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RESEARCH PAPER

Carbon Stock Profiling of Mangrove Ecosystem in the Semarang-Demak Coastal Area for Global Warming Mitigation

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Abstract
Semarang-Demak coastal area is the current location for giant sea wall construction, which also functions as a toll road across two regions. The construction process reduces mangrove land areas that may have ecological destruction. As we know, mangrove areas play an important role in the Semarang-Demak regions as the carbon sink for global warming mitigation. Hence, this study aims to (1) analyze the current capacity of the carbon stock, (2) mangrove vegetation profiling, and (3) develop a sustainable mangrove ecosystem management model in the coastal area of Semarang-Demak. The research was conducted using descriptive exploratory with a non-destructive test using an allometric equation determined based on mangrove tree stands. The results showed that the total above-ground biomass (AGBs) or the potential above-surface biomass content at the study site ranges from 34.72 ± 6.51 Mg/ha up to 101.06 ± 13.71 Mg/ha. Potential carbon stocks (C-stock) at the research site (lowest C-stock) were 16.32 ± 3.06 MgC/ha or ranging from the lowest 59.83 ± 11.21 MgC/ha to the highest 174.17 ± 23.63 MgC/ha for $CO_2{}^{-e}$ (carbon dioxide equivalent emissions). For this reason, an integrated effort is needed between components for the sustainability of the mangrove ecosystem in the coastal area of Semarang-Demak.

Graphical Abstract
The coastal area of Semarang-Demak is currently the location for the construction of the sea embankment toll road project. This development has an impact on reducing mangrove land which has been one of the important ecosystems in the Semarang-Demak area, one of which is a carbon sink for mitigating global warming. The research design in this study is descriptive exploratory with research methods non-destructive test with allometric equation determined based on mangrove stands. It is found that the total Above-ground Biomass (AGBs) or the potential above-surface biomass content at the study site ranges from 34.72 ± 6.51 up to 101.06 ± 13.71 Mg/ha. With a range of potential carbon stocks (C-stock) at the research site, it is known that the lowest C-stock is 16.32 ± 3.06 MgC/ha. The total C-stock, when converted to $CO2^{-e}$ or carbon dioxide equivalent emissions, ranged from the lowest 59.83 ± 11.21 MgC/ha and the highest 174.17 ± 23.63 MgC/ha. For this reason, an integrated effort is needed between components for the sustainability of the mangrove ecosystem in the coastal area of Semarang-Demak. Findings in this research are an additional database for the sustainable management of mangrove ecosystems in the coastal area of Semarang-Demak, Indonesia. As in the diagram developed, mangrove ecosystem management

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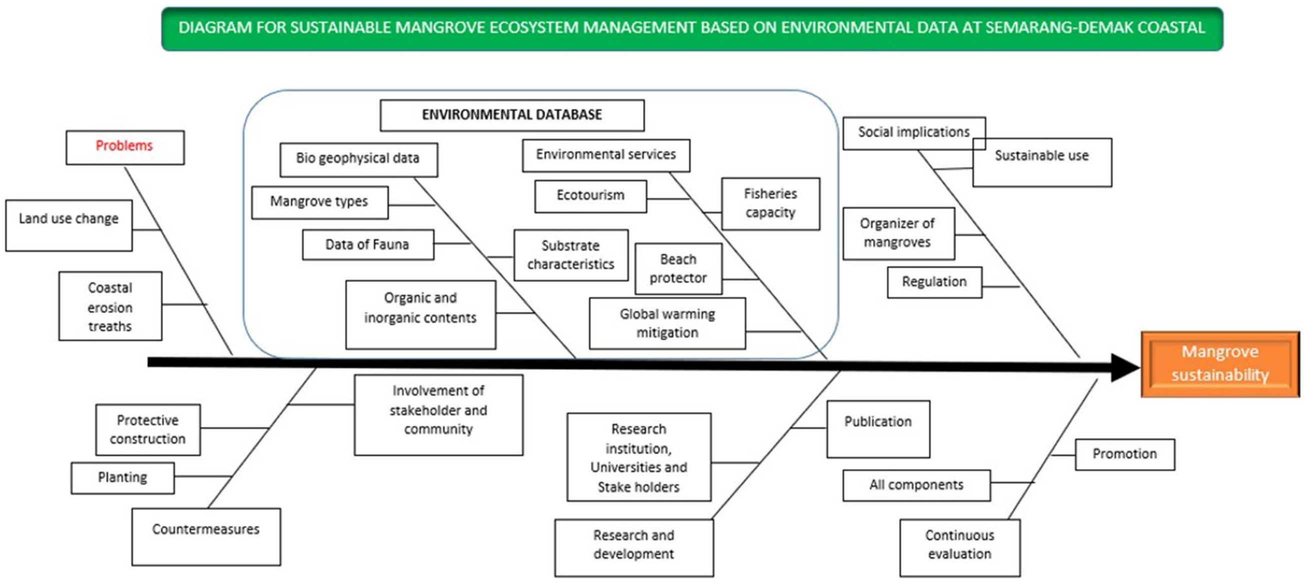
needs to always involve the community in mangrove management, stakeholders, and research institutions and universities to monitor and evaluate environmental components so that the existing database can be managed properly and sustainably.



