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Spatial Dynamics of Mangrove Changes and Their Adaptive Capacity in Kandanghaur District, Indramayu Regency, West Java Province, Indonesia

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Abstract: This study aims to analyze mangrove ecosystems' dynamics and adaptive capacity in the Kandanghaur District, Indramayu Regency. This research method uses a spatial approach, collecting mangrove distribution data by studying Google Earth satellite images from 2009, 2016, and 2023. Data on environmental characteristics, mangrove vegetation density, and mangrove species identification were collected through direct field ground checks using the line transect method. Data analysis techniques were applied by implementing the mangrove ecosystem's adaptive capacity formulation. The results show that mangroves in Kandanghaur District from 2009 to 2023 increased by 70.03 hectares, and the majority of mangroves are distributed along the coast, water channels, and community ponds with a silvofishery system. The adaptive capacity of mangroves in Kandanghaur District varies from low to high, with high adaptive capacity located in two villages, namely Ilir Village and Parean Girang Village, with adaptive capacity values of 0.66 and 0.63, respectively. Mangroves with medium adaptive capacity are in Bulak Village with an adaptive capacity value of 0.60, and mangroves with low adaptive capacity are in Eretan Wetan and Eretan Kulon Villages with an adaptive capacity of 0.40.
Keywords: Indramayu, Adaptive capacity, Kandanghaur, Mangrove.

1. Introduction

Indonesia is a tropical region with a high level of biodiversity, one of which is the mangrove vegetation characteristic of coastal areas. Mangroves are a unique ecosystem in coastal areas, playing multiple roles in the balance of the coastal ecosystem, such as preventing erosion, seawater intrusion, etc. Moreover, mangroves can produce a larger amount of oxygen compared to terrestrial plants and are capable of controlling erosion and seawater intrusion into land areas, as well as retaining debris originating from the land, controlled through their root systems [1]. Mangrove forests are a natural resource of tropical regions that offer significant benefits both ecologically and economically [2]. The availability of mangrove ecosystems can affect the availability of fish resources and benthic biota communities and create a chain in the surrounding areas [3]. Mangroves in Indonesia have been continuously increasing, based on the 2013-2019 Indonesian Mangrove Map (PMN), the area of Indonesian mangroves is 3,311,207 ha, and in the 2021 National Mangrove Map, Indonesian mangroves are 3,364,080 Ha. This indicates that the area of mangroves in Indonesia has increased by 52,873 Ha. This increase shows a positive indication of efforts to rehabilitate and conserve mangrove ecosystems in Indonesia carried out by many parties, both Ministries/Institutions and community groups, especially coastal communities independently [4].

However, some areas have experienced declines due to the conversion of mangrove lands for other purposes, such as for settlements, industry, plantations, and ponds, which is also supported by [5], stating that mangrove forest vegetation in almost every area. The mangrove ecosystem is a priority habitat due to its crucial role in the coastal and marine ecosystems [6]. Vegetation communities grow in intertidal and supratidal areas with sufficient water flow and are protected from large waves and strong tidal currents [7].

The current climate change and global warming are impacting the frequency of extreme weather events and the rise of sea levels [8]. These changes affect the rate of groundwater recharge, such as the frequency and intensity of droughts and floods and the rise of sea level. Consequently, both environmental systems and humans are negatively impacted by climate change [9]. The impact of this phenomenon includes coastal erosion, accretion, seawater intrusion, temperature rise, and tidal flooding, all of which affect the health of the population living in coastal areas [10]. To protect coastal areas from damage, the presence of mangroves must continue to be increased to prevent environmental degradation. This is because mangroves play an important role in increasing their adaptive capacity in responding to natural disasters by acting as protectors of nature [11]. The benefits derived from the high capacity of the mangrove ecosystem include protecting coastal and inland areas of a small island from the impact of waves and sea currents, as well as preventing erosion and seawater intrusion [12]. The Kandanghaur sub-district is within the Indramayu district, bordering the Java Sea. In this area, mangroves grow along almost the entire coastline, resulting from natural growth and planting efforts. Some areas in the Kandanghaur sub-district are experiencing erosion and frequent tidal floods that inundate residential areas in the region. According to a study by [13], the Kandanghaur sub-district experienced erosion of 203 hectares from 1989 to 1999, 136 hectares from 1999 to 2009, and 58 hectares from 2009 to 2019. The worst erosion occurred in Eretan Kulon Village, where the conversion of coastal areas to other uses in this region is the main cause of degradation in the Indramayu coastal area, especially the conversion of mangroves into aquaculture areas [14].

