ASSESSING THE SUSTAINABILITY OF LAGOON-BASED ENVIRONMENTAL WATERFRONT IN THE COASTAL ZONE OF PARIAMAN CITY, INDONESIA

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ABSTRACT

This study aims to assess the environmental characteristics and sustainability potential of lagoon areas along the coastal zone of Pariaman City, Indonesia, for environmental waterfront development. Five natural lagoons, such as Nareh, Manggung, Apar, Talao, and Karan Aur, were selected based on geomorphological analysis and spatial mapping. The study adopts a multi-method approach combining weighted indicator-based environmental assessment and Multidimensional Scaling (MDS) to evaluate sustainability across economic, social, and environmental dimensions. Thirteen environmental indicators were evaluated by six experts using a weighted Likert-scale scoring system. The Intraclass Correlation Coefficient (ICC) analysis confirmed high inter-rater reliability (ICC = 0.82). Results showed that Talao and Karan Aur achieved "Good" environmental quality, while Nareh, Manggung, and Apar were rated "Fair". Key influencing indicators included water quality and riparian buffer vegetation. Spatial zoning analysis further classified development areas into littoral, terrestrial, and urban activity zones based on ecological and planning criteria. Sustainability assessment using MDS identified seven leverage indicators (local revenue, job diversification, accessibility, education, community institutions, environmental conservation, and biodiversity). These indicators were dominant in shaping the coastal development strategy and supported by high model validity (RSQ > 0.74). The study concludes that Environmental Waterfront development in Pariaman City requires integrated strategies that balance ecological integrity, social inclusion, and economic growth. Specific mitigation measures, namely vegetative, structural, and regulatory, are recommended to elevate the environmental quality of all lagoon sites. Findings offer a strategic foundation for sustainable coastal governance and provide a replicable model for similar regions across Indonesia's western coastline.

Key-words: *Coastal zone; Lagoon; Multidimensional Scaling; Pariaman; Waterfront.*

1. INTRODUCTION

Coastal area management has become an increasingly complex and urgent global concern, particularly amid growing pressures of urbanization, climate change, and intensified activities. As transitional zones between land and sea, coastal areas possess high ecological and economic value. However, they remain highly vulnerable to environmental degradation, including coastal erosion, tidal flooding, and unplanned land use (Febriandi et al., 2025). In many cities worldwide, including in Indonesia, the development of waterfront areas has emerged as a key strategy for achieving sustainable coastal management. This approach seeks to holistically integrate ecological, social, and economic functions within waterfront design (Wrenn, 2023; Breen & Rigby, 1993). Cities such as Pontianak, Semarang, and Banda Aceh (Ulee Lheue) have adopted diverse models of waterfront development, ranging from recreational and historical concepts to disaster mitigation-based designs (Rukayah et al., 2018; Uswah & Wang, 2021; Setiawan & Zalfa, 2023).

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In the Indonesian context, coastal zoning and waterfront development are regulated under Law No. 27/2007 on the Management of Coastal Areas and Small Islands, as amended by Law No. 1/2014. This regulation governs the utilization of coastal and small island marine resources, including provisions for coastal water use permits (Hermon et al., 2018; Prarikeslan et al., 2020; Putra et al, 2023). Furthermore, Ministerial Regulation No. 17/2008 explicitly states that coastal areas are conservation zones where the sustainability of natural resources must be preserved (Suedi et al., 2020; Megawati et al., 2023). On a broader national planning scale, Government Regulation No. 47/1997 concerning the National Spatial Planning Framework identifies 516 strategic cities across Indonesia, 216 of which are classified as waterfront cities located along coasts, rivers, or lakes (Winter, 2019; Kurniati, 2013). This highlights the immense spatial and ecological significance of waterfront zones in Indonesia. However, many of these urban waterfronts have experienced functional decline due to ineffective spatial utilization and unregulated development pressure, leading to the loss of their environmental and socio-economic advantages. Such as Pontianak and Banda Aceh, have begun reconfiguring their waterfronts through thematic planning, many other regions remain vulnerable due to fragmented policy implementation and insufficient conservation integration (Dalila et al., 2021).

The coastal zone of Pariaman City reflects a governance crisis in spatial planning (Oktorie et al., 2019; Hermon et al., 2020). With approximately 12.7 km of coastline and four river basins, Batang Mangguang, Batang Piaman, Batang Jirak, and Batang Mangau, the city is geographically diverse. Three of its four subdistricts, North Pariaman, Pariaman Central, and South Pariaman, are coastal, whereas East Pariaman is inland (Oktorie et al., 2019). The region also features unique coastal morphology, including natural lagoons shaped by sediment deposition and longshore drift. However, it is experiencing severe coastal erosion at a rate of 1.98 m per year and significant shoreline changes between 1988 and 2024 (Hermon et al., 2019). Additionally, frequent tidal flooding in low-lying residential areas has exacerbated ecological stress and disrupted social systems in the region. The absence of conservation and mitigation-oriented spatial planning has hindered the region's ability to support sustainable community livelihoods. One concept considered relevant and promising is the Environmental Waterfront approach (Girard et al., 2014; Permana et al., 2017). The lack of implementation of this approach in Pariaman City has led to a critical gap in sustainable coastal conservation and development efforts. The absence of scientifically based mapping of potential zones, along with weak integration of spatial data, stakeholder perceptions, and regional planning policies, highlights the necessity of this study.

This study adopts two main analytical frameworks: 1) the Intraclass Correlation Coefficient (ICC), used to assess the consistency of stakeholder perceptions regarding the characteristics of potential Environmental Waterfront zones (Lu, 2018); and 2) Multi-Dimensional Scaling (MDS), applied to identify sustainability-driving factors through multivariate analysis of ecological, spatial, and social indicators (Patawari et al., 2022). The study focuses on three core dimensions: 1) the environmental aspects, such as coastal morphology, erosion, tidal inundation, and sedimentation; 2) ecological aspects, including environmental carrying capacity and local biodiversity; and 3) social aspects, particularly stakeholder perceptions and involvement in coastal development.

