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Identification of Potential Sites for Integrated Agroindustry Development of Aquaculture and Ecotourism in Coastal Areas Using a Geographic Information System Approach

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Abstract: Determining strategic locations for the development of integrated agroindustry—encompassing aquaculture areas, industrial zones, and ecotourism sites within coastal regions—presents a complex challenge. Each sector carries distinct interests and characteristics, often leading to spatial conflicts. Moreover, ensuring coastal ecological sustainability must remain a top priority throughout the planning process. A comprehensive approach is required to identify locations that not only minimize environmental impacts but also maximize cross-sectoral economic value. This study aims to identify potential locations for the development of an integrated agroindustry in the aquaculture–ecotourism sector. The Analysis of Operational Area of Nature-Based Tourism Attractions (AOA-NBTA) was employed to assess ecotourism potential. The Analytical Hierarchy Process (AHP) was applied to assign weights to industrial development parameters, while Geographic Information Systems (GIS) were used for spatial analysis of potential locations for integrated agroindustrial development. The AOA-NBTA analysis identified Tanjung Pakis Beach as the most promising ecotourism location, with a cumulative score of 3.175. Spatial overlay analysis in the Bekasi–Karawang coastal region revealed that highly suitable (S1) areas account for 20.27% (1,950.961 ha), suitable (S2) areas 18.10% (1,742.823 ha), and unsuitable areas 61.63% (5,933.175 ha). These findings provide a foundation for spatial decision-making in formulating sustainable development policies, particularly in coastal zones.

Keywords: Integrated coastal planning; Development agroindustry; Spatial multi-sector analysis; AHP–GIS integration; Agroindustry-aquaculture-ecotourism zone

1 Introduction

Coastal ecosystems play a vital role in maintaining aquatic ecological balance while supporting the economic sustainability of local communities [1]. The decline in marine capture yields over recent decades has prompted the expansion of aquaculture and pond farming as key alternatives, not only enhancing food security but also stimulating the growth of service, industrial, and recreational sectors [2]. The ecosystem services-based approach serves as a strategic instrument to integrate conservation with cross-sectoral development, particularly in coastal areas where natural resources, economic activities, and sociocultural dynamics are closely interconnected [3]. Therefore, careful planning is required, especially for industrial development that involves other sectors such as aquaculture and ecotourism.

Aquaculture-based industries face considerable challenges in achieving sustainability, including managing production systems, improving commodity productivity, adopting innovative technologies, and implementing principles of the circular economy and bioeconomy [4]. Environmental friendliness is also demanded through the development of production technologies that enhance efficiency while preserving natural resources [5, 6]. The integration of the industrial, aquaculture, and tourism sectors represents a promising strategy to strengthen regional economies. The synergy among these three sectors can significantly contribute to regional development by creating employment opportunities, increasing community income, and expanding access to tourism and recreational activities [7].

Integrating industry, tourism, and aquaculture within a single area allows for more efficient resource utilization with minimal environmental impact. Proper management fosters economic growth without compromising fishery productivity and coastal ecosystem health [8]. Therefore, a comprehensive evaluation of commercial space accessibility across the study area is essential [9]. Strategic site selection becomes crucial to ensure harmonious sectoral synergy. Despite the advantages offered by the integration of industry, aquaculture, and ecotourism, potential conflicts of interest remain, especially when sectoral short-term and long-term priorities differ. Thus, appropriate analytical tools are needed to identify strategic locations that facilitate effective integration.

Geographic Information Systems (GIS) are recognized as highly effective tools for spatial planning and management, enabling comprehensive geospatial data collection, storage, and visualization [10]. GIS technology plays a critical role in determining optimal locations for industrial development integrated with aquaculture. The method can also assess spatiotemporal patterns in multi-population dynamics, strengthening sustainable ecosystem management and conservation efforts, including monitoring spatial-temporal changes related to ecology, climate change, and fishery resource management [11].

Integrated and participatory spatial governance is key to addressing the complexity of coastal area planning [12]. Over the past few decades, coastal zones have experienced significant ecological resilience degradation and increased environmental risks due to accelerated socio-economic development [13]. Both natural threats and intensifying anthropogenic pressures must be carefully addressed when designing sustainable management strategies [14].

Several studies have examined the integrated use of marine ecosystem services and coastal areas, as highlighted by Shakya et al. [3] and Addamo et al. [15], who emphasized limitations in spatial mapping and evaluation during planning processes. The application of GIS to incorporate spatial ecosystem service assessments into spatial planning has been demonstrated by the studies [16, 17]. GIS-based identification of optimal locations for aquaculture development has also been explored by the studies [18–20]. Furthermore, spatial analysis has been utilized to evaluate green growth factors in China's oil and gas industries [21], assess watershed vulnerability to disasters [22], design tourism areas [23], and determine ecotourism suitability using Analytical Hierarchy Process (AHP) and GIS in Uttara Kannada District, India [24].

Nevertheless, research that explicitly integrates aquaculture systems, agroindustrial activities, and ecotourism potential within a single sustainable coastal landscape remains limited. Therefore, this study aims to identify strategic areas for the development of an integrated agroindustry based on aquaculture and ecotourism within a unified ecoregion. Sectoral synergy is pursued through a comprehensive consideration of economic, sociocultural, and ecological aspects. The successful development of such an area requires clear and harmonized evaluative criteria across sectors to ensure appropriate and sustainable site selection.

2 Methodology

2.1 Research Location

This study employed a descriptive-quantitative approach to assess the potential of nature-based ecotourism and to identify strategic locations for the development of integrated agroindustrial zones that combine aquaculture and tourism within a single coastal area.

The selection of ecotourism sites was based on several key criteria: (i) inclusion in the Regional Spatial Plan (RSP) of Bekasi and Karawang Regencies as strategic coastal zones, (ii) the presence of nature-based tourist attractions such as mangrove forests, beaches, and aquaculture ponds, (iii) basic accessibility through land and water transportation networks, and (iv) the participation and economic activities of local communities relevant to ecotourism. These criteria were established through literature reviews, consultations with local stakeholders or experts with domain-specific expertise, and preliminary field surveys. Based on these considerations, five ecotourism sites were designated as objects of analysis using the Analysis of Operational Area of Nature-Based Tourism Attractions (AOA-NBTA) method: Sungai Jingkem, Jembatan Cinta, Muara Gembong Beach, and Muara Beting Beach in Bekasi Regency, as well as Tanjung Pakis Beach in Karawang Regency.

2.2 Assessment of Nature-Based Ecotourism Objects

This analysis employed a modified version of the AOA-NBTA, in accordance with the official guidelines of the Directorate General of Forest Protection and Nature Conservation (PHKA) issued in 2003 and Law No. 10 of 2009 on Tourism issued by the Indonesian Ministry of Environment. The data utilized consisted of primary data, including field surveys, ecotourism observations, and semi-structured interviews through questionnaires and focus group discussions with experts. Secondary data were obtained from the Tourism Office, Forestry Office, Perum Perhutani, RSP documents, Bappeda reports, and supporting literature.

The evaluation of ecotourism potential was conducted using standardized assessment sheets for nature-based tourism, assessed by seven competent experts. Each site was evaluated using a weighting method calculated according to Eq. (1). Data collection was carried out in 2023.

$$\mathrm{S} = N \times B \quad (1)$$

where, S = score of a criterion, N = number of sub-elements within a criterion, B = weight assigned to each parameter. Each parameter/criterion consists of elements and sub-elements that are assessed based on the potential and condition of each location. The assessment results are presented in Table 1.

