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MANGROVE MANAGEMENT STUDIES IN BREBES REGENCY, CENTRAL JAVA, INDONESIA

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ABSTRACT

Human anthropogenic activities, such as land conversion for ponds and agriculture, as well as the development of environmentally unfriendly infrastructure, have contributed to increased environmental degradation. Furthermore, it is driving global temperature increase and climate change, including pressure on the sustainability of mangrove areas such as those in Brebes Regency, Central Java, Indonesia. This study aims to evaluate mangrove management in the Brebes Regency. The study applies qualitative and quantitative descriptive approaches (mixed methods) with the Systematic Literature Review (SLR) method and a survey method to examine the mangrove management that has been implemented. Management aspects include abiotic, biotic, and cultural aspects. The result of the study showed that the coastal ecosystem in the western region of Brebes Regency is dominated by mangrove ecosystems, where most of the mangrove areas have been converted into ponds. The study recommends providing assistance to communities regarding a green economy that supports mangrove sustainability, mitigating the damage of mangrove areas, conserving mangrove areas, and continuously implementing integrated management to ensure sustainability in the future.

Keywords: *mangrove; integrated_management; sustainability, Indonesia.*

INTRODUCTION

Indonesia still has the largest mangrove forests in the world (Bengen et al., 2023). Mangrove forests are a vegetation ecosystem found in tidal areas on the coast, beaches, and small islands (Pramudito et al., 2020). The area of mangrove ecosystems in Central Java Province ranks first in Indonesia, reaching 1,78 million hectares (Sulaiman et al., 2019). Data from the Central Java Maritime Affairs and Fisheries Service in 2011 showed that the area of mangroves in the North Coast of Central Java decreased drastically by 2,458 hectares compared to 2009, when the area was still 95,334 hectares (Rosalia et al., 2023). Coastal areas, especially mangrove ecosystems, which experience many pressures both naturally and due to anthropogenic activities, can result in less productive conditions and are vulnerable to damage (Anjani et al., 2024).

Human activities in daily life have impacted the current environmental conditions. Constantly pressing economic needs encourage humans to be more creative in utilizing land. Land use for economic activities is expanding, one example being in coastal mangrove areas, developing into shrimp ponds (Rahmawati et al., 2024). Factors influencing the reduction of mangrove area include ecological, social, economic, and cultural factors of the local community (Gemilang, 2017). Local residents, through their various life activities to meet their social, economic, and cultural needs, have and continue to utilize the potential of the surrounding natural resources (Lestari, 2022).

Brebes Regency has a dynamically changing coastal area, where land use is very complex, accompanied by unbalanced planning and management of natural resources (Saputro et al., 2021). The coastline of Brebes Regency stretches from the west, bordering the coast of Cirebon Regency, West Java, to the east, bordering the coast of Tegal City. Almost all land use is for inland fisheries, namely fishponds (Garis et al., 2019). Furthermore, Brebes Regency is recorded as the region with the largest population, reaching 2,065,501 people (BPS Kabupaten Brebes, 2025). The majority of Brebes' coastal communities work as fishermen and depend on marine products for their livelihood, either as fishermen, entrepreneurs, intermediary traders, processing workers, fish vendors, or other services (Mahulette et al., 2017).

The existence of mangrove ecosystems supports the economy of coastal communities, especially those who use them as a source of livelihood (Zainuri et al., 2017). In addition, the existence of mangrove ecosystems plays an important role in controlling the global climate, especially related to the function of storing and absorbing carbon (S.D., 2024a) and natural mangrove ecosystems as wetlands that are useful for aquaculture (Ouyang & Guo, 2016) and of course have ecological functions (Gerona-Daga & Salmo, 2022). The total carbon storage value is known to increase with the increase in the area of the mangrove ecosystem (Nugraha et al., 2020). In addition, the mangrove ecosystem functions as a tourist area such as in Kaliwlingi Village, which is shown by the results of the economic valuation analysis, which shows a total economic value of IDR 12,912,098,100 (twelve billion nine hundred twelve million ninety-eight thousand one hundred rupiah) (Christy, 2019). Good land management can support ecosystem sustainability and biodiversity (Kondong et al., 2025). Management can be realized, among other things, through conservation or rehabilitation. Rehabilitation is carried out to restore the function of the mangrove forest ecosystem to its original state (A. Y. N. Annisa et al., 2019). For example, in response to abrasion, the community cultivated mangroves as a conservation effort and developed into mangrove ecotourism in Kaliwlingi Village, Brebes District, Brebes Regency (Ayu Pratiwi et al., 2023).