The object of the study is the coastal zone of Pariaman City, with particular emphasis on five natural lagoon formations resulting from geomorphological processes, specifically longshore drift creating enclosed water bodies (Barnes, 1980; Bondesan, 2017; Putra et al., 2023). These lagoons, distributed along the coastline, were identified through field surveys and satellite imagery as areas with high potential for environmental waterfront development, either existing or in the planning phase. Furthermore, the findings are expected to inform coastal management policies and support sustainable tourism development in Pariaman City. This study aims to assess the environmental characteristics and sustainability potential of lagoon areas along the coastal zone of Pariaman City, Indonesia, for environmental waterfront development.

The novelty of this study lies in its integrative application of weighted environmental assessment and MDS to evaluate the sustainability of natural lagoons as strategic nodes for waterfront urban development. Unlike previous studies that often focus solely on visual or design-oriented aspects, this research quantitatively incorporates physical, ecological, and participatory indicators, validated through ICC analysis. It also offers a replicable model for assessing small-scale coastal systems using localized stakeholder inputs and zoning frameworks, contributing a context-specific scientific basis for sustainable coastal urban planning in mid-sized Indonesian cities.

2. STUDY AREA

The study area is located along the coastal zone of Pariaman City, Indonesia, geographically positioned between 0° 34'30" to 0° 43'30" South Latitude and 100° 6'0" to 100° 12'0" East Longitude. This coastal region is bordered by the Indian Ocean to the west and by Padang Pariaman Regency to the east and north. The landscape is predominantly flat to gently sloping, extending parallel to the shoreline, and is highly vulnerable to coastal hazards such as erosion, tidal flooding, and tsunamis. Bathymetric conditions in the surrounding waters range from shallow (1 m) to deep (over 100 m), with depth contours on the bathymetric map indicating a gradient increasing westward and northwestward. Administratively, the study area encompasses the entire territory of Pariaman City, with a 500 m coastal buffer zone established as the main area of analysis. Spatial data used for mapping include *Satellite Pour l'Observation de la Terre* (SPOT)-6 satellite imagery from 2017, the 1985 Rupa Bumi Indonesia (RBI) topographic map, and field survey data collected in 2021. The study area is shown in more detail in **Figure 1** below.

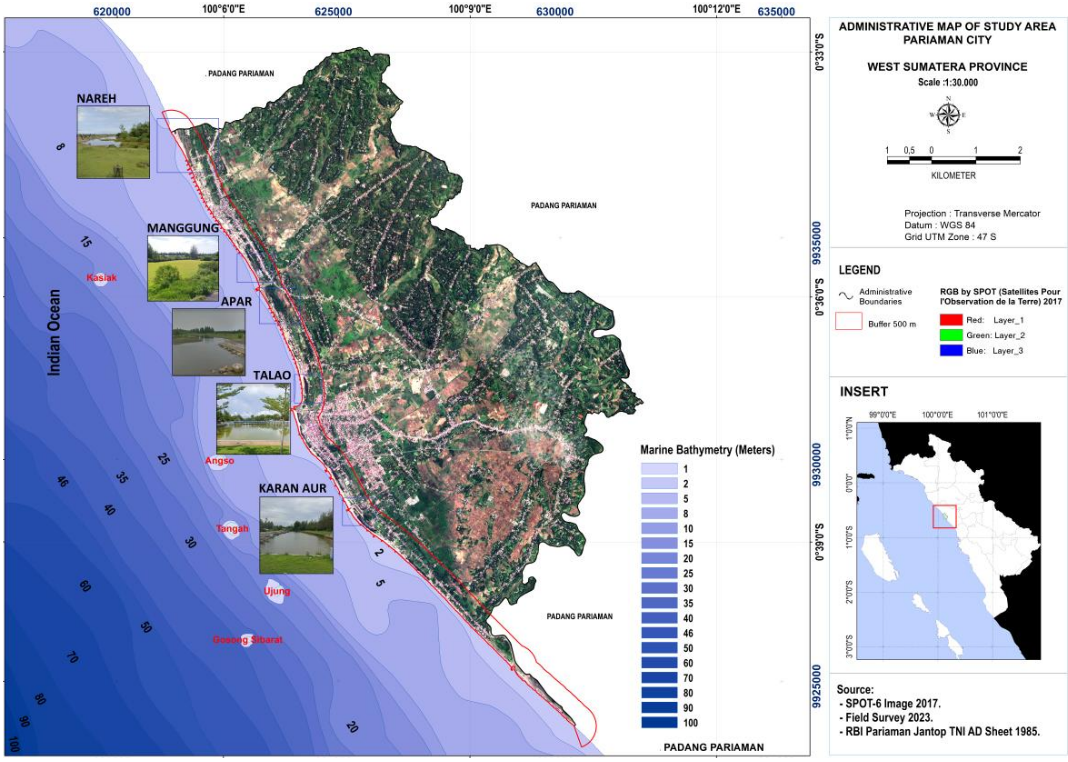

Fig. 1. Location map in the coast of Pariaman City, Indonesia.

This study focuses on five natural lagoons that are geographically distributed along the coastal zone of Pariaman City. These include Nareh Lagoon, located in Padang Birik-Birik and Nareh villages of North Pariaman Subdistrict, covering ±4.8 ha; Manggung Lagoon, situated in Manggung village (North Pariaman), covering ±0.2 ha; Apar Lagoon in Apar village (Central Pariaman), covering ±0.57 ha; Talao Lagoon in Pauh Barat village (South Pariaman), covering ±1.97 ha; and Karan Aur Lagoon, located in Karan Aur village (South Pariaman), covering ±1.24 ha.

These lagoon areas were delineated based on geomorphological features formed by longshore drift and are considered to have high ecological and planning significance for environmental waterfront development. Their spatial extent and strategic positions reflect both natural conservation value and potential for sustainable coastal-based community use.

