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Analysis Of Land Suitability For Tilapia Aquaculture In Tanjung Alam, Asahan Regency

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Abstract−Tilapia aquaculture has become one of the most rapidly growing freshwater fisheries sectors in Indonesia due to increasing market demand, adaptive fish characteristics, and relatively simple cultivation techniques. However, the sustainability and productivity of tilapia farming are highly influenced by land suitability and environmental conditions. This study aimed to analyze land suitability for tilapia cultivation in Tanjung Alam Village, Asahan Regency, North Sumatra. The research employed a descriptive quantitative approach using field observations, water quality measurements, interviews, and Geographic Information System (GIS)-based suitability analysis. The observed parameters included temperature, dissolved oxygen, pH, water depth, current velocity, soil texture, salinity, accessibility, and supporting infrastructure. Data analysis was conducted using a scoring and weighting method to determine the level of land suitability for tilapia aquaculture development. The results indicated that most areas in Tanjung Alam were categorized as moderately suitable (S2) to highly suitable (S1) for tilapia cultivation. Water temperature ranged from 27–30°C, dissolved oxygen ranged from 5.1–7.2 mg/L, and pH values ranged from 6.8–7.8, all of which support optimal tilapia growth. Accessibility and water availability were also considered adequate for sustainable aquaculture activities. The study concludes that Tanjung Alam possesses considerable potential for the expansion of environmentally sustainable tilapia farming. The findings provide strategic recommendations for regional aquaculture planning and sustainable fisheries development.

Keywords: Land Suitability; Tilapia Aquaculture; GIS; Water Quality; Sustainable Fisheries

1. INTRODUCTION

Aquaculture has become one of the fastest-growing food production sectors globally due to increasing demand for fish protein and declining capture fisheries production. In Indonesia, freshwater aquaculture contributes significantly to food security, employment, and regional economic development. Among freshwater fish commodities, tilapia (Oreochromis niloticus) has emerged as one of the most commercially important species because of its rapid growth, high tolerance to environmental conditions, resistance to disease, and strong consumer demand. The Ministry of Marine Affairs and Fisheries of Indonesia continues to encourage tilapia cultivation development as part of national fisheries revitalization programs.

Land suitability analysis is a critical aspect in determining the success and sustainability of aquaculture activities. Improper site selection may lead to environmental degradation, low productivity, disease outbreaks, and economic losses. Therefore, understanding the suitability of physical, chemical, biological, and socio-economic conditions is essential for sustainable aquaculture development. According to recent studies, GIS-based land suitability evaluation has become an effective approach in identifying appropriate aquaculture sites because it integrates environmental parameters and spatial analysis comprehensively.

Tanjung Alam Village, located in Asahan Regency, North Sumatra Province, possesses considerable freshwater resources and community interest in fisheries activities. However, tilapia cultivation in the area is still carried out traditionally with limited scientific assessment regarding land suitability. Farmers often determine cultivation locations based solely on practical considerations without evaluating environmental carrying capacity and water quality characteristics. This condition potentially affects aquaculture productivity and environmental sustainability.

Several previous studies have discussed aquaculture land suitability in different regions. Chentouf et al. (2023) emphasized that GIS-based multi-criteria evaluation methods significantly improve aquaculture site selection accuracy and environmental management. Tarunamulia and Sammut (2023) found that fuzzy GIS analysis effectively identifies environmentally sustainable aquaculture zones in coastal regions. Garza-Martinez et al. (2022) reported that land suitability assessment improves tilapia production efficiency and environmental sustainability in Mexico. Meanwhile, Emilyasari et al. (2023) explained that environmental feasibility strongly influences tilapia farming profitability in floating net cages. Syamsuri and Alang (2023) also highlighted that tilapia aquaculture development requires proper environmental analysis to ensure long-term economic viability.

Despite numerous studies on aquaculture suitability, limited research has specifically examined freshwater tilapia cultivation suitability in Asahan Regency. Previous studies mostly focused on economic feasibility rather than spatial and environmental suitability assessment. Therefore, this study contributes to filling the research gap by integrating water quality measurements, land characteristics, and GIS-based suitability analysis in Tanjung Alam.