Keywords Carbon stock · Mangrove ecosystem · Semarang-Demak coast

Introduction

Semarang-Demak coastal areas are dynamic regions, filled with various industrial, trade, fishery, and residential activities, that are actually treated by erosion, flooding, and tidal flooding. In 2017, Semarang-Demak coastal area eroded an area of 285.07 Ha (Irsadi et al. 2019), which forced more than 200 families to move out to other villages (Buchori et al. 2018; Goldbach 2017; Hillmann and Ziegelmayer 2016). To overcome this problem, the Indonesian government builds a giant sea wall that functioned as a toll road connecting Semarang City and Demak Regency (Hadi et al. 2020). The giant sea wall is a large-long dam construction to prevent seawater from entering the land and prevent tidal flooding. However, the planned construction passes through the mangrove ecosystem along the Semarang-Demak coastal areas, which is covering 304.76 ha in 2017 (Irsadi et al. 2019).

The mangrove areas from Semarang City to Demak Regency play an important role to overcome sea level rises that increase the risk of erosion, flooding, and tidal flooding. Based on the community perception, the mangrove ecosystem is assumed to give various benefits to the social economy of the coastal community, including hard-wind and high-wave protection, and supports fisheries home industries (Irsadi et al. 2020). The mangrove ecosystem also provides alternative livelihood through environmental education tourist attractions managed by local parties. In addition, the mangrove ecosystem provides coastal biodiversity habitat for mangrove, bird, and invertebrate species (Dencer-Brown et al. 2018; Owuor et al. 2019). Moreover, the mangrove ecosystem has also become a place for carbon circulation which is an important factor in global warming (Albert and Cedex 2019).

Therefore, the construction in coastal areas needs to take notice of the conditions and environmental services of the mangrove ecosystem to minimize the negative impact on the community. However, the carbon stock database of Semarang-Demak mangrove ecosystems is lacking and urgent to arrange. Calculation of carbon stock needs to be done immediately because of the pressure on the mangrove ecosystem which can result in land loss due to erosion. Hence, the existence of pressure from the Semarang-Demak giant sea wall makes coastal areas need to be prioritized in sustainable development and management.

Mangrove deforestation is an ecological catastrophe that affects the social, economic, and cultural value of the coastal community (Cahyaningsih et al. 2022). For the several explanations above, an initial mangrove ecosystem profile should be collected to create a mangrove ecosystem database and as a comparison for evaluating giant sea wall construction projects. It is also necessary for the government to develop a sustainable mangrove ecosystem management plan. One of the important data that currently does not exist is carbon stock in the Semarang-Demak mangrove ecosystem. Therefore, this study aims to (1) analyze the current capacity of the carbon stock; (2) mangrove vegetation profiling, and (3) develop a sustainable mangrove ecosystem management model in the coastal area of Semarang-Demak.

Methods

Research Design

The research design was conducted using descriptive exploratory (Casula et al. 2021), for 8 months. The work steps in the research consisted of (1) a preliminary study to analyze the condition of mangroves, (2) field surveys and making research instruments, (3) sampling, (4) carbon stock analysis, (5) developing a sustainable data-based coastal management model on the coast of Semarang-Demak (Fig. 1).

Research Procedure

The steps of research work were carried out as follows:

Preliminary Studies

Steps to get the general condition of mangrove vegetation and environmental factors to determine the study area. Based on the preliminary study, there were three main areas determined as research study including the Trimulyo sub-district in Semarang City, Bedono, and Tambaksloko sub-districts in Demak Regency (Fig. 2). Three locations were chosen because of several criteria, (1) become a construction site for a giant sea wall; (2) have an existing mangrove ecosystem, and (3) intensive mangrove planting location.

Field Survey Data

Survey fieldwork was carried out for in site verification using previous image data. This method was used to cross-check and ensure the satellite image information with the current condition of the research site and mangrove ecosystem locations.

Sampling

Mangroves A transect method was used for measuring mangrove tree stands, Furthermore, sampling was carried out at a distance of 0–20 m, 21–40 m, and so on. Vegetation data were collected using the quadratic method with a size of 20 × 20 m to observe trees/poles with a diameter of 10 cm and more (Yudha et al. 2022). In each plot, a 5 × 5 m plot was made to measure the saplings with a diameter of 2–10 cm (Fig. 3.). For the seedling level, data were collected from each 2 × 2 m plot placed on a 5 × 5 m plot (Park et al. 2021). The observations obtained were then analyzed by the descriptive method.