3. METHODS

3.1. Environmental Quality Assessment Based on Weighted Indicators

This study aimed to evaluate the environmental characteristics of lagoon areas along the coast of Pariaman City, which are considered potential sites for environmental waterfront development. The assessment focused on five primary lagoons, namely Nareh, Manggung, Apar, Talao, and Karan Aur. Each site was evaluated using 13 environmental indicators representing physical, ecological, and spatial aspects through a quantitative approach. The evaluation was conducted by six stakeholders, comprising regional planners, academics, and local government representatives, using a 3-point Likert scale (1 = poor, 2 = fair, 3 = good). Each indicator was assigned a weight determined through expert judgment. The total score for each site was calculated by summing the products of the average rating and the corresponding weight of each indicator. Final scores were then classified into three categories of environmental quality, as shown in **Table 1** below.

Table 1.

Environmental Quality Categories.

Total Score	Category
2.33 – 3.00	Good
1.67 – 2.32	Fair
1.00 – 1.66	Poor

Note: Environmental quality categories are based on the average evaluation scores of lagoon environmental indicators provided by six expert assessors (Primary data, 2025).

3.2. Consistency Testing Using Intraclass Correlation Coefficient (ICC)

To support the classification process of environmental quality categories, the assessment was conducted based on a set of predefined environmental characteristic indicators. These indicators were compiled into an evaluation instrument; each assigned a specific weight based on expert input. The complete list of indicators and their respective weights is presented in **Table 2** below.

Table 2.

Environmental Characteristic Indicators and Assigned Weights according to Leyland & Groenewegen (2024).

No	Indicator	Weight	Data Source
1	Proximity to water body	0.011	Processed data
2	Access to water body	0.007	Processed data
3	Number of water body access points	0.007	Processed data
4	Function of outer buffer zone	0.053	Field observation
5	Building orientation	0.018	Field observation
6	Transport network	0.018	Processed data
7	Building height	0.015	Field observation
8	Structures near buffer zone	0.107	Processed data
9	Riparian buffer vegetation	0.192	Processed data
10	Water quality	0.288	Field observation
11	Aquatic vegetation cover	0.047	Field observation
12	Water odor and color	0.140	Field observation
13	Water body shrinkage	0.097	Environmental Agency

To ensure consistency among assessors, the ICC was calculated using the Two-Way Random Effects, Absolute Agreement model (Model B), as described by Müller & Büttner (1994). This model is appropriate for cases involving multiple raters who are considered a random sample from a larger population, all scoring the same set of items. The ICC formula is expressed as.

$$ICC = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_o^2 + \sigma_e^2}$$

where:
σ_s^2: Variance between subjects (indicators)
σ_o^2: Variance between raters
σ_e^2: Random error

To evaluate the normality of the data, the Shapiro-Wilk test was performed on the residuals. If the data were not normally distributed, the Box-Cox transformation was applied before calculating the ICC. Estimation of the ICC confidence interval was performed using two methods according to Ionan et al. (2014), namely the Generalized Confidence Interval (GCI) for small to medium data, and the Modified Large Sample (MLS) for calculation efficiency in large data. The ICC interpretation can be seen in **Table 3** below.

Table 3.

ICC Value Interpretation.

ICC Value	Reliability Category
ICC > 0.75	High
0.40 ≤ ICC ≤ 0.75	Moderate
ICC < 0.40	Low

3.3. Development Zoning

Interpretation of reliability based on ICC values is the basis for assessing the consistency of assessments between assessors in evaluating environmental characteristics. After the data reliability is declared adequate, the next stage is to determine the area development strategy. One approach used in this study is development zoning based on spatial and functional context, which is divided into two main zones, namely the littoral, terrestrial, and urban activity zones (Clark, 1996; Vallega, 2001), which can be seen in **Table 4** below.

Table 4.

Development Zones according to Clark (1996) and Vallega (2001).

Zone	Description	Examples
Littoral Zone	This zone includes the water bodies (lagoons) as the focal point for environmental activities. Development focuses on water conservation, ecological education, and ecosystem-based tourism.	Coastal lagoons (Talao, Karan Aur), estuaries, river mouths.
Terrestrial Zone	This zone lies within a 100–300 m radius from the coastline, encompassing public green open spaces that function as buffers and ecological corridors. Spatial planning aligns with government regulations on coastal buffer zones.	Beachfront parks (Nareh, Manggung), dune vegetation areas, riparian greenbelts.
Urban Activity Zone	This zone covers the urban hinterland beyond the terrestrial buffer, integrating residential, commercial, and institutional uses while supporting waterfront accessibility, infrastructure, and socio-economic functions.	Market areas, coastal roads, urban settlements (Apar), tourism hubs (Pauh).

3.4. Multi-Dimensional Scaling (MDS)

The analytical method employed in this study is MDS, utilizing the Rapid Appraisal for Sustainability of Environmental Waterfront (Rap-WFS) approach. This technique is adapted from the Rapid Appraisal for Fisheries (RAPFISH) method and has been applied in coastal areas such as the Rapid Appraisal for the Mandeh Region (Rap-MR) studies by Febriandi et al. (2025) and Gusman et al. (2025). The Rap-WFS approach is used to assess the sustainability status of environmental waterfront development in Pariaman City's coastal region in a comprehensive and multidimensional manner. The Rap-WFS analysis consists of six main stages: 1) Identification of sustainability attributes within three main dimensions: economic, social, and environmental; 2) Scoring of each attribute by stakeholders; 3) Application of MDS to map the relative position, influence strength, and relationships among attributes within and across dimensions; 4) Validation of the model using stress and R-squared (RSQ) values; 5) Leverage analysis to determine key attributes influencing sustainability; and 6) Monte Carlo simulation (optional) to test model stability against score variability, although not applied in this study due to sufficient model validity. Scoring was conducted by six key informants representing local government, academics, practitioners, and coastal community members. Data used in MDS were obtained through field observations, structured interviews, and literature review. Analysis was performed using the Statistical Package for the Social Sciences (SPSS) with the Alternating Least Squares Scaling (ALSCAL) module. The sustainability dimensions and corresponding attributes for the Environmental Waterfront development in Pariaman City are presented in **Table 5** below.

