Research Article
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Land Suitability Assessment for White Shrimp (Litopenaeus vannamei) Ponds Using Geographic Information System in the Mulyorejo Subdistrict, Surabaya, East Java

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Abstract: Based on the Regional Spatial Plan (RTRW) of Surabaya for the period 2010-2030, Mulyorejo Subdistrict is designated as a mangrove preservation area that integrates ponds and marshes ecosystems. However, the limited available land and diverse societal conditions have led to economic development focused on natural resources, such as shrimp ponds. In order to ensure responsible and sustainable fisheries and marine utilization, this research aims to analyze the land suitability of L. vannamei ponds in the Mulyorejo Subdistrict using a Geographic Information System (GIS), considering water quality, land use, and geophysics. The methodology employed a land suitability matrix based on scoring and weighting data for each parameter, processed using ArcGIS 10.2 software. Spatial analysis was conducted by overlaying the spatial data of all parameters. Attribute analysis involved summing the scores of all parameters and classifying them into three categories: good (score 81-100), medium (score 63-80), and bad (score 45-62). The obtained data included pH levels ranging from 6.78 to 8.86, salinity levels of 0-25 ppt, nitrate levels of 0.05-0.26 ppt, phosphate levels of 0.04-1.71, soil C/N ratio ranging from 1 to 16, soil types identified as typic epiaquepts and typic endoaquepts, temperature at 28.8°C, evaporation rate of 2.84-4.50 mm/day, annual rainfall of 1,776-2,201 mm, and land use categories comprising settlements, ponds, mangrove forests, and vacant land. Based on the research findings, the land suitability for white shrimp ponds in Mulyorejo Subdistrict covers an area of 425.18 hectares, with the largest portion located in Kalisari Village.

Introduction

Mulyorejo Subdistrict is a coastal area located in the second development unit of Kertajaya, Surabaya City. The total area of this subdistrict is 11.94 km2 and a population density of 87,801 people in 2016 (1). According to the Surabaya City Spatial Plan (RTRW) for the period 2010-2030, the coastal zone in Mulyorejo Subdistrict is designated as a protected mangrove forest area that is integrated with ponds and marshes ecosystems.

According to Article 6, paragraph 1 of Law Number 45 of 2009 on Fisheries, fisheries management within the Indonesian Exclusive Economic Zone (WPP-RI) aims to achieve optimal and sustainable benefits while ensuring the conservation of fishery resources. Therefore, the utilization of fisheries and marine potentials must be well-managed and responsible to ensure sustainable activities and become a major capital for Indonesia's development in the present and future (2). Marine and fisheries development should be oriented towards environmentally friendly fisheries development, prioritizing the conservation of biological resources, and being carried out efficiently and sustainably (3). Hence, this research aims to analyze the land suitability for the development of L. vannamei ponds in Mulyorejo, Surabaya, East Java.

Experimental Section

Water Quality Observation

Water quality observations were conducted with a single measurement at each station, starting from 8:00 AM until 3:00 PM, for a duration of 5 days and the weather was cloudy due to the rainy season. Salinity measurements were taken using a digital salinometer, pH levels were measured using a digital pH meter. In contrast, phosphate and nitrate measurements were obtained by collecting water samples and analyzing them using a refractometer at the Freshwater Fish Culture Laboratory, Sumberpasir, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang.

Solid Data Collection

Soil data collection was performed using a soil auger. Soil samples were collected by inserting the auger vertically into the soil to a depth of 50 cm. The collected soil samples were then placed in plastic bags and labeled with paper labels. Soil C/N ratio analysis was conducted at the Agricultural Crop and Horticulture Agribusiness Development Center (UPT Pengembangan Agribisnis Tanaman Pangan dan Hortikultura), Bedali, Lawang. Soil type data were obtained from digital data released by the Agriculture Land Resources Center (BBSDLP) in 2010.

Climate Data Collection

Climate data was obtained from the daily climate reports of the past five years [2014-2018] released by the official website of the Meteorology, Climatology, and Geophysics Agency (BMKG-online). The data were collected from three stations: BMKG Maritim Perak I Surabaya, BMKG Perak II Surabaya, and BMKG Juanda. These three stations were selected due to their proximity to Surabaya City.

Database Processing

The collected data were used to determine the rainfall, air temperature, and evaporation rate in Surabaya City. Field observations involved measuring the values of temperature, salinity, pH, nitrate, and phosphate in potential pond areas. The coordinates of the water quality data collection stations were determined using GPS. Additionally, field investigations aimed to match the visual conditions in the imagery with the actual visuals on-site, aiding in the creation of land use maps.