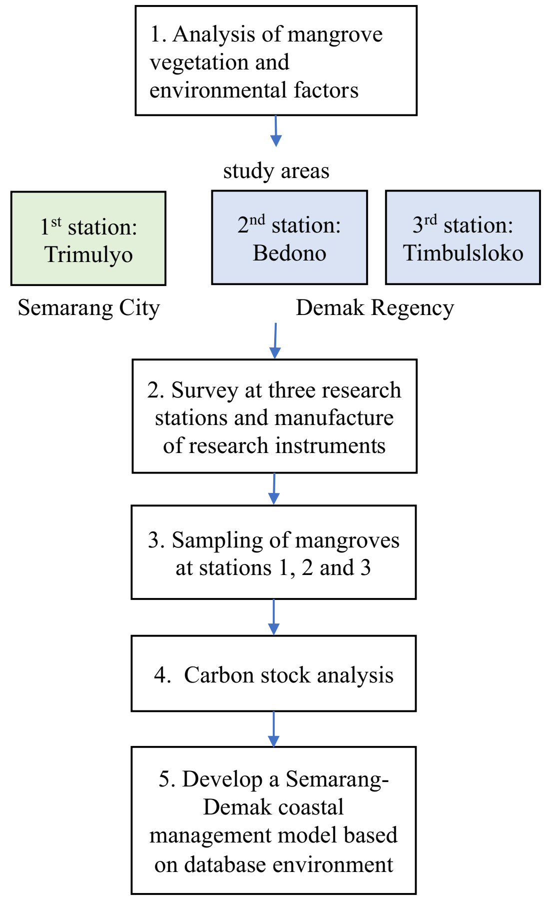


Fig. 1 Steps of research work

Mangrove Area Mangrove area data were taken by satellite image from *google earth* for 2015 and 2020. The data were accessed in the research year (2021).

Data Analysis

Biomass Measurement

The biomass measurement was collected following previous studies (Dutcă et al. 2020; Paul et al. 2018), with modification. Then, the biomass calculation formula for each mangrove species was measured using the allometric models as presented in Table 1.

Then, a calculation to determine the carbon fraction value for the mangrove ecosystem was used the formula:

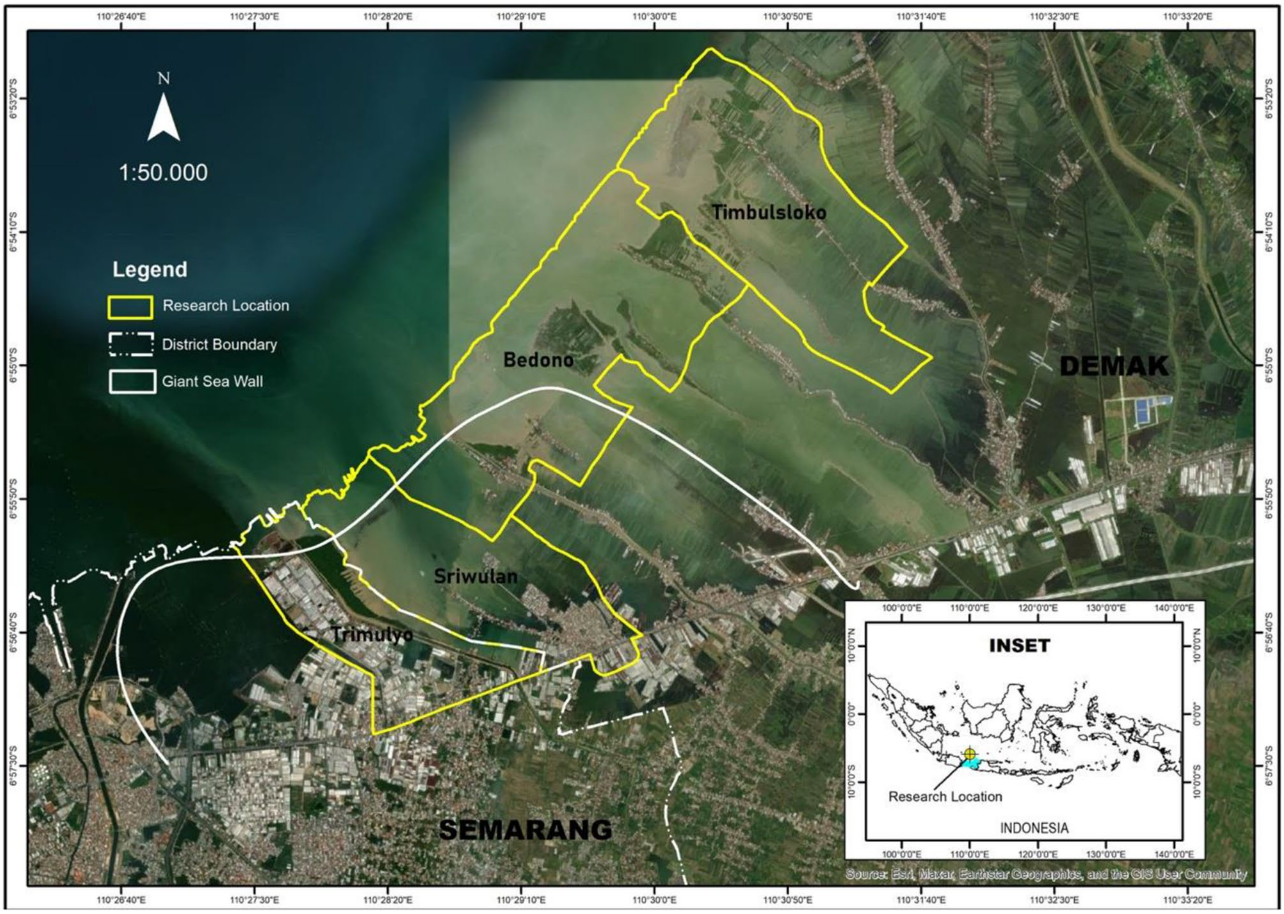


Fig. 2 Research site and giant sea wall location (solid white line) in three sub-districts of Semarang City and Demak