Table 5.

Sustainability Dimensions and Attributes for Environmental Waterfront Development.

Dimension	Attributes
Economic	Local Government Revenue (DE_1), Employment Opportunities (DE_2), Household Income (DE_3), Infrastructure Development (DE_4), Job Diversity (DE_5), Accessibility (DE_6), Purchasing Power (DE_7), Job Training (DE_8), Direct Economic Assistance (DE_9), Community Economic Empowerment (DE_10)
Social	Educational Improvement (DS_1), Community Institutions (DS_2), Youth Development (DS_3), Reduction in Illness Ratio (DS_4), Elderly Support Services (DS_5), Community Deliberation Bodies (DS_6), Digital Information Access (DS_7), Mutual Cooperation (DS_8), Social Solidarity (DS_9), Social Norms and Values (DS_10), Environmental Awareness (DS_11), Community Competitiveness (DS_12)
Environmental	Conservation (DL_1), Biodiversity (DL_2), Expansion of Green Open Spaces (DL_3), Soil Quality (DL_4), Drainage Improvement (DL_5), Clean Water Access (DL_6), Provision of Plant Seedlings (DL_7), Coral Reef Protection (DL_8), Groundwater Conservation (DL_9), Watershed Management (DL_10), Waste Management (DL_11)

The MDS configuration results and leverage analysis were used to identify priority sustainability indicators that require attention in the development of environmental waterfront areas in Pariaman City. The outputs displayed in radar charts and two-dimensional plots support the formulation of sustainable development strategies tailored to the local context.

4. RESULTS

4.1. Environmental Characteristic Assessment and Development Strategy for the Environmental Waterfront Area

The assessment was carried out by six expert evaluators using thirteen indicators encompassing spatial, ecological, and physical aspects. The weighting of each indicator was determined through expert judgement. To ensure inter-rater consistency, an ICC reliability test was conducted. The results yielded an ICC value of 0.82, which falls within the high reliability category. This indicates that the assessments among evaluators were statistically reliable and valid. The evaluation process produced an environmental quality classification, as presented in **Table 6** below.

Table 6.
Environmental Characteristic Assessment of Lagoon Areas for Environmental Waterfront Development.

No	Component	Weight	Nareh	Manggung	Apar	Talao	Karan Aur
Environmental Waterfront Development							
1	Proximity to waterbody[1]	0.011	0.03	0.03	0.03	0.03	0.03
2	Access to waterbody[1]	0.007	0.02	0.02	0.02	0.02	0.02
3	Number of waterbody access points[1]	0.007	0.01	0.02	0.01	0.01	0.02
4	Land use beyond buffer[2]	0.053	0.07	0.11	0.11	0.13	0.13
5	Building orientation[2]	0.018	0.03	0.04	0.03	0.04	0.05
6	Transportation network[1]	0.018	0.02	0.02	0.02	0.02	0.02
7	Building height[2]	0.015	0.03	0.05	0.04	0.05	0.04
Riparian Ecosystem Status							
8	Buildings near the riparian area[1]	0.107	0.21	0.11	0.21	0.11	0.11
9	Riparian buffer vegetation[1]	0.192	0.38	0.38	0.38	0.58	0.58
Aquatic Ecosystem Status							
10	Water quality[2]	0.288	0.72	0.82	0.77	0.86	0.72
11	Aquatic plant coverage[2]	0.047	0.14	0.14	0.14	0.14	0.14
12	Odor and color[2]	0.140	0.42	0.33	0.35	0.42	0.42
13	Waterbody shrinkage[3]	0.097	0.19	0.19	0.10	0.19	0.29
Total Score		**1.000**	**2.27**	**2.26**	**2.21**	**2.60**	**2.57**
Category			**Fair**	**Fair**	**Fair**	**B**	**B**

Note: B = Good; CB = Fair
Data sources: [1] field data analysis; [2] site assessment; [3] regional data (Environmental Agency).

The assessment results indicate that Talao Lagoon scored the highest (2.60), placing it in the "Good" category, followed closely by Karan Aur Lagoon with a score of 2.56 (also "Good"). In contrast, the remaining three lagoons Nareh (2.27), Manggung (2.26), and Apar (2.21) were categorized as "Fair”. This highlights a clear distinction: the two lagoons already developed as environmental waterfront areas (Talao and Karan Aur) demonstrate superior environmental quality compared to those that have not yet been developed. Apar Lagoon received the lowest score, signaling the need for special attention to its environmental conditions. Among the 13 indicators, two showed the highest influence on the final scores: water quality (0.288) and riparian buffer vegetation (0.192). Talao Lagoon received the highest ratings for both indicators, while Apar Lagoon scored the lowest. These findings underscore the strong interdependence between healthy riparian vegetation and well-maintained water quality. As also noted by Putra et al. (2023), effective conservation of riparian zones plays a critical role in sustaining water quality and supporting biodiversity. The oceanographic setting exhibits bathymetric variation from shallow nearshore areas (-2 m) to deeper zones exceeding 8 m. Tidal patterns are predominantly diurnal, producing two high and low tides each day with an average range of 1–2 m. Coastal currents are influenced not only by tidal motion but also by the freshwater outflow of major rivers such as Batang Piaman and Batang Mangguang. Wind and wave dynamics, driven by the Indian Ocean monsoon system, generate moderate wave heights not exceeding 1.2 m (Candra et al., 2024). These oceanographic forces significantly influence sediment transport, lagoon water renewal, and overall ecological balance, particularly in semi-enclosed systems like Apar and Manggung Lagoons, which are more vulnerable to stagnation and pollution during low tidal exchange.

