

# Coastal ecosystem carrying capacity and shrimp farming in Padang Pariaman, West Sumatra, Indonesia

<sup>1,2</sup>Adnal Yeka, <sup>1</sup>Eri Barlian, <sup>3</sup>Eni Kamal, <sup>4</sup>Deni Sarianto, <sup>5</sup>Amelia S. Lubis

<sup>1</sup> Doctoral Program of Environmental Science, Negeri Padang University, Indonesia;  
<sup>2</sup> Polytechnic AUP, Jakarta, Indonesia; <sup>3</sup> Marine, Coastal and Aquatic Resources, Bung Hatta University, Indonesia; <sup>4</sup> Polytechnic of Marine and Fisheries, Dumai, Indonesia;  
<sup>5</sup> Aquaculture Department, Bung Hatta University, Padang, West Sumatra, Indonesia.  
Corresponding author: E. Kamal, ekamal898@bunghatta.ac.id

**Abstract.** The Padang Pariaman Regency, located in West Sumatra Province, is one of the areas experiencing the phenomenon of changes in forest function. This research aimed to analyze the effects of shrimp farming activities on the carrying capacity of coastal areas in West Sumatra, Indonesia. The data processed is land cover data obtained through a visual interpretation process on SPOT 6/7 images for the 2017-2021 period. The results of the analysis of Landsat data in 2017-2018 show that plantation areas still dominate the Padang-Pariaman area with a surface of 36,444 ha or the equivalent of 50.54% of the area. Shrimp farming activities in Padang Pariaman Regency have a significant impact on the environment, especially in terms of organic waste disposal and land cover changes. Intensive and semi-intensive shrimp farming systems contribute greatly to the total dissolved solids discharged into coastal waters, which have the potential to cause eutrophication, decreased water quality, and disruption to marine biodiversity. Land cover changes that occur, especially the conversion of beach sand into shrimp ponds, also raise ecological concerns. Therefore, proper waste management and sustainable land use planning need to be implemented to maintain the balance of coastal ecosystems. In addition, reforestation that occurs in some areas shows a positive step in environmental conservation. Overall, integrated and sustainable coastal management is needed to support the sustainability of shrimp farming and nature conservation in this area.

**Key Words:** shrimp farming, land cover, organic waste, carrying capacity, Landsat.

**Introduction.** Indonesia is presently engaging in extensive economic advancement, particularly in the exploitation of coastal resources (Damastuti & Groot 2017). To effectively plan and manage the utilization of such resources for economic progress, it is imperative to prioritize sustainable methodologies that augment the resource base while concurrently avoiding any detrimental environmental repercussions that may arise during the coastal economic development process (Raynaldo et al 2020; Mukhtar et al 2021). The absence of effective planning for the management of coastal environments can have detrimental consequences that extend over a prolonged period, culminating in severe ecological harm, necessitating extensive time and financial resources for restoration (Putra et al 2023). Hence, it becomes imperative to adopt comprehensive strategies for the preservation and protection of coastal ecosystems, to avert both tangible and intangible detriments, including the perils of environmental contamination (Garcia & Fonseca 2018; Wu & Yang 2018).

Regional growth has resulted in negative environmental repercussions on Sumatra's west coast, with the Padang Pariaman area in West Sumatra being particularly affected. This is explained by the district's function as a barrier that protects against waves coming from the ocean. One of the main causes of the area's changing land cover is unchecked urbanization (Seto et al 2012; Long et al 2014). Changes in land cover can affect landscape structure and the ecology of the area (Gonzalez et al 2012; Agustian et al 2019). Findings from land cover change analysis provide essential input for spatial planning aimed at achieving optimal land utilization while minimizing ecological

degradation. The Padang Pariaman area of West Sumatra is one of the regions undergoing significant forest function changes, including reduction in forest cover and alteration of land use for aquaculture and settlements. To mitigate the adverse impacts of such unplanned land use changes, it is important to conduct spatial analyses and land cover monitoring to inform more sustainable coastal planning strategies (Grêt-Regamey et al 2017).

Coastal water quality plays an important role in supporting ecosystems and the sustainability of fisheries activities, including shrimp farming. Research conducted by Kamal et al (2023) found significant fluctuations in physicochemical parameters such as temperature, salinity, dissolved oxygen levels, and nutrient concentrations such as nitrate and phosphate. Several locations experienced increased organic matter content and eutrophication, which can be associated with anthropogenic activities such as agriculture, industry, and domestic waste. The coastal water quality of Padang Pariaman is influenced by various external factors, thus requiring a more effective management strategy to maintain ecosystem balance. As an area with high aquaculture potential, especially for shrimp ponds, Padang Pariaman faces challenges in managing waste from aquaculture in order to preserve water conditions. Organic waste that is not properly managed can potentially accelerate the eutrophication process, which in turn may affect the ecological balance of coastal ecosystems, as indicated in previous studies (e.g., Aimé et al 2018; Dauda et al 2018). Research by Kamal et al (2023), conducted in the same coastal area of Padang Pariaman, reported elevated concentrations of nitrate, phosphate, and organic matter in several sampling points, indicating ongoing eutrophication processes. These conditions reflect a decline in water quality and suggest that excessive organic input from anthropogenic activities, including aquaculture, may reduce the environmental carrying capacity of the coastal ecosystem.

Padang Pariaman Regency, situated in West Sumatra Province, stands as a susceptible area to the repercussions of regional development, primarily due to its role as a buffer zone. The demand for cultivation space, unattainable in other districts, has led to Padang Pariaman Regency being designated for shrimp cultivation (Putra et al 2023). While fulfilling the need for cultivation space is essential, it must be done judiciously to minimize adverse environmental effects. According to the 2021 records from the Central Bureau of Statistics, the growth of shrimp ponds in Padang Pariaman Regency is projected to be 0.1% annually. This surge in ponds has increased their number, accompanied by a reduction in areas proportionate to the coast and mangrove forests. Over five years, a significant rise of 222 hectares in built-up land has been observed in Padang Pariaman Regency (Schulp et al 2014; Putra et al 2023).