Feasiability Analysis

The land suitability classification was performed by creating a suitability matrix to assess the suitability level based on assigning scores to the limiting factors for L. vannamei cultivation (Table 1). After obtaining the suitability score ranges for each parameter, they were processed using the Reclassify tool in ArcGIS 10.2 to derive three suitability classes: Good, Moderate, and Poor. The Suitability maps for each parameter were then overlaid using the Union tool. The score values for each attribute of the suitability parameters were summed using the Field Calculator tool to obtain the total suitability score for each parameter.

Table 1. Assessment of Parameter Suitability for L. vannamei Ponds.

No	Parameter	Indicator	Range	Value	Weight	Score
1	Salinity	Good	10-20	1	10	10
		Moderate	20-35	0.5		5
		Poor	<10/>35	0		0
2	Nitrate	Good	<0.3	1	5	5
		Moderate	0.3-0.5	0.5		2.5
		Poor	>0.5	0		0
3	pH	Good	6.5-8.5	1	10	10
		Moderate	5.5-5.6/8.5-9.5	0.5		5
		Poor	<5.5/>9.5	0		0
4	Phosphate	Good	>0.2	1	5	5
		Moderate	0.1-0.21	0.5		2.5
		Poor	0.051-0.1	0		0
5	C/N ratio	Good	5-8	1	15	15
		Moderate	8-12	0.5		7.5
		Poor	<5 / >12	0		0
6	Base saturation	Good	>75%	1	10	10
		Moderate	50-75%	0.5		5
		Poor	<50%	0		0
7	Air temperature	Good	25-32 C	1	10	10
		Moderate	12-25 C	0.5		5
		Poor	<12/>32C	0		0
8	Evaporation rate	Good	1-4	1	5	1
		Moderate	4-6	0.5		0.5
		Poor	6-7	0		0
9	Rainfall	Good	<2000	1	10	1
		Moderate	2000-2500	0.5		0.5
		Poor	>2500	0		0
10	Land use	Good	Pond, ricefield, beach	1	20	20
		Moderate	Garden, forest, swamp, mangrove	0.5		10
		Poor	Sattlement, building	0		0
Total				15	100	150

Note: Modified from references (4-8).

Result and Discussion

General Condition

The district of Mulyorejo is geographically located in the eastern part of Surabaya City, with coordinates ranging from 07°14' to 07°17' S latitude and 112°45' to 112°50' E longitude. It is a low-lying area with an elevation ranging from 2 to 7 meters above sea level and a land slope of 0-3%. Administratively, Mulyorejo District is bordered by Bulak District to the north, the Madura Strait to the east, Sukolilo District to the south, and Gubeng and Tambaksari Districts to the west.

The total area of Mulyorejo District is approximately 1,841 hectares and is divided into six urban villages: Manyar Sabrangan Urban Village (approximately 165 hectares), Mulyorejo Urban Village (approximately 303 hectares), Kejawan Putih Tambak Urban Village (approximately 325 hectares), Dukuh Sutorejo Urban Village (approximately 264 hectares), Kalisari Urban Village (approximately 642 hectares), and Kalijudan Urban Village (approximately 142 hectares). The study area for this research is located in Kalisari, Dukuh Sutorejo, and Kejawan Putih Tambak Urban Villages.

The field observation was conducted in three urban villages: Kalisari, Kejawan Putih Tambak, and Dukuh Sutorejo. The selection of these locations was based on the circular letter issued by the City Government regarding the Spatial Planning and Regional Plan of the City, which prioritized the eastern coastal areas of Mulyorejo District as a mangrove protected forest area integrated with aquaculture ponds. The observation parameters included water quality, geophysics, and climate, which were marked using GPS coordinates.

Table 2. Water quality at observation stations.

