Article

Spatial-Planning-Based Ecosystem Adaptation (SPBEA): A Concept and Modeling of Prone Shoreline Retreat Areas

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Abstract: Ecosystem-based adaptation to climate change impacts, such as shoreline retreat, has been promoted at the international, national, and even local levels. However, among scientists, opinions about how to implement it in spatial-planning practices are varied. Science-based environmental factors, human wellbeing, and sustainable development can be strengthened by developing spatial-planning-based ecosystem adaptations (SPBEAs). Therefore, this article aims to assess how the SPBEA model can be developed within an area prone to shoreline retreat. A coastal area of the Sayung subdistrict in Central Java, Indonesia, was selected as a study area because it has experienced a massive shoreline retreat. A multicriteria analysis (MCA) method was employed for developing the model by using the geographic information system (GIS) technique of analysis, divided into three steps: the fishpond zone determination, which involved the analytical hierarchy process (AHP) method in the process of model development; the fishpond site determination; SPBEA fishpond site development. The results show that the SPBEA model is the best practice solution for combatting shoreline retreat because of tidal waves and/or sea-level rise. The spatial site management should empower the coastal protection zone and the sustainable fishpond zone by implementing a silvofishery approach.

Keywords: spatial planning; ecosystem adaptation; fishpond culture

1. Introduction

Climate change has presented a significant impact on the coastal environment. Flooding, abrasion, and shoreline retreat are examples of those impacts caused by storm surge [1], high tide [2], or sea-level rise [3–5] which have been triggered by climate change. The impact is elevating with human behavior in utilizing existing natural resources. Conversion of coastal ecosystems to intensive agricultural areas or settlements and groundwater discharge are examples of human exploitation of the coastal ecosystem which could endanger the coastal area against disaster of storm surges, high tide, sea-level rise, or land subsidence.

Land subsidence is one type of relative sea-level rise related to the local vertical coastal and seafloor motion [3,6].

High tide, tidal wave, and relative sea-level rise, whether individually or in combination, have significant effects on natural-resource systems and the social life of coastal communities [7], one of which is shoreline retreat. Projection models of shoreline retreat as an effect of high tide and relative sea-level rise were created by [3,5,8]. Indeed, [9] showed how shoreline retreat can destroy infrastructure, lead to loss of land, and destroy agricultural land on the north coast of Java. This ongoing shoreline retreat has forced the local community to adapt. Furthermore, [10] studied how societies respond to shoreline retreat threats by infrastructure development to slow down or halt the effects. However, these adaptations will not be a success without an understanding of the coastal ecosystem's functions. To mitigate the effects of ocean-based disasters on the coastal area, the ecosystem services, the ecosystem mechanisms, and the importance of adapting to the changing coastal situation should be understood. Coastal-ecosystem functions and mechanisms, particularly intertidal wetlands, may play an important role in reducing the impact of coastal hazards caused by rising sea levels and tidal waves through their role in wave attenuation, sediment capture, vertical accretion, erosion reduction, and the mitigation of storm surges and debris movement [11].

Ecosystem-based management has been promoted internationally as the best way to ensure the sustainability of marine environments since it is characterized by sustainability, ecological health, and human inclusion in the ecosystem [12]. Science-based environmental factors, human wellbeing, and sustainable development can be strengthened through developing spatial-planning-based ecosystem adaptations (SPBEAs). Accordingly, [13] operationalized how ecosystem-based adaptation can be implemented in urban planning in Sweden from a local government perspective. On the other hand, [3] studied how this ecosystem-based adaptation can be implemented in a rural area for shrimp pond spatial planning. Therefore, the implementation of SPBEA is important within a continuing shoreline retreat-prone area.

The key objective of this study was to assess how the SPBEA model can be developed for an area prone to shoreline retreat. The geographic information system (GIS) technique was applied to develop the model. GIS is an efficient and effective technique since it can assist in modeling and summarizing complex spatial data into a spatially specific requirement in spatial planning [14,15]. The application of GIS as a decision-making tool, especially in spatial planning and spatial adaptation modeling, has been widely implemented in various countries, such as in [16] which studied the use of GIS for aquaculture spatial planning in Europe and [17] which used GIS as a tool to develop an adaptation model to climate change in Greece. Asian countries such as Indonesia have also used GIS as a tool for spatial planning decision support system development [14,18].

The GIS technique applied can also be varied from a simple overlay technique, using a weighted-score analysis up to the development of spatial decision support system tools (SDSS) [16,18]. The development of SPBEA using the GIS technique, on the other hand, cannot rely on a single technique, but rather requires a multicriteria analysis (MCA) combining spatial analysis techniques, such as buffers and overlays, as well as new algorithm development and the use of surveying and remote sensing for generating input data. However, the spatial data and the GIS technique used may vary depending on the specific spatial requirements for planning. For this purpose, a coastal area of the Sayung subdistrict, Central Java, Indonesia, was selected as the study site because it has experienced massive shoreline retreat over the last three decades. At the same time, detailed spatial planning methods with an ecosystem-based approach are not yet available, especially for coastal rural settlement areas. Unlike previous research, the SPBEA model presented herein combines land system data with land suitability data, which are rarely used in the development of spatial planning and adaptation models. Indeed, more advanced techniques such as SDSS tools were not implemented in this study. This SPBEA model focuses on the spatial
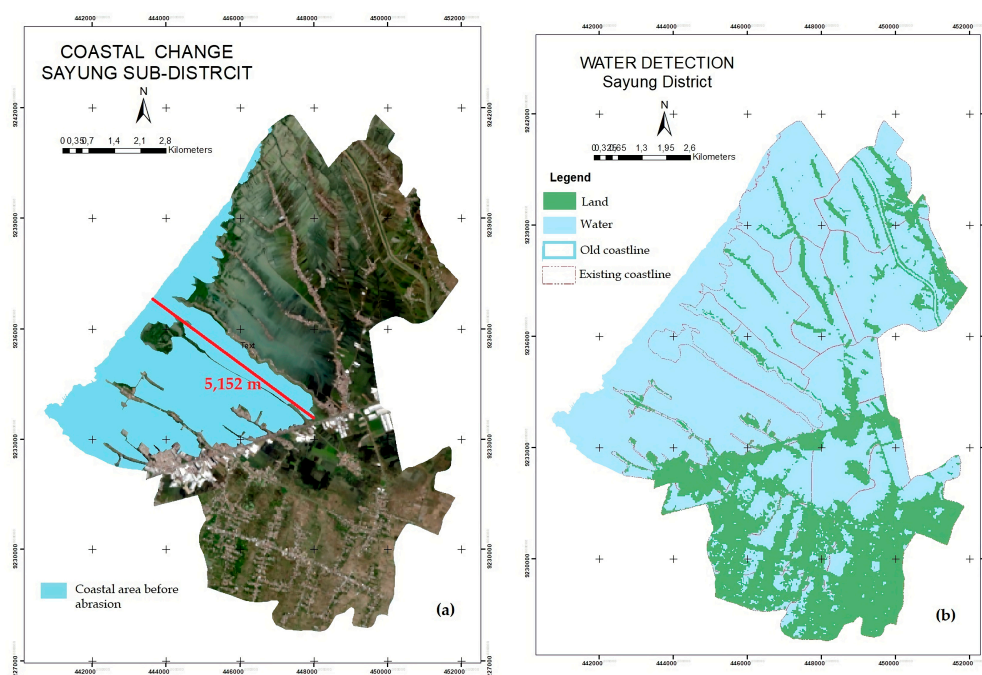
distribution of fishpond culture in the coastal area of rural Sayung, on which the majority of local communities depend as their main livelihood.