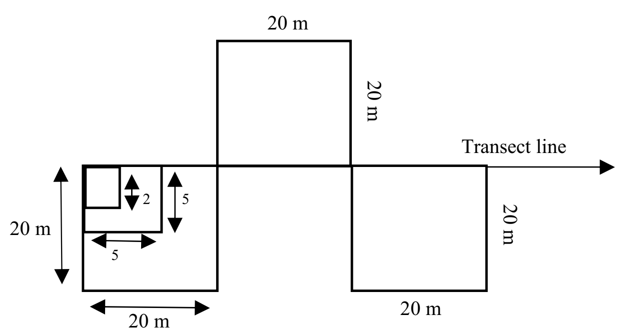


Fig. 3 Mangrove sampling transect chart

$$C_{stand} = AGBs \times c \quad (1)$$

Notes:

C_{stand} = amount of carbon (MgC/ha).

AGBs = biomass (Mg/ha).

c = coefficient value for carbon fraction = 0.47.

Table 1 Allometric model of mangrove tree biomass estimation

Tree type	Allometric model	References
Avicennia marina	$AGBs = 0.1848\ D^{2.3524}$	Zarawie et al. (2015)
Rhizophora spp	$AGBs = 0.128\ D^{2.60}$	Sun et al. (2020)
General equation	$AGBs = 0.251\ D^{2.46}$	Nguyen et al. (2021)
Stake/sapling	$AGBs = \exp[-3.068 + 0.957 \times \ln(DS^2 \times H)]$	Lu et al. (2005)

AGBs aboveground biomass, *D* diameter of tree or sapling diameter at breast high (DBH) in meters, *H* the total tree or sapling height in meters

Estimated Total Carbon Stock and Equivalent Conversion CO_2

The estimated total carbon stock was estimated by adding all carbon stocks in each component (C_{stand} and C_{wood} dead). Each component's carbon stock value is averaged across all plots, then summed to get the total carbon stock and calculated using the following formula.

$$C_{tot} = C_{stand} + C_{dead\ wood} \quad (2)$$

Notes:
C_{tot} = total carbon stock in sample plots (MgC/ha).
C_{stand} = carbon stock in the stand (MgC/ha).
$C_{dead\ wood}$ = carbon stock in dead wood (MgC/ha).
The total carbon stock in the study area was calculated by the formula:

$$C = C_{tot} \times \text{Areas} \quad (3)$$

Notes:
C = total carbon stock in the study area (Mg).
C_{tot} = total carbon stock in the study plot (MgC/ha).
Area = total research area (ha).
The carbon stock (C) was then used to calculate the carbon equivalent conversion using the following formula:

$$CO_2^{-e} = (44/12) \times C_{tot} \quad (4)$$

Notes:
CO_2^{-e} = conversion value of carbon equivalent to CO_2 (Mg).
44/12 = molecular weight ratio between carbon dioxide (44) and carbon (12).
C = total total carbon stock in the study area (Mg).

Statistic Test

Differences in carbon stocks between research sites were analyzed by ANOVA test, followed by the analysis of Pearson correlation to determine the relationship between C-stock and DBH, the diversity index (H'), and density (D). Statistical analysis using SPSS 24.

Model Construction for Sustainable Mangrove Management

Research results made the sustainable mangrove management model fishbone a recommendation for sustainable management of mangrove ecosystems.

Research Results

Mangrove Ecosystem Condition in Semarang-Demak in 2015 and 2020

Based on the satellite image analysis, the mangrove ecosystem changes in 2015 and 2020. The mangrove's shrunk may be caused by erosion or massive development (Fig. 4). The mangrove condition in 2020 is diminishing up to 14.14% compared to 2015.

The mangrove ecosystem in Semarang-Demak is a dynamic area and has changed between 2015 and 2020. Increases in the area occurred in the mangrove area in Trimulyo and Timbulsloko, while the decrease occurred in Sriwulan and Bedono (Table 2). This is probably due to the massive planting process since, but also deforestation as a result of the construction of the giant sea wall. Overall changes in mangrove areas decreased by more than 14% in 2020 compared to 2015.

Mangrove coverage area changes in Trimulyo may be caused by the establishment of mangrove conservation in 2016, as stipulated by the Semarang City Government. It makes mangrove planting programs mainly placed in that place. While decreased mangrove area in Bedono is mainly caused by erosion.

Analysis of Carbon Reserves Contained on the Surface (Aboveground)

Total aboveground biomass (AGBs) or the potential above-surface biomass content at the research site, ranges from the lowest at 34.72 ± 6.51 Mg/ha to the highest at 101.06 ± 13.71 Mg/ha (Table 3). A range of potential carbon stocks (C-stock) at the research site or known as the lowest C-stock is 16.32 ± 3.06 MgC/ha at the Trimulyo location. Then, the highest C-stock was observed from Bedono up to 47.50 ± 6.44 MgC/ha. The total values of C-stock when converted to CO_2^{-e} or carbon dioxide equivalent emissions, ranged from the lowest 59.83 ± 11.21 MgC/ha to the highest 174.17 ± 23.63 MgC/ha. Directly proportional to the total AGBs, C-stock, and CO_2^{-e}, then the carbon stock above the surface in the research location is Bedono > Timbulsloko > Trimulyo, respectively. The results of the statistical test using ANOVA showed significant differences in the average values of AGBs, C-stock, and CO_2^{-e} based on research location 0.007 (< 0.05).

