

MAPPING AND ANALYSIS OF AQUACULTURE POND CONDITIONS IN BANDA ACEH CITY USING SATELLITE IMAGERY AND GIS

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Abstract: Banda Aceh City has significant potential for pond development as an economic source for coastal communities. However, various factors such as environmental damage, social conflicts, the 2004 tsunami disaster and disease outbreak have significantly impacted pond area and productivity. This study aims to map and analyze pond conditions in Banda Aceh City including cultivation systems and biota types. The method used is descriptive analysis with a quantitative approach through satellite imagery interpretation (Landsat 8/OLI, Google Earth) and ground verification with 40 pond farmers. Results showed that extensive systems dominated active ponds in Banda Aceh with a total active area of 7.78 hectares, comprising extensive systems (4.25 ha), semi-intensive systems (2.57 ha), and intensive systems (0.96 ha). Main commodities cultivated include Vannamei shrimp, milkfish and tiger shrimp, with extensive systems predominating across all biota types. Major constraints include disease risk management, limited capital, risk aversions attitude and limited technical knowledge. This study recommends increasing technical assistance, strengthening access to capital, and developing programs to reactivate unused pond infrastructure for sustainable management and market development for the products.

Keywords: aquaculture mapping; GIS; remote sensing; Banda Aceh; sustainable fisheries; active ponds

1. Introduction

Aquaculture ponds represent one of the primary livelihood sources for coastal communities in Indonesia, particularly in Aceh Province. The coastal areas of Banda Aceh City possess significant potential for development as pond cultivation areas due to increasing public consumption of fish and other pond products. The fisheries sector is one of the government's targets in efforts to increase non-oil and gas exports, provide employment opportunities, generate foreign exchange, and serve as a source of food nutrition [1].

The development of aquaculture systems globally has shown varying patterns influenced by technological adoption, environmental conditions, and socio-economic factors. Recent studies have emphasized the importance of spatial analysis in aquaculture planning and management. Geographic Information Systems (GIS) and remote sensing technologies have proven effective for monitoring aquaculture development patterns, assessing environmental impacts, and supporting sustainable planning decisions [2]. The extraction of coastal aquaculture ponds from remote sensing images has been advanced through deep learning models, though challenges remain due to spectral similarities between different land cover types [3].

Various failures affecting pond farmers are suspected to originate from environmental damage to ponds. This situation was also exacerbated by Aceh's security conditions that were not conducive during the conflict with Indonesia, causing increasingly abandoned land. The final blow to brackish water fisheries in Aceh was the occurrence of the tsunami disaster in 2004, which damaged approximately 20 thousand hectares of pond land in Aceh along with the mangrove ecosystem that supports brackish water cultivation.

Global aquaculture production has shown significant growth, with Asia accounting for 89.12% of global land-side aquaculture [4]. In shrimp production specifically, Asia accounts for 83.4% of production, with Pacific white shrimp (*Litopenaeus vannamei*) representing 83% of global shrimp production [5]. However, production patterns vary significantly based on local conditions, technology adoption, and market access.

This research addresses the critical knowledge gap regarding current aquaculture conditions in Banda Aceh following decades of recovery efforts. The study contributes to understanding the persistence of traditional farming systems and provides insights for sustainable aquaculture development in post-disaster coastal regions.

2. Literature Review

2.1 Aquaculture Pond Systems

Ponds represent one type of artificial habitat created by humans located in coastal areas and used as a place for brackish water activities. A pond is an artificial human-made ecosystem consisting of land near the coast that is dammed with surrounding embankments to form a brackish water pool. According to previous studies, ponds are water bodies formed naturally or artificially, ranging in size from 1 m² to 2 ha, and are permanent or seasonal in nature.

Contemporary aquaculture systems are typically classified based on management intensity, technological input, and production levels. Remote sensing and GIS technologies have been increasingly used to guide the selection of suitable areas for aquaculture or conversely, mapping the pond area [6].