The damage or loss of this land certainly causes significant economic losses. Changes in the coastline affect the land entities (area, function, productivity) and population entities (number, structure, and growth) [15]. Seeing this phenomenon, the existence of mangroves in Kandanghaur District must continue to be enhanced to balance the environmental area in the Coastal Area of Kandanghaur District. This study aims to analyze the dynamics of mangrove changes and the adaptive capacity of the mangrove ecosystem in Kandanghaur District, Indramayu Regency, West Java Province.

2. Material and Methods

2.1. Research Location

This study was conducted in the Kandanghaur District of Indramayu Regency and was carried out in 2023. The research location was spread across 5 villages: Parean Girang, Bulak, Ilir, Eretan Wetan, and Eretan Kulon. The details of the research locations are shown in Figure 1.

Figure 1 Research Location

2.2. Research Procedure

2.2.1. Landsat Image Analysis

Image analysis was conducted to obtain data on the mangrove changes in the Kandanghaur Subdistrict from 2009 to 2023. The images used were from Google Earth, and the mangrove areas were digitized using the tools available in Google Earth Pro. The extent and distance of mangroves from human activities were analyzed using the Quantum GIS software with buffering techniques.

2.2.2. Field Observation and Ground Check

Observations are carried out to collect data related to the adaptive analysis of mangroves, including direct surveys of the field and using Landsat images. Field surveys are conducted to obtain data on substrate types, the number of genera, and dominant species. Data on the distance from settlements are obtained from Landsat images. Field checks were carried out to validate the results of image interpretation regarding mangrove objects and validate the existing mangrove density level. Calculation of the density level of mangrove vegetation using a transect line in a direction perpendicular to the sea edge. The transect size for the tree level is 10×10 m^2, for the sapling level 5×5 m^2, and for the seedling level 2×2 m^2. More details as seen in Figure 2.

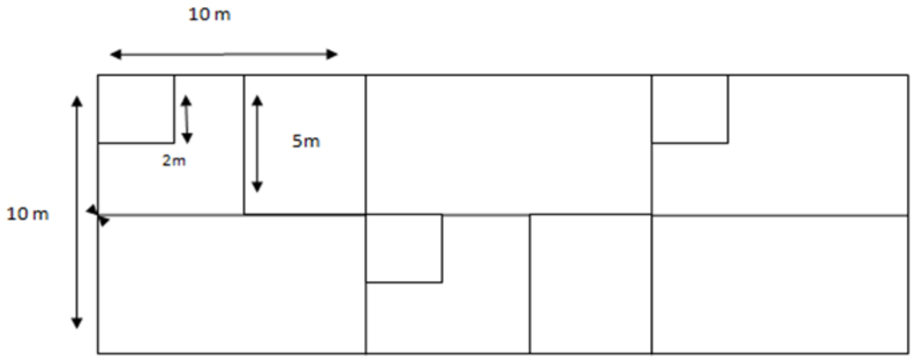

Figure 2 *Transek Line*

2.3. Data Analysis

Analysis to determine changes in mangroves is carried out by comparing images multi-temporally, namely the classification results of images in 2009, 2016, and 2023. The formulation for analyzing changes in mangroves is as follows:

$$\Delta L = \frac{Lt_2 - Lt_1}{\Delta t}$$

Where ΔL (ha) is the rate of change in the area, Lt1 is the area in the initial observation year (ha), and Lt2 is the area in the following observation year (ha). Δt is the difference in time between the initial observation year and the final observation year (years). The results of the change analysis using 2009 imagery data and 2016 imagery data are referred to as Rate of Change I. The change analysis results using 2016 imagery data and 2023 imagery data are referred to as Rate of Change II. The mangrove dimension index is carried out by measuring using the following equation [16]:

$$\mathrm{IDLn} = \sum \left[\frac{NL}{SL}\right] + \sum \left[\frac{NP}{SP}\right]$$

Description:

IDLn : Mangrove Dimension Index
NL : Total sum of all values in the Thickness dimension segments
SL :Total sum of Thickness dimension segments
NP : Total sum of all values in the Length dimension segments
SP :Total sum of Length dimension segments

The classification of the Mangrove Dimension Index (IDMg) ranges from 0.0 to 2.0, detailed as follows [16]:

Very Low = (0.0≤Kp≤0.4)
Low = (0.4<KAE≤0.8)
Medium = (0.8<KAE≤1.2)
High = (0.2<KAE≤0.6)
Very High = (1.6<KAE≤2.0)

To measure the adaptive capacity of mangrove ecosystems, the following equation is used [16]:

$$\mathrm{KpLn} = \sum \left[\frac{\mathrm{Ni}}{\mathrm{N_{maks}}}\right] \times 100\%$$

KpLn : Mangrove Ecosystem Capacity
Ni : Total Value of Measurement Parameters
Nmaks : Maximum Value.

With the following criteria:

Very Low : 0.0 ≤ KpMg ≤ 0.2
Low : 0.2 ≤ KpMg ≤ 0.4
Medium : 0.4 ≤ KpMg ≤ 0.6
High : 0.6 ≤ KpMg ≤ 0.8
Very High : 0.8 ≤ KpMg ≤ 1.0

3. Results and Discussion

3.1. Distribution of Mangroves in Kandanghaur District in 2009, 2016, and 2023

Mangroves in Kandanghaur District, based on satellite imagery monitoring, are evenly distributed along the coast of Kandanghaur District. Based on the analysis of images, the distribution of mangroves in the Kandanghaur District is shown in Figure 3.

Mangrove in 2009

Mangrove in 2016

Mangrove in 2023

Figure 3. Distribution of Mangroves in Kandanghaur District in 2009, 2016, and 2023

Figure 4. Mangrove Change Graph for the period 2009-2023

Tab Based on image analysis, it is observed that the mangrove coverage in the Kandanghaur Subdistrict from the period 2009 to 2023 has increased. In 2009, the mangrove area in this region was 20.15 hectares, which then changed to 44.7 hectares in 2016 and increased to 90.18 hectares by 2023. Between 2009 and 2016, the mangrove coverage in the Kandanghaur Subdistrict increased by 24.56 hectares; from 2016 to 2023, there was an additional increase of 45.47 hectares. This expansion cannot be separated from the many mangrove planting programs carried out by the government, local mangrove farmer groups, and the general public during that period. Apart from that, the coastal environment of Kandanghaur District, especially in Parean Girang Village, is very conducive to mangrove growth as indicated by the salinity parameters which are quite good for mangrove growth, namely 2000 ppm, the type of mud mixed with clay substrate, and the characteristics of the beach.

The density of mangrove vegetation in the Kandanghaur Subdistrict has steadily increased [17]. The pattern of mangrove growth in this area tends to extend beyond the coastline, resulting in land expansion in some areas, such as in Ilir Village, during the 2009-2023 period. The rapid growth of mangroves in Ilir Village is mainly due to numerous river estuaries, which facilitate substantial sediment accumulation, creating suitable habitats for mangrove proliferation. Thus, the increase in mangroves aligns with the heightened sedimentation process from materials transported by river flows to the estuaries [18]. The swift growth of mangroves in the Kandanghaur Subdistrict is not solely due to natural factors; it is also a result of mangrove planting activities conducted by the local government, universities, and other community organizations. The mangrove changes in each village within the Kandanghaur Subdistrict are detailed in Table 1.

Table 1. Changes in The Mangrove Area in The Kandanghaur District

Village	Mangrove Area (ha)			ΔChange 2009-2016	ΔChange 2016-2023
	The year 2009	The year 2016	Year 2023		
Bulak	16.96	21.54	31.25	+4.58	+9.71
Ilir	0.16	9.34	22.77	+9.18	+13.43
Eretan Kulon	0.01	1.83	10.44	+1.82	+8.61
Eretan Wetan	3.02	4.1	7.22	+1.08	+3.12
Parean Girang	0	7.9	18.5	+7.9	+10.6
Total	20.15	44.71	90.18	+24.56	+45.47

Based on Table 1, it is evident that nearly all the villages have experienced an increase in mangrove cover. The largest increase in mangroves during both the 2009-2016 and 2009- 2016- 2023 periods was in Ilir Village, with an addition of 9.18 hectares in the 2009-2016 period and 13.43 hectares in the 2016-

2023 period. The smallest increase in mangroves for both the 2009-2016 and 2016-2023 periods was in Eretan Wetan Village, with an addition of 1.08 hectares in the 2009-2016 period and 12 hectares in the 2016-2023 period.