This mapping used bathymetric data, river networks, administrative boundaries, and key sites, as shown in **Figure 1**. Five areas have been designated as Environmental Waterfront zones. These sites are distributed north to south along Pariaman’s coastline and marked by the city’s administrative limits, bordering Padang Pariaman Regency to the east. The northern part includes Nareh and Manggung waterfronts near dense residential areas and river mouths. The central area hosts the Apar waterfront, located in the city core. The southern area comprises Talao and Karan Aur, both linked to marine tourism and conservation. These zones are connected by coastal roads and shoreline access, offering strong potential for ecosystem-based, community-driven development. The spatial pattern also reveals proximity to rivers such as Batang Piaman and Batang Mangau, vital for water and riparian governance. With this understanding, development strategies for Pariaman's waterfront can focus on strengthening connectivity, optimizing lagoon functions, and enhancing community participation. Further detail is shown in **Figure 2** below.

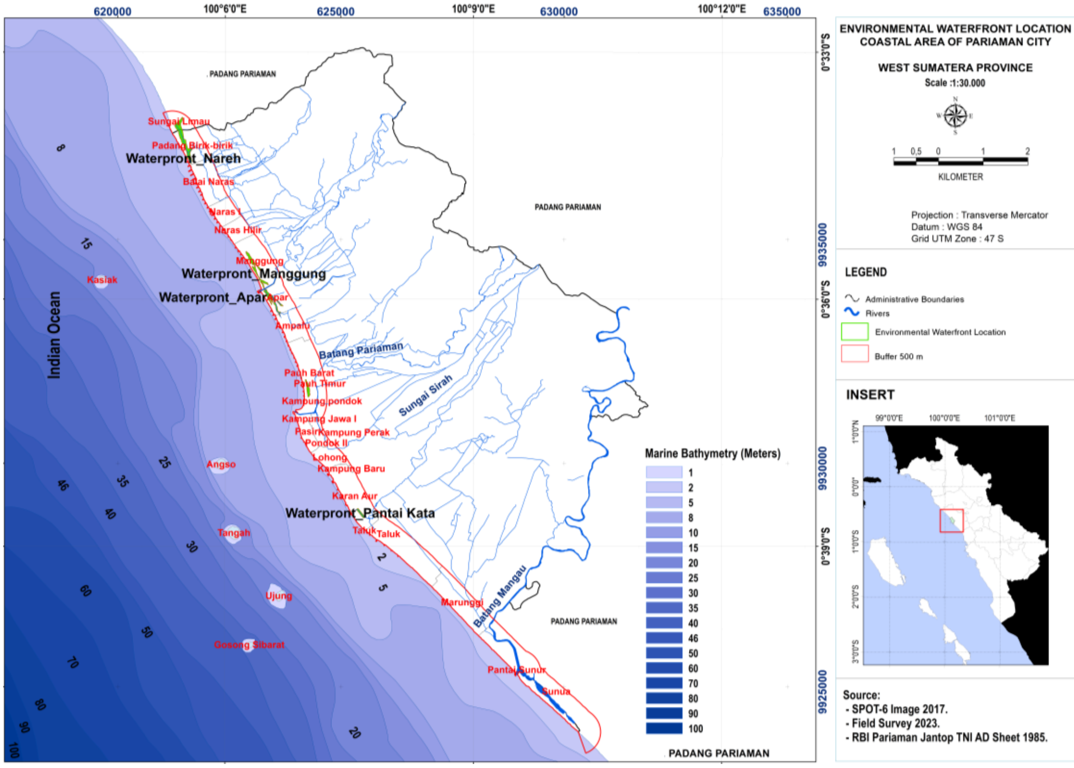

Fig. 2. Location map of Environmental Waterfront Areas in Pariaman City.

The spatial layout of the five waterfront areas demonstrates strong potential for interconnection between water-based zones (lagoons) and adjacent terrestrial zones. These connections could be utilized as green corridors, public open spaces, and ecological linkages. The presence of road infrastructure and the distribution of these areas support an integrated coastal development scenario. Oceanographic factors is essential to spatial planning, as tidal dynamics, river outflows, and wave exposure patterns significantly influence the stability and ecological behavior of both littoral, terrestrial, and urban activity zones. Areas with lower tidal flushing or greater sediment accumulation, such as the northern lagoons of Nareh and Manggung, require zoning strategies that address erosion risks and limited water circulation. Meanwhile, southern lagoons like Talao and Karan Aur, which experience higher tidal exchange and more stable wave conditions, are more conducive to conservation zoning and eco-tourism activities. To guide sustainable coastal development in Pariaman City, all identified environmental waterfront locations were classified into three main spatially and functionally integrated development zones. This classification follows the coastal zoning approach proposed by Clark (1996) and Vallega (2001), as outlined below:

– Littoral Zone: This zone consists of primary water areas, such as lagoons, which serve as focal points for environmentally based activities. Key functions include water quality conservation, aquatic vegetation preservation, and ecosystem-based educational tourism. In locations such as Talao and Karan Aur, the littoral zone has already been optimized as active conservation areas with significant local community involvement. As shown in the spatial map, these lagoons are located near the shoreline and directly connected to river systems like Batang Piaman and Batang Mangau, making them critical for water resource and coastal habitat management.

- Terrestrial Zone: Covering areas within a 100 to 300 m radius inland from the coastline, this zone includes green open spaces, ecological corridors, and coastal buffer strips. It functions as a natural barrier between human activity and the coastal ecosystem. The planning of this zone aligns with national coastal buffer regulations and considers existing infrastructure, residential areas, and connectivity requirements between lagoon zones. Areas like Nareh, Manggung, and Apar show strong potential for terrestrial zone development, particularly due to their proximity to coastal buffers and community access routes.
- Urban Activity Zone: This newly incorporated zone refers to the built-up urban areas beyond the terrestrial buffer that integrate residential, commercial, and socio-economic infrastructure. In the context of Pariaman City, the Urban Activity Zone includes elements such as coastal settlements (e.g., Apar), tourism facilities (e.g., beachfront amenities in Pauh), and transportation corridors that connect inland communities to the coast. This zone plays a pivotal role in supporting waterfront functions through economic activities, accessibility, and institutional presence. Its integration strengthens land-sea interaction and facilitates more inclusive urban coastal planning.