The urgency of this research is closely related to sustainable fisheries development and regional economic empowerment. The increasing demand for tilapia production requires environmentally suitable cultivation areas to avoid ecological degradation. Inappropriate aquaculture expansion may negatively impact water quality, biodiversity, and local ecosystems. Consequently, comprehensive land suitability analysis is essential to support environmentally sustainable and economically feasible aquaculture development.

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This study aims to analyze land suitability for tilapia cultivation in Tanjung Alam Village, Asahan Regency. Specifically, the study evaluates water quality parameters, physical land characteristics, and supporting infrastructure using a scoring and weighting system. The research findings are expected to provide scientific recommendations for local governments, aquaculture practitioners, and communities regarding sustainable tilapia cultivation development.

The contribution of this research lies in providing a comprehensive spatial and environmental evaluation for freshwater tilapia cultivation in Asahan Regency. The study also contributes to sustainable aquaculture planning by integrating environmental suitability analysis with practical fisheries development strategies.

2. RESEARCH METHODS

2.1 Research Location and Time

This study was conducted in Tanjung Alam Village, Asahan Regency, North Sumatra Province, Indonesia. The research location was selected due to its substantial freshwater potential and the presence of active aquaculture communities engaged in tilapia farming activities. In addition, the area has favorable environmental characteristics that support freshwater aquaculture development. Data collection and field observations were carried out over a three-month period, from January to March 2026.

2.2 Research Design

This study employed a descriptive quantitative approach combined with field observations and Geographic Information System (GIS)-based spatial analysis. The research aimed to evaluate the suitability of land for tilapia cultivation by analyzing environmental, physical, chemical, and socio-economic parameters. The study utilized both primary and secondary data sources to obtain comprehensive and accurate information regarding the research area. Primary data were obtained through direct field measurements, observations, and interviews with local fish farmers. Meanwhile, secondary data consisted of topographic maps, regional spatial planning documents, climatological data, and fisheries statistics collected from relevant government institutions and supporting agencies.

2.3 Data Collection Techniques

Data collection was conducted through direct field surveys and laboratory-supported measurements using portable water quality instruments. Several important environmental parameters were observed, including water temperature, dissolved oxygen (DO), pH, salinity, water depth, water transparency, and current velocity. These parameters were selected because they significantly influence tilapia growth and aquaculture productivity. The land suitability assessment applied a scoring and weighting method based on freshwater aquaculture suitability standards. Each parameter was assigned a specific score and weight according to its level of importance in supporting tilapia cultivation. The suitability classification consisted of four categories, namely highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). The suitability index was calculated using the following formula:

$$SI = \frac{\sum(W_i \times S_i)}{\sum W_i}$$

Where:
SI = Suitability Index
Wi = Weight of each parameter
Si = Score of each parameter

2.4 Research Variables

The variables analyzed in this study consisted of several environmental and supporting factors related to tilapia cultivation suitability, including:

1. Physical parameters, including water depth, current velocity, water temperature, and soil texture.
2. Chemical parameters, including pH, dissolved oxygen, and salinity.
3. Accessibility parameters, including road access, water availability, and distance to fish markets.
4. Supporting infrastructure, including electricity availability, transportation facilities, and fisheries infrastructure.

2.5 Data Analysis

The collected data were analyzed using descriptive statistical methods and GIS-based spatial analysis techniques. Suitability classification was carried out through overlay analysis by integrating environmental, physical, and socio-economic variables into a spatial suitability map. The scoring and weighting criteria used in this study were adapted from freshwater aquaculture land suitability standards commonly applied in aquaculture planning studies. The land suitability categories used in this study are presented in Table 1.

Table 1. Category

Suitability Class	Description

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S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
N	Unsuitable

3. RESULTS AND DISCUSSION

3.1 General Description of the Research Area

Tanjung Alam Village is geographically located in Asahan Regency, North Sumatra Province, Indonesia. The area possesses considerable freshwater resources derived from rivers, irrigation channels, and rainfall, which support freshwater aquaculture activities. Most local residents rely on agriculture and fisheries as their primary sources of income. The climate in the region is classified as tropical humid, with annual rainfall ranging from 2,000 to 2,500 mm, creating favorable environmental conditions for freshwater fish cultivation. The topographic condition of Tanjung Alam is generally flat, making the area highly supportive for pond construction and freshwater aquaculture development. In addition, the village has relatively adequate accessibility to fish markets and transportation networks, facilitating aquaculture production and product distribution activities. The availability of water resources throughout the year further strengthens the potential for sustainable tilapia farming development in the area.