Mangrove ecosystem degradation should be detected early for area management and mitigation (Winarso et al., 2023). This is because mangroves can increase resilience to coastal disasters and climate change (Damastuti et al., 2023) and act as a carbon storage ecosystem (Sidik et al., 2023). Increasing ecosystem degradation can also threaten society and human well-being (Yamamoto, 2023). Because it impacts the livelihoods

of many people, collective awareness and the involvement of various stakeholders are required (Arumugam et al., 2020), under the name of integrated management (Shusheng et al., 2023). This study emphasizes the need for continued management of mangrove forest areas to ensure sustainable restoration efforts.

In Brebes Regency, particularly in the northern coastal area, mangrove is a crucial component in supporting the sustainability the sustainability of coastal ecosystem vulnerable to natural pressures and human activities. The Kalianyar mangroves in Prapag Kidul Village, Losari distric and Pandansari Mangrove in Pandansari Village, Wanasari distric are mangrove area that has developed through natural process and community-based rehabilitation and serve a vital ecological function for coastal protection and local fisheries. However, two locations still face various pressures, such as coastal erosion, changes in coastal dynamics and human activities around the mangrove area, especially The Kalianyar mangrove.

To date, scientific studies specifically documenting the biophysical conditions and dynamics of The Kalianyar mangroves ecosystem are limited, especially compared to other more extensively studied mangrove area in Brebes. Therefore, research on the Kalianyar mangrove is crucial to obtain a scientific overview of the ecosystem's condition, level of sustainability, and management challenges. This can the serve as a basis for formulating more effective and sustainable mangrove management and rehabilitation strategies at the local level.

LITERATURE REVIEW

Mangrove

Mangroves are known by most Indonesians as plant communities found in estuaries and coastal areas. In general, the trees in mangrove ecosystems are tolerant of extreme environmental conditions, such as flooded soil and high salinity. These ecosystems are affected by tides. The communities of plants, animals, and other living things (biotic factors), along with the water, soil, and air (abiotic factors) associated with these mangroves, form a mangrove ecosystem (Kathiresan and Bingham, 2001; Primavera et al., 2019; S.D., K., 2024). Mangroves are crucial for life in coastal areas. This vegetation plays a role in protecting coastal areas and maintaining the habitat of associated biota, thereby preserving biodiversity. Mangrove ecosystems, as coastal habitats, are a rich source of biodiversity and serve as ecosystems that absorb large amounts of carbon and store it permanently in the marine environment (Puspaningrum & Suleman, 2023).

Mangroves are reported to have ecological and economic roles. Ecologically, mangroves serve as carbon storage, ecotourism and provide habitat for various types of aquatic organisms, such as fish, mangrove crabs, bivalves, and gastropods. In addition, mangroves also play an important role in supporting the economy for local communities, including the use of firewood and charcoal, and the capture of fishery products such as clams, crabs, shrimp, wangkang, prawns, Sembilang and Tomang fish, white snapper, and Betutu fish (Safitri et al., 2024).

Antropogenic Activities

The reciprocal relationship between living things and the environment that occurs in mangrove forests is considered vulnerable to changes caused by the surrounding environment. Furthermore, mangroves are vulnerable to resource exploitation, which can lead to deforestation and degradation (Cahyaningsih, et al., 2022; Samsumarlin, Rachman, I. & Toknok, B., 2015; Bhagarathi and DaSilva, 2024). Human activities such as cutting down mangrove trees, conversion of mangrove forests into plantations, settlements, industries, irrigated rice fields, rainfed rice fields, and fish or shrimp ponds to fulfill their lives and livelihoods have had an impact on the existence of mangrove forests so far (Mappanganro et al. 2018; Cahyaningsih et al. 2022). Pressure from human activities around mangrove areas can cause damage to the mangrove ecosystem, especially to the biota that live within it. Therefore, mangrove ecological studies are necessary for monitoring, management, and conservation (Aryanti et al., 2021).