Table 1. Ecotourism object assessment based on parameters of each element/sub-element

	Element/Sub-Element	**Score**
Parameter (P).1. Tourism Attraction of the Ecotourism Site (weight (w) = 6)	a. Uniqueness of natural resources:	
	1) Coastal area	30 (if 5/5)
	2) Cave	25 (if 4/5)
	3) River stream	20 (if 3/5)
	4) Flora-fauna	15 (if 2/5)
	5) Local customs	10 (if 1/5)
	b. Number of outstanding natural resources:	
	1) Rocks	30 (if 5/5)
	2) Flora	25 (if 4/5)
	3) Fauna	20 (if 3/5)
	4) Water	15 (if 2/5)
	5) Natural phenomena	10 (if 1/5)
	c. Types of nature-based tourism activities:	
	1) Trekking	
	2) Climbing	30 (>7)
	3) Rafting	25 (6–7)
	4) Camping	20 (4–5)
	5) Educational	15 (2–3)
	6) Spiritual	10 (only 1)
	7) Hiking	
	8) Tent camping	
	9) Fishing	
	d. Cleanliness of the site(absence of)	
	1) Natural debris	30 (none)
	2) Industrial pollution	25 (1–2)
	3) Noisy roads	20 (3–4)
	4) Residential settlements	15 (5–6)
	5) Litter	10 (7 or all)
	6) Disturbing animals	
	7) Vandalism	
P.2. Accessibility of Ecotourism Site (w = 5)	a. Road condition and distance from district capital:	
	1) <44 km	Good: 80/60/40/20
	2) 45–66.5 km	Fair: 60/40/20/10
	3) 67.5–90 km	Moderate: 40/20/15/5
	4) >90 km	Poor:20/15/5/10
	b. Road type:	
	1) Asphalt, >3 m wide	30
	2) Asphalt, <3 m wide	25
	3) Stone/macadam	20
	4) Dirt road	10
	c. Travel time from capital/district:	
	1) 30 min–1 hour	30
	2) 1–1.5 hours	25
	3) 1.5–2 hours	20
	4) 2–2.5 hours	25
	5) >2.5 hours	10

Continued

	Element/Sub-Element	Score
P.3. Surrounding Conditions of the Ecotourism Object (w = 5)	a. Main livelihood of the local community:	
	1) The majority are laborers	30
	2) Small traders/craftsmen	25
	3) Farmers/fishermen	20
	4) Land/boat owners, civil servants	15
	b. Visitor movement space:	
	1) >50 ha	30
	2) 41–50 ha	25
	3) 31–40 ha	20
	4) <30 ha	10
	c. Educational level of local community:	
	1) Mostly high school graduates or higher	30
	2) Mostly junior high school graduates	25
	3) Mostly did not finish elementary school	20
	4) Mostly elementary graduates	15
	d. Community response to nature tourism development:	30
	2) Supportive	25
	3) Moderately supportive	20
	4) Less supportive	10
P.4. Supporting Facilities of the Ecotourism Site (w = 3)	a. Facilities:	
	1) Food & beverage outlets	30 (>4 types)
	2) Water tourism facilities	25 (3 types)
	3) Sanitation (toilets)	20 (2 types)
	4) Rest areas	15 (1 type)
	5) Souvenir shops	10 (none)
	6) Public transportation	
	7) Prayer facilities	
	b. Infrastructure:	
	1) Post office	30 (>4 types)
	2) Health clinic	25 (3 types)
	3) Internet access	20 (2 types)
	4) Parking area	15 (1 type)
	5) Roads/bridges	10 (none)
	6) TV/radio signal	
P.5. Availability of Clean Water (w = 6)	a. Volume:	
	1) Abundant	30
	2) Fairly abundant	25
	3) Limited	20
	4) Very limited	10
	b. Distance of water source from site:	
	1) 0–1 km	30
	2) 1.1–2 km	25
	3) 2.1–4 km	20
	4) >4 km	10
	c. Ease of channeling water to the site:	30
	2) Easy	25
	3) Difficult	20
	4) Very difficult	10
	d. Potability:	
	1) Safe for direct consumption	30
	2) Requires minimal treatment	25
	3) Requires chemical treatment	20
	4) Not suitable for consumption	10
	e. Availability:	
	1) Year-round	30
	2) 6–9 months	25

Continued

	Element/Sub-Element	Score
	3) 3–6 months	20
	4) <3 months	10
P.6. Marketing of the Ecotourism Object (w = 4)	a. Affordable entrance fees	30 (4 types)
	b. Variety of ecotourism products	25 (3 types)
	c. Information delivery facilities	20 (2 types)
	d. Promotion efforts	5 (1 type)

The interval between each ecotourism site classification can be determined by subtracting the lowest score from the highest score and dividing the result by the number of classification categories used. The mathematical formula is as follows:

$$\text{Interval} = \frac{S\max - S\min}{k} \quad (2)$$

where, Interval = the value of the interval used to determine development classifications, S$\max$ = highest score, S$\min$ = lowest score, k = number of development classification categories.

To ensure that the variables used can be measured clearly and consistently, this study establishes operational definitions for each analysis variable. The clean water availability variable is measured based on the distance and access of the ecotourism location to clean water sources (wells, PDAM, or public facilities). The assessment categories are determined as follows: very good (<500 m), good (500–1000 m), sufficient (1000–2000 m), and poor (>2000 m). The land use variable is measured through the interpretation of shape file data (SHP) issued by the Geospatial Information Agency which is verified by field surveys, then categorized according to the RSP into residential areas, industry, mangrove conservation, fish ponds, and tourism. For more details, see Table 2.

Table 2. Operationalization of research variables

Variable	Operational Definition	Indicator/Unit of Measurement	Data Source
Availability of clean water	Distance and accessibility of the site to sources of clean water (wells, PDAM, public facilities)	Very good (<500 m), good (500–1000 m), fair (1000–2000 m), poor (>2000 m)	Field survey, PDAM/ Village data
Land use	Compatibility of actual land use with designation in the Regional Spatial Plan (RSP)	Settlement, industry, mangrove, aquaculture ponds, tourism	Satellite imagery, Geospatial Information Agency (BIG), RSP, field survey
Environmental cleanliness	Cleanliness condition of the ecotourism site	Ordinal scale: very clean–clean fair–poor	Field observation
Accessibility	Availability and quality of road infrastructure/ transport access to the site	Ordinal scale: good–moderate poor	Field survey, Bappeda data
Supporting facilities	Number and adequacy of basic facilities (toilets, prayer rooms, parking, food stalls)	Ordinal scale: adequate–fair–poor	Field observation

2.3 Identification of Potential Locations for Coastal Integrated Agroindustry Development in Aquaculture and Ecotourism Using a GIS Approach

The analysis of potential locations for the development of agroindustry-aquaculture-ecotourism was conducted using a GIS approach, which integrates spatial data with the AHP method [25]. The data utilized included shapefiles (SHP) obtained from the National Geospatial Information Agency's 2019 dataset, topographic maps (Rupabumi Indonesia/RBI) of Bekasi and Karawang Regencies, the RSP for the period 2011–2031 from the Department of Spatial Planning and Public Works of Bekasi and Karawang, as well as Landsat 8 OLI TIRS satellite imagery dated 2023-09-06.

The parameters for determining industrial site suitability were evaluated using the Pairwise Comparison Questionnaire method, which was designed to ensure both reliability and validity in capturing the relative importance of each parameter. Reliability was assessed through the Consistency Ratio (CR), where a CR value of less than 0.1 is considered acceptable, indicating consistent and reliable judgments among evaluators. Content validity was evaluated through expert review to ensure that all relevant parameters were comprehensively included. The pairwise comparison was conducted using the Expert Choice software, applying the scoring scale developed by Saaty [25].

The weighting of criteria in the AHP was conducted by involving seven experts selected purposively. The selection criteria were as follows: (i) expertise in ecotourism, coastal conservation, fisheries/aquaculture, agro-industry, or spatial planning; (ii) a minimum of five years of academic or professional experience; and (iii) representation from diverse institutional backgrounds, including academia, local government officials, and community-based practitioners. This purposive selection was intended to ensure comprehensive perspectives and maintain diversity of viewpoints. The weighting process followed the standard AHP methodology as proposed by Saaty [25] and was further reinforced by methodological guidelines from the study [26], ensuring that the resulting weights are academically robust and reliable.