2. Materials and Methods

2.1. The Study Area

Sayung is a subdistrict on the northern coast of the Demak district, Central Java, Indonesia (see Figure 2). This coastal area has arisen from river sediment forming a quarter alluvium geologic formation [19] and has a reddish-brown alluvium soil type to the north and hydromorphic alluvium to the south [20]. The coastal area of Sayung is a lowland with relatively flat topography, i.e., slope less than 2% and elevation of 0–5 m above sea level [21].

This area has experienced massive shoreline retreat caused by relative sea-level rise related to land subsidence, land-use conversion, and high tide. The area has lost 25 km^2 of land to the sea [22], or about 5152 m of coastline has moved inland [23], which can be seen in Figure 1a. Research by [24] indicates that the land subsidence in this area ranges from 8.35–12.31 cm per year, with an average sea level increase of about 8.294 cm per year [21]. Because of these changes, tidal inundation, which locals call "rob", occurs daily in the study area, not only at high tide but also at low tide [25]. The inundation of seawater is illustrated in Figure 1b, which shows the normalized difference water index (NDWI) image using the near-infrared (NIR) and shortwave infrared-1 (SWIR-1) bands of Landsat 8 Oli.

Figure 1. (**a**) Illustration of shoreline retreat area in the Sayung subdistrict (blue), overlaid on an image from Landsat 8 Oli on 29 July 2020 and [28]; (**b**) water detection of Sayung subdistrict based on normalized difference water index (NDWI) according to an image from Landsat 8 Oli 29 July 2020, which may correlate with the inundation problems.

Land use in this subdistrict is dominated by fishponds in the north and rice fields in the south, with areas of 5825.66 ha and 13,621.7 ha, respectively [29]. The land use has been linked to local communities, whose livelihood depends on the farms and fishponds [30]. Indeed, a map of the land system shows that the coastal area is a better land system for aquaculture and mangrove ecosystems, as a KJP (kajapah) land system type, an intertidal swamp under halophytic vegetation, with sedimentary alluvium soil [31,32]. Considering the environmental problems that occur in this area, [33] suggested that the implementation of an ecosystem-based approach would be a solution for sustainable management. There-

fore, a design based on spatial-planning-based ecosystem adaptation (SPBEA) needs to be developed.

Figure 2. Location of the study area, obtained from Google Maps and [26,27].

2.2. Methodological Design of SPBEA Model

A multicriteria analysis (MCA) was incorporated into the GIS environment to develop a model [34]. The SPBEA model was developed in three steps (Figure 3). The first was the fishpond zone determination sub-model, which involved an analytical hierarchy process (AHP) method in model development. The output of this step was the land potential for fishponds. The second was the fishpond site determination, where the output was the model of spatial allocation for fishponds. The third step was the SPBEA fishpond site development, with the output being the SPBEA site management planning model.
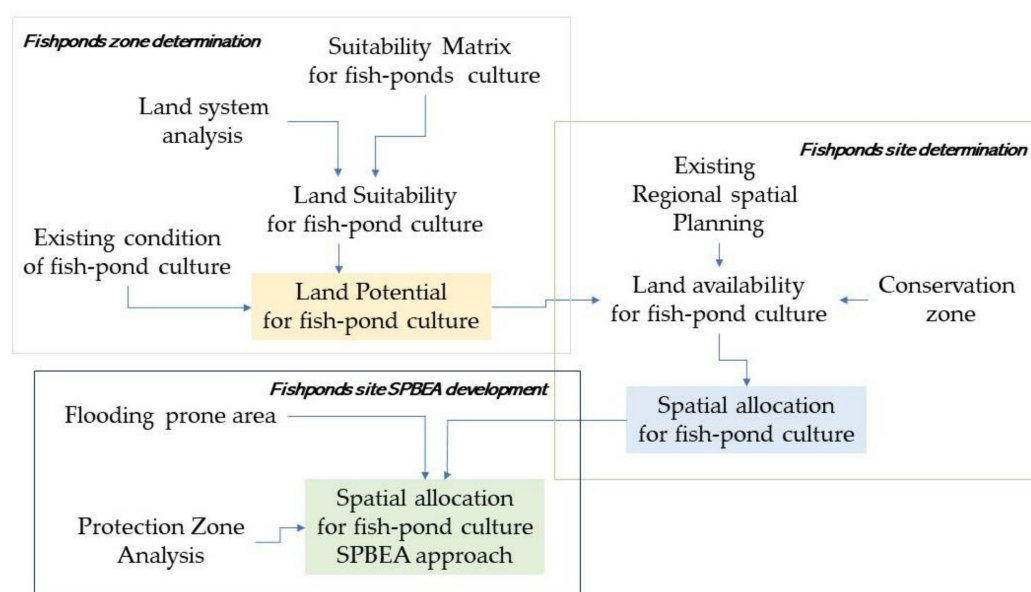
The data for this study consisted of the following:

(a) Land system digital map of Demak district scale 1:50,000 from the Badan Informasi Geospasial (BIG).

(b) Land-use/land-cover data obtained from the Badan Informasi Geospasial (BIG) digital Rupabumi map (base map) of Sayung at a 1:5000 and 1:25,000 scales.

(c) Spatial plan of Demak District of Regional Government of Demak, year 2020.

(d) High-resolution orthorectified image of Timbulskolo village obtained from BIG.

(e) Landsat 8 Oli image derived on 29 July 2020, downloaded from https://earthexplorer.usgs.gov/ (accessed on 22 January 2021).

(f) Soil map of Demak District at a 1:50,000 scale obtained from Balai Besar Sumberdaya Lahan Pertanian (BBSDLP).

(g)   The slope data obtained from the BIG seamless digital elevation model (DEM) and National Bathymetry website (https://tides.big.go.id/DEMNAS (accessed on 22 January 2021)).

(h)   pH, salinity, social, and environment information from field data, obtained in February and December 2020.

(i)   Flood-prone area derived from normalized difference water index (NDWI) of Landsat 8 Oli.

(j)   Green belt and protection zone derived from the spatial analysis of Rupabumi map, Landsat 8 Oli image, and high-resolution orthorectified image of Timbulsloko village.

Figure 1 summarizes and explains the use of the data for development of the SPBEA. The three steps of the activity are explained in more detail in the upcoming sections.

Figure 3. The steps of spatial-planning-based ecosystem adaptation (SPBEA) model development.

2.2.1. Fishpond Spatial Zone Determination

An integration of two processes for land suitability analysis was used to determine the appropriate zone for fishpond cultivation, i.e., suitability for fishpond culture-based AHP and suitability based on land system. The GIS technique of algorithm-based overlay analysis, intersection overlay, spatial joint, and simple query was employed in this step.

The Suitability for Fishpond Culture-Based AHP

The AHP method was employed because it can reduce subjectivity in decision-making by providing a collection of selection filters (hierarchies), thus allowing a choice between complex alternatives [35]. Three experts in spatial environments and spatial marine culture were involved in the process of algorithm development using the AHP method. The AHP judgment was derived by identifying the scaled hierarchical structure of the parameters, followed by developing and normalizing the pairwise comparison matrix to synthesize the priority level to obtain the weight values, and then the weighted decision was calculated on the basis of the normalized matrix and the eigenvectors [36].

The weight of each criterion or sub-criterion was determined by comparing the paired matrices in the context of the AHP [37]. This analysis allowed us to define the prioritization of each parameter. However, the subjective preferences of researchers might lead to inconsistencies in the definition of prioritization. Therefore, to define the acceptable value for this inconsistency, the consistency ratio (CR) was calculated. A CR value less than 0.1 denotes consistency (Table 1).

Table 1. Analytical hierarchy process (AHP) judgment matrix and consistency ratio assessment.