Land cover changes in Padang Pariaman Regency are largely driven by discrepancies of more than 25% between the officially planned spatial layout and actual land use, indicating weak enforcement of spatial planning policies (Putra et al 2023). Changes occurred in the function of the coastal forest area of Padang Pariaman Regency, which should cover 40% of the total area, but currently it comprises many shrimp open pond areas that cause uncontrolled environmental degradation. Environmental issues are a result of immature land management practices. Failure to regulate changes in land cover results in a more than 25% discrepancy between planned spatial patterns and actual land cover (Song et al 2016; Fadhillah et al 2019). A portion of Padang Pariaman Regency's 30.5% non-oil palm plantation area has been converted into a shrimp pond. This demonstrates how the state of the plantations in the Regency of Padang Pariaman is concerning and frequently dire. This research aimed to assess the environmental impacts of shrimp farming on coastal ecosystems in Padang Pariaman, West Sumatra, Indonesia, through land cover change analysis and water quality indicators relevant to coastal carrying capacity.

## **Material and Method**

***Research timing and location.*** This research was conducted from January to July 2023 in the coastal area of Padang Pariaman, West Sumatra. Water sampling was carried out at six stations strategically selected to represent different types of land use and land

cover changes across the region. Station I represents offshore seawater conditions; Station II is located in coastal waters near areas with high land use conversion; Station III is located in shrimp pond water; Station IV is in river water affected by upstream land use; Station V represents estuarine water; and Station VI is located at the outlet of pond effluents entering coastal waters (Figure 1). The location of each station was chosen based on satellite-derived land cover data (2017–2021), which showed significant vegetation loss and conversion into shrimp ponds and settlements in certain areas. Stations II and VI, in particular, are situated near zones of intensive and semi-intensive aquaculture development where previous vegetation cover (e.g., plantation or beach sand) has been reduced. These spatial arrangements enabled the assessment of how land cover changes influence nutrient concentrations in the adjacent waters.

**Research methodology.** The research employed a mixed-methods approach combining exploratory and descriptive research with spatial analysis and environmental impact assessment. The theoretical framework used is based on the concept of environmental carrying capacity, which emphasizes the balance between anthropogenic pressures (e.g., shrimp farming) and the ecological thresholds of coastal systems. This framework guided both the interpretation of land cover dynamics and the analysis of nutrient loading in relation to aquaculture development. Two types of data were used in this study: (1) basic data, in the form of the Indonesian Earth Map (scale 1:50,000; year 2017), which served as a reference for land cover classification; and (2) processed data, obtained through visual interpretation of SPOT 6/7 satellite imagery for the years 2017 to 2021. These images, with a spatial resolution of 1.5 m panchromatic and 6 m multispectral, were selected due to their compatibility with medium-scale coastal land use analysis, as supported by Fallati et al (2017). While the spatial resolution of SPOT 6/7 may not capture micro-scale annual changes at the level of each sampling station, it remains sufficient to detect broader patterns of land conversion, such as the expansion of shrimp ponds or loss of vegetative cover, that correlate spatially with water sampling locations. To address limitations in spatial precision, field verification and cross-referencing with administrative and field survey data were conducted to enhance the interpretation accuracy (Fallati et al 2017).

**Data collection.** This research carried out two stages in the data collection. The first stage was calculating shrimp cultivation waste and the next stage was identifying land cover in coastal areas.

**Shrimp farming waste.** Calculating shrimp farming waste is done by measuring organic waste from shrimp ponds and waste around the coast. Measuring organic waste is done by calculating the weight of feed, waste and Total Suspended Solid (TSS). Organic waste in the form of total solid suspension from the results of shrimp cultivation activities is determined using the following calculation formulae (Sfez et al 2015):

$$C_{an} = \frac{(L \times P_1) \times 1000}{V_{tb}} \quad \text{and} \quad C_{n-1} = \frac{(C_{b(n-1)} \times V_{tb}) + (L \times P_{(n-1)}) \times 1000}{V_{tb}} \quad \text{and} \quad C_1 = \sum (Q\% \times C_{a(n-1)})$$

Where:

$C_{an}$  - concentration of pond waste on day n ( $\text{mg L}^{-1}$ );

$C_1$  - total concentration of waste discharged to the coastal area ( $\text{mg L}^{-1}$ );

$Q\%$  - percentage of water exchange (%);

$C_{b(n-1)}$  - concentration of waste discharged on the previous day ( $\text{mg L}^{-1}$ );

$V_{tb}$  - volume of the pond (L);

$P$  - amount of feed given ( $\text{g day}^{-1}$ );

$L$  - proportion of total feed that becomes waste (dimensionless);

$N$  - production day (1, 2, ..., n).

Land cover is considered as the carrying capacity of coastal areas. The data processing involves a fundamental geometric approach, ensuring the persistent integrity of the outer boundaries and research area dimensions that have been consistent over multiple years. Visual interpretation, conducted at a scale of 1:25,000, entails digitizing alterations in land cover from the baseline data, utilizing the most recent imagery. The foundational dataset is referred to as the 2017 land cover map, while the processed data comprises land cover information for the years 2018, 2019, 2020, and 2021. Following the completion of the geometry laboratory activity, a verification process will be initiated in the field. This verification involves employing the purposive sampling method to assess the accuracy of the maps.

