agency programs support mangrove rehabilitation                                  | 0.13   | 3       | 0.43        |
| 2            | There are opportunities for developing mangrove-based ecotourism                                                   | 0.13   | 3       | 0.43        |
| 3            | Potential for developing businesses based on mangrove forest products (e.g., fishery products, honey, handicrafts) | 0.10   | 2       | 0.24        |
| 4            | New technologies or innovations can help mangrove conservation                                                     | 0.08   | 2       | 0.14        |
| 5            | There are opportunities for multi-stakeholder collaboration (government, community, private sector, academia)      | 0.14   | 3       | 0.49        |
| <b>Total</b> |                                                                                                                    |        |         | <b>1.72</b> |
| No           | Ancaman                                                                                                            |        |         |             |
| 1            | Threats from land use changes such as conversion to ponds or infrastructure and settlements                        | 0.10   | 2       | 0.24        |
| 2            | The impact of climate change (sea level rise, abrasion) on mangrove areas                                          | 0.12   | 3       | 0.33        |
| 3            | There is pressure from industry, mining, or infrastructure development                                             | 0.09   | 2       | 0.20        |
| 4            | Illegal logging or illegal activities in mangrove areas                                                            | 0.10   | 2       | 0.24        |
| 5            | Pollution from land threatens mangrove ecosystems                                                                  | 0.10   | 2       | 0.24        |
| <b>Total</b> |                                                                                                                    |        |         | <b>1.02</b> |

In Table 10 above, it can be seen that the opportunity matrix value is 1.72 and the threat matrix value is 1.02. This results in a total matrix value of 2.74, which indicates that mangrove area management has considerable opportunities compared to the existing threats.

**c. SFAS (Strategic Factor Analysis Summary)**

Next, calculations were performed on the IFAS and EFAS tables to determine the most appropriate strategy. Based on these two tables, the coordinates were determined as shown in the following analysis diagram:

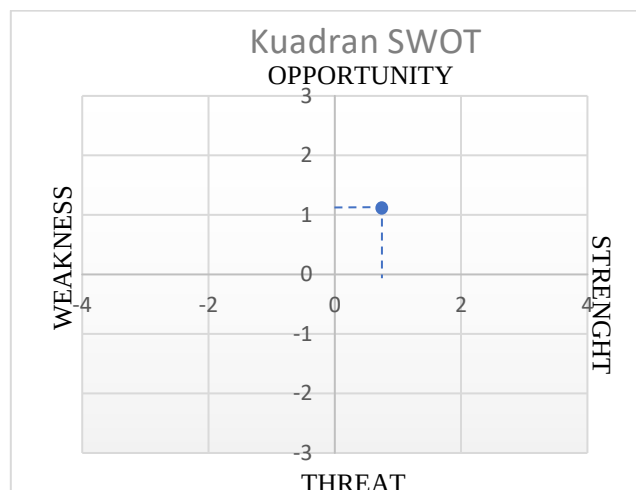


Figure 2. Swot Quadrant Analysis

The SWOT quadrant analysis in Figure 2 indicates that mangrove ecosystem management at Cemara Beach is positioned within the Strength–Opportunity (SO) quadrant, suggesting that management strategies should optimize existing ecological strengths and external opportunities to support sustainable conservation. The analysis revealed strong institutional support, relatively well-preserved mangrove ecosystems, high biodiversity, and significant ecotourism potential, supported by opportunities for rehabilitation programs and multi-stakeholder collaboration.

**Strength–Opportunity (SO) Strategy**

The SO strategy emphasizes strengthening mangrove conservation through regulatory support, sustainable ecotourism development, and collaborative rehabilitation programs. Government regulations play an important role in controlling land use and supporting sustainable mangrove management [23]. Mangrove-based ecotourism may enhance ecosystem conservation while improving local economic conditions and community participation [24]. Collaboration among government agencies, local communities, NGOs, and academic institutions is essential to improve rehabilitation effectiveness and long-term ecosystem resilience. Mangrove rehabilitation also contributes to shoreline protection, sediment stabilization, and carbon sequestration, thereby supporting climate change mitigation efforts [25].

**Weakness–Opportunity (WO) Strategy**

The WO strategy focuses on reducing management weaknesses through environmental education and improved community participation. Increasing public awareness regarding the ecological and economic importance of mangroves is necessary to minimize ecosystem degradation and strengthen conservation practices. In addition, strengthening legal protection and rehabilitation governance is important for reducing land-use conflicts and supporting sustainable mangrove management in accordance with Presidential Regulation No. 73 of 2012 concerning the National Strategy for Mangrove Ecosystem Management.

**Strength–Threat (ST) Strategy**

The ST strategy utilizes existing ecological and institutional strengths to address environmental threats such as pollution, land conversion, and climate change impacts. Effective environmental monitoring and regulatory enforcement are essential to maintain ecosystem sustainability. Mangrove ecosystems function as natural coastal protection systems by reducing wave energy, preventing abrasion, and improving coastal environmental quality through biofiltration processes [27]. In addition, mangroves contribute significantly to carbon sequestration and climate resilience [28].

#### **Weakness–Threat (WT) Strategy**

The WT strategy emphasizes minimizing ecosystem vulnerability through community-based monitoring and sustainable management practices. Monitoring and evaluation activities are important for assessing rehabilitation effectiveness and preventing mangrove degradation [29]. Overall, the SWOT analysis highlights the importance of integrated management approaches involving conservation, institutional support, community participation, and sustainable ecotourism development to enhance long-term mangrove ecosystem sustainability at Cemara Beach.

### **CONCLUSION**

The study confirms that mangrove expansion at Cemara Beach from 2019 to 2024 increased regional carbon storage capacity. Mangrove cover increased by 4.97 ha, accompanied by a rise in total carbon stocks from 14,728.26 tons C to 16,252.45 tons C. Mangroves remained the primary contributor to carbon sequestration, highlighting their important role in climate change mitigation. The increase in mangrove cover indicates successful natural regeneration and community-based rehabilitation efforts. SWOT analysis identified strong ecological potential and regulatory support; however, challenges such as limited funding, land degradation, and low public participation remain significant. Sustainable mangrove management therefore requires integrated strategies involving policy strengthening, community participation, and long-term monitoring. This study also demonstrates the effectiveness of integrating remote sensing, Google Earth Engine, and SWOT analysis for mangrove management and blue carbon assessment in coastal ecosystems.

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