Sustainability Status of the Mangrove Forest Management in the Coastal Areas of Indramayu Regency

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Abstract*—Pollution of water resources, whether in seas, lakes, or rivers, has been occurring for years. This puts tremendous pressure on the coastal environment, especially in reducing environmental quality and biodiversity, causing habitat loss, and ultimately reducing the quality of life of the surrounding community. Based on the eco-structure, the condition of the mangroves on the coast of Indramayu has experienced degradation. This study aims to analyze the sustainability status of mangrove forest management in the coastal areas of Indramayu Regency by applying Multidimensional Scaling (MDS) and Rap-KMforest which is modified from Rapid Appraisal for Fisheries (RAPFISH) to evaluate the sustainability of the mangrove forests multidimensionally. Based on the results of the analysis, the mangrove forests in the coastal areas of Indramayu Regency are generally less sustainable in all four dimensions, with index values of 47.67 for the ecological dimension, 29.28 for the economic dimension, 44.14 for the social dimension, and 42.94 the institutional dimension. The lack of sustainability of the mangrove ecosystem in Indramayu Regency is also shown in the results of the leverage analysis on each attributes, where the dominant attributes or sensitive attributes are: the use of the area for tourism (3.71%) for ecology dimension, the number of informal sectors (3.48%) for the economic dimension, the attention of mangrove researchers (3.98%) for the social dimension, and the capability of the implementation apparatus (3.90%) for institution dimension. Thus, effective strategies are needed to improve the sustainability of mangrove forests in the Indramayu Regency by considering sensitive factors.

***Keywords*—sustainability, mangrove, multidimensional scaling, Rap-KMforest**

I. Introduction

As a tropical country, Indonesia has remarkably diverse coastal resources, one of which is the mangrove ecosystem, an environmental balancing ecosystem in coastal areas. There are around 3.1–3.7 million hectares of mangrove forests with high species diversity in Indonesia, which is more than 20% of the world's mangrove forests [1, 2]. Currently, mangrove forests have become one of the natural resources that are experiencing a decline in both quantity and quality. Consolidated studies have reported a decline in global mangrove cover of 8600 km^2 between 1990 and 2020, with the greatest decline occurring in South and Southeast Asia (3870 km^2). Furthermore, a previous study has shown aquaculture and agriculture as the main drivers of mangrove deforestation, with impacts varying across regions [3].

In Indonesia alone, the area of mangrove forests has decreased by 930 km^2 from 2000 to 2014 [2]. This is in line with the statement of [4] that approximately 41.9% of mangrove forest ecosystems in Indonesia have experienced deforestation. According to National Mangrove Map [1], based on the results of satellite image monitoring, the area of mangroves in Indonesia was 3,112,989 ha in 2011. Meanwhile, based on the 2021 National Mangrove Map of Indonesia, the area of mangroves in this country has increased to 3,364,080 ha. This is possible due to the numerous rehabilitation programs carried out by the government, NGOs, and corporations through their CSR programs. One of the government programs that plays a significant role in increasing the area of mangroves is regulated in the Regulation of the President of the Republic of Indonesia Number 120 of 2020 on Peatland and Mangrove Restoration Agency. This regulation is focused on accelerating the implementation of mangrove rehabilitation in work areas in North Sumatra Province, Riau Province, Riau Islands Province, Bangka Belitung Province, West Kalimantan Province, East Kalimantan Province, North Kalimantan Province, Papua Province, and West Papua Province. As a form of implementation of this regulation, a mangrove planting program has been carried out in several areas, including in the Karangsong Ecotourism Area, Indramayu Regency [5, 6].

Indramayu is one of the regencies in West Java Province which has a coastline of approximately 114.1 km and has great potential for the growth of mangroves and other coastal vegetation. Based on the Master Plan for Indramayu Regency Regional Economic Development 2015–2025, Indramayu Regency has a relatively large forest potential of 43,027.41 ha, where 40,653.41 ha is under State Control and 2,374 ha is Community Forests. The types of commodities cultivated in these areas include teak forests, covering an area of 21,144.37 ha, brackish/mangrove forests (protected forest areas), covering an area of 8,023.55 ha, and eucalyptus forests, covering an area of 5,130.75 ha.

Mangrove forests in Indramayu Regency are one of the areas in West Java with the worst level of destruction. Based on data from the Department of Fisheries and Maritime Affairs, Indramayu Regency had a mangrove area of 17,782 ha in 2008. However, this area of mangrove forests has decreased drastically to 12,706 ha in 2016 and even left 2.228 Ha in 2017 according to the land use interpretation analysis [7].

