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Integrating Water Quality Data and GIS to Evaluate Aquaculture Suitability in Coastal Zone in Sumenep Regency

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Abstract– Land suitability is a critical factor determining the success of vannamei shrimp aquaculture in coastal pond systems. This activity exhibits spatial characteristics as well as diverse biophysical and socio-economic conditions across locations, making spatial analysis essential. However, many high-intensity ponds have not fully utilized Geographic Information Systems (GIS) for site selection and management, even though this approach can significantly reduce production risks. This study was carried out through a survey method by collecting water-quality parameters, including pH, temperature, salinity, dissolved oxygen (DO), nitrate, and phosphate. Land suitability was assessed using a scoring method based on weighted water-quality parameters. The analysis produced a thematic suitability map covering a total area of 7,249 m^3, revealing variations among pond units. Pond 1 (2,138 m^3) was classified as S1, while Pond 2 (1,879 m²) and Pond 3 (1,868 m²) fell within S1. Pond 4 (1,368 m²) was categorized as S1, indicating the suitable for sustainable aquaculture. These findings provide an important basis for optimizing sustainable pond management. This outcome further facilitates the establishment of water-quality management priorities and supports productivity enhancement efforts to achieve optimal aquaculture performance.

Keywords: land suitability, sustainable aquaculture, vannamei shrimp, water quality, gis-based analysis, coastal pond management.

I. introduction

Vannamei shrimp (Litopenaeus vannamei) has become one of the most prominent export species in global aquaculture (Garlock et al., 2024). Since its introduction to Indonesia in 1999, the species has consistently shown high production performance and has played a major role in revitalizing the country's shrimp-farming industry (Yakubu et al., 2025). Compared with other cultivated shrimp, vannamei offers several biological and economic advantages, including superior survival rates, the availability of high-quality Specific Pathogen Free (SPF) seed, strong tolerance to intensive stocking, enhanced disease resistance, and efficient feed utilization (Farantika et al., 2020).

The sustainable aquaculture of vannamei has also been adopted as a strategic response to the decline in tiger shrimp (Penaeus monodon) production. Although P. monodon farming expanded rapidly during the 1990s (Chakrabarty et al., 2014), yields later dropped sharply due to WSSV outbreaks (Mustafa et al., 2022). These events caused substantial financial losses and led many farmers to abandon their ponds, leaving extensive areas unmanaged (Chakrabarty et al., 2014).

The coastal area of Sumenep Regency, East Java, Indonesia holds considerable potential for aquaculture development, yet its existing ponds remain underutilized. Only limited shrimp and fish farming operations are currently active in the region. This study therefore aims to evaluate the suitability of pond areas in particularly abandoned or inactive units through the application of Geographic Information Systems (GIS). The use of GIS in aquaculture site assessment and management offers significant advantages by improving decision-making accuracy and minimizing the risk of production failure. (Shunmugapriya et al., 2021).

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II. Research Methods

1. Research Timeline, Study Area, and Data Collection Procedures

This study was conducted over a four-month period in the coastal area of Sumenep Regency, East Java, Indonesia. All research activities were carried out within the pond area that served as the primary focus of the investigation. The dataset consisted of primary water-quality samples, which were processed to obtain detailed information on the environmental conditions of the ponds. Additionally, GeoEye satellite imagery was utilized for spatial analysis to ensure accurate interpretation and visualization of the study area.

2. Analytical Methods and Data Processing Techniques

The land suitability assessment was conducted by assigning weights and scores to each parameter in accordance with the rule-based criteria for pond suitability. This process produced a classification of suitability levels based on the total aggregated values of all evaluated parameters.

2.1 Weighting of Parameters

The evaluation of land suitability for pond aquaculture is a systematic and multi-parameter analytical process. A key stage in this assessment involves assigning weights that indicate the relative importance of each parameter, such as water quality, soil properties, or topographic conditions, in determining production success. Numerical scores are then used to quantify the actual condition of the site for each parameter. The weighting and scoring procedures are carried out based on a standardized rule base table for aquaculture suitability, ensuring consistency, transparency, and objectivity. Each parameter generates a partial value, which is subsequently combined to produce an overall suitability score. This final value serves as the basis for determining the suitability category of the site. This stage is not merely a numerical exercise. It represents an integrative synthesis of environmental information that results in a comprehensive classification, providing a scientifically grounded foundation for decision making in the planning and sustainable development of aquaculture areas.

2.2 Clipping

The clipping stage is applied to isolate specific areas that fall within a predetermined boundary. In this study, the boundary of the pond area served as the clipping extent, ensuring that only spatial information contained within the aquaculture zone was included in the final analysis.