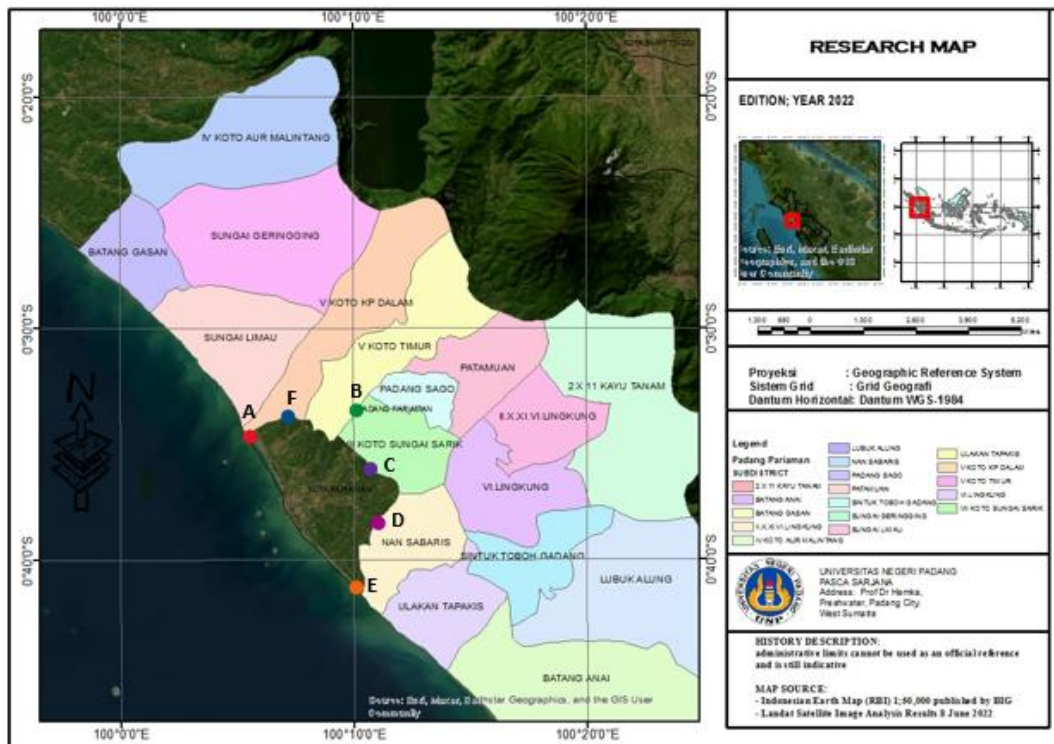


Figure 1. Location of research implementation.

**Data analysis.** Shrimp cultivation waste analysis data was analyzed descriptively using figures and tables. Meanwhile, coastal area land cover data is analyzed descriptively using a map display. The four main elements in the process of re-interpreting land facets consist of morphology, morphogenesis, morpho-chronology, and morpho-arrangement. Morphology was identified based on slope and shape data using DEMNAS data with a resolution of 8 meters. The genesis of land units seen from surface material processes is related to the land formation process. Morpho-chronology was analyzed based on the sequence of objects on the earth's surface using a combination of SPOT and DEMNAS imagery. The final stage of land facet analysis is the morpho-arrangement, which explains the relationship between one landform and another (Li et al 2018; Bhuiyan et al 2020). To quantify this relationship, a Spearman correlation analysis was conducted between vegetation cover class and water quality parameters (TSS,  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ ,  $\text{NH}_3$ ,  $\text{NO}_2^-$ ) across the six stations.

**Results.** The results of monitoring shrimp farming activities in Padang Pariaman Regency during one planting season/production cycle based on the level of cultivation technology (Intensive and semi-intensive). In detail, the characteristics of Vaname shrimp cultivation based on the level of technology applied in Padang Pariaman Regency can be seen in Table 1 below.

Table 1

Characteristics of tiger prawn cultivation based on technology level in Padang Pariaman Regency

<i>Parameters</i>	<i>Cultivation technology</i>	
	<i>Intensive</i>	<i>Semi intensive</i>
Plot area (m <sup>2</sup> )	3,000	3,000
Stock density (tail m <sup>-2</sup> )	150	100
Number of stockings	450,000	300,000
Maintenance period (days)	90	90
Survival (%)	90	90
Number of shrimps surviving	405,000	270,000
Amount of feed (kg)	17,280	12,600
Average weight per tail (g)	33.33	33.33
Production biomass (kg)	13,500	9,000
Feed conversion ratio	1.28	1.4
Pond water change (month)	5% (1), 10% (2), 10% (3) and 15% (4)	3% (1), 5% (2), 10%(3) and 15% (4)

Shrimp farming activities carried out intensively and semi-intensively in coastal areas can produce waste in the form of TSS, which contributes to the decline in water quality. Increased TSS concentrations in water can affect transparency, reduce dissolved oxygen levels, and disrupt the lives of other aquatic organisms. Figure 2 shows the relationship between maintenance time and TSS concentration mg L<sup>-1</sup> in coastal waters due to waste discharge from intensive and semi-intensive shrimp ponds in the coastal area of Padang Pariaman Regency.

Table 2 presents the simulated waste load and environmental response for intensive and semi-intensive shrimp farming systems in Padang Pariaman. The intensive system produced a higher feed input (17,280 kg) compared to the semi-intensive system (12,600 kg), resulting in a greater estimated waste load of 4,320 kg versus 3,150 kg, respectively, assuming 25% of feed becomes waste. The TSS concentration reached 283.3 mg L<sup>-1</sup> under intensive conditions and 241.3 mg L<sup>-1</sup> under semi-intensive conditions.

Table 2

Simulated waste load and environmental carrying capacity under intensive and semi-intensive shrimp farming

<i>Scenario</i>	<i>Feed input (kg)</i>	<i>Estimated waste (kg; 25% of the input)</i>	<i>TSS (ppm)</i>	<i>Ammonia (ppm)</i>	<i>Status vs. Carrying capacity</i>
Intensive	17,280	4,320	283.3	0.404	Exceeds
Semi-intensive	12,600	3,150	241.3	0.136	Within limit

Similarly, ammonia (NH<sub>3</sub>) levels were higher in the intensive ponds (0.404 mg L<sup>-1</sup>) than in semi-intensive ponds (0.136 mg L<sup>-1</sup>). These values were then compared with the estimated environmental carrying capacity limits for the coastal waters. The simulation indicated that intensive aquaculture practices tend to exceed the environmental thresholds, particularly in terms of organic matter and nutrient loads, while semi-intensive systems remain within acceptable limits. This suggests that the semi-intensive approach is more aligned with sustainable environmental management under current coastal conditions.