Most of the coastal areas of Indramayu Regency are affected by abrasion at a rate of 9–10 m per year. Maryanto *et al.* [8] reported in his study that the area of abrasion in the coastal area of Indramayu Regency in the period of 1994–2009 was 3900.41 ha, with an average abrasion rate of 23.64 Ha/year. Meanwhile, the sedimentation area was 650.29 ha, with an average sedimentation rate of 4.81 Ha/year. In addition, around 8,233 ha of land located in 8 sub-districts are considered critical. Based on a previous

study by Wicaksana *et al.* [9], the area of mangrove forest cover in one of the villages in Indramayu, namely Cemara Village, decreased by 507.82 ha (51%) from 1998–2018. This decrease in the mangrove area was followed by an increase in the pond area of 403.51 ha.

Considering the above phenomena, a thorough evaluation with comprehensive analysis in all sectors, including ecological, economic, social, and legal/institutional is heavily needed as feedback in examining the sustainability of mangrove ecosystem management in an integrated and sustainable manner. Good mangrove forest management must aim to create productive and sustainable mangrove forests. According to Sanjaya [10], the concept of sustainability in the management of natural resources is that sustainable development must apply the principles of fairness in the environmental/ecological, economic, and social sectors. Thus, sustainable mangrove forest management aims to synergize ecological, economic, and social interests.

One of the available methods for assessing the sustainability of natural resources is the Multidimensional Scaling (MDS) approach. This technique has been used in numerous prior studies, including those conducted by Haris *et al.* [11] and Rani *et al.* [12], to assess the sustainability of mangrove forests in several places. According to Trisnanto *et al.* [13], the use of the MDS method is quite reliable for holistic and quick assesment of the of a natural resource sustainability status.

Many studies in South Asia related to mangrove forests have been carried out previously more on mangrove management such as ecoturism mangrove [14] or mangrove restoration [15]. Research related to mangrove sustainability has also been conducted in Vietnam [16], Philippines [17], and Malaysia [18]. The research states that sustainable management can be achieved through an improvement of local community policies and practices, as well as collaboration between the government and local communities. The difference between this research and studies on mangrove sustainability in Southeast Asia is that the attributes used depend on regional conditions. Studies that assess the sustainability of mangrove forests in the areas of Indramayu Regency, which is the center of mangroves in West Java, are still very limited. Meanwhile, the condition of the mangroves in this area is extremely alarming due to the large amount of deforestation that occurred. By understanding their sustainability status, rehabilitation or restoration programs can be carried out and strategies to increase the sustainability of these mangrove forests can be identified.

II. Materials and Methods

This study applies the Multidimensional Scaling (MDS) method, which is a statistical technique that attempts to transform multimedia into simpler dimensions [19, 20]. To evaluate the sustainability of mangrove forests in a multidimensional manner, Rap-Kmforest, which is the modification of the Rapid Appraisal for Fisheries (RAPFISH) method is utilized. The stages in the Rap-KMforest ordination analysis in this study are as follows: (1) determining attributes in ecological, economic, social, and institutional dimensions; (2) scoring each attribute based on the sustainability criteria for each dimension; (3) performing the Rap-KMforest ordination analysis using the MDS method to determine ordination points and stress values; (4) assessing the index values and sustainability status of mangrove forest management for each dimension and multidimensionally; (5) carrying out the sensitivity analysis (leverage analysis) to determine sensitive variables that influence the sustainability of the mangrove areas; and (6) conducting the Monte Carlo analyses to take into account aspects of uncertainty.

The attributes for each dimension are determined and assessed based on literature studies, field observations, and calculation results or secondary available data. The determination of attributes also involved stakeholders from the Fisheries and Marine Service, academics, and the community through observation, interview, and focus group discussion. The rationale for selecting specific attributes for each dimension of sustainability depends on the conditions and the characteristics of the area.

Table 1 shows the dimensions and attributes for analyzing the sustainability of the mangrove forest management in the coastal areas of Indramayu Regency.