Based on the total carbon stock at the study site, AM stands to contribute 65.79% or around 64.76 MgC/ha of carbon stock (Fig. 5). Total C-stock in AM stands was the highest compared to other stands. Successively the total C-stock by type of stand at the study site from the highest to the lowest was AM > RM > AA > SO > RS.

The relationship between total C-stock and other variables, including DBH average size, mangrove density (D), and diversity index (H') was analyzed using a bivariate correlation test (Table 4). Based on the 2-tailed significant value of Pearson correlation, between C-stock and DBH size is $0.001 < 0.05$, which means that there is a significant correlation between the C-stock variable and DBH. Furthermore, the relationship between C-stock and density (D) has a Sig value. (2-tailed) of $0.002 < 0.05$, which means that there is a significant correlation between the

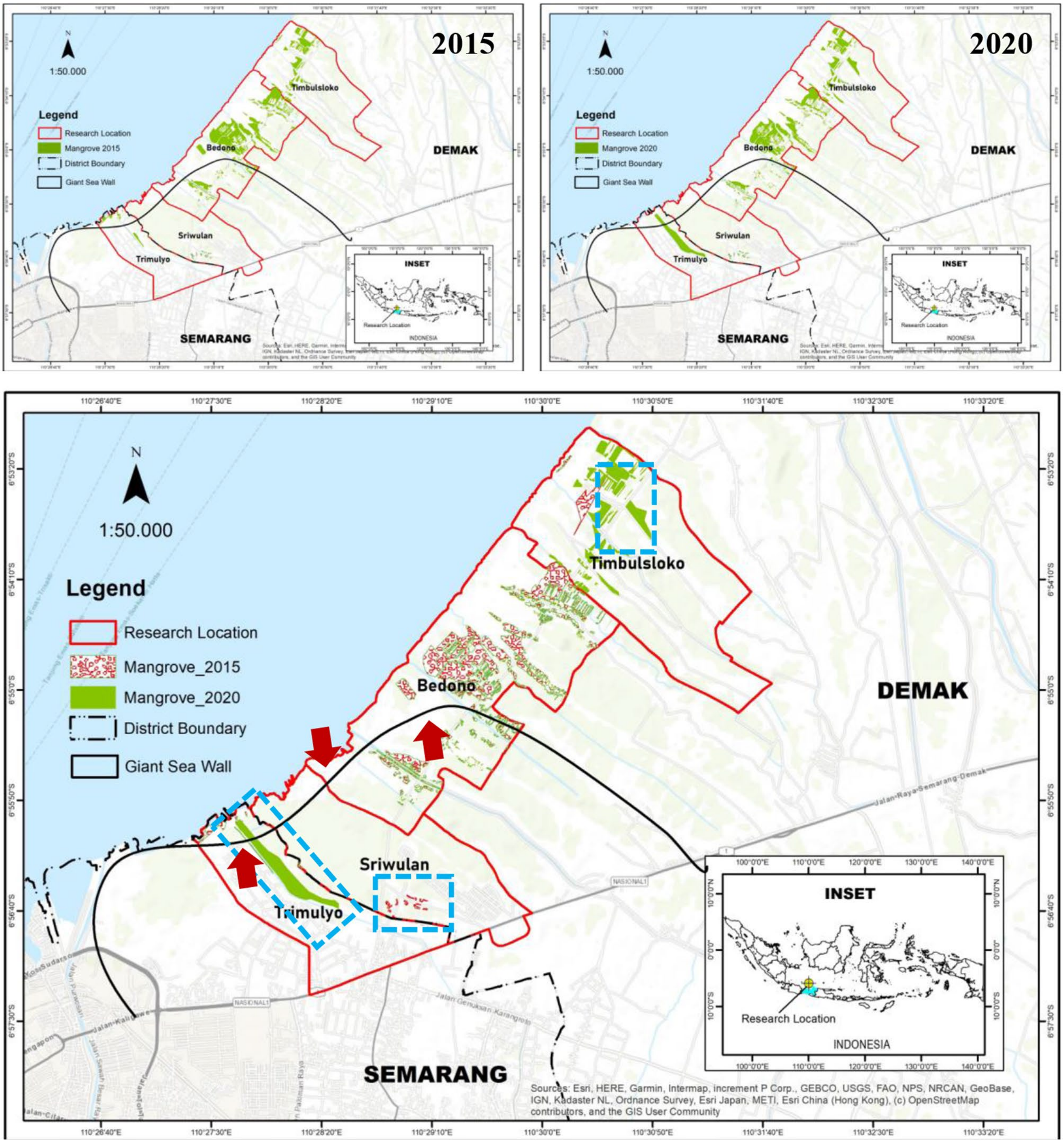


Fig. 4 The condition of the mangrove ecosystem in 2015, 2020, and its comparison (bottom). The blue box with the dotted line represents mangrove ecosystem expansion due to the massive rehabilitation activities. while the red arrows indicate the areas affected by the giant sea wall construction

C-stock variable and density. Meanwhile, the relationship between C-stock and diversity index (H') has a sig value (2-tailed) of $0.607 > 0.05$, which means that there is no significant correlation between the C-stock variable and the diversity index.