The load of organic waste in the form of TSS which is disposed of in coastal areas from the results of intensive shrimp cultivation activities with an area of 3,000 m<sup>2</sup> from the first day to the 90<sup>th</sup> day during one maintenance cycle is presented in Figure 2. The highest waste concentration between days 1-90 was 27.95 mg L<sup>-1</sup> which was found on day 90. If seen from the weight perspective, the highest waste discharged into coastal

waters between days 1-90 was 61 kg found on day 90. At the end of the rearing period (harvest), the shrimp ponds are dried by pouring the entire volume of pond water (3000 m<sup>3</sup>) into the waters. When flushing the pond waste concentration (TSS) was 23.85 mg L<sup>-1</sup>, and the total weight of waste discharged into coastal waters at the time of flushing was 95.4 kg TSS.

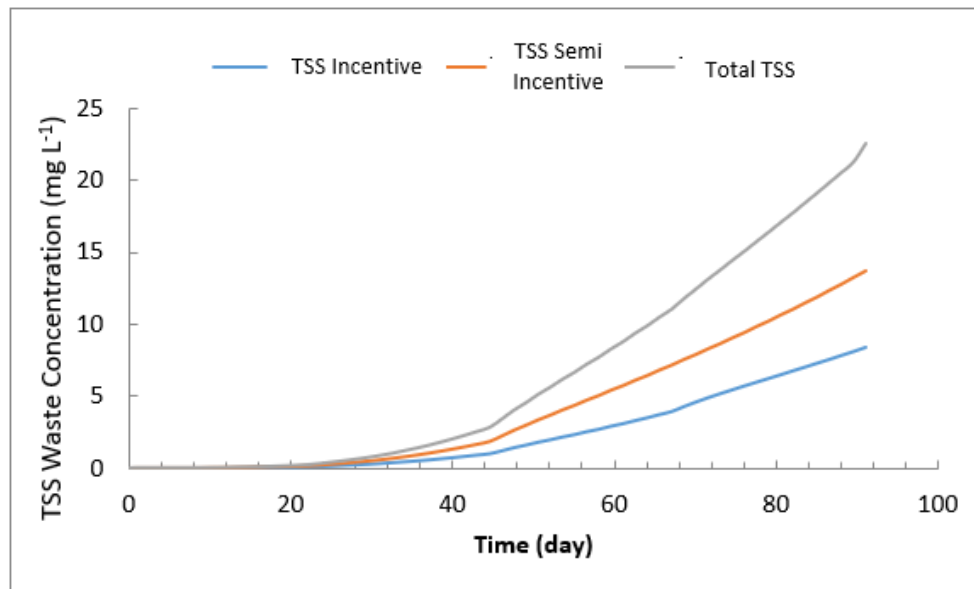


Figure 2. The relationship between maintenance time and TSS waste concentration (mg L<sup>-1</sup>) in coastal waters.

The total weight of waste generated during the maintenance period was estimated at 924.86 kg TSS ha<sup>-1</sup>. This includes both the solid waste produced inside the pond system and the portion that is eventually discharged into the coastal waters through water exchange. Based on the results in Figure 3, the estimated amount of waste discharged to coastal areas per hectare during one production cycle is 9,676 kg TSS ha<sup>-1</sup> for intensive ponds and 6,737 kg TSS ha<sup>-1</sup> for semi-intensive ponds. The variation in waste discharged is influenced by the level of technology and total pond area.

Figure 3 illustrates the Spearman correlation coefficients ( $\rho$ ) between vegetation cover and five key water quality parameters: total suspended solids (TSS), nitrate (NO<sub>3</sub><sup>-</sup>), phosphate (PO<sub>4</sub><sup>3-</sup>), ammonia (NH<sub>3</sub>), and nitrite (NO<sub>2</sub><sup>-</sup>). The strongest negative correlation was observed between vegetation cover and ammonia concentration ( $\rho = -0.88$ ), indicating that areas with lower vegetation cover tend to have significantly higher levels of ammonia. TSS also showed a strong negative correlation ( $\rho = -0.79$ ), suggesting a similar pattern where reduced vegetation corresponds with higher sediment load. Nitrate, phosphate, and nitrite showed weaker correlations ( $\rho < |0.5|$ ), and were not statistically significant.

Coastal water quality is greatly influenced by the content of nutrients such as nitrogen (N) and phosphorus (P), which come from various sources, including natural processes (in situ), non-cultivated areas, and fisheries cultivation activities (Figure 4).

In aquatic ecosystems, the presence of N and P in balanced amounts is very important to support primary productivity. However, if there is excessive accumulation due to cultivation waste and other anthropogenic activities, it can cause eutrophication which has a negative impact on the ecosystem, such as an explosion of phytoplankton populations and a decrease in dissolved oxygen levels. To understand the extent to which various sources contribute to the nutrient load in the coastal waters of Padang Pariaman Regency, an analysis of N and P concentrations was carried out based on the available water volume. Table 3 presents the results of calculating the total nitrogen and phosphorus loads from each source and their concentrations in the waters.