Table 1. Attribute of each dimension

Dimension	Attribute
Ecology	(1) Environmental sanitation (2) Groundwater utilization (3) Utilization of areas for tourism (4) Land utilization for fishponds (5) Water pollution (6) Coastal abrasion (7) Sedimentation in mangrove areas (8) Pressure on mangrove area
Economi	(1) Financial support (2) Potential and number of tourist visits (3) Percentage of Fish Resources Income (4) Indirect benefits (5) Government budget for mangrove management (6) Employment (7) Number of poor people (8) Average income against regional minimum wage (9) Number of informal sectors (10) Community purchasing power (11) Direct benefits of mangroves (12) Accessibility of mangrove areas
Social	(1) Resistance to policy (2) Frequency of community meetings (3) Attention of mangrove researchers (4) Community awareness (5) Social impact on the community (6) Social conflict (7) Participation in mangrove management (8) Community education level (9) Knowledge of the environment (10) Utilization of resources
Institutional	(1) Law enforcement (2) Relationship between central and regional governments (3) Legality of mangrove areas (4) Integration of management programs (5) Capability of implementing apparatus (6) Decision-making system (7) Commitment of conservation makers (8) Involvement of community institutions (9) Availability of management regulations

The sustainability index value for each dimension is visualized in the form of a kite diagram and analyzed multidimensionally to determine the sustainability point or position of the mangrove forest management. In the Rap-KM Forest method, the sustainability index value is obtained within the range of 0 (bad) to 100 (good). To ease the

determination of the sustainability status, the index values are grouped into bad (0–25); less (26–50); quite (51–75); and good (76–100) [21].

III. Result and Discussion

A. Distribution of Mangroves in Indramayu Regency in 1989, 2002, 2015, and 2022

Based on the analysis of Landsat 5 images in 1989, Landsat 7 images in 2002, Landsat 8 images in 2015, and Landsat 8 images in 2020, mangrove areas in Indramayu Regency are known to be evenly distributed throughout all sub-districts located on the coast. Fig. 1. displays the maps of mangrove distribution in Indramayu Regency in 1989, 2002, 2015, and 2022, while Fig. 2. shows a graph of changes in mangrove areas in Indramayu Regency in those years.

As seen in Fig. 3, the area of mangrove forests in Indramayu Regency has decreased from 3,397.81 ha in 1989 to 1,852.42 ha in 2002 and continued to decline to 1,052.79 ha in 2015. This means that the mangrove areas in Indramayu Regency decreased by 1,545 ha from 1989 to 2002 and by 799.63 ha from 2002 to 2015. According to Sodikin *et al.* [22], changes in mangrove areas from 1989 to 2002 were quite significant since many people converted mangrove forests into fishponds during that period. From 2015 to 2022, on the other hand, the total area of mangrove forest in Indramayu Regency has increased by 148.21 ha. Based on the results of Landsat image monitoring in 2022, the widest distribution of mangroves is in Cantigi District. According to a study by Zahudah *et al.* [23], the types of mangroves found in Indramayu Regency include: *Avicenia alba, Avicenia officinalis, Rhizopora apiculata, Bruguiera cylindrica, Sonneratia ovata, Sonneratia Caseolaris, Nypa fruticans, Acanthus ilicifolius L, Sesivium portulacastrum, Wedelia biflora, Ipomoea pescaprea, dan Stachytharpheta jamaicensis.*

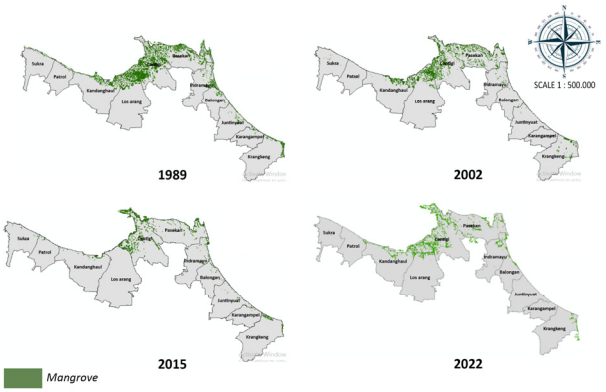


Fig. 1. Map of mangrove distribution in 1989, 2002, 2015, and 2022.

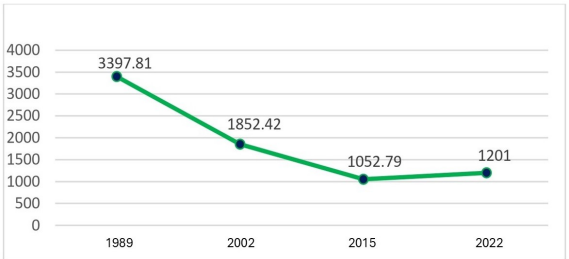


Fig. 2. Changes in mangrove area in Indramayu Regency in 1989, 2002, 2015, and 2022.