3.2. *Adaptive Capabilities of the Mangrove Ecosystem in Kandanghaur District*

3.2.1. *Mangrove Dimension Index (MDI)*

The mangrove dimension index (MDI) value in Kandanghaur District for all villages is in the Very Low category. However, if the MDI values are sorted, the lowest is in The Eretan Wetan District with an MDI of 0.085. This is because the mangroves in Eretan Wetan Village are small in size and distributed unevenly. Apart from that, the sledding water area is widely used for shipping lane activities, and in some land areas, the residential density is quite high. The highest MDI value is in Ilir Village because it has extensive mangrove vegetation spread across water channels and community ponds with a silvofishery system. The mangroves in Ilir Village are located quite far from residential areas. The higher the mangrove dimension index (MDI) of a mangrove ecosystem in an area indicates that the ecosystem is spread widely and evenly. Conversely, a lower MDI value indicates that the ecosystem distribution is relatively narrow [12]. Judging from the highest mangrove dimension index values, it is found in Bulak and Parean Girang villages, this happens because the mangroves in these two villages are evenly distributed. The mangrove dimension index (MDI) values in Kandanghaur District are shown in Figure 5.

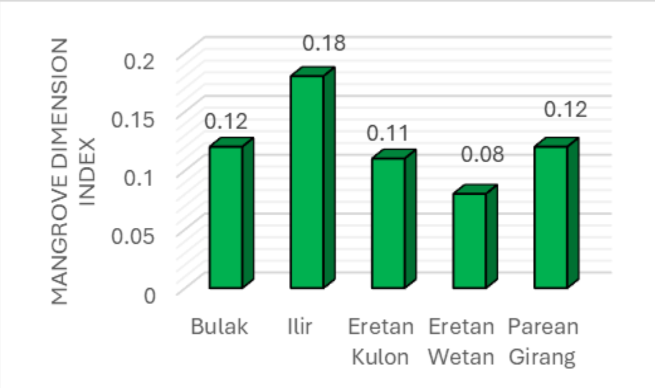

Figure 5. Mangrove Dimension Index (MDI) Value Diagram

3.2.2. *Types of Substrate and Vegetation of Mangroves in Kandanghaur Subdistrict*

Based on observations conducted across all villages in the Kandanghaur Subdistrict coastal area, the existing substrate types substrates are muddy and sandy mud. This is due to several areas being river estuaries. The types of mangroves encountered in the field generally consist of *Avicennia spp.* and *Rhizophora spp*. These mangrove species dominate the region. This dominance of mangroves is some of the mangroves in Kandanghaur District are planted plants and do not come from nature. People prefer planting Avicennia marina, Avicennia lanata, Rhizophora mucronata, Rhizopora apiculata compared to other species because these two species can adapt well to the environment and reproduce quickly [19]. This indicates that the area's physical characteristics are highly suitable for mangrove growth. Mangrove forests grow in areas where the soil is muddy, silty, or sandy and are periodically flooded by seawater. The frequency of flooding determines the composition of the mangrove forest vegetation, receiving an adequate supply of fresh water from the land through river flows and protection from large waves and strong tidal currents [20]. The type of substrate and salinity greatly influence the types of mangroves that grow [20].

Most mangroves thrive well on muddy substrates [21]. The distribution of mangroves in the Kandanghaur Subdistrict is predominantly in pond areas with a silvofishery system. The silvofishery model used combines the Ampang part and Ampang inti silvofishery models. The silvofishery pond areas in the research location are situated near the coast, and the local community utilizes ponds integrated with mangrove plants to cultivate tiger prawns (*Pennaeus monodon*) and milkfish (*Chanos chanos*). The local community also exploits the presence of mangroves for catching mud crabs [22]. Besides being located in pond areas, mangroves are also found along water channels (canals) in the research area. These water channels function to let water in and out. The types of mangroves found in the water channels (canals) are *Rhizophora spp.* and *Avicennia sp*, locally referred to as bakauan and api-api plants [23].

3.2.3. *Mangrove Vegetation Density in Kandanghaur District*

The mangrove vegetation density in Kandanghaur District was obtained by conducting direct measurements in the field using the transect line method. The mangrove vegetation density in the Kandanghaur District is presented in Figure 6.