3. In-Situ Data Processing

In situ data were obtained through direct water sampling within the pond area. Samples were collected randomly from several points across the coastal zone, including ponds located near the shoreline, those positioned around river outflows, and ponds situated close to residential areas. The sampled water represented a mixture of inflow and outflow sources at each pond unit, ensuring a representative description of the culture environment. The collected water was placed into two separate containers. The first container was reserved for nitrate and phosphate analysis, and one drop of concentrated sulfuric acid was added to stabilize the sample. The second container was used for dissolved oxygen assessment and was wrapped in newspaper and black plastic to prevent changes in oxygen concentration caused by exposure to sunlight. Measurements of temperature, pH, and salinity were carried out directly in the field using a refractometer and pH meter. Subsequent laboratory analyses for nitrate, phosphate, and dissolved oxygen were performed at the Faculty of Fisheries and Marine Science, Diponegoro University.

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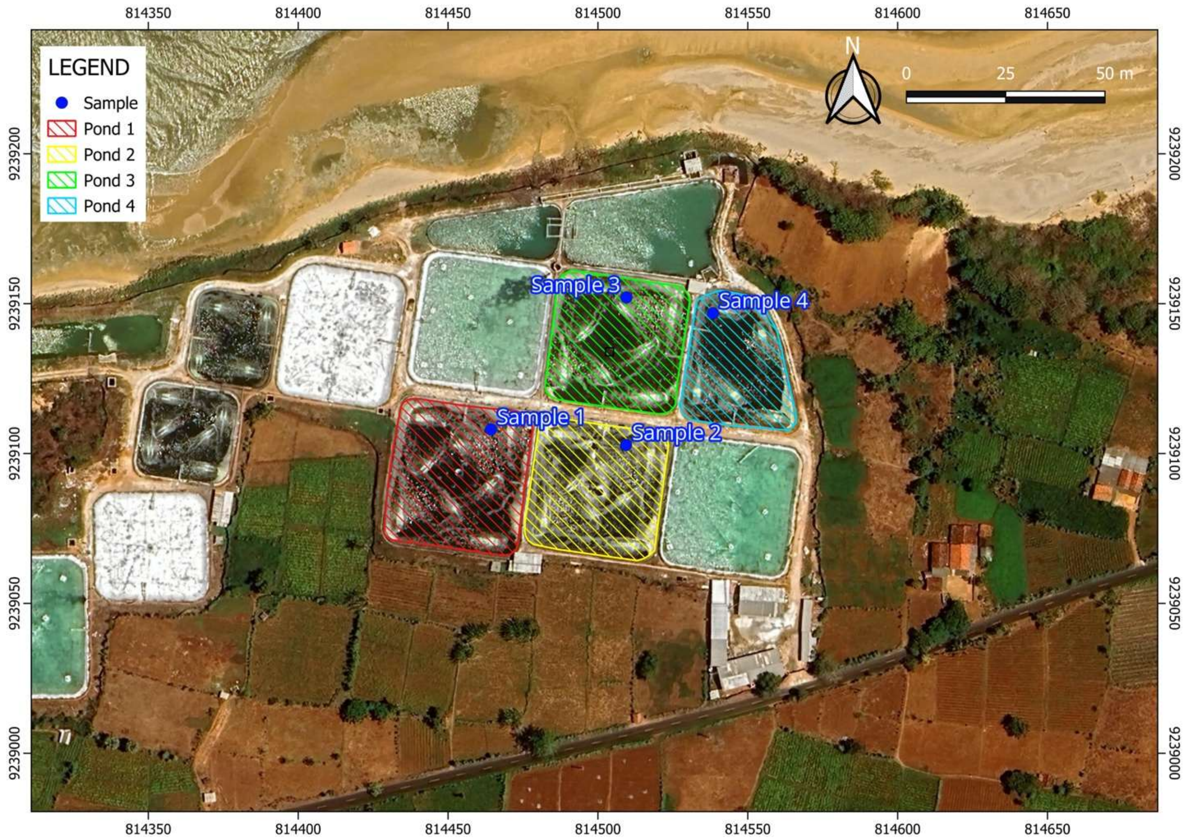

Figure 1. Sampling Location

III. RESULT AND DISCUSSION

The measured water quality parameters (Table 1) indicate that temperature ranged from 25 to 31 °C. This interval remains close to the optimal range for Litopenaeus vannamei cultivation, which is generally reported between 25 and 30 °C. Temperature is a key regulator of various physiological processes in shrimp, including survival, growth performance, reproductive activity, behavior, molting frequency, and overall metabolic rate. In addition, elevated temperatures can reduce oxygen solubility in water, subsequently affecting the comfort and stability of the shrimp culture environment.