B. Sustainability of the Mangrove Ecosystem in Indramayu Regency

In this study, the sustainability of the mangrove ecosystem in Indramayu Regency was analyzed using the Multidimensional Scaling (MDS) method with the Rapid Appraisal for the Status of Mangrove Forest (Rap-Mforest) analysis tool. The dimensions analyzed in this study are ecological, economic, social, and institutional dimensions. Those four are considered to represent the sustainable status of the mangrove ecosystem in the Indramayu Regency based on the results of field observations and literature studies. For all dimensions, 26 sustainability indicators were developed, consisting of 7 attributes for the ecological dimension, 5 attributes for the economic dimension, 6 attributes for the social dimension, and 8 attributes for the institutional dimension (See Table 1).

The sustainability index value of each dimension (ecological, economic, social, and institutional) can be seen in Fig. 3.

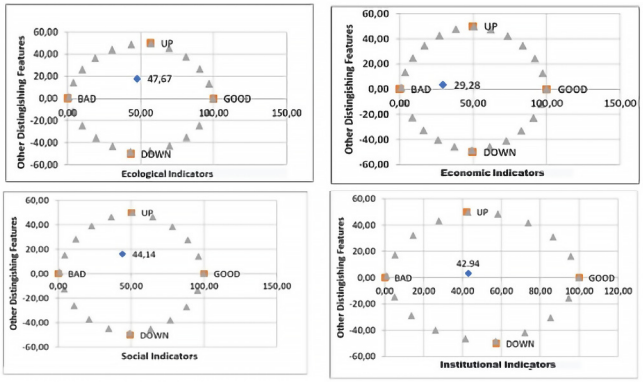
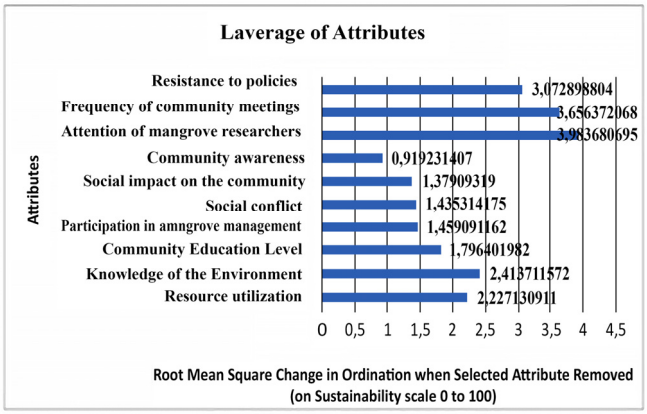
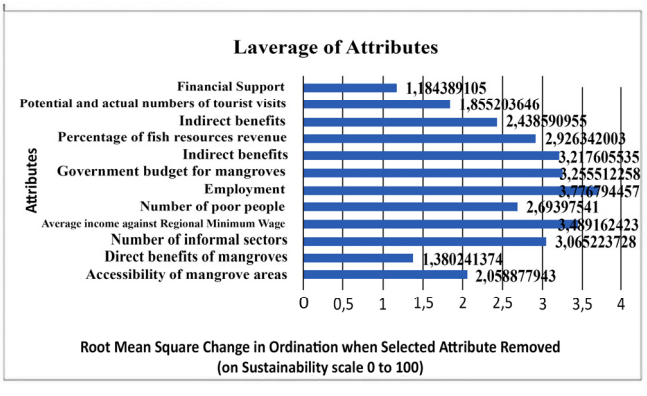


Fig. 3. Sustainability index value of the ecological, economic, social, and institutional dimensions