Rehabilitation of Mangrove

Mangroves rehabilitation programs have been extensively implemented in various parts of the world (Field, 1999), and in Southeast Asia, most rehabilitation efforts have used a trial-and-error approach without an integrated framework, ecological information base, or consideration of community involvement. As a result, few of the implemented programs have been successful (Aksornkoae, 1996; Al-khayat and Jones, 1999; Bandaranayake, 1998). According to Brown et al. (2014), many mangrove rehabilitation efforts in Indonesia have failed, and the primary cause is the mistaken belief that mangrove rehabilitation can be easily achieved through planting, primarily using seedlings of the *Rhizophora* genus. One massive program that can serve as a lesson is the coastal restoration and mangrove planting in Aceh after the tsunami of December 26, 2004, where approximately 27,532 ha of coastal area was allocated for mangrove planting. Evaluation results indicate that the program's success rate is still far from expectations, and contributing factors include changing environmental conditions, incorrect location selection, inadequate preparation and experience, weak coordination, and unclear spatial planning (Wibisono et al., 2006). Many reports on the implementation of mangrove rehabilitation programs only report the number of seedlings planted and the area planted, and only a few report evaluation results, let alone failures (Djamaluddin, 2018).

RESEARCH METHODOLOGY

A systematic literature review (SLR) is a research design conducted to systematically synthesize existing research evidence. The data used is secondary data sourced from institutions and scientific publications (Tim Penyusun, 2020). The concepts reviewed include mangroves, their impact from anthropogenic activities, and existing mangrove ecosystem management practices (Anggreini & Susilawati, 2023). This research conducted from Mei to Agustus 2025 in Brebes Regency. Brebes Regency is located at (6°44' - 7°21' South Latitude and 108°41' - 109°11' East Longitude). Based on its

geographical position, Brebes Regency has boundaries: North –Java Sea; South – Banyumas Regency; West – West Java Province; East–Tegal Regency and Tegal City. Brebes Regency consists of 17 (seventeen) sub-districts and 297 villages/wards with an area of 1,769.62 km². Bantarkawung District is the largest sub-district (208.18 km²), and the sub-district with the smallest area is Kersana District (26.97 km²). Brebes Regency has 5 (five) sub-districts, which include coastal areas in the northern part, namely Losari, Tanjung, Bulakamba, Wanasari, and Brebes Districts (Figure 1). The southern region is mostly located in the highlands, while the northern region is located in the lowlands. The highest sub- district is Sirampog Sub-district, at an altitude of 875 meters.