The eigenvalue and eigenvector values were calculated to determine the comparative weights using the pairwise comparison matrix. Subsequently, the CR was evaluated to ensure the reliability of the comparisons. The CR value was calculated through the following steps: Calculating the Consistency Index (CI) using the formula:

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - n}{n - 1} \tag{3}$$

where, CI = Consistency Index, $\lambda\mathrm{max}$ = Principal Eigenvalue, n = Number of elements in the matrix. Calculating the Consistency Ratio (CR) is performed using the following formula:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}} \tag{4}$$

where, CR = Consistency Ratio, RCI = Random Consistency Index, which depends on the number of elements (n) in the pairwise comparison matrix. The standard RCI values are presented in Table 3.

Table 3. Random Consistency Index (RCI) values

OM	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

Note: OM: Order of Matrix; RI: Random Index.

The AHP was employed in this study to determine industrial feasibility criteria due to its simplicity, ease of application, and ability to produce accurate outcomes within a multicriteria assessment framework. Recent advances in Multicriteria Evaluation (MCE) integrated with GIS have demonstrated significant potential in spatial decision-making, particularly in identifying suitable locations for development [27]. Empirical applications of AHP in participatory multicriteria assessments include wetland restoration in the Jianghan Plain, China [28], precision land-use planning in Iran [29], and agricultural land suitability analysis in China [30]. Further methodological advancements are reflected in studies on sustainable surface water planning through the Integrated Index of Vulnerability to Diffuse Contamination (IIVDC) [31], as well as land suitability assessment for aquaculture in western Ethiopia using MCE [32]. Based on these diverse applications, AHP can be effectively combined with multiple approaches; hence, the integration of AOA-NBTA, AHP, and GIS in this study is considered appropriate and provides a solid scientific foundation to support accurate spatial decision-making.

3 Result

3.1 Tourism Object Development Assessment

The evaluation of nature-based tourism attractions was based on six primary parameters: visual appeal, accessibility, environmental conditions, availability of supporting facilities, access to clean water, and marketing aspects. As summarized in Table 4, Tanjung Pakis Beach received the highest score in the tourism attractiveness category, totaling 630 points, while Muara Beting Beach and Muara Gembong Beach recorded the lowest scores, at 330 and 300 points, respectively. The high score of Tanjung Pakis Beach was attributed to its extensive coastline, the presence of coastal pine vegetation, and a diverse range of recreational activities. These include fishing, jogging, camping, banana boat rides, horseback or carriage riding, sand play, and swimming. All these activities are supported by a clean and well-maintained environment, enhancing the site's overall appeal to visitors.

In contrast, attractions such as Jembatan Cinta and Sungai Jingkem emphasize mangrove ecosystem-based ecotourism. Key activities offered include boat tours, wild fishing, and brackish water aquaculture involving milkfish, shrimp, and seaweed cultivation. Although these areas possess high ecological value, their appeal tends to be limited to niche visitor segments. Muara Beting and Muara Gembong beaches also exhibit significant potential through their mangrove forests and rich wildlife, including migratory birds and the endangered Javan langur. However, weak management and inadequate maintenance have hindered their development as fully-fledged ecotourism destinations.

These findings highlight the need for integrated planning and design, emphasizing improved site management and ensuring long-term sustainability [23].

Accessibility is a key factor influencing visitor mobility from their place of origin to the destination, encompassing travel distance, road conditions, and journey duration. According to Table 4, Jembatan Cinta and Sungai Jingkem scored the highest in accessibility, each with 80 points, as they are located along well-maintained roadways approximately 44 km from the Bekasi Regency administrative center. Both sites lie on the inter-provincial route connecting Jakarta, Bekasi City, and Bekasi Regency, with asphalt-paved roads averaging more than 3 meters in width. A similar condition is observed at Tanjung Pakis Beach. Although it is administratively part of Karawang Regency, it is geographically more accessible from Bekasi Regency is due to its proximity to the boundary between the two regions. These three sites—Jembatan Cinta, Sungai Jingkem, and Tanjung Pakis Beach—each recorded the highest accessibility score of 700. In contrast, Muara Beting Beach and Muara Gembong Beach received the lowest scores of 400, primarily due to longer travel times and inadequate road infrastructure.

Table 4. Assessment results of Nature-Based Tourism Attractions (NBTA) in Bekasi/Karawang Regency

Parameter	Jembatan Cinta	Sungai Jingkem	Pantai Muara Beting	Pantai Muara Gembong	Pantai Tanjung Pakis
Tourism Attraction (weight = 6)					
Uniqueness of Ecotourism	25	25	15	10	25
Outstanding Natural Resources	25	25	15	15	25
Type of Tourism	20	15	10	10	30
Cleanliness of Site	25	25	15	15	25
Total	95	90	55	50	105
Score	570	540	330	300	630
Accessibility (weight = 5)					
Road Condition	80	80	40	40	80
Road Type	30	30	25	25	30
Travel Time from City	30	30	15	15	30
Total	140	140	80	80	140
Score	700	700	400	400	700
Surrounding Conditions (weight = 5)					
Main Livelihood	30	30	30	30	30
Visitor Movement Space	10	10	10	10	30
Community Education Level	25	25	25	25	25
Community Response	30	30	25	25	30
Total	95	95	90	90	115
Score	475	475	450	450	575
Supporting Facilities (weight = 3)					
Infrastructure	40	30	10	10	50
Facilities	50	50	20	20	50
Total	90	80	30	30	100
Score	270	240	90	90	300
Availability of Clean Water (weight = 6)					
Water Volume	25	25	20	20	30
Distance from Water Source	30	25	10	20	30
Water Flow Feasibility	25	25	10	20	30
Potability	25	25	10	10	25
Availability	25	25	20	20	30
Total	130	125	70	90	145
Score	780	750	420	540	870
Marketing (weight = 4)					
Marketing	15	15	5	5	25
Total	15	15	5	5	25
Score	60	60	20	20	100
Total Score	2,855	2,765	1,710	1,800	3,175
Development Classification	Potential	Potential	Less Potential	Less Potential	Highly Potential

Factors such as road condition, surface type, and travel duration are critical parameters in assessing the quality of destination accessibility. Accessibility plays a strategic role in supporting tourism development, particularly by enhancing visit efficiency, visitor comfort, and overall satisfaction with available services [9]. The state of transportation infrastructure, including road quality, directly influences regional connectivity, thereby facilitating greater movement of people and goods and generating broader economic benefits [33].

The surrounding socio-environmental conditions also serve as critical factors in supporting the development of nature-based tourism sites. Community support, the availability of space for visitor activities, and the types of local livelihoods, as observed in Jembatan Cinta, Sungai Jingkem, and Tanjung Pakis Beach, are considered positive indicators. Although the education level of residents remains relatively low, with the majority having completed only junior secondary school and working primarily as fish pond laborers or fishermen, all study sites demonstrate considerable potential for further development. This potential is reinforced by active community participation, as reflected in the evaluation results presented in Table 4. The presence of ecotourism in the study areas has also contributed positively to the local economy through increased household income.

The availability of infrastructure and public facilities such as electricity, telecommunications networks, road access, clean water, and other public amenities plays a vital role in ensuring the sustainability of tourism destinations. The analysis results indicate that Tanjung Pakis Beach has the most comprehensive facilities, earning the highest score of 300 and being classified as highly potential. In contrast, Muara Beting and Muara Gembong beaches recorded the lowest scores, each receiving 90. Meanwhile, Jembatan Cinta and Sungai Jingkem were considered moderately potential for further development, with scores of 270 and 240, respectively (Table 4).