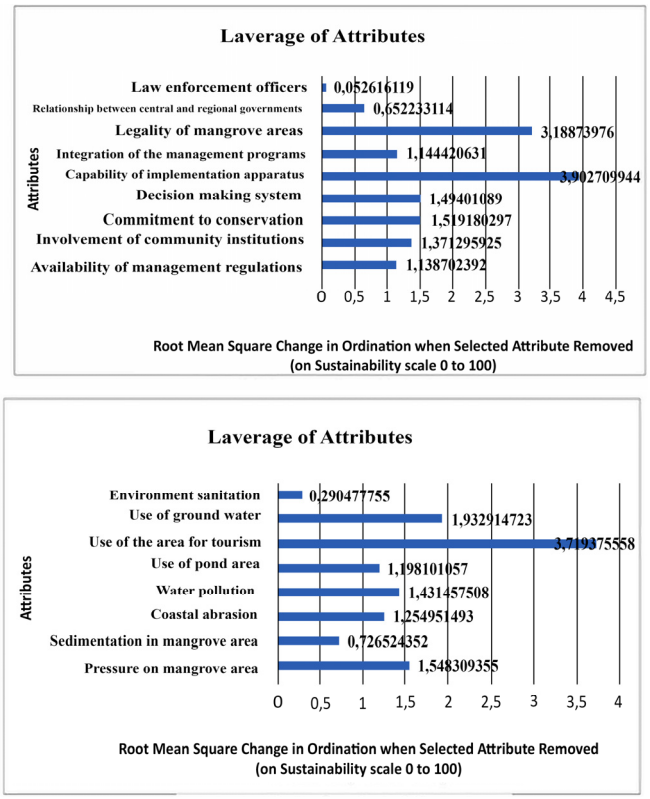


Fig. 4. Leverage analyses of social, economic, institutional, and ecological dimensions.

Based on the analyses of mangrove ecosystem sustainability in Indramayu Regency, the index values of the ecological, economic, social, and institutional dimensions were 47.67, 29.28, 44.14, and 42.94, respectively. These values indicate the lack of sustainability of mangroves in this region.

Furthermore, leverage analysis was performed to observe sensitive attributes in the sustainability of the mangrove ecosystem in the Indramayu Regency, where attributes that are declared as leverage factors are those with a Root Mean Square (RMS) value ≥ 2% [24]. Changes in the value of this leverage will affect the sustainability index value of the mangrove ecosystem in Indramayu Regency in each dimension. The results of the leverage analysis are presented in Fig. 4.

The Root Mean Square (RMS) value of each attribute in each dimension is obtained from the results of the leverage analyses, as shown in Table 2.

Based on Table 2, in the ecological dimension part, the use of the area for tourism is found to have a dominant role in influencing the sustainability of the mangrove ecosystem in the Indramayu Regency. With the use of mangrove areas for ecotourism, both the government and surrounding communities have made greater management efforts. It is hoped that the mangroves will become more sustainable, and their cleanliness will be maintained so that the function of the mangroves can become more optimal. This is in line with the results of a prior study by Safuridar and Andiny [25] and Paembonan *et al.* [26] which found that the existence of ecotourism areas in coastal areas will provide environmental support for these areas. In addition, mangrove ecotourism areas can open employment opportunities, increase income, improve community welfare, and many others.

Table 2. RMS values of the leverage analysis

Indicator	RMS (%)	Information
Ecology Dimension		
Environmental sanitation	0.29	Not Sensitive
Groundwater utilization	1.93	Not Sensitive
Utilization of areas for tourism	**3.71**	Sensitive
Land utilization for fishponds	1.19	Not Sensitive
Water pollution	1.43	Not Sensitive
Coastal abrasion	1.25	Not Sensitive
Sedimentation in mangrove areas	0.72	Not Sensitive
Pressure on mangrove area	1.54	Not Sensitive
Economic Dimension		
Financial support	1.18	Not Sensitive
Potential and number of tourist visits	1.85	Not Sensitive
Percentage of Fish Resources income	**2.43**	Sensitive
Indirect benefits	**2.92**	Sensitive
Government budget for mangrove management	**3.21**	Sensitive
Absorption of labor	**3.25**	Sensitive
Number of poor people	**3.77**	Sensitive
Average income against regional minimum wage	**2.69**	Sensitive
Number of informal sectors	**3.48**	Sensitive
Community purchasing power	**3.06**	Sensitive
Direct benefits of mangroves	1.38	Not Sensitive
Accessibility of mangrove areas	**2.05**	Sensitive
Social Dimension		
Resistance to policy	**3.07**	Sensitive
Frequency of community meetings	**3.65**	Sensitive
Attention of mangrove researchers	**3.98**	Sensitive
Community awareness	0.91	Not Sensitive
Social impact on the community	1.37	Not Sensitive
Social conflict	1.43	Not Sensitive
Participation in mangrove management	1.45	Not Sensitive
Community education level	1.79	Not Sensitive
Knowledge of the environment	**2.41**	Sensitive
Utilization of resources	**2.22**	Sensitive
Institution Dimension		
Law enforcement	0.05	Not Sensitive
Relationship between central and regional governments	0.65	Not Sensitive
Legality of mangrove areas	**3.18**	Sensitive
Integration of management programs	1.44	Not Sensitive
Capability of implementing apparatus	**3.90**	Sensitive
Decision-making system	1.49	Not Sensitive
Commitment of conservation makers	1.51	Not Sensitive
Involvement of community institutions	1.37	Not Sensitive
Availability of management regulations	1.13	Not Sensitive