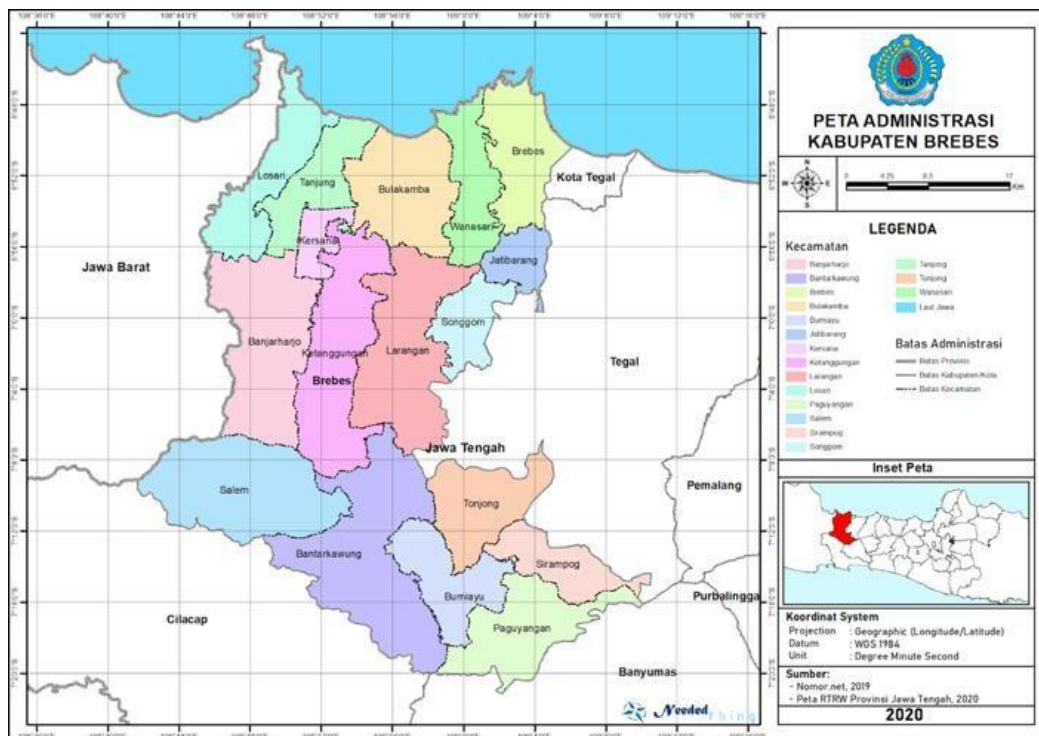


Figure 1. Administrative Map of Brebes Regency.
<https://neededthing.blogspot.com/2020/12/peta-administrasi-kabupaten-brebes.html>

The tools used include camera, car, laptop, paper and pen. The research employed mixed methods, analyzing data qualitatively and quantitatively. Mixed methods research is a type of research that combines two research methods, quantitatively and qualitatively, integrated to form new findings and then draw conclusions (Subagyo, 2020; (Hakim Nasution et al., 2024). Primary data was collected through surveys at the research sites, field observations, and activity reports from the Brebes Regency Environmental Agency and Regional Development Planning Agency (BAPPEDA). Articles related to mangrove management and/or ecosystems in Brebes Regency were also reviewed.

RESULTS AND DISCUSSION

Environmental Control and Management

Brebes Regency has four priority environmental issues: land conversion, waste management, reduced water availability, water pollution, and disaster risk. Several programs being pursued include a) the Adiwiyata program; b) the climate village program; c) physical environmental activities as part of environmental rehabilitation efforts; d) waste management and utilization; e) collaboration between all parties in the clean environment, reforestation, and reforestation movement; f) hazardous waste management; and g) community participation in environmental management.

Coastal environmental management in Brebes Regency faces persistent pressures from land uses conversion, water pollution (Figure 1) and increasing climate related risk, all of which directly affect mangrove ecosystems. In Kalianyar (Prapag Kidul), mangrove management is limited by narrow land availability, high wave exposure and proximity to small scale aquaculture activities, resulting in low survival rates of planted mangroves and reduced ecological stability. Community-led adaptive measures, such as bamboo fencing to protect seedlings from wave action and boat traffic, demonstrate local resilience but remain insufficient to fully support long-term restoration. In contrast, the Pandansari mangrove area (Wanasari) benefits from larger restoration areas and more structured management, enabling mangroves to function more effectively as coastal buffers and regulators of water quality.



Figure 2. Waste accumulation in coastal mangrove areas

Differences in socio-economic integration further explain the contrasting outcomes between the two sites. In Kalianyar, where livelihoods are dominated by fishing and informal labor such as crab processing, mangrove conservation provides limited direct economic benefits, constraining sustained community participation. Conversely, Pandansari has successfully integrated mangrove conservation with ecotourism and alternative income generation, strengthening institutional coordination and local engagement. This comparison highlights that mangrove sustainability is shaped not only by ecological conditions but also by governance capacity and livelihood alignment, emphasizing the need for integrated social-ecological management to enhance resilience in small-scale coastal systems.

The pollution seen in the coastal area does not only originate from residential activities, but is also influenced by marine debris carried by currents and waves as well as waste from upstream rivers that flow into the coast, so that plastic waste and other inorganic materials accumulate in calm areas such as around mangroves and piers, especially during low tide; this condition shows that pollution is cross-regional, so that its control must be carried out in an integrated manner from upstream to downstream through the restoration of waste management in river basins, control of marine debris, increasing participation of coastal communities, and rehabilitation and protection of mangroves as a natural ecological fortress that requires coordination across sectors and regions.