2.2 Cultivation System Types

a. Extensive (Traditional) Systems

Extensive aquaculture systems are characterized by their reliance on natural productivity with minimal external inputs, utilizing natural food sources within the culture unit where additional feed inputs are not added intentionally [7]. Extensive shrimp ponds are typically built in tidal areas of seawater and mangrove areas. The shape of extensive pond plots is generally irregular with an area of 1 plot between 3-10 ha/plot. Around the pond plots, there are water trenches called 'caren' with a depth of 30-50 cm and a width of 5-10 m. The caren surrounds a platform with a depth of 30-40 cm. In the center of the pond plot, there is a small plot for fry.

According to systematic literature review, extensive systems are defined as those that always supply the output function of 'harvesting' and have at least one of the input functions, with no treatment functions applied [7]. The advantages of traditional ponds include environmental friendliness, allowing extensive shrimp cultivation systems to be conducted sustainably. However, extensive pond systems have the weakness of non-optimal productivity due to low stocking density. The most common biota kept in this system are milkfish (*Chanos chanos*) and tiger shrimp (*Penaeus monodon*), which is an indigenous Indonesian shrimp. However, tiger shrimp cultivation faces challenges from disease outbreaks.

b. Semi-intensive Systems

Semi-intensive ponds are an improvement over extensive (traditional) cultivation systems. Semi-intensive pond cultivation systems use regular plot shapes, generally rectangular, with an area of 1-3 ha per plot.

Research indicates that semi-intensive systems mainly rely on natural food sources but are also supported by supplementary feed or fertilization, where feeding is carried out at least twice per week and fertilizing once per week [8]. Water exchange is widely used in semi-intensive systems to improve water quality, as well as chemicals such as lime can be added to disinfect and dry semi-intensive ponds. The common biota in this system are milkfish (*Chanos chanos*), tiger shrimp, and Vannamei shrimp (*Litopenaeus vannamei*).

c. Intensive Systems

Intensive cultivation generally uses smaller plots, ranging from 0.2-0.5 ha per plot, aimed at facilitating control and water management. Maintenance pond plots can be made entirely of soil or soil with HDPE tarpaulin cover and it equipped with drainage channels in the center. The pond bottom is made of hard gravel layers, and there are pools for water treatment before being introduced into pond plots.

Intensive ponds have permanent drainage pipes useful for disposing of waste carried during rain and wind, usually located in pond corners. Heavy feeding significantly impacts water quality due to feed settling at the bottom; therefore, siphoning is necessary. Modern intensive systems face challenges in achieving high productivity while maintaining environmental sustainability[9]. The biota in this system is predominantly Vannamei shrimp, which has advantages including rapid growth and disease resistant.

3. Method

3.1 Time and Location

This research was conducted over approximately 2 years from 2022, to April 2024. The research location was in the coastal areas of Banda Aceh City, Aceh Province, covering 4 sub-districts: Syiah Kuala, Kuta Alam, Kuta Raja, and Meuraxa.

3.2 Tools and Materials

Tools used in this research included Landsat 8/OLI satellite imagery, high-resolution imagery from Google Satellite, GIS software including QGIS 3.14, computers, notebooks, pens, and GPS for location determination.

3.3 Data Collection Methods

The method used in this research was descriptive analysis with a quantitative approach through direct observation of active pond conditions using satellite imagery and GIS. This research also conducted structured interviews with 45 pond farmers to determine cultivation activity parameters that could not be obtained through geographic information systems.

Active ponds were identified based on the following criteria: (1) presence of water in satellite imagery, (2) visible infrastructure maintenance, (3) confirmation of ongoing cultivation activities through farmer interviews, and (4) evidence of recent harvesting or stocking activities.

3.4 Data Types and Sources

Primary data was obtained through direct field interviews with 45 pond farmers selected through purposive sampling. Secondary data consisted of satellite imagery obtained from USGS and Google Earth, including general conditions of the research area and data related to research objectives.

3.5 Data Analysis

Data was analyzed using descriptive statistical methods and spatial analysis techniques. Ground-truthing was conducted to validate satellite imagery interpretation, with a validation accuracy of 87% achieved through field verification.

4. Finding and Discussion

4.1 Pond System Condition Identification in Banda Aceh

Based on the economic system identification data in Table 2 below, it is known that pond systems in Banda Aceh area include extensive, semi-intensive, and intensive systems.