Stations	Coordinates (UTM)		Village	Parameter			
	X	Y		Salinity (‰)	pH	Nitrate (mg/L)	Phospate (mg/L)
1	699456	9197575	Dukuh Sutorejo	20	8.5	0.07	0.14
2	699822	9197376	Dukuh Sutorejo	25	8.7	0.07	0.15
3	699468	9197586	Dukuh Sutorejo	0	7.8	0.08	0.79
4	699132	9196471	Dukuh Sutorejo	16	8	0.12	0.27
5	698628	9197789	Dukuh Sutorejo	20	8.74	0.14	0.29
6	698537	9197804	Dukuh Sutorejo	14	9.1	0.09	0.16
7	698621	9197645	Dukuh Sutorejo	8	9.4	0.08	0.17
8	698613	9197709	Dukuh Sutorejo	8	9.2	0.12	0.22
9	699283	9197363	Dukuh Sutorejo	0	9	0.13	0.09
11	699287	9197160	Dukuh Sutorejo	20	8.38	0.26	0.35
12	699678	9195908	Kalisari	0	7.6	0.09	0.88
13	699322	9195740	Kalisari	0	9.2	0.05	0.18
14	699244	9194385	Kalisari	0	7.9	0.11	0.40
15	700420	9196125	Kalisari	20	7.2	0.08	0.28
16	700324	9196153	Kalisari	17	7.66	0.06	0.17
17	700296	9196408	Kalisari	20	8.2	0.08	0.14
18	700296	9196408	Kalisari	20	7.92	0.08	0.13
20	699244	9194385	Kejawan Putih Tambak	0	7.69	0.11	0.75
21	699266	9194434	Kejawan Putih Tambak	4	8.36	0.13	0.45
22	699408	9194513	Kejawan Putih Tambak	3	8.22	0.10	1.71
23	699713	9194721	Kalisari	0	7.38	0.10	1.18
24	697563	9196615	Kalisari	0	8.55	0.11	0.76
25	697183	9196079	Kalisari	0	7.4	0.06	0.69
26	697072	9196601	Kalisari	0	7.73	0.19	0.40
27	697085	9197065	Kalisari	0	8.31	0.13	0.28
28	697519	9197443	Kalisari	0	8.58	0.24	0.33
29	697569	9197433	Mulyorejo	0	8.46	0.12	0.44
30	697088	9197367	Kalisari	0	8.02	0.15	0.86
31	698644	9195665	Kalisari	0	8.74	0.06	0.08
32	698964	9196274	Kalisari	0	7.87	0.10	1.13
33	698963	9196200	Kalisari	0	7.31	0.08	0.04
34	698963	9196200	Kalisari	0	7.75	0.12	0.21
35	697072	9196601	Kalisari	0	7.73	0.19	0.40
36	697085	9197065	Kalisari	0	8.31	0.13	0.28