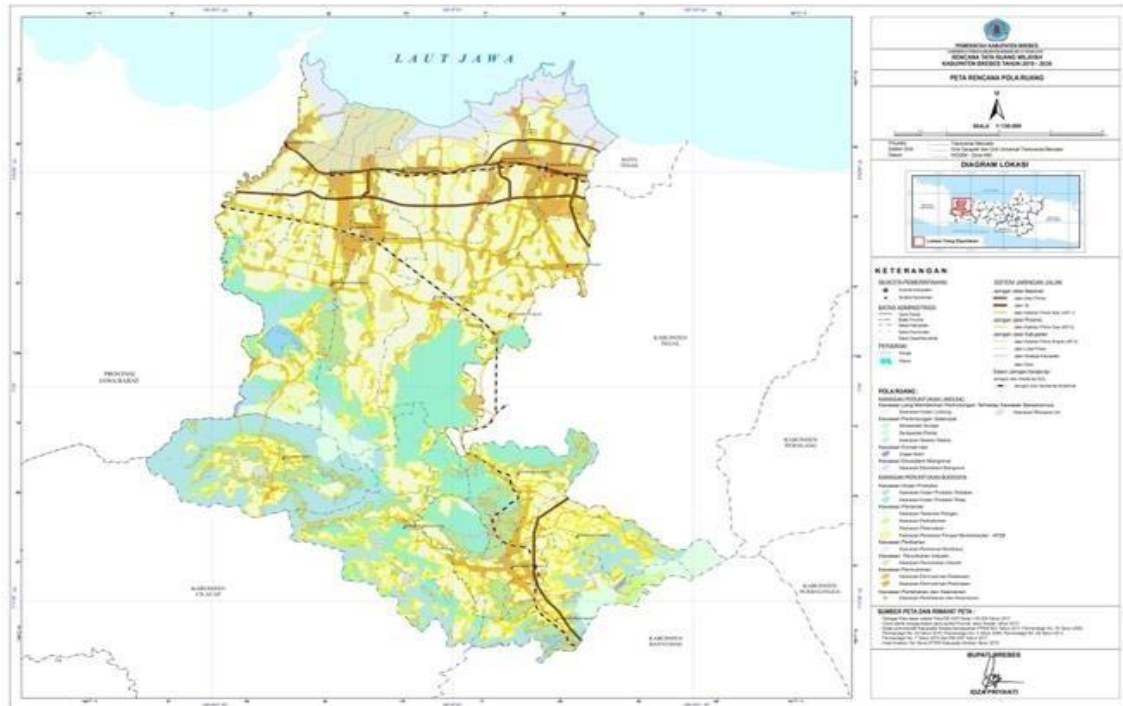


Figure 2. Brebes Regency Spatial Planning Map (Source: <https://sirentang.brebeskab.go.id/rtrw>)

Mangrove Ecosystem Area

The presence of coastal mangrove areas undeniably provides opportunities for life and livelihoods for local communities. The 2023 Brebes Regency Statistics Agency (Brebes Regency Communication, Informatics, and Statistics Office 2024) shows that the economic structure of Brebes Regency is still dominated by the agriculture, forestry, and fisheries business sector, contributing 34.28% to the Brebes economy. The next largest business sector is the processing industry, contributing 18.83%. According to the Integrated Coastal Zone Management (ICZM, 2024) report, the economy of the people on the west coast of Brebes Regency is based on farming and fishing, with agriculture and fisheries still the dominant sectors. Furthermore, limited infrastructure and access to education and healthcare remain factors in the region's well-being, which are continually being pursued.

The decrease area of mangrove ecosystems has become a primary focus of mangrove management. Land use for mangrove forests in Brebes Regency is recorded at 140,290 hectares (DPSDAPR Brebes Regency, 2023). Land use by purpose in Brebes Regency is presented in full in Table 1.