The availability of clean water was analyzed based on supply volume, source distance, distribution system, and water quality. Tanjung Pakis Beach received the highest score (870) due to its abundant water supply, proximity to the source (less than 1 km), and a well-established distribution system supported by the regional water utility company. In contrast, Muara Beting Beach recorded the lowest score (420) as a result of limited access, inadequate distribution, and poor water quality for consumption (Table 4).

In terms of marketing aspects, Tanjung Pakis Beach again ranked highest with a score of 100, followed by Jembatan Cinta and Sungai Jingkem, both showing promising development prospects. Marketing strategies, including affordable ticket pricing, digital promotions, and diversification of tourism products, have proven effective in attracting visitors.

Overall, the results of the Nature-Based Tourism Attraction assessment identified Tanjung Pakis Beach as the most promising site, with a cumulative score of 3,175, followed by Sungai Jingkem (2,855) and Jembatan Cinta (2,765), both categorized as potential. Meanwhile, Muara Gembong Beach (1,800) and Muara Beting Beach (1,710) were classified as having less potential. These scores represent an aggregate of six key parameters: tourism appeal, accessibility, environmental conditions, supporting facilities, clean water availability, and marketing, evaluated across five sites in Bekasi and Karawang Regencies.

3.2 Determining Potential Locations for Integrated Aquaculture–Ecotourism Agroindustry Development

Decision-making based on GIS is a strategic approach for selecting optimal spatial alternatives in addressing land-use planning issues. The utilization of spatial data enables the identification of locations based on potential land-use conflicts, aesthetic value, and regulatory compliance [34]. A coastal agroindustry zoning map for Bekasi and Karawang Regencies was generated through an overlay process involving eight spatial parameters, analyzed using weightings derived from the AHP.

Table 5. Expert weighting analysis results on agroindustry site selection parameters

Parameter/Criteria	E1 (%)	E2 (%)	E3 (%)	E4 (%)	E5 (%)	Average (%)
Altitude	7.94	6.52	7.56	8.96	10.50	8.30
Slope	12.32	14.15	12.11	6.66	7.91	10.63
Raw Material Access (pond distribution)	19.44	9.91	33.18	26.73	13.72	20.60
Water Source Access (river)	9.68	8.84	11.19	8.55	13.29	10.31
Road Access Distance	24.70	34.26	18.11	26.16	30.44	26.73
Proximity to Residential Area	6.24	5.21	5.00	5.11	6.75	5.66
Proximity to Business Center (market)	5.09	4.15	4.89	3.92	4.62	4.53
Land Use	14.59	16.96	7.96	13.91	12.77	13.24

Note: E = Expert.

The AHP results yielded a CR of 0.084112 ($CR < 0.1$), indicating a logically acceptable level of consistency in the pairwise comparison matrix [35]. As shown in Table 5, the three highest-priority parameters for determining suitable agroindustrial zones were proximity to road access (26.05%), distance to raw material sources (20.60%), and land use (13.24%). These three factors carried the highest weights among the eight criteria analyzed in assessing industrial site feasibility.

Table 6. Parameter suitability classification and area distribution

Parameter	Feature/Class	Unit	Suitability	Score	Percent (%)	Area (Ha)
Access to road	0–500 m	m	Highly Suitable	5	83.92	108,141.22
	500–1000 m		Suitable	4	11.11	14,314.84
	1,000–1,500 m		Moderately Suitable	3	2.56	3,293.38
	1,500–2,000 m		Less Suitable	2	1.39	1,786.56
	>2,000 m		Not Suitable	1	1.03	1,324.58
Access to raw materials (ponds)	0–500 m	m	Highly Suitable	5	12.05	15,531.34
	501–1,000 m		Suitable	4	1.03	1,327.58
	1,001–1,500 m		Moderately Suitable	3	0.89	1,148.35
	1,501–2,000 m		Less Suitable	2	0.86	1,104.49
	>2,000 m		Not Suitable	1	85.17	109,748.82
Land use	Vacant Land		Highly Suitable	5	0.12	149.84
	Plantation/Industry		Suitable	4	0.00	0.08
	Dry Land		Moderately Suitable	3	0.00	0.00
	Agricultural Land		Less Suitable	2	5.51	7,093.49
	Residential Area, etc.		Not Suitable	1	94.37	121,487.04
Land slope	0–3%	%	Highly Suitable	5	0.22	285.03
	4–8%		Suitable	4	3.88	4,998.70
	9–15%		Moderately Suitable	3	18.55	23,897.28
	16–30%		Less Suitable	2	45.70	58,892.19
	>30%		Not Suitable	1	31.65	40,787.19
Access to water source (river)	0–50 m	m	Highly Suitable	5	17.50	22,553.19
	51–250 m		Suitable	4	45.10	58,118.99
	251–500 m		Moderately Suitable	3	26.13	33,668.36
	501–750 m		Less Suitable	2	8.36	10,767.98
	>750 m		Not Suitable	1	2.91	3,752.07
Altitude	0–24 m	mdpl	Highly Suitable	5	73.24	94,381.57
	25–49 m		Suitable	4	17.66	22,753.89
	50–74 m		Moderately Suitable	3	8.89	11,458.28
	75–100 m		Less Suitable	2	0.19	246.93
	>100 m		Not Suitable	1	0.02	19.86
Distance to residential area	0–2 km	km	Highly Suitable	5	94.69	122,021.42
	2–5 km		Suitable	4	5.20	6,707.16
	5–10 km		Moderately Suitable	3	0.10	132.00
	10–15 km		Less Suitable	2	0.00	0.00
	>15 km		Not Suitable	1	0.00	0.00
Distance to business center (market)	0–10 km	km	Highly Suitable	5	99.68	128,450.38
	10–15 km		Suitable	4	0.32	410.20
	15–20 km		Moderately Suitable	3	0.00	0.00
	20–25 km		Less Suitable	2	0.00	0.00
	>25 km		Not Suitable	1	0.00	0.00

3.2.1 Road access parameter

The analysis of road accessibility parameters indicated that the highly suitable category covers 83.92% of the study area, totaling 108,141.22 hectares (Table 6). This area is largely composed of locations with strong potential for agroindustrial development, supported by direct access to main roads and auxiliary networks that enhance distribution and logistics efficiency.

These findings are consistent with expert evaluations, which ranked road access as the highest-weighted parameter due to its strategic role in economic efficiency, employment opportunities, travel time reduction, vehicle operating costs, logistics functions [36], and energy efficiency [37]. Road infrastructure also underpins the transportation system as a primary driver of regional development [33], improves access to labor markets [38], and facilitates the sustainable supply of raw materials [39]. The spatial analysis results for road accessibility parameters are visualized in Figure 1.

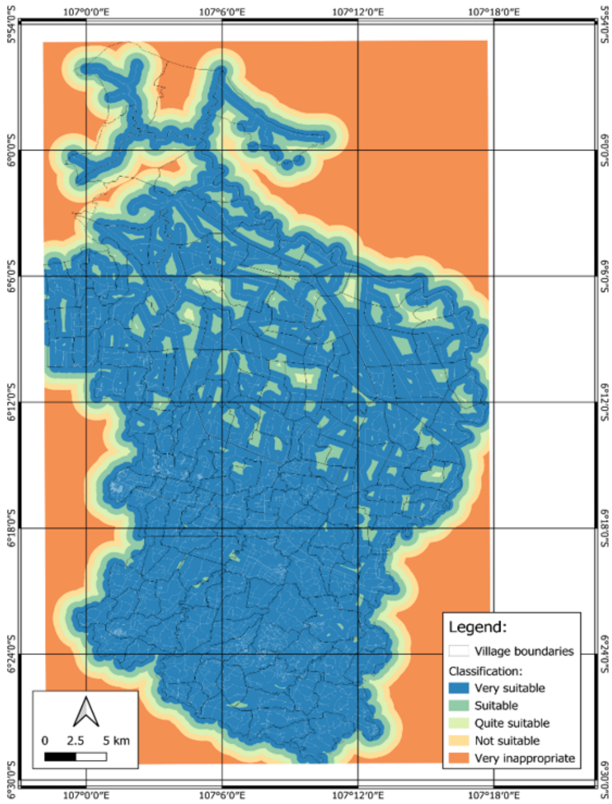

Figure 1. Road access parameter map

3.2.2 Proximity to raw material sources

Proximity to raw material sources is a critical factor in establishing agroindustrial facilities, particularly within the aquaculture sector. Locating production sites near supply points enhances operational efficiency, as aquaculture commodities are perishable and require rapid handling during transportation and storage. Such proximity helps shorten supply chains, lower logistics costs, reduce spoilage risks, and accelerate production cycles. From an environmental perspective, shorter transport distances also contribute to reduced carbon emissions, aligning with sustainability principles [40].