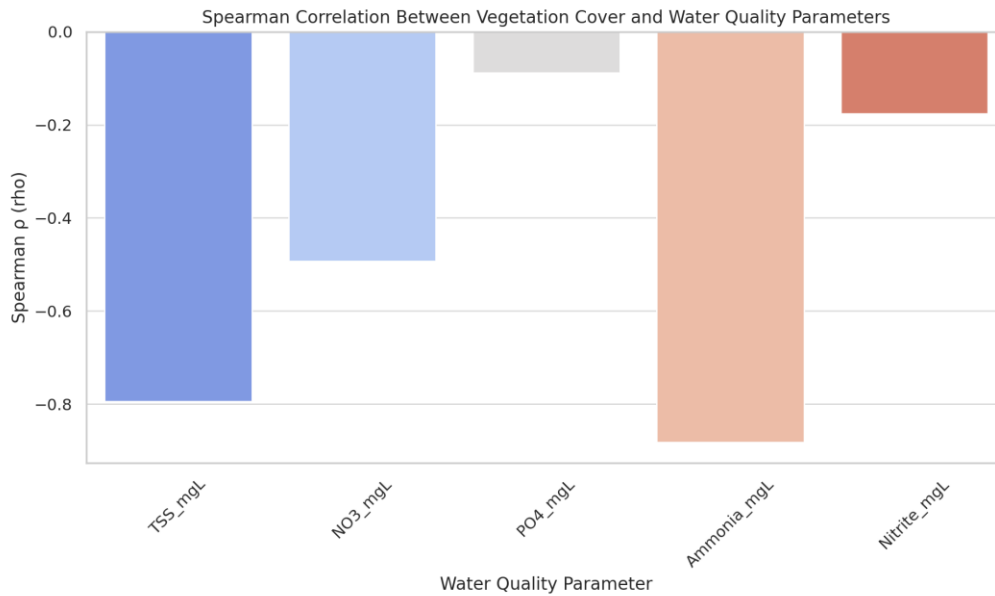


Figure 3. Spearman correlation between vegetation cover and water quality parameters in 6 sampling stations.

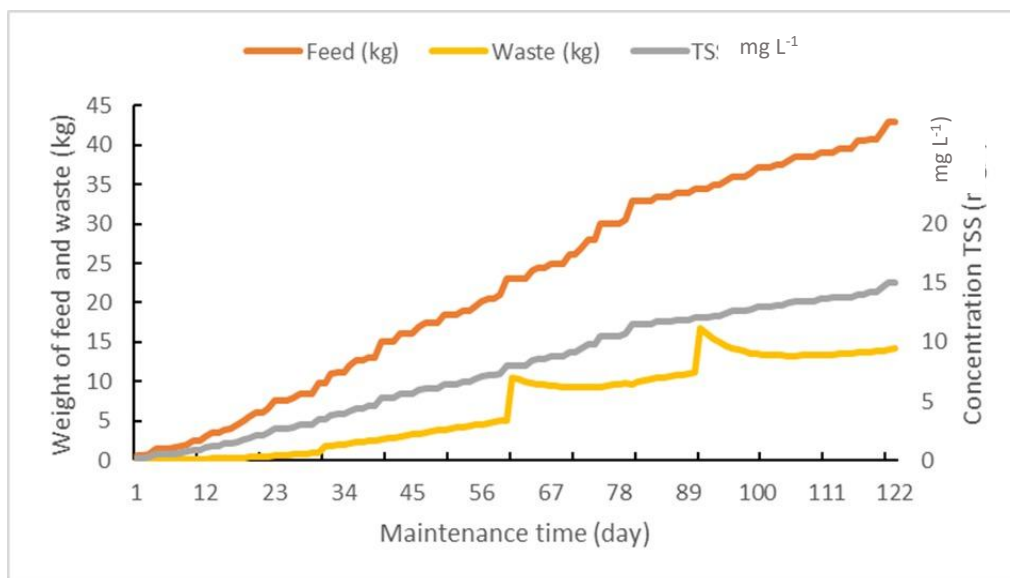


Figure 4. Feed dosage and waste produced for an intensive shrimp pond covering an area of 1,600 m<sup>2</sup> during one rearing cycle.

Table 3  
N and P concentrations in coastal waters of Padang Pariaman Regency under carrying capacity conditions

Parameter	In situ (ton)	Non-cultivated land runoff (tons)	Cultivation (tons)	Total (tons)	Coastal water volume (m <sup>3</sup> )*	Concentration (mg L <sup>-1</sup> )
(1)	(2)	(3)	(4)	(5=2+3+4)	(6)	(7=5/6x10 <sup>6</sup> )
N	19.52	14.03	3.40	36.95	50,936,256	0.72
P	6.60	1.11	0.58	8.29	50,936,256	0.16

\*Ministry of Marine Affairs and Fisheries (MMAF 2021) and bathymetric profiles derived from Landsat imagery (US Geological Survey 2022) and GEBCO Compilation Group (2021).

The land cover map resulting from visual interpretation has a total of 94.81% with a kappa index of 0.93. The interpretation results are high because they meet the minimum

accuracy requirements of >85% and a kappa value >0.8. The commission error was dominated by misclassification between moor and shrub. The same hue, texture, color, and size lead to misinterpretation. The presence of a bund in the image also indicates that the area is a dry moor, but when the field check was carried out the moor was no longer used and had become a shrub. The omission landscape is characterized by an abundance of gardens and forests. The omission error occurs because the existing plantation crops have the same physical appearance as forest plants so the boundaries between the two are blurred. The land cover map was redefined following the accuracy test to generate a higher-quality map.

Identifying trends in changes in land cover is one of the keys to maintaining the existence of natural ecosystems in an area. Padang Pariaman Regency has a unique land cover change trend because it is close to a coastal and tourist area. The results of the analysis of land cover data in 2017-2018 show that plantation areas still dominate the Padang Pariaman Regency area with an area of 36,444 ha or the equivalent of 50.54% of the area of Padang Pariaman Regency. Spatially, plantation areas are spread across the North, East and Southeast (Figure 5).