Meanwhile, the economic dimension has more sensitive and dominant attributes than other dimensions, namely the percentage of fish resources income, indirect benefits, government budget for mangroves, employment, number of poor people, average income, number of informal sectors, people's purchasing power, and accessibility of mangrove areas, with the most dominant attribute being the number of poor people. All these sensitive attributes are interrelated. If the percentage of fish resources decreases, economically, people's income also decreases. Related to the government budget for mangroves, it is also related to labor absorption, the number of informal sectors, and people's purchasing power. The impact of all of this is that the number of poor people will increase, which is the most dominant factor. In this economic dimension, the presence of mangroves directly and indirectly brings economic benefits, for example from the processing of mangroves into several foods, beverages, and medicinal products. This finding related to. Blanton *et al.* [14] that the economic dimensions that are the driving factors include, contribution from mangrove ecotourism activities, absorption of labor, changes in the progress of economic conditions for the community, contribution of ecotourism compared to other businesses, average relative income and

the surrounding community towards the regional minimum wage. According to Rosulva *et al.* [27], several mangrove species, such as *Avicennia* sp, *Bruguiera* sp, *Rhizophora* sp, and *Sonneratia* sp, can be processed into types of food (i.e., chips, cakes, and *dodol*), drinks, and other complementary ingredients. Furthermore, there is a positive linear relationship between the presence of mangrove forests and fish catches, where areas with greater mangrove density will produce greater fish catches [28].

Attributes that dominantly affect the social dimension are resistance to policies, frequency of community meetings, attention of mangrove researchers, knowledge of the environment, and resource utilization. These attributes are interrelated, mangrove management policies will affect the level of community participation involved in mangrove conservation activities, such as the frequency of meeting activities will be influenced by existing policies. If the community rarely participates in socialization activities for mangrove ecosystem environmental knowledge, then the utilization of mangrove resources becomes uncontrolled and will affect the sustainability of the mangrove ecosystem in the area. The most dominant attribute in the social dimension is the attention of mangrove researchers. In this regard, the community feels the need for attention from mangrove researchers. This shows that researchers have a prominent role in the sustainability of mangrove forests in the Indramayu Regency because they are expected to provide overviews of mangroves in the Indramayu Regency from various aspects and be able to synergize with the local government and community. The finding of the social dimension in the knowledge of the environment is related to [26].

For the institutional dimension, the dominant attributes are the legality of the mangrove area and the capability of implementation apparatus. Among all attributes in this dimension, the capability of implementation apparatus is the most dominant attribute in affecting the sustainability of the mangrove ecosystem in this region. This is understandable since the capable implementation apparatus can effectively manage and monitor the management of the mangrove areas, thus being able to maintain its sustainability. According to Gunawan *et al.* [29], sustainable institutional design must focus on synergy and coordination between stakeholders as well as the involvement of surrounding communities. Mangrove management institutions, especially local ones, have an important role in making regulations that can control the use of mangrove resources fairly and prevent the development of free-rider behavior which can threaten the existence of mangroves [30]. In the Indramayu Regency, managers of mangrove areas consist of local government, non-governmental organizations (NGOs) or environmental foundations, and farmer groups.

From the results of the leverage analyses as seen in Table 2, the sensitive attributes of each dimension have an RMS value of ≥ 2%. These attributes have a dominant role in influencing the sustainability of the mangrove ecosystem in the Indramayu Regency. Monte Carlo analysis was then carried out to determine and evaluate the impact of random errors for each attribute to assess the sustainability of mangroves in the Indramayu Regency. This Monte Carlo analysis is also used to test the level of confidence in the total index value and each dimension caused by procedural errors or understanding of the attributes, variations in scoring due to differences of opinion, the stability of the MDS analysis process, data entry errors or missing data and stress values that are too high. The results of the Monte Carlo analyses indicate the stability of the results of the Rap-Tape Ordination and leverage analyses. Fig. 5 shows the results of the Monte Carlo analyses on all four dimensions.