Beyond logistics efficiency, direct access to raw materials influences market demand responsiveness, input diversification, resource efficiency, and ecological stability of the area [41]. Spatial analysis revealed that 15,531.342 hectares (12.05%) of the study area fall under the highly suitable category in terms of proximity to raw material sources (Table 6). The integration of this parameter within the aquaculture–agroindustry–ecotourism development framework is essential for ensuring long-term success. A spatial visualization of the proximity-to-raw-materials parameter is presented in Figure 2.

3.2.3 Land use parameter

Land use ranks third in expert priority evaluations due to its crucial role in ensuring industrial site suitability without compromising ecosystem integrity or disrupting social activities. Risk-based spatial planning is essential to prevent environmental degradation [42], avoid land-use conflicts, and promote spatial optimization for sustainable development [43].

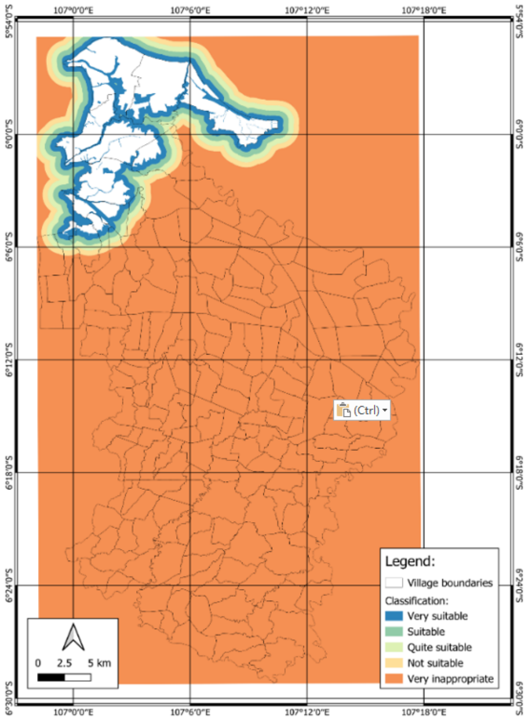

Figure 2. Proximity to raw material sources parameter map

The coastal areas of Bekasi and Karawang are predominantly composed of non-productive lands such as swamps, shrublands, and paddy fields. Only 149.84 hectares (0.12%) of the area is classified as highly suitable, while 94.37% fall into the unsuitable category (Table 6). In the context of agroindustrial development, residential zones, educational facilities, and critical infrastructure are not recommended for conversion. Strategic site selection requires accurate information on land and water availability, both of which are vital to ensuring long-term sustainability [44].

Currently, the coastal zones of both regencies are facing significant ecological challenges due to shoreline abrasion and mangrove deforestation, which have resulted in habitat fragmentation and declining environmental quality. The spatial visualization of land use suitability is presented in Figure 3.

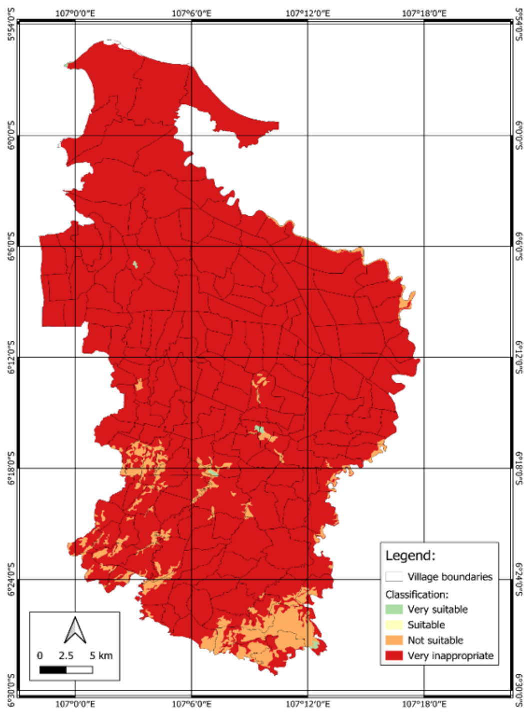

Figure 3. Land use parameter map

3.2.4 Slope parameter

Land slope is a critical parameter in determining agroindustrial site suitability, as steep gradients increase the risk of erosion and landslides, especially in areas with high rainfall [45]. The analysis results indicate that highly suitable areas cover 40,787.193 hectares, accounting for 31.65% of the total study area (Table 6). Overall, the coastal topography of Bekasi and Karawang are predominantly composed of lowland plains with minimal slopes, offering significant potential for industrial development, particularly for integrated agroindustrial initiatives combining ecotourism and aquaculture. The spatial visualization of slope suitability is presented in Figure 4.

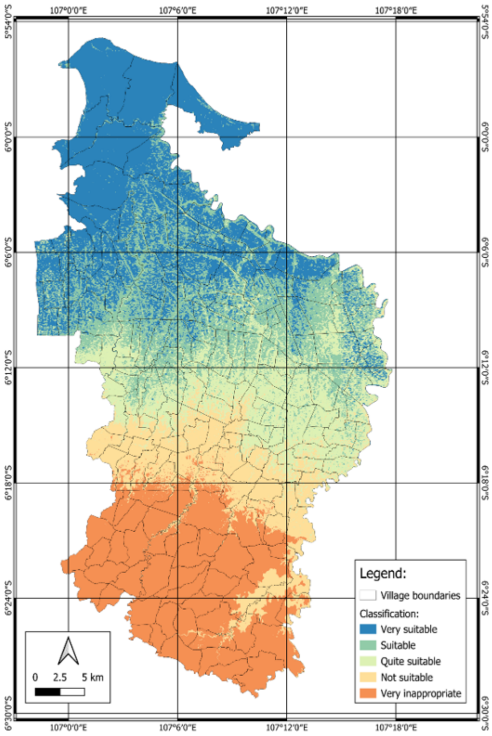

Figure 4. Slope parameter map

3.2.5 Proximity to water sources (rivers)

Proximity to rivers or water bodies is an important parameter in determining agroindustrial site suitability, as it is directly linked to the risk of environmental pollution. While access to water sources is essential for production processes, excessive proximity may increase the likelihood of wastewater discharge into aquatic ecosystems [46]. Therefore, proper wastewater management is crucial, particularly in regions with limited water supply. Ideally, agroindustrial facilities should be located at a minimum distance of 51–250 meters from both water bodies and residential areas to prevent conflicts over resource use and to protect local water availability.

Spatial analysis revealed that 17.50% of the study area, or approximately 22,553.19 hectares, falls under the highly suitable category for the water source proximity parameter (Table 6). This reflects the high potential of the coastal regions of Bekasi and Karawang for agroindustrial development, as these areas are situated in the downstream section of the Citarum River Basin. Mapping of water sources is essential to support industrial sustainability [47], taking into account both the quality and quantity of water supply [32, 48], particularly for agroindustry integrated with aquaculture and ecotourism sectors. The spatial analysis results for this parameter are illustrated in Figure 5.