Through a three-zone framework, the development of environmental waterfronts in Pariaman aims not only to provide recreational space but also to emphasize ecological sustainability, spatial control, and community engagement in preserving coastal integrity. The analysis of the five lagoons identified for Environmental Waterfront development reveals varying conditions and characteristics in terms of spatial layout, ecological status, and supporting infrastructure. Not all sites meet the full set of ideal criteria, such as accessibility, land use beyond the riparian zone, riparian buffer vegetation, and water quality aesthetics. These disparities highlight the need for targeted mitigation efforts to elevate the status of those rated as "Fair". A summary of deficiencies and recommended mitigation measures for each site is provided in **Table 7** below.

Table 7.

Mitigation Actions for Components in Lagoon Areas for Environmental Waterfront Development.

No	Component	Lagoon Areas					Mitigation Actions
		[1]	[2]	[3]	[4]	[5]	
1	Proximity to waterbody	√	√	√	√	√	
2	Access to waterbody	√	√	√	√	√	
3	Number of access points to waterbody	-	-	√	√	√	Increasing access to water bodies
4	Land use beyond buffer	√	√	√	√	√	Adding other functions to the area
5	Building orientation	√	√	√	√	√	The building backs onto the area to create a facade that faces the lagoon area
6	Transportation network	√	√	√	√	√	Plan access to the water body so it leads directly there (not cutting through), which affects the orientation of surrounding buildings.
7	Building height	-	-	-	-	√	Set maximum building height to avoid obstructing views into the area under regional regulations.
8	Buildings near riparian buffer	√	√	√	√	√	Confirming border boundaries
9	Riparian buffer vegetation	-	-	√	√	√	Planting trees in riparian areas
10	Water quality	√	√	√	-	-	Controlling domestic waste entering the waters; Making policies and imposing sanctions on perpetrators of pollution, both households and industries; and Monitoring and implementing policies that have been made
11	Aquatic vegetation cover	√	√	√	-	-	
12	Odor and color	√	√		-	-	
13	Waterbody shrinkage	√	√	√	-	√	Dredging for sedimentation material; Planting vegetation in riparian areas; and Equipping inlets with water treatment

Lagoon Area Legend: [1] Nareh; [2] Manggung; [3] Apar; [4] Talao; [5] Karan Aur.

As shown in **Table 7**, the Talao and Karan Aur lagoons have generally met nearly all assessment indicators and require minimal corrective actions. However, continued monitoring is still needed for aquatic vegetation coverage and the control of odor within the water body to maintain current environmental standards. In contrast, the Apar and Manggung lagoons demand special attention, particularly in terms of water quality, riparian buffer vegetation, and the spatial arrangement of buildings near the riparian zone. For instance, in Apar, visible issues such as garbage accumulation and the absence of riparian vegetation highlight the need for reforestation along buffer zones, stricter control of domestic and industrial waste discharge, and a strengthened role of the riparian buffer as an ecological barrier. In the case of Nareh Lagoon, the main constraints are related to building orientation and non-supportive land use beyond the buffer zone. To address this, it is recommended to revise spatial zoning to prevent direct building orientation toward the lagoon and to introduce additional public space functions within the buffer area. Overall, the proposed mitigation strategies can be categorized into three types: vegetative (e.g., reforestation of riparian zones), structural (e.g., improved water access infrastructure), and policy-based (e.g., shoreline zoning regulations and waste discharge control mechanisms). These measures aim to elevate the environmental quality of all lagoon sites to the "Good" category, thereby enabling each to be equally viable for sustainable Environmental Waterfront development, balancing ecological integrity, social function, and economic potential in Pariaman City.

4.2. Assessment of Sustainability Factors and Strategy Identification for Environmental Waterfront Development Using MDS

Economic Dimension

The visualization of the MDS analysis for the economic dimension is presented in **Figure 3**, which displays the relative positioning of ten economic sustainability indicators in a two-dimensional radar graph. The figure illustrates the extent to which each indicator contributes to the sustainability of Environmental Waterfront development in the coastal areas of Pariaman City.

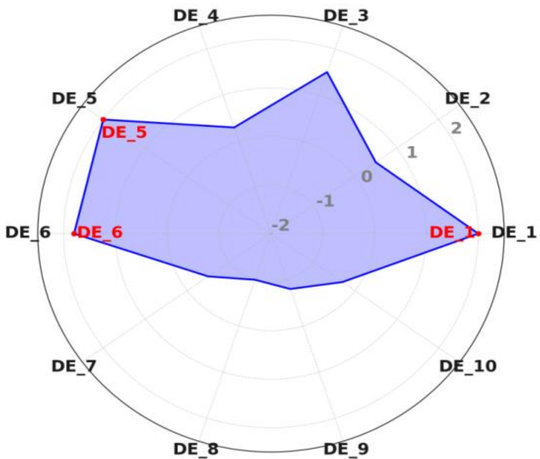

Fig. 3. MDS Modeling Results of Key Economic Sustainability Factors.

Informations:
DE_1 (Local Revenue); DE_2 (Employment Opportunities); DE_3 (Community Income); DE_4 (Facility Development); DE_5 (Job Diversification); DE_6 (Accessibility); DE_7 (Purchasing Power); DE_8 (Workforce Training); DE_9 (Direct Economic Assistance); DE_10 (Community Economic Empowerment).