3.2 Water Quality Analysis

Water quality is one of the most critical factors influencing fish growth, survival, feed efficiency, and aquaculture productivity. Based on field observations and laboratory measurements, the water quality parameters in the study area generally met the standards required for tilapia cultivation.

3.2.1 Temperature

The water temperature measured in the research area ranged from 27°C to 30°C. These temperatures are considered highly suitable for tilapia cultivation because tilapia can grow optimally within a temperature range of 25°C–32°C. Water temperature directly affects fish metabolism, appetite, feed conversion efficiency, and growth performance.

$$25^{\circ}C \leq T \leq 32^{\circ}C$$

Optimal temperature conditions contribute significantly to maintaining physiological stability and increasing aquaculture productivity. The findings of this study are consistent with the research conducted by Robisalmi et al. (2023), who reported that appropriate water temperatures improve tilapia growth performance and feed utilization efficiency in aquaculture ponds.

3.2.2 Dissolved Oxygen (DO)

The dissolved oxygen (DO) concentration in the study area ranged from 5.1 to 7.2 mg/L. These values indicate that oxygen availability in the ponds was adequate to support tilapia growth and survival. Tilapia generally requires dissolved oxygen concentrations above 4 mg/L for optimal physiological performance.

$$DO > 4\, mg/L$$

Adequate dissolved oxygen levels support fish respiration, metabolic activity, immune system performance, and feed conversion efficiency. Conversely, low dissolved oxygen concentrations may cause stress, reduced growth, and increased susceptibility to disease. Therefore, maintaining stable oxygen concentrations is essential for sustainable aquaculture management.

3.2.3 pH Analysis

The pH values recorded during the study ranged from 6.8 to 7.8, indicating neutral to slightly alkaline water conditions. These values fall within the optimal range required for tilapia cultivation, as tilapia can grow effectively at pH levels between 6.5 and 8.5.

$$6.5 \leq pH \leq 8.5$$

Appropriate pH conditions are important because they influence fish metabolism, nutrient availability, and the toxicity level of certain compounds in water. Stable pH conditions also contribute to maintaining overall pond ecosystem balance and improving aquaculture productivity.

3.2.4 Salinity

Salinity levels in the freshwater ponds were measured at below 2 ppt, which is categorized as highly suitable for freshwater tilapia cultivation. Although tilapia possesses a relatively high tolerance to salinity fluctuations, freshwater conditions remain the most favorable environment for optimal growth and reproduction. Low salinity conditions help

maintain osmotic balance and reduce physiological stress in fish. Therefore, the salinity conditions in Tanjung Alam support sustainable freshwater tilapia farming activities.

3.3 Land Suitability Assessment

The land suitability assessment was conducted using a scoring and weighting method that integrated physical, chemical, and accessibility parameters.

Table 2. The suitability classification results

Parameter	Observed Value	Suitability Class
Temperature	27–30°C	S1
Dissolved Oxygen	5.1–7.2 mg/L	S1
pH	6.8–7.8	S1
Water Depth	80–150 cm	S2
Salinity	<2 ppt	S1
Accessibility	Good	S2
Infrastructure	Moderate	S2

Based on the assessment results, most areas in Tanjung Alam were categorized as highly suitable (S1) and moderately suitable (S2) for tilapia cultivation. Environmental conditions, particularly water quality parameters, strongly support aquaculture development. However, several supporting factors, such as infrastructure and transportation accessibility, still require improvement to maximize aquaculture productivity and distribution efficiency.

3.4 GIS-Based Spatial Analysis

The GIS-based spatial analysis demonstrated that suitable aquaculture zones were predominantly distributed near freshwater sources and transportation access routes. Overlay analysis integrating water quality, topography, accessibility, and supporting infrastructure indicated that approximately 70% of the research area could potentially be utilized for tilapia aquaculture development.