3.2.6 Elevation parameter

Elevation is a key parameter considered in the selection of industrial sites, particularly for aquaculture-based agroindustries. Locations with elevations ranging from 0 to 24 meters above sea level (masl) are classified as highly suitable for industrial development (Table 6). Spatial analysis indicates that approximately 94,381.571 hectares, or 73.24% of the study area, fall within this category, demonstrating substantial potential for the development of industries integrated with aquaculture and ecotourism sectors.

Elevation is a strategic variable due to its direct correlation with natural disaster risks, such as flooding [49] and landslides [45]. It also plays a significant role in the planning of disaster prediction systems, early warning mechanisms, and both short- and long-term mitigation strategies. The coastal regions of Bekasi and Karawang

Regencies, with average elevations between 5–10 masl, topographically meet the requirements for integrated industrial development. The spatial visualization of the elevation parameter is presented in Figure 6.

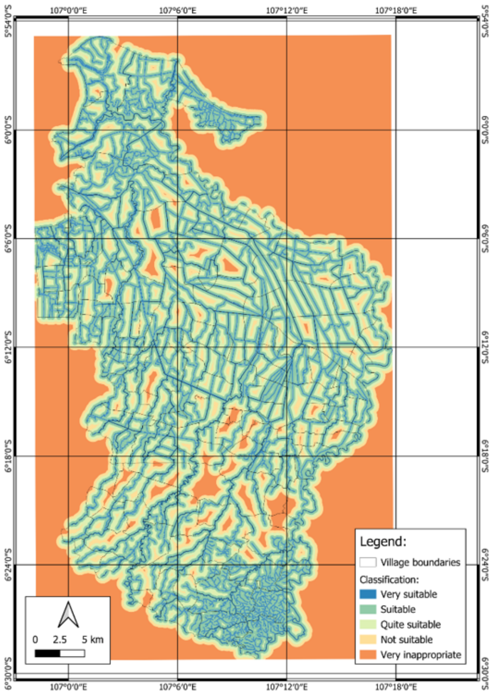

Figure 5. Proximity to water sources (river) parameter map

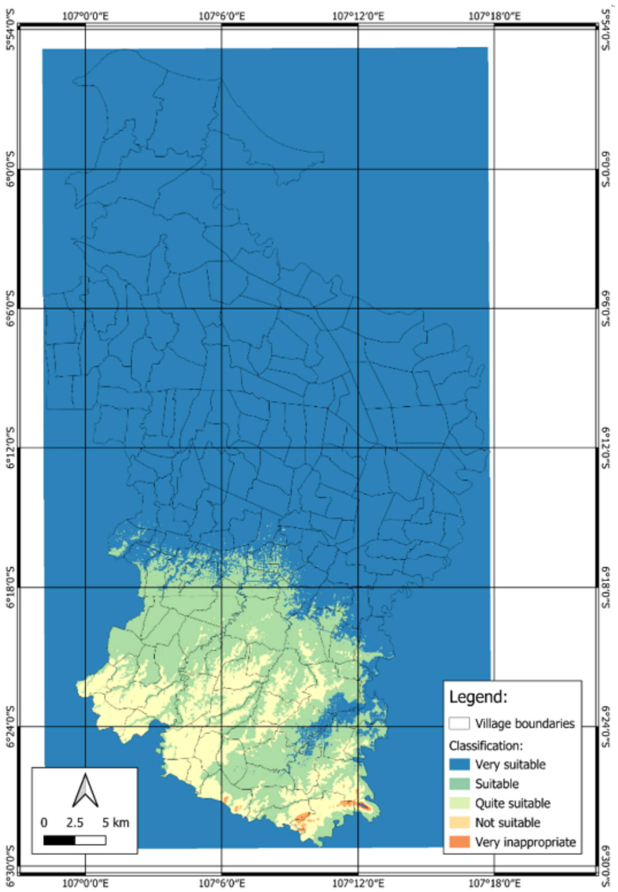

Figure 6. Elevation parameter map

3.2.7 Accessibility to residential areas parameter

Based on the interpretation of Landsat 8 satellite imagery, a thematic map of residential zones was generated and is presented in Figure 7. The mapping results indicate that 122,021.42 hectares, or approximately 94.69% of the study area, fall within the highly suitable category for agroindustrial development (Table 6), excluding the red-marked zones on the map, which represent permanent residential areas that are not eligible for land conversion.

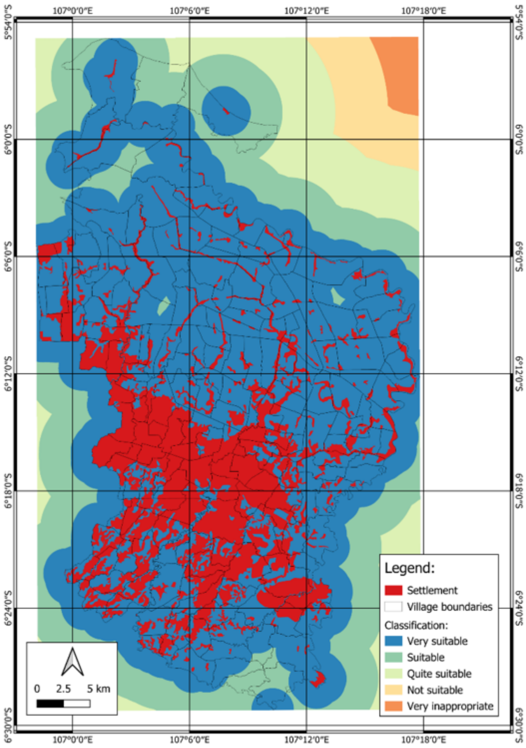

Figure 7. Residential accessibility parameter map

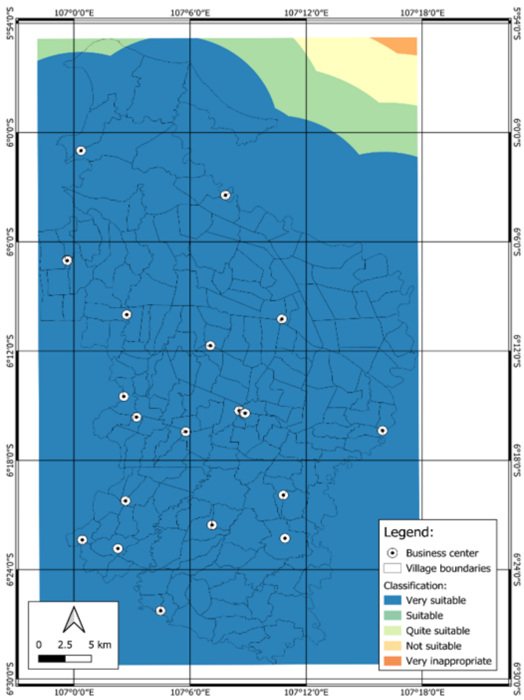

Figure 8. Market accessibility parameter map

Proximity to residential areas is a critical parameter in industrial site selection, as it influences spatial planning, population density, and environmental quality. Regulating industrial development near residential zones helps achieve a balance between land availability, accessibility, social acceptance, and distribution efficiency [50]. This evaluation is useful for mapping population density and preserving community well-being [24]. Therefore, agroindustrial development must consider strategies that minimize potential impacts on the environment, labor resources, and the availability of natural assets [51].

3.2.8 Proximity to business centers (Markets)

Proximity to business centers is a strategic factor in industrial site selection, as it significantly influences the economic value of a region, particularly in terms of market access and interregional distribution [52]. Spatial analysis reveals that 128,450.378 hectares, or 99.68% of the total study area, are classified as highly suitable (Table 6), indicating minimal spatial constraints in accessing markets for agroindustrial development.