	DC	DR	LU	So	Sl	pH	Sa	Priority
DC	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.8
DR	0.5	1.0	2.0	2.0	2.0	3.0	3.0	1.4
LU	0.5	0.5	1.0	2.0	2.0	3.0	3.0	1.2
So	0.5	0.5	0.5	1.0	2.0	3.0	3.0	1.0
Sl	0.5	0.5	0.5	0.5	1.0	3.0	3.0	0.8
pH	0.3	0.3	0.3	0.3	0.3	1.0	2.0	0.5
Sa	0.3	0.3	0.3	0.3	0.3	0.5	1.0	0.4
				λ				7.398
			Consistency Index (CI)					0.066
			RI					1.32
			Consistency Ratio (CR)					0.050

Note: DC = distance to coastline, DR= distance to rivers, LU = land use, So = soil, Sl = slope, Sa = salinity.

Continuing from the AHP result, the coastal area was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N) [38,39]. Then, a land suitability matrix was defined according to the priority of the weight of each respective parameter from the AHP assessment (Table 2).

Table 2. Suitability matrices for fishpond culture.

Parameters	W	Suitability Classification (Weight Scoring)								Ref
		S1		S2		S3		N		
		Class	S	Class	S	Class	S	Class	S	
		Environment								
DC (m)	1.8	300–500	4	>500, <4000	3	100–300	2	<100, >4000	1	[1]
DR (m)	1.4	<500	4	500–1000	3	1000–1500	2	>1500	1	[3]
LU	1.2	Pd, WL	4	SF, O, RF	3	MO, CL	2	St, GY, Ind, Rv	1	[1]
Soil	1.0	Alluvial	4	Entisol	3	Inceptisol	2	Ultisol	1	[1]
Slope (%)	0.8	≤2	4	>2, ≤5	3	>5, ≤10	2	>10	1	[2]
		Water quality								
pH	0.5	6.5–8.5	4	5.5–6.5, 8.5–9.5	3	4.0–5.5; 9.5–0.5	2	<4.0, >10.5	1	[1]
Salinity (‰)	0.4	15–25	4	25–30	3	5–15, 30–35	2	<5, >35	1	[1]

Note: DC = distance to coastline, DR = distance to rivers, LU = land use, W = weight, S = score, Ref = reference, Pd = ponds, WL = wetlands, SF = swamp forest, O = orchard, RF = rice fields, MO = mixed orchards, CL = croplands, St = settlements, GY = graveyards, Ind = industrial, Rv = rivers.

The formula for suitability classification was defined from this matrix. According to [36], the equation can be defined as follows:

$$S_i = \sum w_i s_i, \tag{1}$$

where S_i is the suitability class i, w_i is the weighting factors class i, and s is the scoring value of parameter i for suitability class i.

Then, by implementing the AHP results, the following equation was obtained:

$$S_i = 1.8 s_{i_1} + 1.4 s_{i_2} + 1.2 s_{i_3} + 1.0_{i_4} + 0.8_{i_5} + 0.5\, s_{i_6} + 0.4 s_{i_7}, \tag{2}$$

where 1.8 to 0.4 is the weighting or priority value of parameter i to n.

The determination of the suitability class interval (x) using Equation (1) can be defined as follows:

$$x_i = \frac{\sum ws_{imax} + ws_{imin}}{2}. \tag{3}$$

The interval classes were defined as $S_1 => x_1$, $S_2 = x_1$ to x_2, $S_3 = x_2$ to x_3, and $N =< x_3$, where x_1 is the average value of (S_1) and (S_2), x_2 is the average value of class (S_2) and (S_3), and x_3 is the average value of class (S_3) and N, and (S_1) is very suitable, (S_2) is moderately suitable, (S_3) is marginally suitable, and (N) is unsuitable.

Integrating the Suitability for Fishpond Culture-Based AHP with Land System Analysis

The authors of [40] stated that a land system is a land facet assembly with geomorphological and geographical relationships and with recurring land, soil, and vegetation patterns. Land systems consist of eight categories: lithology, hydrology, climate, vegetation, land use, soil, topography, and land fragmentation [41]. These physical land system characteristics have already been implemented for land suitability for agriculture, livestock (cattle), brackish fisheries, and agroforestry [41]. For this study, the land system analysis consisted of the spatial categorization of the land into the land unit which was the most suitable for fishpond culture.

The Sayung subdistrict has three types of land systems: (a) an intertidal swamp under halophytic vegetation (KJP), (b) coalescent estuarine/riverine plains in dry areas (MKS-F1-e), and (c) a fluvial plain with poor drainage in a dry area (MKS-F1-d) [31]. In the Sayung case, KJP is the most suitable land system for brackish fisheries, ponds, and mangrove cultivation [32]. This is related to the characteristics of this land, i.e., an intertidal swamp under halophytic vegetation, low and wide coastal land that is partly inundated, average rainfall between 400 and 3100 mm, 2–10 wet months and 0–7 dry months per year, and a marine group [32,42]. The land system is used to complement the characteristics of land suitability for fishpond culture obtained from land suitability-based AHP. Integrating both land system analysis and land suitability-based AHP allows defining the most precise land suitability for the area of interest, as expressed in the following equation:

$$S_{S_i} = S_{i_A} - S_{i_L},$$ (4)

where S_{S_i} is the suitability class i, S_{i_A} is suitability class i derived from the AHP-based analysis, and S_{S_L} is the suitability class derived from land system analysis.

Land Potential Analysis

The objective of the fishpond culture zone selection is to identify the potential land to be used as a fishpond zone. The land potential analysis was developed using both the land suitability classes and the existing land conditions of areas under fishpond culture. The potential zone was defined by adding the assessment of the multiple years featuring fishpond culture, in which the pond production was good and profitable for the local farmers. The potential classes were still defined by the class of suitability, as defined above. The equation can be explained as follows:

$$S_{P_i} = S_{S_i} + S_{P_e},$$ (5)

where S_{P_i} is the potential fishponds class i and S_{P_e} is the existing pond.

2.2.2. Fishpond Spatial Site Determination

A parcel of land may have the potential to be developed into a fishpond culture site, but it may not be available for future use due to certain criteria in the SPBEA design. To be available, potential land must not be part of a conservation or other protected areas, such as greenbelts along the coast and rivers; moreover, they must have a clear ownership status and must be part of the spatial planning zone. Conservation is an efficient and effective means of addressing biodiversity loss, helping to buffer society from the effects of climate change, and maintaining critical ecosystem services on which all societies depend upon [43]. Indeed, coastal greenbelts are important for the prevention of coastal erosion and the reduction of other natural hazards, such as tidal surges [44]. The GIS technique of

buffering, with an intersecting spatial overlay of intersecting, following the algorithm can be applied for this step.

The algorithm used in the land availability analysis is as follows:

$$S_{a_i} = S_{P_i} - c - I_m^o,$$ (6)

where S_{a_i} is land available class *i*, P_i is the potential area class *i* for fishpond culture, *c* is the conservation zone, and I_m^o is the land use of class *m* to *o*.

However, the availability status of the land remains unclear without considering the regional spatial regulation and policy. Thus, the assessment of the SPBEA should be adjusted to the regional government regulations on spatial planning. The land is only available in a cultural zone defined by the fishery cultivation zone and the zone for rural settlement. The output of this assessment is the spatial allocation for fishpond culture and can be described in the following algorithm:

$$S_{A_i} = S_{a_i} - SP_x^y,$$ (7)

where S_{a_i} is the land allocation for fishponds, S_{a_i} is available land for fishponds, and SP_x^y is the spatial zone for zone *x* and *y*.