Table 1. Land Use by Purpose in Brebes Regency

No.	Land cover	Area (Ha)
1	Upland Forest	33.181,276
2	Teak Forest	10.386,958
3	Community Forest	1.329,443
4	Mangrove Forest	140,290
5	Mixed Gardens	11.263,589
6	Fields/Dry Fields	10.004,526
7	Tea Plantations	554,834
8	Asphalt/Concrete/Dirt Road Network	106,202
9	Sand/Land Dunes	10,655
10	Settlements	20.025,477
11	Savanna	58,903
12	Irrigated Rice Fields	52.443,116
13	Rainfed Rice Fields	19.537,314
14	Brushes	371,864
15	Rivers	2.452,879
16	Fishponds	13.141,588
17	Reservoirs	792,159
18	Ponds	15,935
	Total	175.817,008

Source: DPSDAPR (Water Resources Management and Spatial Planning Agency) Brebes Regency, 2023 (Pemerintah Kabupaten Brebes, 2024)

In Table 1, the area of mangrove forests is recorded as very small, only 140,290 hectares, while the area of ponds is 13,141,588 hectares. Reality shows that Indonesia, as an archipelagic country, in this case, the coastal area, policymakers have made efforts (with a long history) in mangrove management. However, economic factors are the main "influence" in changing the existence of mangrove ecosystems into ponds. This condition has given rise to environmental concern responses from various parties, including the government, industry, NGOs (Non-Governmental Organizations), research institutions, and the general public. Recalling the mandate in the Law on Environmental Protection and Management (UPPLH) Number 32 of 2009, it is detailed that Environmental Protection and Management are systematic and integrated efforts carried out to preserve environmental functions and prevent pollution and/or environmental damage including planning, utilization, control, maintenance, supervision, and law enforcement (UPPLH No 32 Tahun 2009, n.d.). Concerns about the estimated loss of ecological functions provided in the form of environmental services by mangrove ecosystems due to deforestation have revived the targets for the reforestation of mangrove areas. Based on land use data in protected areas in Table 2, outlining the planned mangrove ecosystem areas as protected areas in

the Brebes Regency Spatial Plan (RTRW), most of which have been implemented (vegetation cover in the form of mangroves).

Table 2. Land Cover in Protected Areas

No.	Area Name	Area (Ha)	Land Cover (Ha)			
			Vegetation	Building area	Open area	Land area
1	Nature Reserve	53,56	36,49	-	-	17,08
2	Mangrove Ecosystem	195,45	188,61	0,05	-	6,78
3	Protected Forest	6.169,51	6.169,51	-	-	-
4	Reservoir Surrounding	137,00	97,38	1,23	-	38,39
5	Coastal Boundary	497,43	2,99	-	494,44	-
6	River Boundary	1.121,20	921,38	94,36	53,22	52,24

Source: Revised Brebes Spatial Plan (RTRW), Land Cover Classification Without Landsat Satellite Imagery Surveillance for the 2023 Recording Year (Pemerintah Kabupaten Brebes, 2024)

Furthermore, Brebes Regency is being prepared as a location for a Large-Scale Mangrove Nursery and a Mangrove Center of Excellence with a current mangrove area of 1,416.67 Ha. The distribution of locations according to data from the Brebes Regency Fisheries Service in 2023 was in 12 (twelve) locations, namely Randusanga wetan (202 Ha), Randusanga kulon (289.2 Ha), Kaliwlingi (431 Ha), Sawojajar (113.5 Ha), Bangsri (10 Ha), Pulogading (15 Ha), Grinting (49 Ha), Krakahan (44.87 Ha), Pengaradan (51.4 Ha), Prapag kidul (60 Ha), Karangdempel (59.25 Ha), and Limbangan (91.25 Ha).

The mangrove ecosystem in Brebes Regency plays a crucial role in supporting the sustainability of the coastal economy, which is still dominated by the agriculture and fisheries sectors. In the Kalianyar mangrove area (Prapag Kidul Village) and Pandansari (Wanasari District), mangroves serve as an ecological buffer for fishing activities and coastal protection. However, the contribution of mangroves to strengthening the local economy shows significant differences. Kalianyar's mangroves face limited area and pressure from fishpond activities, thus limiting direct economic benefits to the community. In contrast, the Pandansari area boasts a more consolidated and structured mangrove area, enabling it to support ecological functions as well as economic development based on ecotourism and mangrove rehabilitation.