Accessibility to business centers facilitates industrial growth, market expansion, labor mobility, and encourages regional innovation and collaboration [53, 54]. Furthermore, such connectivity enhances supply chain integration and supports sustainable economic development [55, 56]. The proximity of industrial sites to business hubs offers a strategic advantage for the aquaculture–ecotourism sector, which is an integral component of the integrated agroindustrial system. The spatial analysis results for this parameter are illustrated in Figure 8.

3.3 Potential Areas for the Establishment of Integrated Aquaculture–Ecotourism Agroindustry

Industrial Designated Zones (IDZ) are land areas officially designated for industrial activities in accordance with the RSP, as mandated by Regulation of the Minister of Industry No. 30 of 2020. All major industries and related sectors within each Industrial Growth Center Region (IGC) are required to be established within the IDZ boundaries.

The designation of IDZ locations is stipulated in the RSP at the regency/municipal level, necessitating policy integration among spatial planning, environmental protection, and industrial development. These findings contribute theoretically to a broader understanding of spatial impacts and the interplay between environmental regulation and ecologically-based industrialization approaches [57]. The criteria and spatial analysis results for all industrial site selection parameters are presented in Table 6.

The spatial approach to identifying potential locations for integrated agroindustrial development in the aquaculture –ecotourism sector is intended to minimize conflicts of interest. This strategy is effective in anticipating land-use overlaps between the energy and agriculture sectors [58], preventing agrarian conflicts with indigenous communities [59], and avoiding tensions caused by the proximity of industrial functions to residential zones [60]. The spatial distribution map of potential development sites is illustrated in Figure 9.

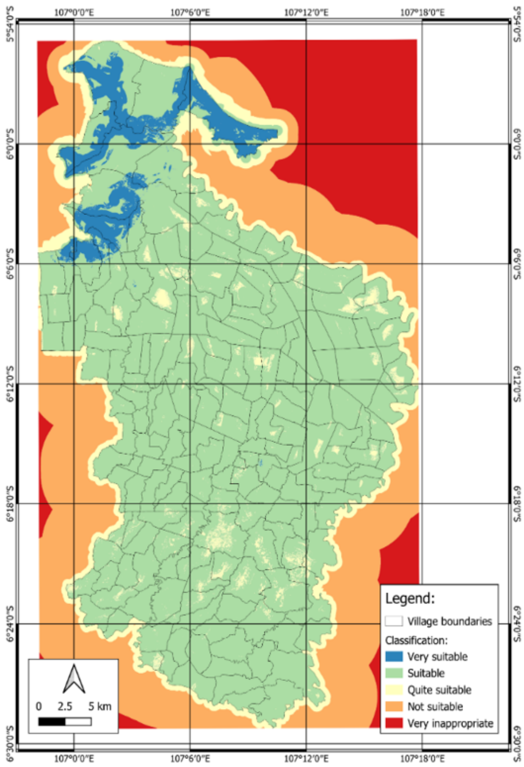

Figure 9. Spatial analysis map of potential agroindustrial development areas

The study produced a classification of potential industrial development areas into five levels of land suitability: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N1 and N2 (unsuitable), as presented in Table 7. Each category is visualized with a distinct color on the map to facilitate spatial interpretation. The analysis indicates that S1 areas cover 9,109.994 hectares, representing 7.07% of the total study area. This classification is based on eight key parameters: road accessibility, proximity to raw material sources, land use, slope, surface water access, elevation, distance to residential zones, and proximity to business centers.

Table 7. Classification and area of potential agroindustry allocation zones

Class	Color	Description	Area (Ha)	Percent (%)
S1	Blue	Highly Suitable	9,109.994	7.07
S2	Green	Suitable	115,371.716	89.53
S3	Yellow	Moderately Suitable	4,378.858	3.40
N1	Orange	Not Suitable	0.015	0.00
N2	Red	Highly Unsuitable	0.000	0.00
		Total	128,860.583	100.00

The RSP serves as a national strategic policy instrument for spatial governance and functions as a reference for long-term development planning. In this study, an analysis was conducted to assess the alignment between the industrial feasibility scoring results and the RSP map of Bekasi–Karawang Regencies in order to evaluate the spatial consistency of potential sites with existing spatial plans. The analysis was based on the RSP documents for the 2011–2031 period.

The overlay results revealed that 1,061.79 hectares were designated for industrial use, 995.18 hectares for fisheries (aquaculture), and 53.80 hectares for tourism zones (Table 8). The spatial integration of agroindustrial land suitability with the official RSP zoning is visualized in Figure 10.

The integration of the industrial sector with aquaculture as a raw material source and ecotourism as a strategic land-use component represents a key element in sustainable spatial planning. The proximity of industrial sites to supply points is essential for ensuring supply chain continuity and long-term competitiveness [51]. A locally driven development approach not only stimulates growth in the secondary and tertiary sectors but also generates employment opportunities in rural and coastal areas, improves land-use efficiency, reduces poverty, and strengthens the trajectory of sustainable development [61]. The areas classified as highly suitable in this study meet all criteria required for the development of an integrated agroindustrial zone that encompasses aquaculture and ecotourism sectors.

Figure 11 presents a map of potential locations for the development of integrated agroindustrial zones with ecotourism. The map was produced through an intersection process between the land suitability map, based on weighted industrial site selection parameters, and the RSP of Bekasi–Karawang Regencies. As classified in Table 9, the distribution of suitability classes indicates that the N1 (unsuitable) category dominates the landscape, covering 5,933.175 hectares or 61.63% of the total analyzed area. The S1 (highly suitable) category comprises 1,950.961 hectares (20.27%), while the S2 (moderately suitable) category accounts for 1,742.823 hectares (18.10%). No areas were classified under the N2 (highly unsuitable) category.

Table 8. Area allocation based on regional spatial planning

No.	Description	Area (Ha)	Percent (%)
1	Protected Forest	2,752.62	28.55
2	Limited Production Forest/Residential Housing	2,747.48	28.50
3	Mangrove Protected Forest	1,235.68	12.82
4	Industry	1,061.79	11.01
5	Fisheries	995.18	10.32
6	Rural Settlement	340.56	3.53
7	Urban Settlement	253.25	2.63
8	Industrial Protected Forest	117.31	1.22
9	Tourism	53.80	0.56
10	River Border Area	34.70	0.36
11	Public Cemetery (TPU)	24.82	0.26
12	Sediment Area	18.25	0.19
13	Food Crops	5.19	0.05
	Total	9,640.62	100.00

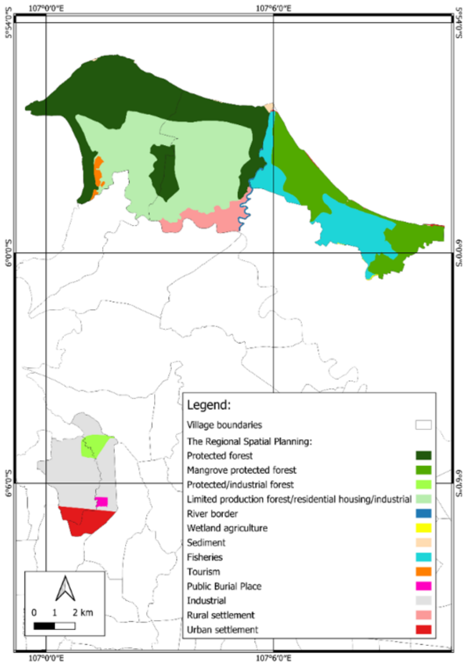

Figure 10. Spatial analysis map based on the Regional Spatial Plan (RSP)