Salinity values at the study site were recorded between 24 and 35 mg L^{-1}. Although these levels slightly exceed the most favorable range of 15–20 mg L^{-1}, L. vannamei can still perform well due to its broad tolerance to salinity fluctuations. Physiologically, variations in salinity influence the osmoregulatory mechanisms of shrimp. With its high adaptive capacity, L. vannamei is able to maintain growth even when salinity conditions deviate from the optimum threshold.

The pH of pond water ranged from 7.3 to 8.4, which is still suitable for the maintenance and growth of L. vannamei, as the recommended pH for optimal cultivation lies between 7.5 and 8.5. A stable pH range is essential for supporting feeding activity, metabolic processes, and successful molting. Conversely, excessively low pH may hinder molting and reduce shrimp survival.

Dissolved oxygen (DO) concentrations at the sampling sites ranged from 3.6 to 4.1 mg L^{-1}, approximating the ideal conditions for L. vannamei, which typically requires 4–7 mg L^{-1} to maintain normal growth. Both insufficient and excessive DO levels can disrupt shrimp physiology and consequently reduce growth performance, as noted by Yan et al. (2013). DO represents the amount of oxygen available in the water column for respiration and metabolic energy production that supports growth and reproduction. Moreover, dissolved oxygen is fundamental for aerobic decomposition of organic and inorganic materials (Jiang et al., 2005).

Water transparency in the ponds ranged from 35 to 70 cm, whereas the recommended transparency for L. vannamei culture is 30–40 cm (Venkateswarlu et al., 2019). Transparency exceeding 40 cm indicates overly clear water, while values below 20 cm reflect highly turbid conditions. Turbidity is commonly driven by increased suspended particles such as fine sediments, sand, and various microorganisms (Zhang et al., 2006). Transparency is an important indicator because it reflects the depth of light penetration that supports photosynthetic activity and provides insight into vertical stratification of water clarity within the pond (Boyd & Pine, 2010).

Table 1. Water Quality Parameter Observations

Parameter	Range	Unit
Temperature	25-31	℃
Salinity	24-35	Mg/L
pH	7.3-8.4	-
Dissolved Oxygen (DO)	3.6-4.1	Mg/L
Water Transparency	35-70	cm
Nitrate	0.3-3.0	ppm
Nitrite	1.2-2.7	ppm

Measured nitrate concentrations ranged from 0.3 to 3.0 ppm, indicating that the availability of inorganic nitrogen in the water column remained within a range that can still be utilized by aquatic organisms. Nitrate serves as an essential nutrient supporting protein synthesis in aquatic biota and primary producers (Schuler & Boardman, 2010). For shrimp aquaculture, the preferred nitrate range is reported to be approximately 0.7–3.2 mg L^{-1} (Boyd & Pine, 2010; Venkateswarlu et al., 2019). Nitrate levels in culture systems are influenced by the efficiency of bacterial nitrification and by environmental conditions including pH, dissolved oxygen, and temperature (Valencia-Castañeda et al., 2019).

Nitrite concentrations measured in the ponds ranged from 1.2 to 2.7 ppm, values that approach the threshold known to impair shrimp growth. In aquaculture operations, nitrite should ideally remain below 1 ppm, as concentrations exceeding this level may limit physiological performance and have adverse effects on shrimp health (Schuler & Boardman, 2010; Venkateswarlu et al., 2019). As shrimp increase in size and age, feed inputs generally rise, leading to greater organic deposition at the pond bottom. Uneaten feed undergoes microbial decomposition and can release various nitrogenous compounds, including nitrite (NO_2^-). The accumulation of nitrite from this process increases toxicity risks, particularly in intensive systems with high feeding rates (Valencia-Castañeda et al., 2019). These conditions highlight the importance of proper feed management to prevent excess organic buildup and the formation of harmful metabolites (Ambasankar & Ali, 2002; Huang et al., 2004).

IV. CONCLUSION

The assessment of land suitability demonstrated clear spatial variability across pond units in the Teluk Awur coastal area, highlighting the importance of integrating water-quality parameters with GIS-based spatial analysis. The suitability map produced from weighted scoring revealed that Pond 1 was classified as S1, indicating highly favorable conditions, while Ponds 2 and 3 fell within S2–S3, reflecting moderate to conditional suitability. Pond 4 was categorized as S3, suggesting the need for targeted improvements. These findings provide a scientifically grounded basis for refining site management, enhancing environmental monitoring, and supporting sustainable development of vannamei shrimp aquaculture in previously underutilized pond areas.

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