2.2.3. Fishpond Spatial Site SPBEA Development

Following the result of the fishpond sites, the site management analysis for fishpond culture was carried out using a high-resolution remote-sensing image analysis obtained from the BIG equipped with field data to determine the existing land use, followed by a site-planning analysis. A visual interpretation was employed for high-resolution remote-sensing images, which classified the area into mangrove, net ponds, fishponds, settlements, gardening/roads, and rivers. For the site-planning analysis, the fishpond design followed [45] regarding the design and followed a modification of [46] for the percentage of mangroves in a pond area. The percentage of mangrove was 40% to 60% depending on the location's exposure to ocean or rivers. An *NDWI* model was also employed to assess the tidal flooding into the area (Figure 1b). The algorithm of *NDWI* can be explained as follows:

$$NDWI = \frac{NIR - SWIR_1}{NIR + SWIR_1},$$ (8)

where *NIR* is the infrared band of Landsat 8 Oli and $SWIR_1$ is the shortwave infrared band of Landsat 8 Oli.
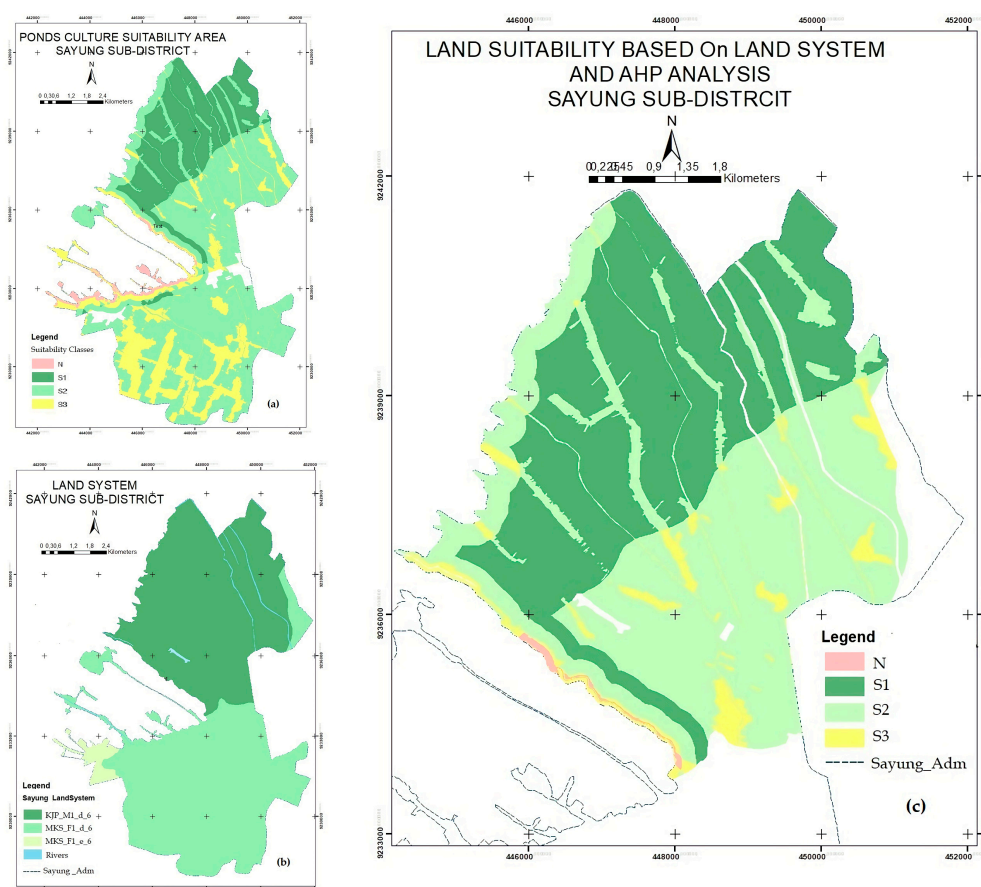
In terms of the detailed location, the site analysis focused on the coastal villages that were most affected by the shoreline retreat due to tidal waves and abrasion.

3. Results and Discussion

3.1. Fishpond Zone Determination

The result of GIS analysis for land suitability-based AHP showed that the fishpond culture zone could be classified into highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N) (Figure 4a). However, there were spatial differences in the distribution of pond culture when the assessment of the land systems was applied (Figure 4c). Each unit in the land system classified the landscape according to the principles of ecology, where it was assumed that there was a close relationship among the lithology, hydroclimate, landforms, soil, and organisms [41,47,48].

The Sayung subdistrict has three units of land systems: KJP intertidal plain, MKS fluvial plain, and MKS estuarine plain (Figure 4b). An assessment of the suitability of the land systems to be allocated as fishponds can be seen in Table 3.

Figure 4. Fishpond zoning: (**a**) suitability zone based on AHP analysis; (**b**) land system map of Sayung subdistrict [31]; (**c**) land suitability based on land system and AHP suitability analysis.

Table 3. Characteristics of the land systems of the Sayung subdistrict.

Parameters		Land System	
		KJP	MKS
Physiographic	Slope (m) elevation (%)	<2 <2	<2 2–9.9
Morphology		Flat	Flat to gently sloping
Landform		Swamp	Estuarine Riverine plains
Genesis		Marine	Fluvial
Land use		Aquaculture, Mangroves	Paddy fields Cropland Settlements Industry
Geology	Lithology	Sedimentary	Sedimentary
	Rock type	Alluvium, Recent estuarine-marine	Recent estuarine-marine, Riverine
Climate	Rainfall (mm)	400–3100	1000–2400
	Wet months	2–10	1–4
	Dry months	0–7	5–9
Soil	Type	Alluvium Association of sulfaquents, hydraquents	Association of tropaquepts, fluvaquents, ustropepts
	Solum (cm)	>150	Peat: 0–10 Mineral > 150
	Texture	Sandy loam to clay loam	Clay loam, silty clay loam, sandy clay loam
	pH	7	<7

Table 3. *Cont.*

Parameters	Land System	
	KJP	**MKS**
Drainage	Poor Drainage	Poor to moderate
Groundwater depth (cm)	0–45	0–45
Salinity	Moderately saline	None to very slightly saline
Suitability	Brackish fisheries Ponds Mangroves	Agriculture Settlements

Source: [32,49].

It can be seen that, according to the parameters of a land system, the KJP land system is the most suitable for fishpond culture.

By considering the conditions of the ponds, the GIS analysis of the potential land for fishpond cultivation is shown in Figure 5. This potential fishpond planning was supported by the multiyear fishpond activities, whereby the livelihood of the local community depends on aquaculture land, which consists of 750 hectares and has produced milkfish and shrimp since 1995 [50].

Figure 5. Land potential for fishpond culture.

3.2. Fishpond Spatial Site Determination

Following the land potential analysis results, land availability (Figure 6a) and land allocation (Figure 6c) were spatially defined.