Based on the radar chart in **Figure 3** above, three indicators DE_1 (Local Revenue), DE_5 (Job Diversification), and DE_6 (Accessibility) stand out with the highest positions relative to others. These indicators, visually highlighted in red, play a dominant role in explaining the economic sustainability of waterfront development in Pariaman. Their elevated scores and prominent locations on the graph indicate their stronger contribution compared to other variables in the model. The validity of the MDS model is supported by a Stress value of 0.68032, which remains within acceptable distortion limits, and an RSQ value of 0.78, indicating that 78% of stakeholder perception variance regarding economic indicators is effectively explained by the MDS configuration. This confirms that the model is sufficiently representative in capturing the complexity of relationships among the economic sustainability indicators. Substantively, DE_1 (Local Revenue) emerges as a critical indicator, underscoring the necessity for coastal development efforts to generate tangible fiscal benefits for the region, whether through optimized tourism, taxation, or service retributions. DE_5 (Job Diversification) reflects the need for inclusive and adaptive employment sectors suited to coastal contexts, such as ecotourism, environmental services, conservation work, and water-based transportation. DE_6 (Accessibility) highlights the importance of developing infrastructure, enhancing inter-area connectivity, and providing public amenities that support the mobility of residents and tourists to and within waterfront zones. These findings suggest that in formulating economic development strategies for the coastal area, the Pariaman City Government should prioritize policies that enhance local revenue, create diverse employment opportunities, and improve integrated access systems. These three pillars serve as the foundation for sustainable Environmental Waterfront development that is not only economically efficient but also inclusive and future-oriented.

Social Dimension

The visualization of the MDS analysis for the social dimension is presented in **Figure 4**, which displays the spatial configuration of twelve social sustainability indicators in a two-dimensional radar chart. This graphic illustrates the relative contribution of each indicator to the social sustainability of the Environmental Waterfront areas in Pariaman City.

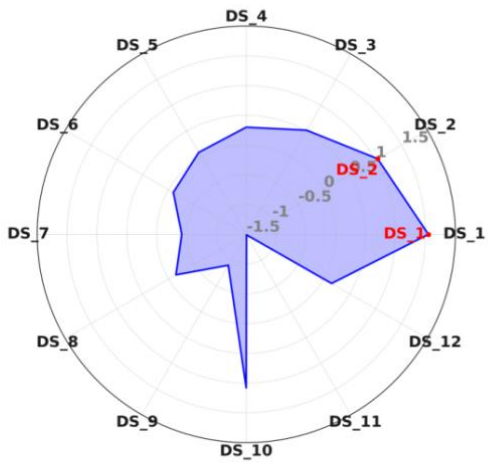

Fig. 4. MDS Modeling Results of Key Social Sustainability Factors.

Informations:

DS_1 (Education Improvement/Human Development Index); DS_2 (Community Institutions); DS_3 (Youth Empowerment Programs); DS_4 (Reduction in Illness Rate); DS_5 (Elderly Care and Support); DS_6 (Consensus-Building Bodies); DS_7 (Digital Information Access); DS_8 (Community Cooperation); DS_9 (Social Solidarity); DS_10 (Values and Morality); DS_11 (Environmental Awareness); DS_12 (Community Competitiveness).

The radar chart in **Figure 4** above DS_1 (Education Improvement/HDI) and DS_2 (Community Institutions) as the two most prominent indicators. Visually marked in red and occupying the highest coordinates in the graph, these indicators play a central role in explaining the social sustainability of coastal Environmental Waterfront development. The MDS model demonstrates strong validity, with a Stress value of 0.78371, which remains within an acceptable threshold for complex social dimensions, and an RSQ value of 0.74, indicating that 74% of stakeholder perception variance is well captured by the model. These values support the strategic significance of DS_1 and DS_2 as key leverage factors. Substantively, DS_1 (Education/HDI) reflects the foundational role of education in advancing social development in coastal communities. Higher levels of education correlate with greater adaptability, broader civic engagement, and stronger capacity for environmental stewardship in waterfront areas. Education also fosters ecological awareness and enhances public understanding of the functions and importance of the coastal environment. Meanwhile, DS_2 (Community Institutions) underscores the importance of active local institutions, such as community organizations, customary councils, and environmental stewardship groups. These institutions serve not only as platforms for mediation and collective decision-making but also as key actors in conservation, spatial consensus-building, and the preservation of local values and norms in the context of coastal development. These findings carry significant strategic implications for the Pariaman City Government, suggesting a need to prioritize education sector strengthening and the establishment or reinforcement of local institutions. These two pillars are critical for building a socially inclusive and sustainable Environmental Waterfront areas.

Environmental Dimension

The visualization of the MDS analysis for the environmental dimension are illustrated in **Figure 5**, which presents a two-dimensional radar chart mapping the relative positions of eleven environmental sustainability indicators. These indicators were used to evaluate their respective contributions to the development of Environmental Waterfront areas in Pariaman City.

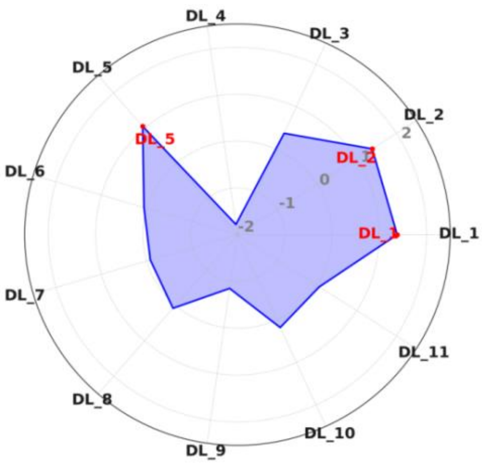

Fig. 5. MDS Modeling Results of Key Environmental Sustainability Factors.

Informations:
DL_1 (Conservation); DL_2 (Biodiversity); DL_3 (Expansion of Green Open Spaces); DL_4 (Soil Quality); DL_5 (Drainage Improvement); DL_6 (Access to Clean Water); DL_7 (Seedling Distribution); DL_8 (Coral Reef Protection); DL_9 (Groundwater Conservation); DL_10 (Watershed Management); DL_11 (Access to Sanitation).