Table 1. Active pond area identification

System Area (hectares)	Extensive	Semi-intensive	Intensive	Total
Area	4,25	2,57	0,96	7,78

Based on the analysis above, extensive systems dominate active fish ponds in Banda Aceh city with an area of 4.25 hectares (54.6%), followed by semi-intensive systems at 2.57 hectares (33.0%), and intensive systems at 0.96 hectares (12.3%). The total area of active fish ponds in Banda Aceh is 7.78 hectares, representing approximately 0.13% of the total city area.

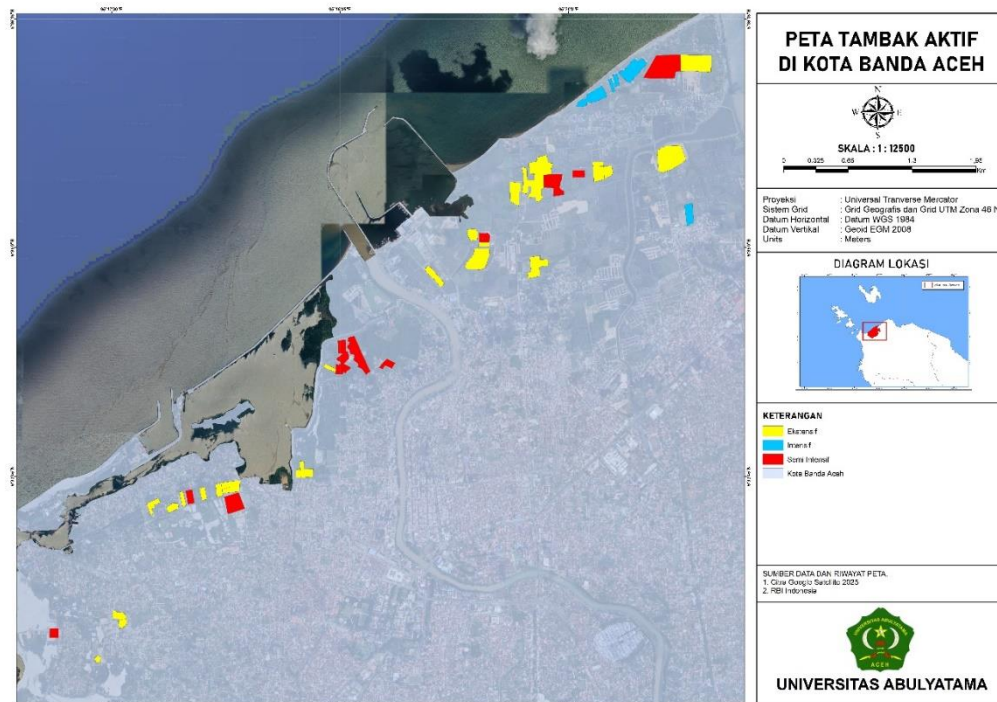


Figure 1. Map of pond systems in Banda Aceh City

According to the data from field observation, the most common biota kept by extensive farmers is tiger shrimp and the most common in semi-intensive systems is vannamei shrimp. The only biota kept using intensive system is Vannamei shrimp. Detail can be seen in table 2.

Table 2. Pond system condition identification

Biota	System (%)		
	Extensive	Intensive	Semi-intensive
Vannamei shrimp	65	17.5	17.5
Milkfish	86	-	14
Tiger shrimp	87.5	-	12.5
Other biota	62	-	38

The pond system most used by farmers for each cultivated biota is the extensive system, such as Vannamei shrimp at 65%, while intensive and semi-intensive systems for Vannamei shrimp both amount to 17.5%. This occurs because facilities and infrastructure used in intensive and semi-intensive systems are more expensive than extensive systems, causing most pond farmers to maintain extensive cultivation systems. Moreover, extensive systems offer multiple advantages including lower disease risk, reduced capital requirements, and environmental sustainability. Research shows that 70% of active ponds in Banda Aceh are owned by local residents obtained through inheritance, contributing to the preservation of traditional farming methods passed down through generations.