Land suitable for marine culture is not necessarily allocated for cultivation. Many requirements must be fulfilled so that fishpond culture activities can proceed, such as not being included in a protected area, having a clear status of land ownership, and being compliant with regional spatial-planning regulations (Figure 6b). The authors of [51] claimed that conservation areas are a key component in defining the allocation of coastal-space use to reduce the risk of adverse impacts of climate change. Indeed, in defining a spatial site allocation for marine culture, a collection of relevant information and a review of policy and legal frameworks will need to be undertaken [33], such as the regulation of spatial planning.
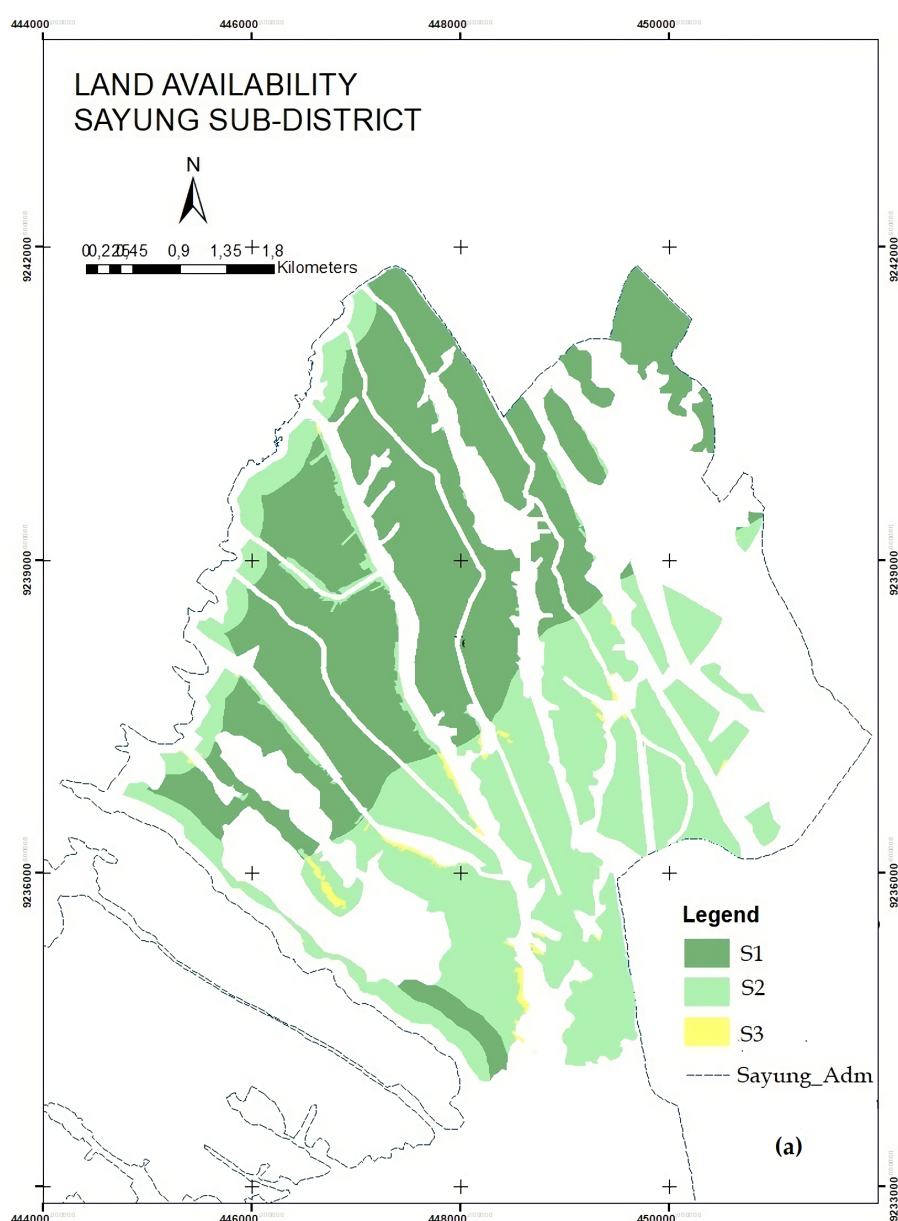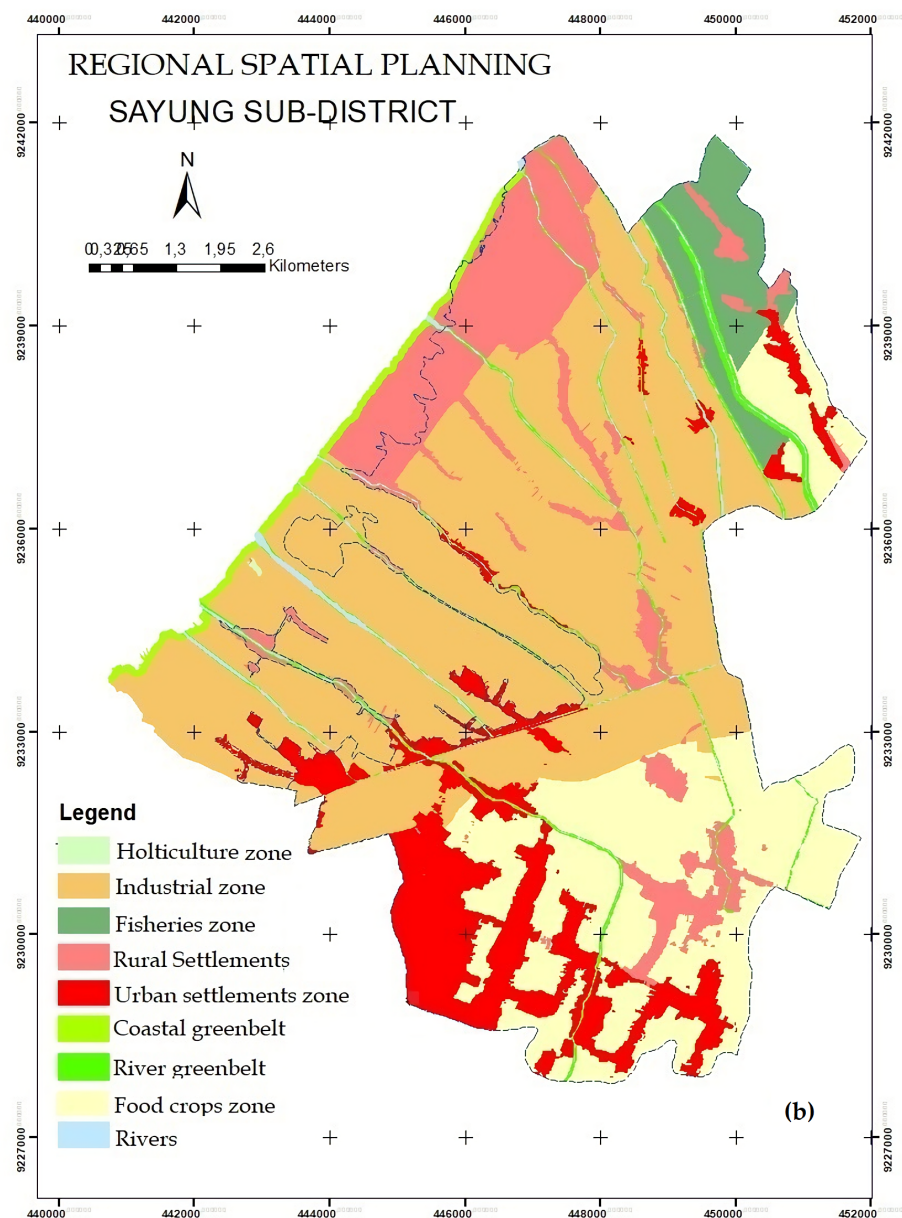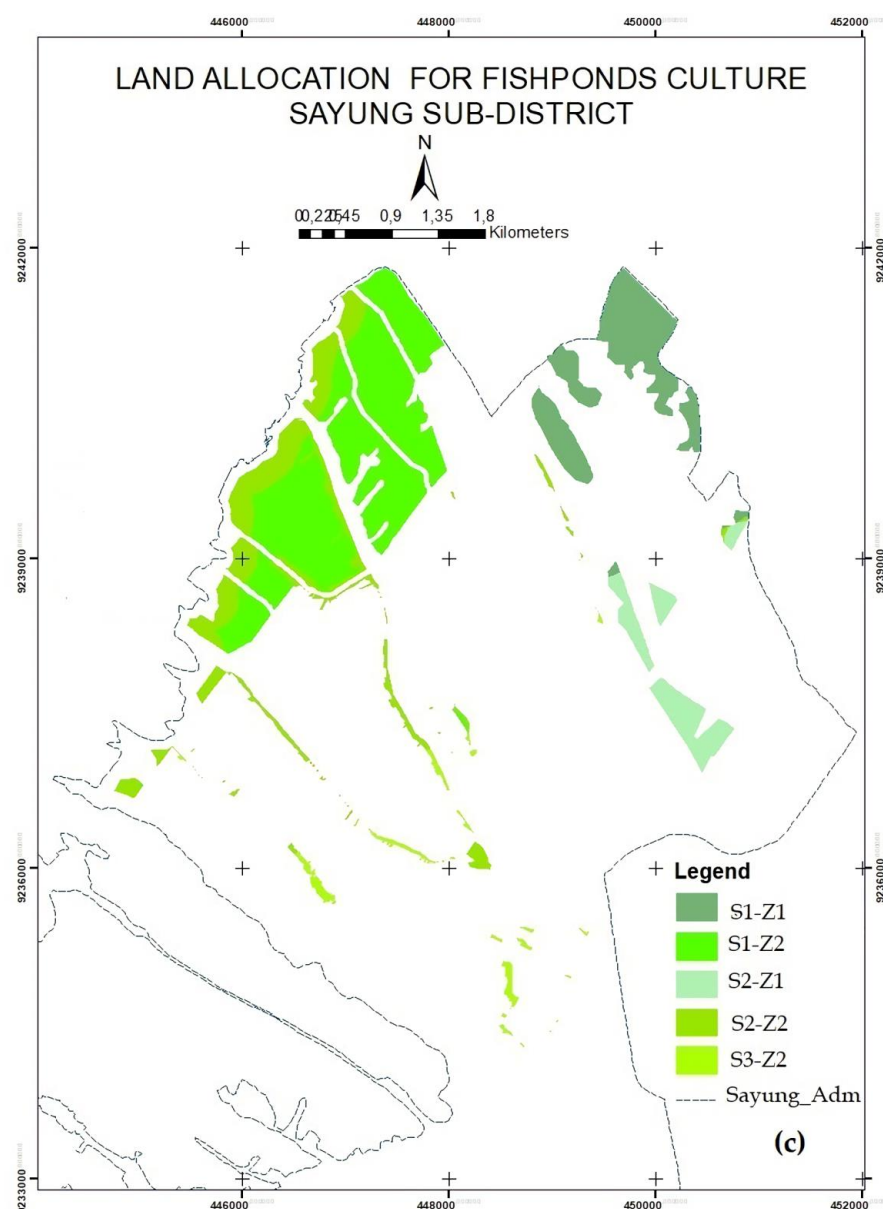