Land use data shows that the area of mangroves in Brebes is much smaller than the area of fishponds, reflecting the strong economic incentives driving the conversion of mangroves into fishponds. This condition has resulted in a decline in the capacity of mangroves to provide ecosystem services, especially in areas with limited area like Kalianyar. Although spatial planning policies and mangrove rehabilitation programs have been implemented, their effectiveness is highly dependent on biophysical and institutional conditions at the local level. A comparison between Kalianyar and Pandansari shows that mangrove management integrated with spatial planning, strengthening community institutions, and sustainable economic incentives tends to result in more stable and resilient mangrove ecosystem conditions.

Mangrove Ecosystem Management

The mangrove ecosystem has been known as a natural fortress in warding off the large waves that hit coastal areas. Strong roots and perfect structures

form rows of mangroves that can be relied upon for years, becoming a habitat for various types of fish and endemic biota. The management of the mangrove ecosystem that has been carried out is inseparable from the potential for extreme wave disasters and abrasion in Brebes Regency. There are 5 (five) sub-districts recorded that experience potential losses from abrasion disasters in Brebes Regency, namely Losari, Tanjung, Bulakamba, Wanasari, and Brebes. Based on the Landsat satellite imagery map, coastal erosion data in 5 (five) sub-districts on the north coast of Brebes Regency is

656.22 ha with an erosion rate of 54.69 ha per year, Document Information on Regional Environmental Management Performance (DIKPLHD Brebes Regency, 2024). In more detail, efforts to reduce abrasion disasters are carried out by constructing breakwaters, revetments, and forming sea walls (groins). Planting mangrove trees, preserving coastal forests, and maintaining and preserving coastal areas, such as rocks and components around the coast.

Various efforts to preserve the mangrove ecosystem have been carried out and have involved various parties, including developing mangrove ecotourism areas, mangrove planting activities funded by various parties (self-funding, HUT BUN, Kehati Foundation, Microsoft CSR, Cita Buana CSR, Buni Karsa CSR, PT Lintaserta CSR, GEF SGP, DKP, and, in 2023, as many as 200,000 (two hundred thousand stems) funding sources from PLN). Furthermore, mangrove management has been carried out by local communities by processing mangrove fruit into Pedada Mangrove syrup (*Sonneratia caseolaris*). In addition, efforts to care for the mangrove ecosystem are also made by various Foundations (NGOs). The KEHATI Foundation strives to disseminate information that raises awareness about the ecological and economic functions of mangrove forests to the wider community, especially to social media users (kehati.or.id). Because mangrove management involves various stakeholders, its implementation must continue to be monitored and evaluated to determine what extent it is efficient and effective according to targets. Fragmented management, lack of communication between various levels of management, and other issues developing at the village level must be addressed.

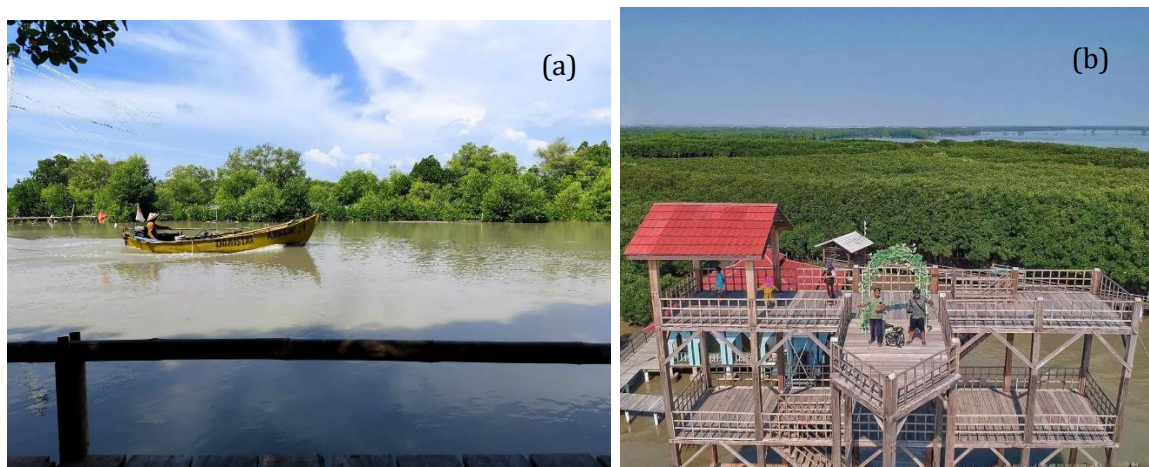


Figure 4. Mangrove ecosystem in Kalianyar (a) and Pandansari (b)