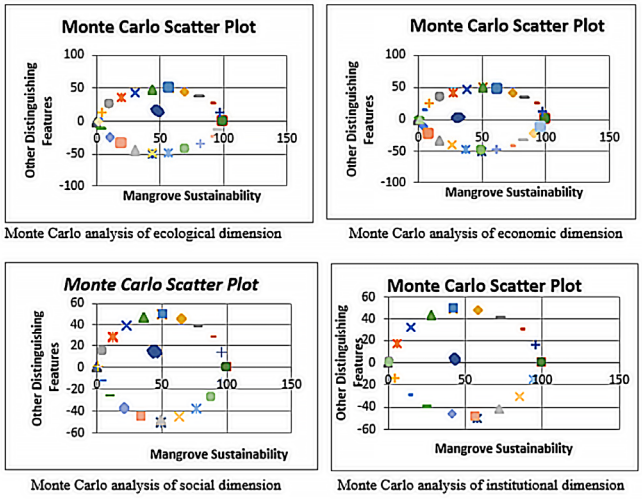


Fig. 5. Monte Carlo analyses all four dimensions.

The Monte Carlo analysis (Fig. 5.) produced a quite good result for the ecological dimension (no significant error range) shown by the accumulation of points resulting from MDS repetitions between values of 47.3–50.1, meaning that the coordination points are close to each other. This indicates that errors in scoring each attribute and variations in scoring due to differences in opinion are relatively small, and errors in data entry can be avoided. Similarly, the economic dimension also achieved a quite good result (no significant error range) located in the value range of 31.3–38.3, meaning that the ordination points are near each other. Meanwhile, the points of the social dimension are between the values of 41.3–51.2, while the points of the institutional dimension are between the values of 41.3–47.4.

C. Analysis of the Sustainability Status of the Mangrove Ecosystem in Indramayu Regency

Table 3 presents the results of the analyses of the mangrove ecosystem sustainability in Indramayu Regency on ecological, economic, social, and institutional dimensions using the multidimensional scaling method.

Compared to the other three dimensions, the economic dimension is more dominant in influencing the sustainability of the mangrove ecosystem. The sustainability index values of all dimensions are displayed in Fig. 6.

Based on the results of the analysis, the mangrove ecosystem in Indramayu Regency is considered less sustainable because of the sensitive attributes influence, which are the usage of the area for tourism, the number of informal sectors, the attention of mangrove researchers, and the capability of implementation apparatus. This is in line with a prior study on mangrove sustainability by Sangchumnong [31] which revealed that efforts to increase mangrove sustainability are based on the concept of a creative economy, which includes planting mangroves, offering water sports activities, and running seafood

restaurants. All these efforts must be promoted based on 1) careful design and planning which are in line with creative ideas; 2) carefulness in designing and planning tourism development following the market; 3) involvement of communities capable of thinking, planning, managing resources, and sharing consequences; and 4) concept of sustainable tourism. In this regard, Buncag [32] argued that the evaluation of mangrove the forest management system is a useful mechanism for sustainable mangrove forest management. In Indonesia, such evaluation has been adopted as a planning and management tool for mangrove forest sustainability.

Table 3. Results of the analyses of mangrove ecosystem sustainability

No	Dimension	Number of Attributes	*Rap-Tape* Analysis Results Number of sensitive atributes	*Monte Carlo*	Sustainability Status
1	Ecology	8	47.67	1	47.3-50.1	Less sustainable
2	Economy	12	29.28	9	31.3-38.3	Less sustainable
3	Social	10	44.14	5	41.3-51.2	Less sustainable
4	Institution	9	42.94	2	41.3-47.4	Less sustainable

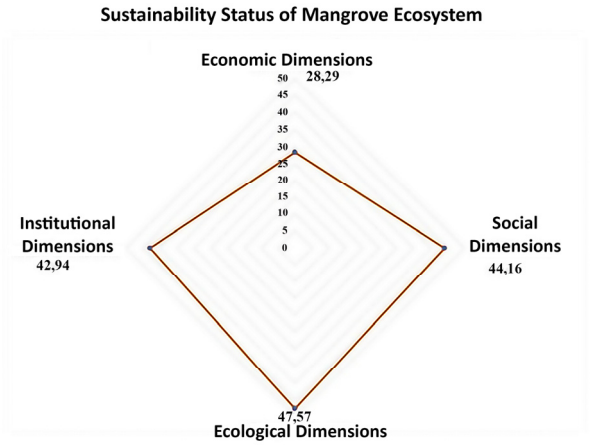


Fig. 6. Kite diagram of the Sustainability Index Value of the mangrove ecosystem in Indramayu Regency.