Discussion

Based on the satellite image calculation, the mangrove area in the Semarang-Demak coastal area in 2015 and 2020 decreases up to 24.64 Ha. The mangrove forest is partly

Table 2 Changes in mangrove area at the study site in 2015 and 2020

Village	Mangrove area (Ha)		Change (%)
	2015	2020	
Trimulyo	23.63	38.58	63.27
Sriwulan	2.76	1.18	− 57.25
Bedono	102.83	31.69	− 69.18
Timbulsloko	38.01	72.14	89.79
Total	167.23	143.59	− 14.14

A negative value represents a decreased area of mangrove coverage

deforested in particular places, such as in Bedono, due to erosion as a natural process. This result is in line with the previous research that describes erosion as the main factor that destructs the Semarang-Demak coastal areas (Ismanto et al. 2016; Sriyana et al. 2020; Sugianto et al. 2022). Furthermore, this study found the fact that the giant sea wall construction contributes to the mangrove forest destruction in recent years. The giant sea wall is a multipurpose construction built by the government to prevent Semarang-Demak coastal areas from erosion caused by sea-level rises and tidal flooding. The construction is built across the mangrove ecosystem, including in Trimulyo Sub-District in Semarang City, Sriwulan, Bedono, and Tambaksloko Sub-District in Demak.

Coastal area destruction started in the 1990s when the fisheries extensification program was first encouraged to increase shrimp production and export. The shrimp farmers clear mangrove forests to expand fishponds and increase their productivity (Ilman et al. 2016; Lukman et al. 2019). However, it destructs and damages coastal line areas that are difficult to recover until today. Then, mangrove planting had been conducted since the 2000s as a national strategy to rehabilitate coastal areas as well as a mitigation program against high waves, water intrusion, and erosion in the Semarang-Demak coastal area. The mangrove forest is useful to reduce waves, strong winds (del Valle et al. 2020), ecotourism (Khakhim et al. 2021), and carbon sink preventing global warming (Kandasamy et al. 2021; Zhu and Yan 2022).

The mangrove area in Semarang City-Demak Regency is potentially beneficial for storing carbon stocks. Mangrove plants are estimated to absorb up to 75–150 Tg C/ha/year of carbon from the atmosphere (Mutiatari et al. 2018). The conversion of mangrove land into commercial, industrial and residential areas contributes to the reduction in the potential for carbon stock storage. The total biomass potential of the mangrove ecosystem in Semarang City reaches 32.55 tons/ha in ponds to 77.26 tons/ha in river areas. Likewise, the highest amount of carbon content above the surface is found in mangrove river ecosystems, which is 397.00 tons/ha. Meanwhile, the mangrove forest ecosystem reached 293.42 tons C/ha (Martuti et al. 2017).

Furthermore, the *Avicennia marina*, the most abundant species in Semarang-Demak coastal area, is the highest contributor to carbon stocks source, followed by *Rhizophora mucronata* and *A. apiculata*. Species dominancy of *A. marina* is highly contributing to mangrove ecosystem

Table 3 Total AGB, C, and CO_2^{-e} above the surface at the study site

Location	Type	AGBs (Mg/ha)	C-stock (MgC/ha)	CO_2^{-e} (MgC/ha)
Timbulsloko	AA	33.12 ± 8.94	15.64 ± 4.19	57.34 ± 15.37
	AM	31.42 ± 6.87	14.77 ± 3.23	54.14 ± 11.83
	RM	8.75 ± 2.17	4.11 ± 1.02	15.08 ± 3.77
	RS	0.20 ± 0.11	0.09 ± 0.05	0.34 ± 0.19
	Total	73.63 ± 13.87[a]	34.61 ± 6.51[a]	126.90 ± 23.90[a]
Bedono	AM	74.19 ± 10.97	34.87 ± 4.15	127.85 ± 18.90
	RM	26.87 ± 18.31	12.63 ± 8.60	46.31 ± 31.56
	Total	101.06 ± 13.71[ab]	47.50 ± 6.44[ab]	174.17 ± 23.63[ab]
Sriwulan	AA	N/A	N/A	N/A
	RM	N/A	N/A	N/A
Trimulyo	AA	2.08 ± 0.64	0.98 ± 0.3	3.58 ± 1.10
	AM	32.17 ± 6.44	15.12 ± 3.03	55.45 ± 11.10
	RM	0.04 ± 0.04	0.02 ± 0.02	0.07 ± 0.07
	SO	0.43 ± 0.31	0.20 ± 0.14	0.74 ± 0.53
	Total	34.72 ± 6.51[b]	16.32 ± 3.06[b]	59.83 ± 11.21[b]

The difference test between research locations used ANOVA, the difference showed significant results <0.05

AGB Aboveground biomass (Mg/ha), *C-stock* Carbon stock (MgC/ha), CO_2^{-e} carbon equivalent of CO_2 (MgC/ha), *AA Avicennia alba*, *AM Avicennia marina*, *RM Rhizophora mucronate*, *RS Rhizophora stylose*, *SO Sonneratia* sp, *N/A* not applicable