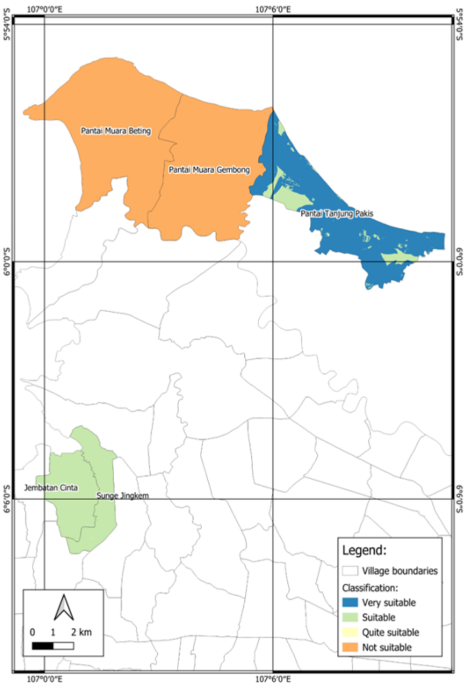

Figure 11. Spatial analysis map of integrated aquaculture–ecotourism agroindustrial development areas

Table 9. Classification and area of potential integrated eco-industrial zones after spatial plan intersection

Class	Color	Description	Area (Ha)	Percent (%)
S1	Blue	Highly Suitable	1,950.961	20.27
S2	Green	Suitable	1,742.823	18.10
S3	Yellow	Moderately Suitable	0.268	0.00
N1	Orange	Not Suitable	5,933.175	61.63
N2	Red	Highly Unsuitable	0.000	0.00
		Total	9,627.227	100.00

These results reflect a spatial mapping process that successfully integrated biophysical factors, accessibility, and spatial planning policy, thus providing a solid foundation for region-based planning of sustainable agroindustrial –ecotourism development zones.

The development of integrated agroindustry combining aquaculture and ecotourism should be guided by sustainability principles, including resource availability, spatial distribution, global value chain integration, regulatory frameworks, circular economy practices, and the adoption of technology [62]. From an ecotourism perspective, such integration has the potential to stimulate local economic growth by creating new employment opportunities for communities [63, 64]. However, the successful implementation of this model requires cross-sectoral collaboration, involving market expansion, strategic investment, adaptive policies, and alignment of interests among stakeholders [65].

The GIS-based approach used in this study proved effective in identifying potential sites for industrial development. In addition to mapping physical and social parameters, GIS can analyze land-use change dynamics in coastal areas [66], including Muara Gembong, Muara Beting, Jembatan Cinta, and Sungai Jingkem in Bekasi Regency, as well as Tanjung Pakis Beach in Karawang Regency. Previous studies have also emphasized the strategic role of GIS in optimizing and sustaining land-use integration [67].

Locations such as Tanjung Pakis (Karawang), Sungai Jingkem, and Jembatan Cinta (Bekasi) exhibit high spatial suitability and hold strong potential to attract investment and enhance the performance of aquaculture–ecotourism-based industries [68]. The integration of these three sectors serves as a flagship strategy to accelerate sustainable development in the coastal regions of Bekasi and Karawang Regencies.

4 Discussion

4.1 Interpretation of Analysis of Operational Area of Nature-Based Tourism Attractions and Ecotourism Potential

The AOA-NBTA analysis identified Tanjung Pakis as the ecotourism site with the highest potential (score 3,175), supported by factors such as accessibility, cleanliness, facilities, availability of clean water, and marketing. These factors have been widely recognized as key determinants of coastal destination attractiveness [9, 64]. Compared to conventional zoning approaches, AOA-NBTA demonstrates superiority by applying measurable multicriteria parameters, thereby producing quantitative classifications and objective development priorities [23]. The methodological position of AOA-NBTA is also reinforced within Indonesia's national regulatory framework, as it aligns with the official guidelines of the Directorate General of Forest Protection and Nature Conservation (PHKA, 2003) and Law No. 10 of 2009 on Tourism, ensuring its validity both academically and in policy implementation.

4.2 Spatial Analysis and Spatial Planning Policy

The GIS analysis revealed that 20.27% of the area was classified as highly suitable (S1), 18.10% as suitable (S2), and 61.63% as not suitable (N1). These results highlight the importance of prioritizing development in S1 and S2 zones in alignment with the RSP to prevent land-use conflicts [16, 17]. Without integrated management, coastal areas face the risk of overlapping functions among settlements, mangrove conservation, and industrial activities [13, 60].

This study contributes to the advancement of an Integrated Coastal Zone Management (ICZM) framework based on the integration of three sectors: aquaculture as the production base, agro-industry as the driver of value chains, and ecotourism as a catalyst for the creative economy. This framework enhances conventional ICZM models by incorporating a more inclusive dimension of economic productivity [8, 12]. Previous studies [69–75] have demonstrated that cross-sectoral integration improves efficiency and sustainability, although most were limited to two sectors. By formulating the integration of three sectors simultaneously, this research introduces a novel ICZM framework that is more comprehensive and adaptable, with potential applications not only in Indonesia but also across coastal regions of other countries, both developing and developed.

4.3 Environmental Sustainability Implications

The Bekasi–Karawang coastal region faces challenges of abrasion, mangrove degradation, and pollution that weaken ecosystem resilience, similar to conditions observed in the Sundarbans, Bangladesh [66], and along China's coasts [13]. The integration of aquaculture, agro-industry, and ecotourism offers a potential solution through circular economy principles, whereby aquaculture waste can be utilized by industries while ecotourism promotes ecosystem rehabilitation [64, 72]. This approach is consistent with the blue economy paradigm, which seeks to balance economic growth with the conservation of marine and coastal ecosystems [8, 73]. Similar practices have begun to be adopted in Southeast Asia, such as fisheries-based ecotourism in the Philippines and Vietnam, and community-based mangrove conservation in Thailand. These examples reinforce the relevance of this study's findings as a model for sustainable coastal development in the regional context.

4.4 Economic Potential and Empowerment of Coastal Communities

The integration of the three sectors has the potential to enhance coastal community welfare through income diversification, job creation, and the development of the creative economy. Mangrove- and beach-based ecotourism creates new entrepreneurial opportunities, while agro-industry increases the added value of local products and strengthens supply chains [4, 71]. This integration also supports community-based development by engaging local communities in destination management and local industries [64]. A study by Angulo-Valdes et al. [8] in Cuba demonstrated that integrating recreational fisheries with ecotourism enhances community participation while simultaneously improving resource management. Accordingly, the model proposed in Bekasi–Karawang Regency holds significant potential to be replicated as an inclusive and sustainable coastal empowerment framework.

5 Conclusion

This study developed an integrated spatial decision framework to support sustainable coastal development by aligning agroindustry, aquaculture, and nature-based ecotourism within the Bekasi–Karawang coastal region. By combining AOA-NBTA for ecotourism assessment, AHP for multi-criteria weighting, and GIS-based spatial analysis, the approach accommodated cross-sector requirements while incorporating key biophysical constraints, accessibility, and proximity to essential resources and markets. The additional intersection with the official Regional Spatial Plan strengthened policy relevance and helped reduce potential land-use conflicts by identifying priority zones that are both spatially feasible and institutionally consistent.

The results indicate that development opportunities are concentrated in specific coastal subareas where access, supporting infrastructure, and environmental conditions are more favorable, while other subareas require stricter safeguards due to higher vulnerability and management constraints. These findings provide practical inputs for ICZM by clarifying where integrated investments can be prioritized and where conservation-oriented strategies should lead.

Future work should incorporate dynamic hazard and climate-related layers, broader stakeholder participation beyond expert judgment, and site-level environmental impact assessment to refine zoning decisions and ensure that integrated development delivers long-term ecological resilience and community benefits.

Author Contributions

Conceptualization, S.K. and T.B.; methodology, S.K., T.B., and K.S.; investigation, S.K.; data collection: S.K.; formal analysis, S.K. and M.; writing— original draft, S.K.; writing—review & editing, T.B., M., and K.S.; supervision, K.S. All authors have read and approved the final manuscript.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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