To maintain the sustainability of the mangrove area on the coast of Indramayu, a strategy must be developed by considering the dominant factors or sensitive attribute that influence the sustainability of the mangrove ecosystem in the area.

The implication of this finding is to provide information to local governments, especially the Indramayu Regency, to restore mangroves based on attribute strategies that are sensitive to each dimension.

In the ecological dimension, the strategy that needs to be implemented is optimizing the use of mangrove land as an ecotourism area. This step can be realized through a comprehensive feasibility study of several mangrove areas in Indramayu, to make it a sustainable ecotourism destination. This study must include an analysis of the potential of the mangrove ecosystem, environmental impacts, and the involvement of local communities in managing the area. With community involvement, it is hoped that they can feel the direct benefits of ecotourism, thereby increasing awareness of the importance of mangrove conservation.

In the economic dimension, the main strategy is the socialization of the community regarding the mangroves function from an economic aspect. The socialization can be in the form of training and workshops that teach the community about the use of mangroves in various value-added products such as food, drinks, and medicines. For example, processing mangrove leaves into herbal tea or using mangrove wood for handicrafts. This strategy is expected to not only increase the income of the surrounding community but also create new sustainable jobs, thereby reducing dependence on other natural resources that are more environmentally damaging.

Furthermore, in the social dimension, increasing and disseminating information about the uniqueness and characteristics of mangroves to the community is necessary. This can be done through educational and outreach campaigns involving schools, local communities, and non-governmental organizations. By increasing the public understanding of the ecological and economic value of mangroves, it is hoped that there will be a greater interest in conservation activities. In addition, the knowledge base and the development of better policies can be supported by attracting researchers to conduct further studies in the mangrove areas of the Indramayu Regency.

In the institutional dimension, the strategy needed is to strengthen and tighten regulations related to land ownership, especially in mangrove areas. This effort must involve collaboration between the government, communities, and non-governmental organizations to formulate fair and transparent policies. Clear regulations will help avoid overlapping land/mangrove area ownership status, which has the potential to cause conflict between the community and the local government/institutions. In addition, there needs to be an effective monitoring mechanism to ensure that mangrove area management is carried out sustainably and responsibly so that its benefits can be felt by future generations.

The global implication is to play a role in the restoration activities that have been initiated by the United Nations (UN). UN has recognized mangrove restoration efforts in Southeast Asia as part of its Decade on Ecosystem Restoration, which runs from 2021–2030. In the research that has been carried out by Gerona-Daga and Salmo [33] to restore mangroves, it is necessary to know the sensitive attributes that affect mangroves. So, this research can contribute to the attributes that can be used in restoring the mangroves of the Indramayu Regency.

IV. Conclusion

The mangrove ecosystem in Indramayu Regency is found to be less sustainable in all dimensions, with the index values of the ecological, economic, social, and institutional dimensions being 47.67, 29.28, 44.14, and 42.94, respectively. The less sustainable status of the mangrove ecosystem in Indramayu Regency is also shown by the results of the leverage analysis for each attribute, where the sensitive attributes that dominantly influence the sustainability of the mangrove ecosystem in Indramayu Regency are the use of the area for tourism (3.71%), the number of informal sectors (3.48%), the attention of mangrove researchers (3.98%), and

the capability of the implementation apparatus (3.90%). To maintain the sustainability of the mangrove ecosystem, the application of mangrove rehabilitation strategies by paying attention to these dominant factors is highly necessary.

Based on the findings of this study, for the sustainability of mangrove management, it is recommended to carry out several alternative activities, including conducting a feasibility study in developing sustainable ecotourism by involving local communities so that they feel the direct benefits and increase awareness of the importance of conservation. In addition, training/workshops need to be held to educate the community about the use of mangroves as value-added products, which can increase income and create new jobs. It is also necessary to conduct educational and outreach campaigns regarding the uniqueness of mangroves which are important for increasing community participation and research interest. Collaboration between the government, community, and non-governmental organizations is essential to carry out effective supervision and ensure sustainable and responsible management so that it can provide long-term benefits for future generations.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions at every stage of this study, namely data collection, data analysis, data interpretation, and article preparation. Lina Warlina conducted research; Sodikin, Lina Warlina analyzed the data and wrote the paper. The authors have also approved this article for inclusion in IJESD.

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