Superscript letters ([a,b]) indicate differences between subsets

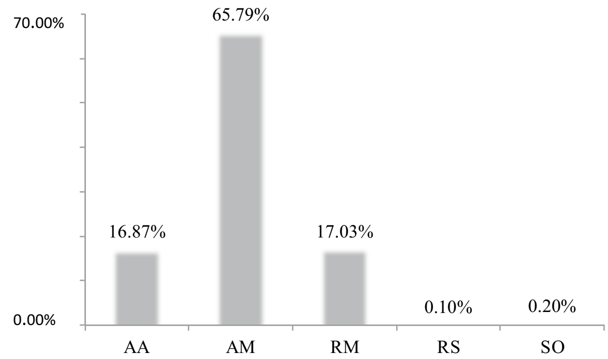


Fig. 5 Distribution of C-stock based on mangrove species constituent in the study site. AA *Avicennia alba*, AM *Avicennia marina*, RM *Rhizophora mucronate*, RS *Rhizophora stylose*, SO *Sonneratia* sp

Table 4 Person correlation coefficient value between C-stock, DBH, density, and Diversity Index

		H	DBH	D	C-stock
H	Pearson correlation	1	396	− 0.019	238
	Sig. (2-tailed)		379	967	0.607
DBH	Pearson correlation	396	1	0.829*	0.944**
	Sig. (2-tailed)	379		0.021	0.001
D	Pearson correlation	− 0.019	0.829*	1	0.938**
	Sig. (2-tailed)	967	0.021		0.002
C-stock	Pearson correlation	238	0.944**	0.938**	1
	Sig. (2-tailed)	0.607	0.001	0.002	

*Correlation is significant at the 0.05 level (2-tailed)

H' Diversity Index, *DBH* diameter at breast high, *D* density, *C-stock* potential carbon stock

**Correlation is significant at the 0.01 level (2-tailed)

carbon stocks deposition. The abundance of tree stands of *A. marina* is caused by massive planting activities that had been conducted since the 2000s using three main species of mangrove, including *A. marina*, *R. mucronata* and *A. apiculate* (Martuti et al. 2022). The planting activities are initiated by the government and followed up by private sectors through a corporate social responsibility program (Rakhmanissazly et al. 2018; Soesilowati et al. 2021). In the current planting program, the academicians encourage related stakeholders to increase mangrove ecosystem biodiversity by planting additional various species, including *R. apiculate, R. stylosa*, *Sonneratia alba*, *S. ovata,* and *Bruguiera gymnorhiza* (Rahmila and Halim 2018).

Physiologically, *Avicennia* sp and other mangrove species remove excess salt from the tissue through salt glands and secrete the remaining salt through the leaf base, making them tolerant to hypersalinity (Theuerkauff et al. 2018). Furthermore, the unique characteristic of the *Avicennia* and *Rhizophora* genera, i.e. strong roots, seeds, and stems, make those species' seedlings survive in muddy habitats and strong tidal waves. These characteristics also cause *Avicennia* and *Rhizophora* to be the most dominant genera in the mangrove ecosystem, compared to *Sonneratia* and *Bruguiera* which are difficult to grow because of high tides disruption during the seedling process (Chowdhury et al. 2012; Pilato 2019; Scanlan 2022). Therefore, the characteristics of mangrove species need to be considered and adjusted to the topographic coastal characteristics and contours of Semarang-Demak, when carrying out rehabilitation after giant-sea wall construction.

However, the mangrove diversity may not important in carbon reserve value Based on the correlation analysis among variables, carbon stocks, diversity index, density, and stem diameter, that reserve value is only determined by the plant size and species density. The bigger the stem diameter, the higher the contained biomass and C stock in organic form (Pragasan 2022). In addition, high tree density is associated with more biomass and high organic carbon stock in a mangrove ecosystem (Khadanga and Jayakumar 2020; Ma et al. 2020; Salunkhe et al. 2018). However, the destruction of mangroves also contributes to a large number of carbon emissions. Therefore, it needs a holistic coastal ecosystem management policy to manage the mangrove ecosystem, thereby increasing its beneficial effect on the community.

This study may be useful to develop a database for the sustainable management of mangrove ecosystems in the coastal area of Semarang-Demak. For this reason, a comprehensive rehabilitation plan should be arranged by involving multi-stakeholder partnership in sustainable action. based on the analysis, we suggest a management action through potential future research, community development, and joining programs across a multisectoral approach (Fig. 6).

Based on the mangrove management diagram, various environmental data of the mangrove ecosystem should be collected in the early study before policymaking, and this research is one of the preliminary studies on the biogeophysical data faction. Other studies should be run on the environmental services provided by the mangrove ecosystem for establishing an environment database. Then, the other study shall focus on the community socio-culture and economy in terms of mangrove management, and multi-stakeholders partnership to create a holistic and sustainable mangrove action plan.

The application of the benefits of mangroves from an environmental, economic, and social point of view certainly requires cross-sectoral integrated action between the government, the community, academia, the business sector, and the media to accommodate all intersecting interests.