The application of Geographic Information System (GIS) technology significantly improved the accuracy and effectiveness of land suitability evaluation because spatial data could be integrated and visualized comprehensively. GIS analysis also facilitates the identification of priority aquaculture development zones while minimizing environmental conflicts and land-use competition. The findings support the study conducted by Chentouf et al. (2023), which emphasized that GIS-based multi-criteria analysis is highly effective in supporting environmentally sustainable aquaculture planning and resource management.

3.5 Discussion

The results of this study indicate that Tanjung Alam Village possesses substantial environmental potential for sustainable tilapia aquaculture development. The observed water quality parameters, particularly temperature, dissolved oxygen, and pH, were within optimal ranges required for tilapia growth and productivity. These findings are consistent with previous studies emphasizing the importance of environmental suitability in aquaculture development. Garza-Martinez et al. (2022) reported that appropriate environmental conditions significantly improve tilapia production efficiency and aquaculture sustainability. Similarly, Emilyasari et al. (2023) explained that proper environmental management positively influences tilapia farming profitability and production stability. The land suitability classification results indicate that the environmental carrying capacity of Tanjung Alam remains supportive of aquaculture expansion. Nevertheless, several limitations were identified, including limited infrastructure development, traditional cultivation techniques, and inadequate transportation facilities in some aquaculture zones.

Accessibility conditions in the research area were categorized as moderately suitable. Although the village is connected by transportation networks, certain aquaculture locations still experience accessibility challenges during periods of heavy rainfall. Consequently, infrastructure improvement programs are necessary to support fish distribution, market access, and overall aquaculture efficiency. From an ecological perspective, sustainable aquaculture development requires proper environmental management to prevent water pollution and ecosystem degradation. Excessive feed application, poor waste management, and uncontrolled pond expansion may negatively affect water quality and environmental sustainability. Therefore, environmentally friendly aquaculture practices, including efficient feed management and regular water quality monitoring, should be promoted among fish farmers. The implementation of GIS-based land suitability analysis in this study provides important advantages for fisheries planning and decision-making processes. Spatial analysis enables policymakers and fisheries managers to identify suitable aquaculture development areas while minimizing environmental risks and spatial conflicts. Tarunamulia and Sammut (2023) emphasized that GIS and fuzzy set analysis are highly effective approaches for identifying environmentally sustainable aquaculture zones.

Socio-economic conditions in Tanjung Alam also support aquaculture development. Most respondents expressed positive perceptions regarding tilapia farming expansion because it provides additional employment opportunities and contributes to household income improvement. Tilapia cultivation is considered economically promising due to stable market demand, relatively simple cultivation methods, and favorable growth performance. Despite the favorable environmental conditions, climate variability and environmental changes remain important challenges for aquaculture

sustainability. Variations in rainfall patterns, water availability, and temperature fluctuations may affect pond productivity and water quality stability. Therefore, adaptive aquaculture management strategies are required to ensure long-term sustainability and environmental resilience. Overall, this study contributes significantly to regional aquaculture planning and sustainable fisheries development in Asahan Regency. The research findings can serve as scientific references for policymakers, fisheries extension officers, investors, and local communities in determining appropriate and environmentally sustainable aquaculture development areas.

4. CONCLUSION

The results of this study indicate that Tanjung Alam Village in Asahan Regency possesses considerable potential for tilapia aquaculture development based on land suitability analysis. Environmental parameters such as temperature, dissolved oxygen, pH, salinity, and water availability generally meet the requirements for optimal tilapia cultivation. The suitability assessment classified most areas as highly suitable (S1) and moderately suitable (S2), indicating that the region can support sustainable freshwater aquaculture activities. GIS-based spatial analysis further demonstrated that suitable cultivation zones are widely distributed near freshwater sources and accessible transportation routes. Although several limitations remain, particularly regarding infrastructure and traditional management practices, the overall environmental conditions are supportive of aquaculture expansion. Sustainable fisheries management strategies, including environmentally friendly cultivation practices and infrastructure improvements, are necessary to ensure long-term productivity and ecological sustainability. This research provides important scientific information for regional aquaculture planning and contributes to sustainable fisheries development policies in Asahan Regency.

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