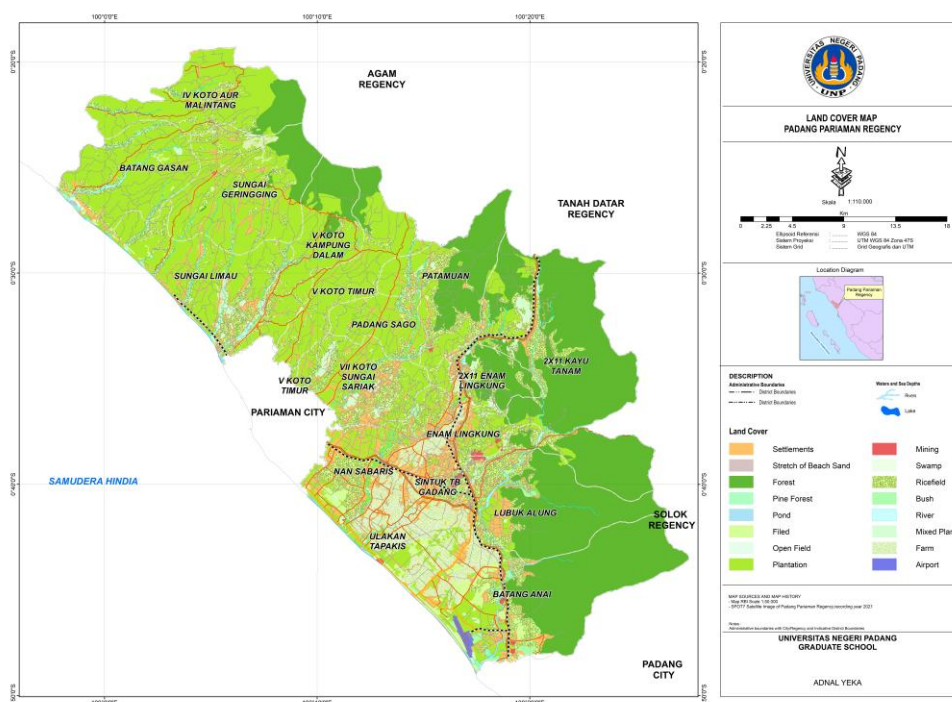


Figure 5. Land cover map in Padang Pariaman Regency.

Management of plantation areas in Padang Pariaman Regency is classified as good. Based on the land cover map (Figure 5) and comparative spatial analysis from 2017–2021, significant land use changes occurred in Lubuk Alung, Batang Anai, and Ulakan Tapakis sub-districts. These areas showed a shift from agricultural/open land to settlements and aquaculture zones. The existence of forests and rice fields does not have a specific pattern, but the two are associated in harmony. Interestingly, most of the rice fields in Padang Pariaman Regency are not carried out on land with flat relief. Even at several points, such as in Tandikek, Geringing River, Kayu Tanam and Kampung Dalam, rice fields are carried out on land that has undulating relief with a terraced conservation pattern. This phenomenon is caused by the existence of flat land in this area that is used for settlements. Settlements are still the most dominant land cover after forests, plantations and paddy fields in 2017-2021, with an area of 13,374,359.572 ha. The area of settlements has not changed significantly in 2017-2021. The plantation areas converted to pond areas are located to the north and south of Padang Pariaman Regency. The area has a typology of flat and sandy land, so it is suitable for development as a pond area with the condition that good conservation practices are observed.

Beach sand is the type of land cover that has changed its function the most in the 2017-2021 period. Administratively, the conversion of sand dunes was carried out in Batang Anai, Ulakan Tapakis, Nan Sabaris, Sungai Limau and Batang Gasan sub-districts. The largest conversion of stretches of sand into shrimp ponds occurred in Batang Anai and Sungai Limau Districts, reaching 28 ha. Conversion of fields into settlements in 2017-2021 did not occur. A field survey conducted in 2021 shows that the type of plantation that is mostly cultivated in the area is oil palm. The results of interviews with key informants stated that there had indeed been a conversion of fields into plantations under a leasing system by the company to the community but had reached its peak in 2017. Oil palm plantations from 2017 to 2021 did not experience an increase in area. The addition of oil palm plantations in Padang Pariaman did not occur because the areas previously available for oil palm plantation development have gradually decreased due to land conversion into settlements, shrimp ponds, and other non-plantation uses, rather than limitations caused by environmental or nutrient conditions. The partitions of land cover in Padang Pariaman Regency in 2021 can be seen in Table 3.

The moorland areas did not increase during the 2017-2021 period. During this period, moorlands were commonly found in sub-districts of Sungai Limau, IV Koto Aur Malintang, Padang Sago, V Koto Kampuang Dalam, 2 X 11 Kayu Tanam, V Koto Timur, Sungai Sariak, Patamuan, and six other areas. The conversion of originally vacant land into crop fields by the community was primarily driven by land use change and local agricultural needs, rather than by environmental factors such as nutrient levels in coastal waters. In general, forest area in 2017-2021 also decreased because it was converted into settlements, moors and plantations. Interestingly, there is a fairly large area to the east of Padang Pariaman that has been converted into forest. Based on interviews with key informants, the area was originally a plantation but due to the detrimental impact on the environment and community, it was switched back to a forest area.

Land cover changes during the 2017-2021 period was predominantly observed in the southern part of Padang Pariaman Regency, as shown in the land cover map (Figure 5). Sub-districts such as Lubuk Alung, Batang Anai, and Ulakan Tapakis experienced notable conversions of land cover, particularly from agricultural and open areas to built-up land uses. In the eastern region, significant changes were limited to Sungai Limau and Batang Gasan sub-districts. These observations are based on visual interpretation of land cover data and administrative overlays. While Table 4 shows minimal change in land cover percentages at the regency level, spatial interpretation reveals localized land use shifts in specific coastal sub-districts, especially Lubuk Alung, Batang Anai, and Ulakan Tapakis. These local changes are not visible in aggregated totals, highlighting the importance of spatial disaggregation for ecological interpretation. The most dominant change in land cover in Lubuk Alung Sub-District is from fields into offices and settlements. Padang Pariaman Regency is composed of four landforms, namely alluvial, Andosol, Latosol, and Mediterranean (Figure 6).

Although the aggregated land cover values show little variation from 2017 to 2021, this does not imply land use stability throughout the region. Localized changes, particularly in coastal zones, were detected through spatial interpretation of satellite imagery and field validation. However, the available data resolution did not allow for consistent indexing or statistical regression at the sub-district scale. Future studies with higher spatial and temporal resolution are required to test the hypothesis more rigorously. Although the aggregated land cover data from 2017 to 2021 (Table 4) indicate relatively stable proportions, spatially, there are localized land use changes in specific coastal sub-districts such as Batang Anai, Lubuk Alung, and Ulakan Tapakis. These areas experienced limited conversion from vegetated land to shrimp ponds and settlements. However, the changes in vegetative land cover do not spatially align with the locations of nutrient discharge or sampling stations. Thus, based on the available data, we cannot conclude a direct influence of shrimp waste on terrestrial vegetation dynamics. Instead, the most affected component is the aquatic ecosystem, as reflected by nutrient concentrations and suspended solids in the water column.