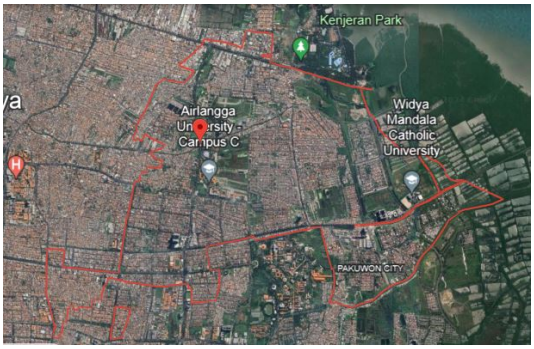

Figure 1. Administrative Boundary Map of Mulyorejo District

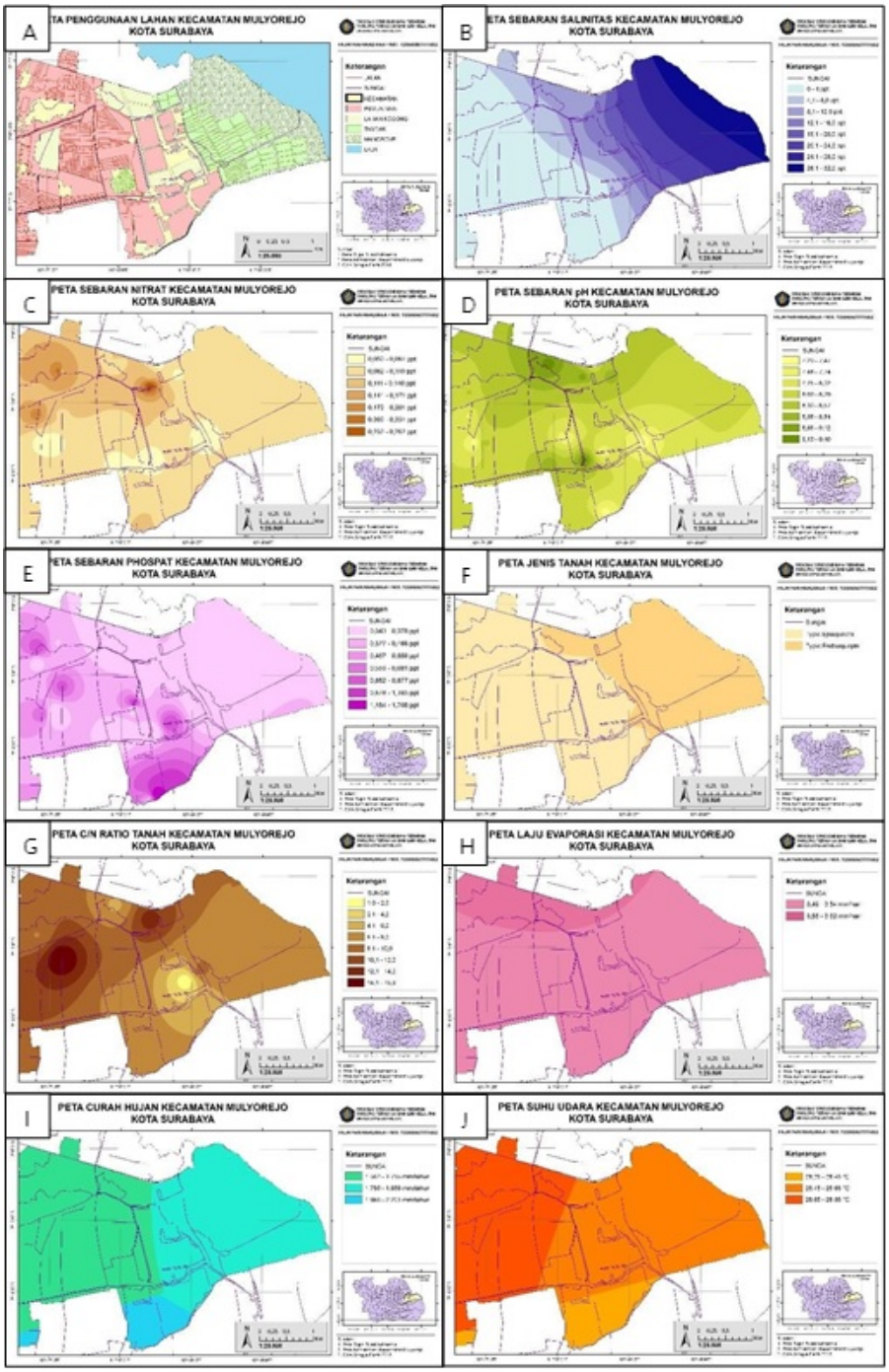

Figure 2. Map of Mulyorejo with land use (a), salinity distribution (b), nitrate distribution (c), pH distribution (d), Phosphate distribution (e), soil types (f), soil C/N ratio (g), evaporation rate (h), rainfall (I), and air temperature (j)

In shrimp pond aquaculture, the water used must meet specific criteria for the survival of shrimp (9). The water quality parameters measured in this study included acidity level (pH), salinity, nitrate, and phosphate. Sampling points for water quality were taken from various locations in the three urban villages, including inlet and outlet of the ponds, pond water, and other water channels. The results of the water quality observations can be seen in Table 2 and the map of parameter distribution is presented in Figure 2.

Figure 2A depicts the land use map of Mulyorejo District, which includes shrimp ponds, mangrove forests, settlements, and vacant land. Mangrove areas are suitable for the cultivation of L. vannamei. Further research is still needed to understand the relationship between the shrimp ecosystem and mangroves. Previous studies have indicated negative impacts on shrimp production within mangrove ecosystems (10).

Water quality parameters such as salinity, nitrate, pH, and phosphate are illustrated in Figures 2B to 2E. The distribution pattern of water salinity in the Mulyorejo District, ranging from 0-25 ppt, which aligns with the accepted salinity standards for L. vannamei cultivation, falling between 10-25 ppt, with the optimal range being 15-25 ppt. Nitrate distribution in the same area, which spans from 0.050 to 0.262 ppt. This nitrate concentration is vital as it stimulates the growth of essential natural food sources like klekap, plankton, and algae for fish, a critical factor in shrimp farming. The algae, particularly phytoplankton, thrive optimally at nitrate levels between 0.9-3.5 mg/L (11). Examining the pH values in Figure 2D reveals a range from pH 7.3 to 8.7 within the study locations, with the lowest pH in Kejawan Putih Tambak and Kalisari, and the highest in Dukuh Sutorejo and Mulyorejo neighborhoods. However, all pH levels fall within the suitable range of 7.5-8 for L. vannamei cultivation. Lastly, the distribution of phosphate, ranging from 0.043 to 1.705 ppt, indicating a natural nutrient supply from weathering processes and human activity waste. The phosphate content observed aligns with the optimal range for shrimp farming, as suggested by a reference (8), which is >0.2 ppt. Collectively, these observations suggest that the environmental conditions in the research location are conducive to L. vannamei cultivation.