Figure 6. *Cont.*

Figure 6. *Cont.*

Figure 6. Fishpond spatial site allocation: (**a**) available land for fishponds; (**b**) regional spatial planning [52]; (**c**) land allocation for fishpond culture.

The local government of Demak district issued regional regulation No. 1/2020 [52] concerning the spatial plan for Demak district, whereby the Sayung coastal area was planned to be developed into rural and urban settlements along with industrial and fishery culture zones (Figure 6b). This made the ponds' possible spatial allocation site smaller than it would otherwise be. The most suitable spatial land allocation was in the fishery culture zone, whereas the highly suitable class (S1-Z1) dominated the analysis results (Table 4). Meanwhile, in the rural settlement zone, it is still possible to develop fishpond culture activities. Rural areas do not consist solely of settlements; there are also agricultural, fishery, and livestock activities which are the main source of livelihood for the rural population. The national law of villages, (Law No. 6 of 2014), as stated by [53], supports the idea that villages are the economic strength of rural areas, where the agricultural sector is the main pillar of social activities. In developing countries, the lives of rural people are very dependent on the natural resources available in their environment [54]. Thus, in rural areas that are at risk of coastal retreats and tidal floods, adaptation in aquaculture is required

to improve the existing ecosystem. Maintaining some of the ecosystem services is a path toward sustainable coastal aquaculture [55].

Table 4. Classification and land allocation for fishponds in fishing zones and rural settlements.
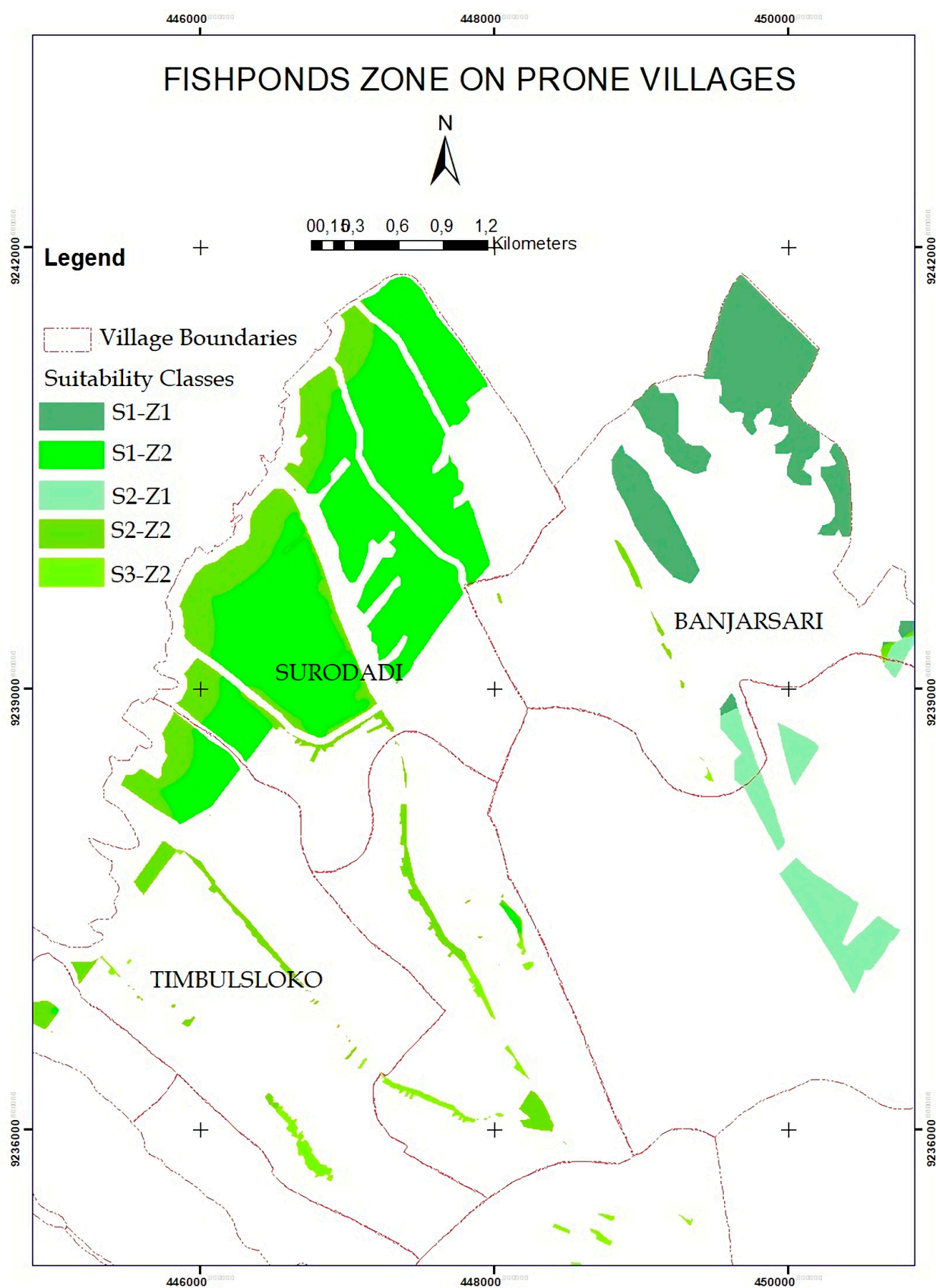
Fisheries Zone		Rural Settlement Zone	
Classes	Area	Classes	Area
S1-Z1	2015.53	S1-Z2	14,691.73
S2-Z1	1645.57	S2-Z2	29,451.67
S3-Z1		S3-Z2	11,966.78

Within the rural settlement zone, the highly suitable class (S2-Z2) dominated the spatial analysis results (Table 4).