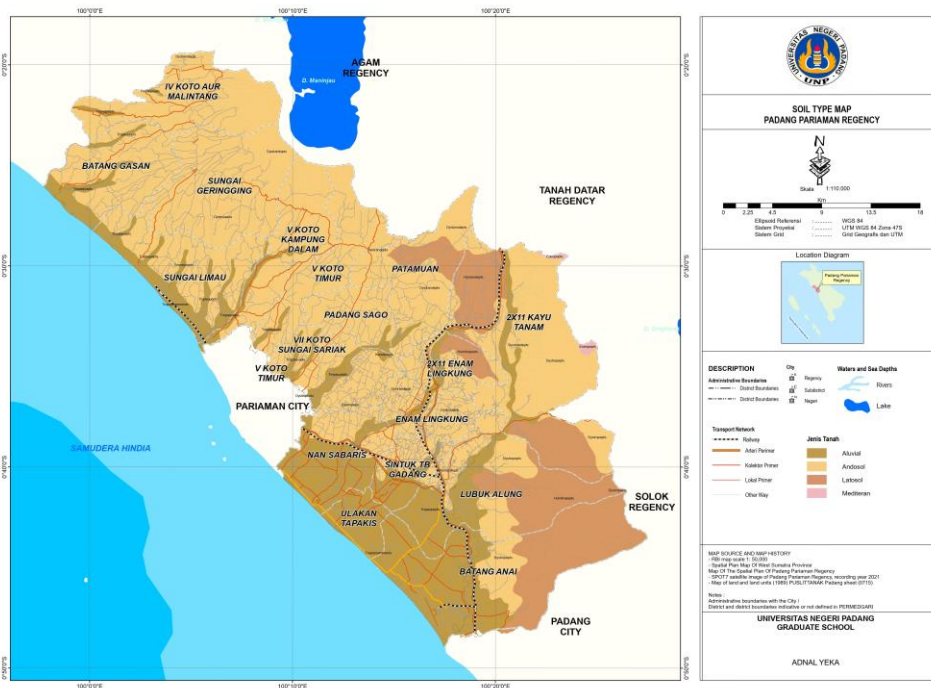


Figure 6. Soil type map of Padang Pariaman Regency.

The Singgalang subdistrict contributes to the fertility of the landscape in Padang Pariaman Regency. This is evident from the abundant production of food crops and plantations in the upstream areas of the regency, particularly in the 2X11 Kayu Tanam, Patamuhan, V Koto Kampung Dalam, and Sungai Geringging subdistricts. The process of transporting soil occurs in alluvial landforms located along rivers that originate in Padang Pariaman. At an overall scale, the alluvial landform units in Padang Pariaman District look very small and overlap with other landforms (Figure 5). The results of the overall analysis, show that the Padang Pariaman Regency's landscape is dominated by slopes of 0-8%, while the sandy area has a slope of 8-15%. The total surface is composed of a flat area of 51,378 ha or 38%, a gentle slope area of 37,698 ha or 28%, steep slopes of 28,019 ha or 21%, and very steep slopes 3,972 ha or 3% (Figure 7).

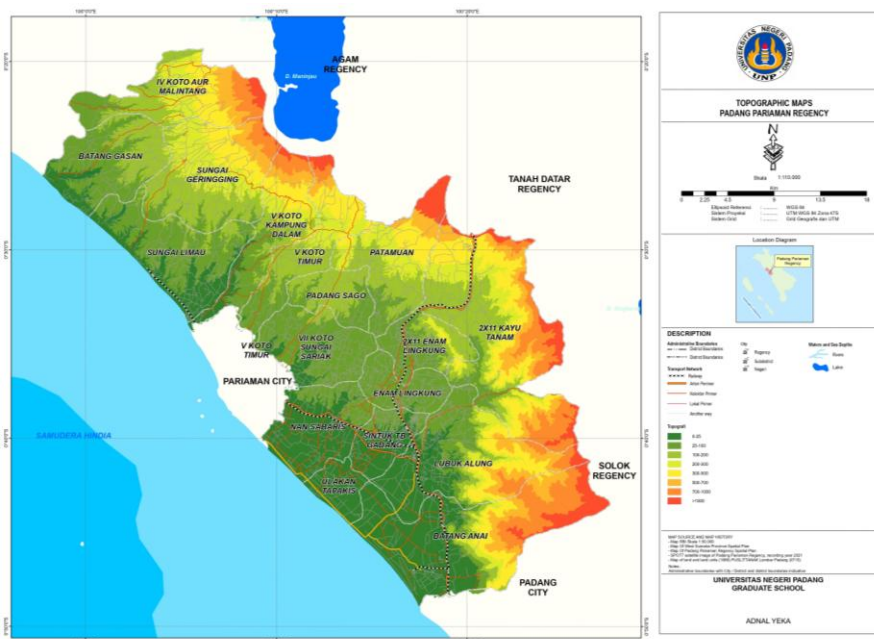


Figure 7. Topological map of Padang Pariaman Regency.