Figure 2F shows that the land in Mulyorejo District consists of typic endoaquepts and typic epiaquepts soil types, which belong to the alluvial soil group. Land suitable for pond cultivation is characterized by sufficient water saturation, preventing rapid water infiltration (12). Conversely, soil types with low water saturation can hinder pond cultivation activities. Typic endoaquepts soil has a water saturation level of 75% or higher, while typic epiaquepts has a saturation level between 50-75%. Therefore, this land is considered suitable for L. vannamei cultivation. Figure 2G displays a C/N ratio range of 1-16. C/N ratio that is too high can potentially lead to plankton blooming, while a ratio that is too low can make it difficult to cultivate natural food sources. The optimal C/N ratio for L. vannamei cultivation land is in the range of 5-15 (7). Therefore, it can be concluded that the land in Mulyorejo District is still suitable for L. vannamei cultivation. Figure 2H depicts the evaporation rate in Mulyorejo District, which does not significantly differ and ranges from 3.49 to 3.62 mm/day. The lowest evaporation rate occurs from April to July, while the highest evaporation rate is observed from September to November (13). Therefore, the climatic conditions in Mulyorejo District are considered suitable for L. vannamei cultivation. Figure 2I explains the rainfall intensity in Mulyorejo District, which ranges from 1,562 to 2,201 mm/year. The variation in rainfall distribution at the research location is not significantly different and still falls within suitable conditions for L. vannamei cultivation. Figure 2J shows the air temperature in Mulyorejo District ranging from 28.25 to 28.85 °C. This range does not vary significantly and is still suitable for pond cultivation. High fluctuations in air temperature during extreme periods can affect L. vannamei pond cultivation activities (14), as excessively high or low temperatures can disrupt shrimp metabolism balance, making them more susceptible to diseases and mortality. Extreme temperatures occur in April - May and October – November (15).

The score values for each attribute of the feasibility parameters are summed using the Field Calculator tool, resulting in the total feasibility score for each parameter. The analysis results after overlaying the data can be seen in Figure 3A below.

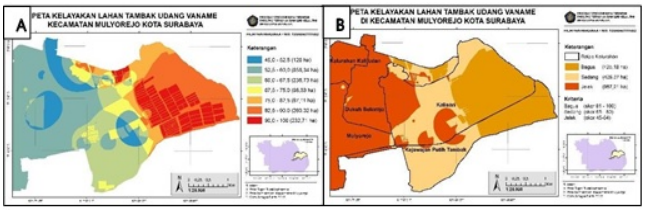

Figure 3. The assessment of the feasibility of shrimp pond cultivation land in Mulyorejo District after performing the overlay (A) and after being categorized (B)

From the overlay results (Figure 3A), it can be observed that the feasibility scores range from 47.5 to 100. Based on the feasibility matrix (Table 1), the range considered to meet the requirements for L. vannamei cultivation is 100-85, while scores among 65 to 82.5 are considered moderate, and scores between 65.5-47.5 are deemed poor, meaning they are not suitable for L. vannamei cultivation. These score ranges are used to determine the feasibility area.

Based on the analysis of attributes and spatial data, it is evident that out of the total pond area in Mulyorejo District, the land area classified as 'good' covers 425.18 hectares. This land generally consists of mangrove forests, ponds, and rice fields (Figure 2A) and is distributed across several neighborhoods, with 22.89 hectares in Dukuh Sutorejo, 268.41 hectares in Kalisari, and 134.68 hectares in Kejawan Putih Tambak. The land area classified as 'moderate' is 426.37 hectares, which includes rice fields and vacant land. The 'poor' category covers 987.21 hectares and mainly comprises residential areas and buildings, making it unsuitable for L. vannamei pond cultivation due to the high cost involved in changing the existing conditions.

Conclusion

The suitable land for cultivating vannamei shrimp in the Mulyorejo District is approximately 425.18 hectares, with the largest area located in Kalisari Village, which is a mangrove forest area. Based on the analysis of feasibility parameters, water and soil quality in the Mulyorejo District vary in suitability, while based on geophysical parameters, it is considered suitable for L. vannamei cultivation.

Declarations

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Conflict of Interest

The author declares no conflicting interest.

Data Availability

The unpublished data is available upon request to the corresponding author.

Ethics Statement

Not applicable.

Funding Information

Not applicable.

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