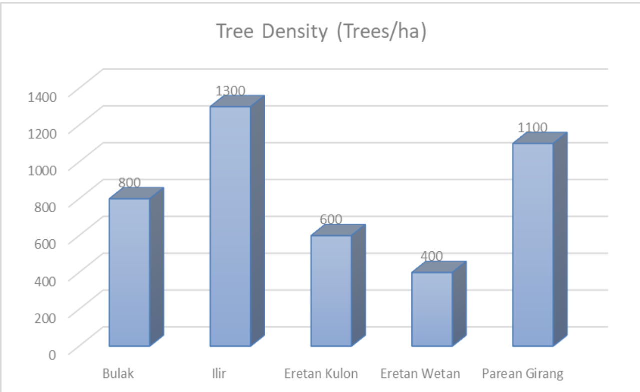

Figure 6 Diagram of Mangrove Vegetation Density in Kandanghaur Sub-district

Based on Figure 6, it is evident that the highest mangrove density is in Ilir Village, with 1,300 trees/ha. The lowest density is found in Eretan Wetan Village, with 400 trees/ha. The low density in Eretan Wetan Village is due to the proximity of mangroves to human activities (settlements), resulting in many mangrove areas being degraded by the activities of the inhabitants. Mangrove density is important for the functioning of mangroves in maintaining the balance of the mangrove ecosystem, as the density of mangrove vegetation has a significant impact on wave attenuation [24] and serves as a habitat for marine biota [25].

3.2.4. Adaptive Capacity

Mangroves in the Kandanghaur Subdistrict serve as environmental balancers in the coastal area. The mangrove ecosystem plays a role in the protection of coastal areas and in enhancing their adaptive capacity. Based on the analysis, the adaptive capacity of mangroves in the Kandanghaur Subdistrict is shown in Table 2.

Table 2. Adaptive Capacity of Mangroves in Kandanghaur Subdistrict

Vilage	DI	DS	VD	NG	ST	DHA	AC	Category
Bulak	0.12	Rhizophora	800	3	Mud	3885.789	0.60	Medium
Ilir	0.18	Avicennia	1300	3	Mud	1120.14	0.66	High
Eretan Kulon	0.11`	Avicennia	600	2	Sandy mud	57.21	0.44	Low
Eretan Wetan	0.08	Rhizophora	400	2	Sandy mud	118.36	0.40	Low
Parean Girang	0.12	Rhizophora	1100	3	Mud	3814.9	0.63	High

Description: DI: Dimension Index, DS: Dominant Species, VD: Vegetation Density (trees/ha), NG: Number of Genera, ST: Substrate Type, DHA: Distance From Human Activity, AC: Adaptive Capacity.

The reference for analyzing adaptive capacity involves using mangrove data 2023, with a total mangrove area of 90.18 hectares spread across five villages in the Kandanghaur Sub-district. Table 1 shows that villages possessing mangrove ecosystems categorized under high adaptive capacity are located in Ilir Village and Parean Girang Village, with adaptive capacity values of 0.66 and 0.63, respectively. This could be attributed to the dense mangrove coverage in these areas, as a thick and evenly distributed mangrove expanse along the coast is highly effective for mitigating disasters occurring in coastal regions [26]. Eretan Kulon and Eretan Wetan villages have low adaptive capacity values due to the fewer mangroves in these two villages. The lower the adaptive capacity value of a mangrove ecosystem, the lesser its role in protecting the area. Observing the current conditions and their impact, I noticed that the Eretan area frequently experiences tidal floods and is prone to erosion. The tidal floods in Eretan Wetan Village often paralyze all community activities, including tourist attractions. The floods, occurring almost daily, have an average height of up to 70 centimeters. Despite the frequent tidal floods, the community chooses to continue living in their area, even though relocation to other areas has been proposed [27].

4. Conclusion

Based on the analysis, it can be concluded that the changes in mangroves that occurred in Kandanghaur District during the 2009-2016 period have increased, and this increase occurred almost throughout the coastal areas of Kandanghaur District. Over 14 years (2009-2023 period), the mangroves in Kandanghaur District have increased by an area of 70.03 hectares. The types of mangroves in the area generally consist of 2 species, namely Avicennia spp. and Rhizophora spp. The adaptive capacity of mangroves in Kandanghaur District varies from low, medium, to high categories, with the low-capacity category found in Eretan Wetan and Eretan Kulon villages, the medium category in Bulak village, and the high adaptive capacity in Ilir and Parean Girang villages.

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