3.3. Fishpond Spatial Site Management

The results of the spatial site allocation for fishpond culture showed that only a small area of the three villages in the Sayung subdistrict could be further developed into fishpond areas, specifically, the area of the northern coasts of the Timbulsloko, Surodadi, and Banjarsari villages (Figure 7). For Banjarsari, the results of the spatial suitability analysis were consistent with the regional spatial plan, which designated it as a fishery culture zone, but not with Timbulsloko and Surodadi villages, which were designated to be rural settlements. Meanwhile, the southern region of the villages is more developed as agricultural land. It seems that the utilization of the area for agriculture by the local community needs to be considered in the spatial planning because it has become part of the local community's sociocultural life. This is in line with [56], which stated that the ideals of rural development should include the empowerment of rural society, the protection of environmental quality, the conservation of local resources, the preservation of local cultural heritage, and the sustainable defence of agricultural land.
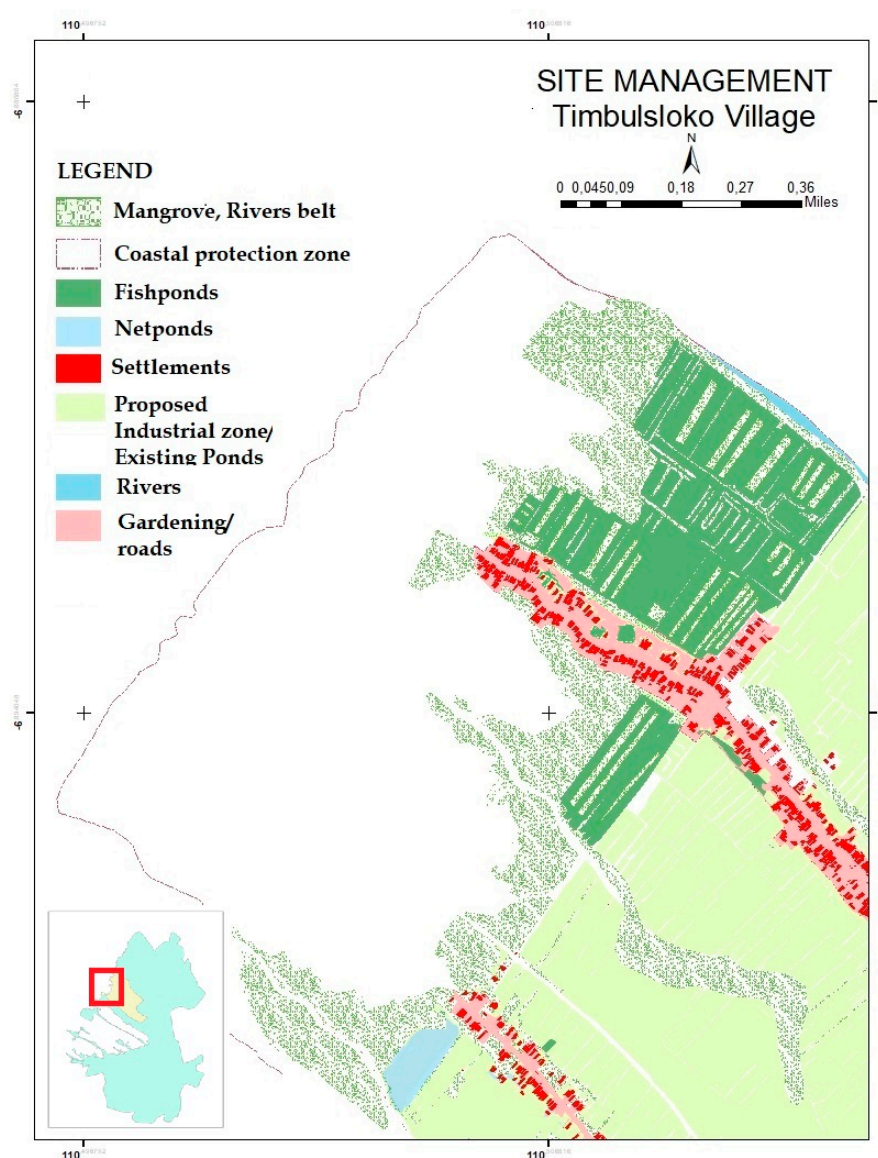
The problem with the above allocation is the degree to which the sustainability of cultivation activities can be achieved, due to the presence of a very intensive coastal retreat and the occurrence of daily tidal floods that have affected the region (Figure 1a,b). A coastal adaptation of detailed marine spatial planning has to be employed to mitigate this threat from the ocean [57]. A strategy for adaptation that would also manage the environment and aquaculture is needed. In this case, [11,13,58,59] suggested spatial-based ecosystem adaptation (SPBEA) as the solution for coastal management to face the threat of the ocean. The two villages bordering the sea, Timbulsloko and Surodadi, experienced a decline in the area of ponds due to exposure to tidal waves. The area of fishponds in Surodadi experienced a decrease of 28%, with a decrease of 70% in Timbulsloko [50]. For further analysis, the village of Timbulsloko, which has experienced the most severe abrasion, became the focus of the SPBEA assessment.

Figure 7. Administrative boundaries of fishpond zone. Zoning can be found in the three villages of Timbulsloko, Surodadi, and Banjarsari.

Site Management of Timbulsloko Village

As an area prone to coastal inundation, the SPBEA model of Timbulsloko has to consider the features of the protection zone, the coastal and river belt zone, the fishpond and net pond zone, and the settlement and its infrastructure zone in its detailed spatial analysis. These features were identified as the result of field observation, whereby the village can be spatially designed as a fishing village. In addition to being able to maintain the culture and lifestyle of coastal communities which are dependent on aquaculture, a rural fishing village can also be an attraction for ecotourism. The authors of [60,61] support the claim that fisheries and tourism create benefits for the local community because a fishing village has the potential to develop as a destination for marine tourism. Indeed, findings from [62] also support that fishing-based coastal village planning is a valid approach for strengthening the economy of coastal communities. The result of SPBEA analysis by using a visual interpretation of high-resolution images integrated with the detailed analysis of the spatial allocation can be seen in Figure 8.
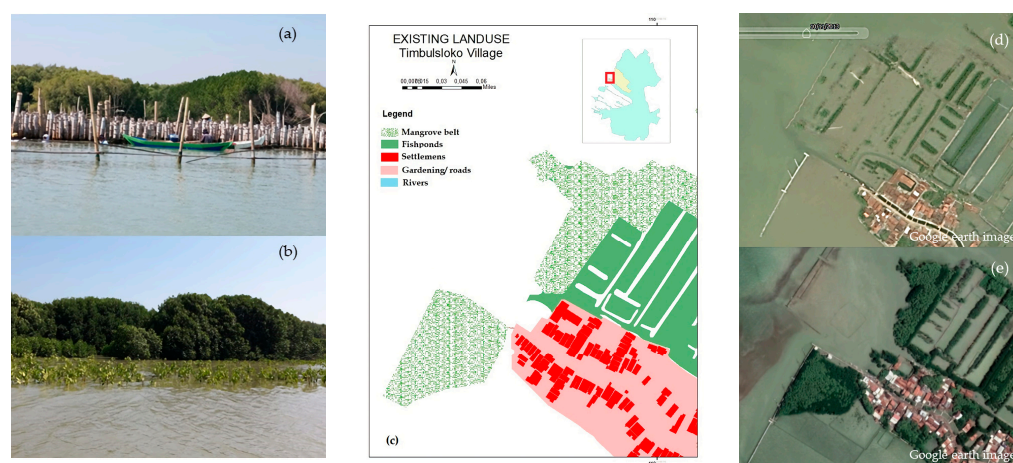

Figure 8. Site-planning management of SPBEA.