Table 3. Social identification of pond ownership (%)

Biota	System	Ownership		
		Private	Usage Rights	Rent
Vannamei	Extensive	61	4	35
	Semi-intensive	28	36	36
	Intensive	100	0	0
Milkfish	Extensive	61	6	33
	Semi-intensive	67	0	33
Tiger shrimp	Extensive	72	14	14
	Semi-intensive	100	0	0
Other biota	Extensive	63	12	25
	Semi-intensive	20	0	77

The ownership analysis reveals important insights into system adoption patterns. Private ownership predominates in intensive systems (100%), reflecting the higher capital investment and long-term commitment required. In contrast, extensive systems show more diverse ownership arrangements, with significant rental and usage rights components (35-38% combined), making aquaculture more accessible to farmers with limited capital. This pattern aligns with findings that productive capital constraints hold back small farmers from adoption of intensive systems, while smallholder cultivation predominates in Indonesian agriculture, accounting for about 87% of total cultivation [10,11]. The flexibility in ownership arrangements for extensive systems serves as an important entry point for new farmers and supports the sector's inclusivity.

4.2 Extensive System Dominance

The research findings reveal a concerning trend the dominance traditional aquaculture methods and declining intensive system adoption in Banda Aceh. This pattern contrasts with global aquaculture development trends but reflects specific local conditions and constraints.

There are several factors that causes this trend. Firstly, limited capital prevents farmers to modernize their ponds. The high initial investment required for intensive systems remains prohibitive for most local farmers. Traditional extensive systems require minimal external inputs, making them more accessible to resource-limited communities.

Secondly, the risk-aversion attitude of farmers post-tsunami recovery and the disease outbreak of shrimp disease. White Spot Syndrome Virus (WSSV) first occurred in Indonesia in 1994 and later spread to South Aceh [12], causing significant economic losses to shrimp farmers. Intensive farming systems with high stocking densities are more susceptible to rapid

disease transmission and higher mortality rates during outbreaks [13]. approximately 60% of disease losses in shrimp aquaculture have been caused by viral pathogens [14]. Major viral diseases affecting shrimp in Indonesia include White Spot Syndrome Virus (WSSV) and Acute Hepatopancreatic Necrosis Disease (AHPND), which have become major threats to *Litopenaeus vannamei* cultivation [15]. These diseases have contributed to farmers' preference for extensive systems as a risk management strategy and cause many shrimp ponds in Banda Aceh inoperative.

Thirdly, technical knowledge. Limited access to technical training and extension services constrains farmers' ability to adopt and manage intensive systems effectively. Lastly, limited infrastructure, electricity supply, poor road networks, and inadequate cold chain facilities constrain the viability of intensive systems.

This traditionalization trend has significant implications for sector development. While traditional systems provide important livelihood support, maintain cultural practices and safer from disease, they may limit the sector's ability to respond to growing market demands and compete in regional markets.

5. Conclusion and Recommendations

5.1 Conclusions

1. Active pond cultivation in Banda Aceh City covers 7.78 hectares, with extensive systems predominating (4.25 ha, 54.6%), followed by semi-intensive (2.57 ha, 33.0%) and intensive systems (0.96 ha, 12.3%).
2. Biota types cultivated by pond farmers include vannamei shrimp (49%), milkfish (26%), tiger shrimp (10%), and other biota (15%) including tilapia, snapper, catfish, white shrimp, and crabs.
3. The persistence of extensive systems reflects local constraints including, limited capital access, risk aversion, and inadequate technical support. Traditional extensive systems provide natural advantages for disease prevention, particularly against viral diseases such as WSSV
4. A significant portion of pond infrastructure remains inactive, representing untapped potential for sector expansion.

5.2 Recommendations

1. Strengthen Extension Services: Provide comprehensive technical assistance and training programs focused on disease prevention and management while improving system productivity.
2. Disease-Resistant Intensification: Develop intensification programs that incorporate disease management protocols and maintain the disease resistance advantages of traditional systems.
3. Improve Access to Capital: Develop targeted financing schemes that include disease insurance and risk management components for pond farmers.
4. Infrastructure Reactivation Program: Implement systematic surveys and rehabilitation programs for unused pond infrastructure with emphasis on disease prevention measures.
5. Market Development: Strengthen value chains and market linkages to provide economic incentives for sustainable intensification.

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