The radar chart in **Figure 5** above three dominant indicators–DL_1 (Conservation), DL_2 (Biodiversity), and DL_5 (Drainage Improvement)–each visually marked in red and positioned within the most influential quadrant. Their prominent spatial locations in the chart indicate shared directional contributions and stronger leverage in promoting environmental sustainability in Pariaman's coastal areas. The MDS model used for this dimension demonstrates sufficient validity, with a Stress value of 0.72161, which remains within acceptable thresholds for interpreting social-environmental systems, and an RSQ value of 0.76, meaning 76% of stakeholder perception variability regarding environmental indicators is well represented by the model. This affirms the spatial configuration's reliability in identifying the most critical sustainability factors. Substantively, DL_1 (Conservation) reflects the importance of preserving coastal ecosystems as ecological buffers for the city. Conservation efforts include the protection of mangrove forests, coastal vegetation, and riparian zones that mitigate disaster risks and maintain ecological balance. DL_2 (Biodiversity) emphasizes safeguarding the richness of local species–both flora and fauna–as an integral part of coastal ecosystems and a valuable resource for sustainable ecotourism development. Meanwhile, DL_5 (Drainage Improvement) points to the necessity of efficient water infrastructure management to prevent tidal flooding and waterlogging, as well as to maintain water quality and public health in coastal settlements. These findings underline that strengthening these three indicators should be a strategic priority in Pariaman's environmental development agenda. This approach not only plays a critical role in mitigating environmental risks but also in supporting the long-term ecological productivity and resilience of the Environmental Waterfront areas.

4.3. Integrated Findings and Strategic Leverage Indicators for Sustainable Environmental Waterfront Development

Based on the results of the MDS analysis across the three main sustainability dimensions, seven key indicators were identified as the most influential in determining the success of Environmental Waterfront development in Pariaman City. These indicators occupy dominant positions in the spatial configuration of the MDS model and hold the highest coordinate values in their respective radar charts, making them leverage indicators for sustainability.

The seven key indicators are DE_1–Local Government Revenue (PAD); DE_5–Job Diversification; DE_6–Accessibility; DS_1–Education Improvement (Human Development Index); DS_2–Community Institutions; DL_1–Conservation; and DL_2–Biodiversity. These indicators serve as the core foundation for designing an adaptive, inclusive, and sustainable coastal development strategy.

The concept of Environmental Waterfront development is not merely a spatial planning framework but represents an integrated approach that addresses environmental degradation while promoting the conservation of coastal resources. From an economic standpoint, sustainability in coastal zones is strongly influenced by the ability of the region to increase local revenue (DE_1) through optimized utilization of spatial potential, particularly in tourism, taxation, and service-based fees. Job diversification (DE_5) underscores the need to expand economic activities in coastal areas, including environmental services, ecotourism, and maritime transportation. Meanwhile, accessibility (DE_6) is vital for enhancing regional connectivity and supporting the mobility of both residents and tourists toward coastal destinations. In the social dimension, sustainability is largely shaped by education (DS_1), which fosters environmental awareness, civic engagement, and community adaptability to environmental changes and emerging economic opportunities. Community institutions (DS_2) play an essential role in spatial governance, social consensus-building, and the preservation of local cultural values relevant to coastal development. From an environmental perspective, the leading indicators, namely conservation (DL_1) and biodiversity (DL_2) highlight the importance of safeguarding coastal ecosystems, including mangrove forests, shoreline vegetation, and marine biodiversity.

These elements serve as ecological buffers and represent a strong foundation for conservation-based ecotourism. These findings provide a solid framework for the Pariaman City Government to develop action plans and strategic policies centered around these seven leverage indicators. The involvement of key stakeholders, including academics, conservation organizations, local communities, and the private sector is essential in co-designing development programs that are collaborative, realistic, and sustainability-oriented.

5. CONCLUSIONS

This study provides a comprehensive assessment of the environmental, spatial, and sustainability characteristics of lagoon areas designated for Environmental Waterfront development in Pariaman City. The environmental assessment revealed that Talao and Karan Aur Lagoons achieved a "Good" classification, supported by strong water quality and riparian vegetation. In contrast, Apar Lagoon, scoring the lowest, requires intervention due to poor buffer conditions and visible waste. Manggung and Nareh Lagoons were also rated "Fair", indicating a need for better land use planning and vegetation restoration. The spatial classification into littoral, terrestrial, and urban activity zones supports an integrated planning approach. Littoral zones in Talao and Karan Aur serve conservation and ecotourism functions, while terrestrial zones in Nareh, Manggung, and Apar offer green infrastructure opportunities. The urban activity zone around the lagoons supports socio-economic functions, access, and governance. This tri-zonal structure enhances spatial clarity and urban ecological integration. To improve environmental quality, three mitigation strategies are proposed: 1) Vegetative (e.g., riparian planting), 2) Structural (e.g., water access improvement), and 3) Policy-based (e.g., zoning enforcement). The MDS analysis identified seven key indicators as critical for sustainable development: DE_1 (Local Revenue), DE_5 (Job Diversification), DE_6 (Accessibility), DS_1 (Education), DS_2 (Community Institutions), DL_1 (Conservation), and DL_2 (Biodiversity). These represent strategic pillars for a resilient waterfront model. Economic sustainability depends on optimizing revenue, job diversity, and access; social sustainability relies on education and local institutions; and environmental sustainability is anchored in conservation and biodiversity. Overall, the integration of weighted indicator analysis, MDS-based evaluation, and tri-zonal planning offers a novel, replicable framework for Indonesia’s coastal cities. These findings provide a foundation for an adaptive and inclusive coastal strategy in Pariaman. Its success requires active collaboration among government, communities, conservation groups, and the private sector. With strong synergy, Pariaman’s waterfront areas could serve as a national model for sustainable coastal governance, balancing ecological integrity, socio-economic development, and spatial resilience.

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