Figure 8 illustrates the concept of SPBEA consisting of the following features: (a) the protection zone which considers the previous coastline as the boundary, (b) the mangrove belt area which, in the future, can be developed into a mangrove ecotourism area, (c)

fishponds under the concept of silvofisheries, which can be designed either as a food stock or as an agri-tourism object, (d) the settlement areas, (e) net ponds, and (f) gardening areas that are consistent.
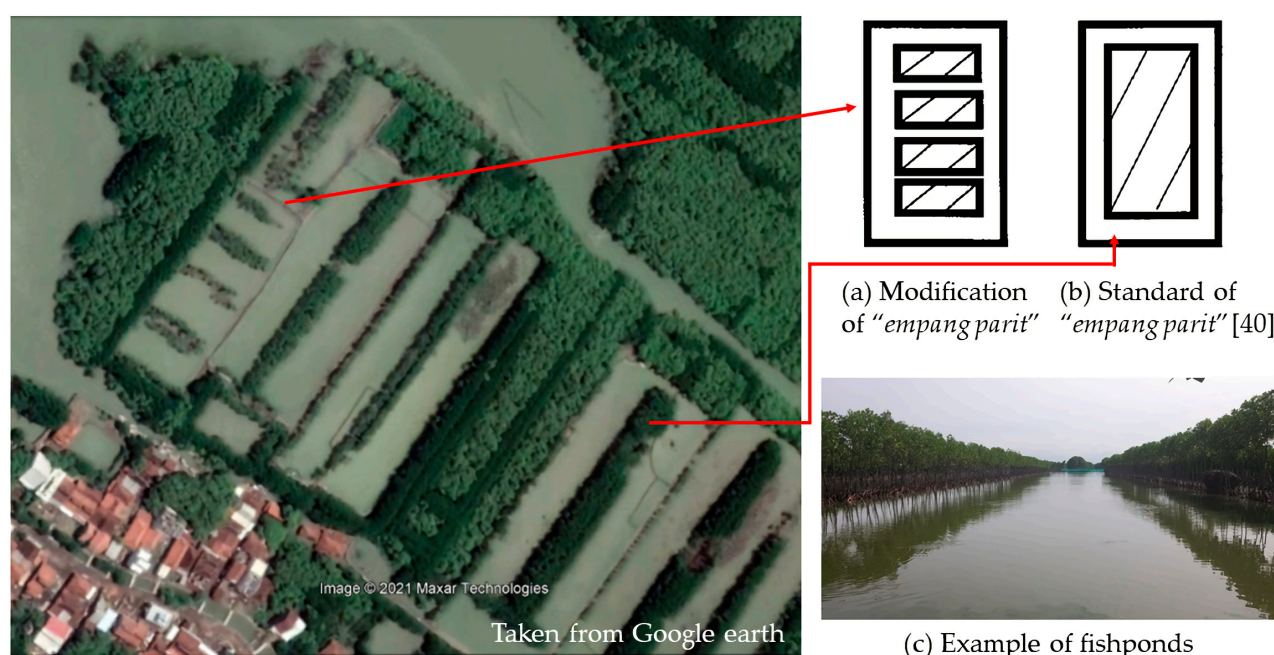
The coastal belt protection zone was predicted from visual interpretation of sedimentation and the existing hybrids within the coastline. Timbulsloko has implemented a conservation strategy for its coastal areas through a hybrid engineering method. Hybrid engineering combines technological and ecosystem-based solutions that use a permeable structure as a sediment trap, followed by mangrove planting once sedimentation begins to form [63] (Figure 9a,d). At some sites, this method has succeeded in forming new mangrove belts as a coastal protection ecosystem against the effects of abrasive tidal waves (Figure 9d). The use of mangrove belts is not the only method of coastal protection, however, and the fishpond activities of the local community should also follow an ecosystem-based approach which can be assessed and predicted visually in the image. Fishpond spatial-planning-based ecosystem adaptation is capable of maintaining the sustainability of ecosystems and environmental conservation, along with minimizing disputes between resource users [14]. Indeed, implementing fishpond spatial-planning-based ecosystem adaptations can assist decision-makers to address environmental impacts from a spatial perspective and can make planning decisions more transparent [64].

Figure 9. An example of how the cultivation of the fishponds can be implemented with environmental adaptation: (**a**,**d**) the hybrid engineering technique, developed as trap sediments; (**b**) mangrove belt development as a protection zone for fishpond culture and rural community activities; (**c**) spatial illustration of Timbulsloko in applying hybrid technology and silvofisheries; (**e**) how the mangrove belt and silvofisheries have been developed.

The most suitable fishpond management method for this purpose is the silvofishery method, as can be visually interpreted. The authors of [3] proved that the ecosystem adaptation of silvofisheries has succeeded in increasing not only the economic value of fish farms but also the value of the environment, through what is described as an economic–ecologic approach. In Timbulskolo, several pond farmers have begun putting this concept into practice, as seen in Figure 10.

In contrast to the SPBEA, there is an industrial area that has been planned in the regional spatial planning [52]. This area can be proposed for introducing ponds, since industrial activities may have an impact on the SPBEA of coastal rural areas.

Figure 10. Silvofishery practices in Timbulsloko, which can be categorized as (**a**) modification of empang sari type and (**b**) empang sari standard, while (**c**) fishpond example in the study area.

3.4. What We Have Learnt about the SPBEA Analysis

Conceptually, the above results show how GIS analysis was used in the development of the SPBEA model. The design of the SPBEA concept was carried out hierarchically, starting from the determination of the zone, in this case, the fishpond culture zone, to the configuration of the site in the available and allocated zones, and then to a detailed SPBEA assessment within the site allocated for development (see Figure 3). This spatial analysis structure implements the concept proposed by [33] for the potential steps in spatial planning and management processes for inland aquaculture. In contrast to the many studies of spatial suitability analysis that are generally conducted based on AHP, the development of the SPBEA filters the results of the land assessment analysis using the land system data, which is defined by the basic characteristics of the land's natural conditions. The input of the land system in the SPBEA analysis represents an improvement of the ecosystem approach, the characteristics of which can be derived from the land system spatial data. Aspects of restoring the natural conditions of the ecosystem can also be used for zoning by providing spatial information of conservation areas and greenbelts. The same is also done in a more detailed spatial arrangement of the site, where ecosystem components must also be part of the fishpond culture spatial zone. Therefore, the basic spatial data used for the SPBEA model have been fully acknowledged, including land system, land use, soil, slope, climate, water parameters, conservation zone, land ownership, and/or government spatial plans. Meanwhile, the features in SPBEA should at least include the protection zone, greenbelt, ponds, settlements, and infrastructure. This study has also shown that the SPBEA concept is a solution to climate change impacts, particularly in coastal areas.

4. Conclusions and Recommendations

This study conceptually defined the process of SPBEA analysis in a hierarchical manner, along with the spatial data needed. A spatial algorithm was also developed to support the SPBEA method. It seems that development of the spatial system needs to be carried out in the future to integrate the process, the data, and the algorithm as rules for shaping the SPBEA model. Thus, in the future, it can become the guideline for the implementation of SPBEA issues. Furthermore, site-based SPBEA arrangement

requires input from the local community as a direct object of spatial planning. Therefore, a community-based SPBEA approach is needed, which is often a weakness in spatial planning practice, especially in developing countries. This is a realm of government policy, both local and central, that needs further consideration to achieve sustainable spatial planning and prosperous rural communities.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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