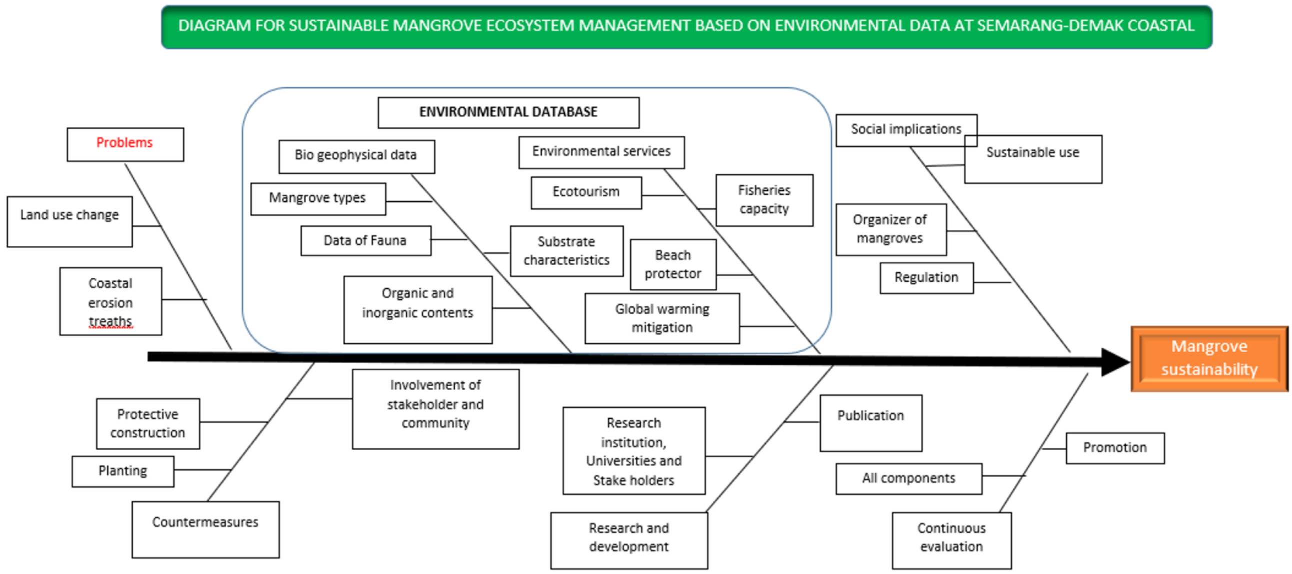


Fig. 6 Diagram of sustainable ecosystem management

(López-Pérez et al. 2017; Rahatmawati et al. 2021; Soesilowati et al. 2021). The integrated management is carried out to prepare and plan the protection and development of the mangrove ecosystem holistically. The existence of good and sustainable management of mangrove ecosystems is expected to improve environmental quality in coastal areas, while maintaining the biodiversity and productivity of coastal ecosystems (Martuti et al. 2018, 2020).

Since 2018, the Semarang City Government create a community-based mangrove protection program through a mangrove working group. This group is a forum for friendship and cooperation between mangrove activists in the city of Semarang, consisting of various levels of society. In protected areas and natural resources (Armitage 2005; Cox et al. 2010; Pretty 2003). Social institutions supported by various sectors will certainly encourage the role of the community through the spirit of togetherness to protect the mangrove ecosystem.

The Semarang City program's effectiveness is proven by an increase in the area of mangrove cover, diversification of livelihoods, and improving the quality of coastal ecosystems. Furthermore, social institutions are needed to increase the role of the community, and it is applied also in the Sayung District of the Demak Regency, However, the comprehensive joined program seems not well developed and not prioritized by the Demak Regency government. Because only a small part of the erosion-affected areas may make mitigation program priority only focused on industrial, public housing, and facilities affected by the tidal flooding, not on mangrove rehabilitation. Furthermore, the giant sea wall program is also considered the main solution for the Demak Regency government to solve erosion and tidal flooding in coastal areas, rather than strengthen community-based rehabilitation.

Conclusion

The lowest carbon stock is 16.32 ± 3.06 MgC/ha at the Trimulyo location and the highest is 47.50 ± 6.44 MgC/ha at the Bedono location. The total C-stock when converted to CO_2^{-e} or carbon dioxide equivalent emissions ranged from the lowest 59.83 ± 11.21 MgC/ha to the highest 174.17 ± 23.63 MgC/ha. Directly proportional to the total AGBs, C-stock, and CO_2^{-e}, the carbon stock above the surface, from the highest to the lowest, is Bedono > Timbulsloko > Trimulyo. The area of mangroves on the Semarang-Demak border in 2020 has decreased compared to 2015. An integrated action is needed between components for the sustainability of the mangrove ecosystem in the coastal area of the Semarang-Demak. A holistic action plan should be conducted by involving multi-stakeholders for integrated mangrove management. We suggest, several activities involving, (1) the community as the main actors in mangrove rehabilitation; (2) the government as a policy-maker providing financing support for infrastructure and technology transfer, financial stimulants, and coordinator; (3) academics for feasibility studies and program consultants; (4) non-government organizations (NGOs) for monitoring and mentoring; (5) private sector through corporate social responsibility (CSR) funding to develop community empowering program, and; (6) media, as disseminator and knowledge transfer agents.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest in the data collection, management, or funding.

Ethical Approval Unethical actions were not made.

Consent to Participate All authors gave consent to participate in this publication.

Consent for Publication All authors gave consent for publication in the International Journal of Environmental Research.

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