Mangrove ecosystems function as critical natural coastal defenses by attenuating wave energy, stabilizing sediments, and supporting coastal biodiversity. In Brebes Regency, where coastal erosion poses significant risks, mangrove management has become a key strategy for disaster mitigation, particularly in erosion-prone areas such as Losari and Wanasari. Mangrove areas in Kalianyar (Prapag Kidul) and Pandansari (Wanasari) both serve as protective coastal buffers; however, their effectiveness differs due to contrasting biophysical and management conditions. Kalianyar mangroves are constrained by limited spatial extent and direct exposure to wave action, which reduces restoration success, whereas Pandansari benefits from broader mangrove belts that enhance shoreline stability and ecosystem functionality. Details are shown in Table 3.

Table 3. Comparison of Mangrove Management between Kalianyar and Pandansari

Aspect	Kalianyar	Pandansari
Initial ecosystem condition	Degraded mangrove ecosystem located adjacent to settlements and fisheries-related activities	Severely degraded mangrove ecosystem due to coastal abrasion and land-use conversion
Main pressures	Domestic marine waste, aquaculture activities, and boat operations	Coastal abrasion, seawater intrusion, and damage to aquaculture ponds
Management objectives	Mangrove restoration and reduction of coastal pollution impacts	Coastal protection and abrasion control
Management approach	Community-based mangrove rehabilitation	Structural and vegetative rehabilitation driven by government programs
Role of local communities	Involved in planting and limited maintenance activities	Involved primarily as implementers of rehabilitation activities
Role of government/institutions	Program facilitator and technical assistance provider	Main actor in planning and implementation
Management outcomes	Mangrove growth observed but constrained by persistent pollution and waste accumulation	Mangroves relatively effective in reducing abrasion and partially utilized for processed products and batik production
Key challenges	Recurrent pollution and weak solid waste management	Sustainability of rehabilitation efforts and ongoing environmental degradation

Mangrove management in Brebes combines structural coastal defenses with community-based rehabilitation initiatives supported by multi-stakeholder funding. In Kalianyar, local communities have implemented adaptive protection measures by installing bamboo fences along mangrove areas frequently used as boat routes, aiming to prevent physical damage to mangrove roots and seedlings during docking and navigation. This low-cost, self-funded intervention reflects local ecological knowledge and community resilience but provides only partial protection against strong wave energy and long-term erosion. In contrast, Pandansari demonstrates more integrated management, where rehabilitation is supported by spatial planning, institutional coordination, and livelihood-based incentives such as ecotourism and mangrove-derived products. These contrasting approaches highlight that effective mangrove management requires not only restoration efforts but also site-specific adaptive measures, governance support, and alignment with local socio-economic contexts to ensure long-term sustainability.

CONCLUSION

This paper shows that mangrove management in Brebes Regency is strongly influenced by land use dynamics, governance capacity, and the integration of environmental protection with local livelihoods. Despite the implication of environmental control programs and regulatory frameworks, extensive conversion of mangrove areas into aquaculture ponds continues to reduce ecosystem functions, particularly in western coastal zones. In contrast, northern coastal areas such as Kalianyar and Pandansari demonstrate the potential of mangroves as coastal protection systems, blue carbon reservoirs, and community-based economic resources, although their effectiveness varies due to spatial constraints and management approaches. The findings highlight the importance of adaptive, site-specific mangrove management supported by coherent land use policies, strengthened local institutions, and green economic incentives. Future research should focus on long term evaluation of ecosystem services, restoration effectiveness, and livelihood impacts to support sustainable and evidence-based coastal governance.

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