Table 4

## Area and percentage of land cover in Padang Pariaman Regency between 2017-2021

Classification	Year									
	Cover 2017		Cover 2018		Cover 2019		Cover 2020		Cover 2021	
	ha	%	ha	%	ha	%	ha	%	ha	%
Stretch of beach sand	6,629,633.74	4.50	6,629,633.44	4.50	6,629,633.14	4.50	6,629,632.84	4.50	6,629,632.54	4.50
Forest	47,436,327.74	32.20	47,436,327.49	32.20	47,436,327.24	32.20	47,436,326.99	32.20	47,436,326.74	32.20
Pine forest	6,475,710.63	4.40	6,475,710.28	4.40	6,475,709.93	4.40	6,475,709.58	4.40	6,475,709.23	4.40
Pond	4,433.15	0.00	4,433.55	0.00	4,433.95	0.00	4,434.35	0.00	4,434.75	0.00
Field	1,778,403.02	1.21	1,778,402.67	1.21	1,778,402.32	1.21	1,778,401.97	1.21	1,778,401.62	1.21
Open field	28,555.49	0.02	28,555.19	0.02	28,554.89	0.02	28,554.59	0.02	28,554.29	0.02
Settlement	13,374,359.57	9.08	13,374,359.82	9.08	13,374,360.07	9.08	13,374,360.32	9.08	13,374,360.57	9.08
Oil palm plantation	1,045,126.15	0.71	1,045,125.80	0.71	1,045,125.45	0.71	1,045,125.10	0.71	1,045,124.75	0.71
Plantation	45,323,392.57	30.77	45,323,392.32	30.77	45,323,392.07	30.77	45,323,391.82	30.77	45,323,391.57	30.77
Mining	260,095.99	0.18	260,095.69	0.18	260,095.39	0.18	260,095.09	0.18	260,094.79	0.18
Ricefield	15,890,232.10	10.79	15,890,231.90	10.79	15,890,231.70	10.79	15,890,231.50	10.79	15,890,231.30	10.79
Swamp	59,343.22	0.04	59,342.97	0.04	59,342.72	0.04	59,342.47	0.04	59,342.22	0.04
Semak	618,392.36	0.42	618,392.01	0.42	618,391.66	0.42	618,391.31	0.42	618,390.96	0.42
Bush	1,658,888.55	1.13	1,658,888.30	1.13	1,658,888.05	1.13	1,658,887.80	1.13	1,658,887.55	1.13
Farm	6,421,745.14	4.36	6,421,744.94	4.36	6,421,744.74	4.36	6,421,744.54	4.36	6,421,744.34	4.36
Other provision	291,638.39	0.20	291,638.04	0.20	291,637.69	0.20	291,637.34	0.20	291,636.99	0.20
Total number	147,296,277.81	100.00	147,296,274.41	100.00	147,296,271.01	100.00	147,296,267.61	100.00	147,296,264.21	100.00

**Discussion.** The increase in total suspended solids concentration in coastal waters due to shrimp farming activities is one of the main indicators in assessing the environmental impact of aquaculture systems. Based on Figure 2, it can be seen that TSS concentrations increase along with maintenance time, with the highest values in intensive ponds compared to semi-intensive ponds. This indicates that higher density cultivation systems produce greater amounts of organic and inorganic waste, which contributes to increased water turbidity. This significant increase in TSS can affect the quality of the aquatic ecosystem around the pond and reduce the environmental carrying capacity for other aquatic organisms. A study by Zhou et al (2024) stated that intensive pond systems tend to produce more waste compared to semi-intensive or extensive systems, mainly due to the high use of artificial feed and metabolism of cultivated organisms. This waste consists of leftover feed, feces, and organic and inorganic particles that accumulate in the water, causing an increase in TSS which can have a negative impact on light penetration and primary productivity in aquatic ecosystems. Large increases in TSS can also cause stress for aquatic biota, especially organisms that depend on clear water conditions for respiration and photosynthesis.

The results of this study are in line with the findings of Yusoff et al (2024), which showed that the accumulation of TSS in pond systems can accelerate the sedimentation and eutrophication processes, which ultimately reduce the dissolved oxygen (DO) content in the water. High TSS concentrations can inhibit gas exchange in the water column, thereby reducing the quality of habitat for marine organisms such as phytoplankton, zooplankton, and wild fish around the pond area. This condition can disrupt the balance of the coastal ecosystem, especially if pond waste is not managed properly through a recirculation system or the use of adequate waste treatment technology. The findings of this study highlight the environmental impact of shrimp farming activities in Padang Pariaman Regency, particularly in relation to organic waste discharge and land cover changes. Intensive and semi-intensive shrimp farming systems contribute significantly to the TSS released into coastal waters (Aimé et al 2018; Li et al 2019). The monitoring results show that the highest waste concentration recorded during one production cycle was 27.95 mg L<sup>-1</sup> on day 90, with the total waste discharged reaching 61 kg. At the end of the production cycle, when pond water was flushed into the coastal waters, the TSS concentration was 23.85 mg L<sup>-1</sup>, and the total waste discharged was 95.4 kg. The cumulative waste released during the rearing period, including the final flushing, was 924.86 kg TSS per 0.16 ha. When scaled to a hectare, intensive shrimp farms discharged approximately 9,676 kg TSS ha, while semi-intensive farms contributed 6,737 kg TSS ha (Torun et al 2022). These waste loads have potential implications for the carrying capacity of coastal ecosystems. Excessive organic waste accumulation may lead to eutrophication, reduced water quality, and potential disturbances in marine biodiversity. Given the importance of sustainable aquaculture, it is crucial to implement waste management strategies, such as sedimentation ponds, biofilters, and controlled water exchange systems, to mitigate environmental impacts (Dauda et al 2018).

The land cover analysis further reveals changes in Padang Pariaman Regency between 2017 and 2021. The plantation sector remains dominant, covering 36,444 ha (50.54% of the total area). Although the aggregated land cover data from 2017 to 2021 show relatively stable proportions at the regency level, spatial interpretation suggests localized shifts in land use across Padang Pariaman Regency. Interestingly, plantations are well distributed in the northern, eastern, and southeastern regions. The presence of forests and rice fields shows no particular pattern, but their coexistence suggests a balanced ecosystem. Terraced rice fields, observed in locations such as Tandikek and Sungai Geringging, demonstrate an adaptive strategy to undulating landscapes, ensuring efficient water management and soil conservation (Kalantzi & Karakassis, 2006; Taranger et al 2014).

The quantity of waste produced from shrimp farming in the coastal areas of Padang Pariaman is statistically correlated with increased nutrient concentrations in coastal waters, particularly ammonia ( $\rho=-0.88$ ) and TSS ( $\rho=-0.80$ ), indicating eutrophication risk if unmanaged (see Figure 3). These results support the conclusion that waste from uneaten feed, feces, and shrimp metabolic byproducts contribute

significantly to nitrogen and phosphorus loads in the water (Alauddin 2022; Pratiwi et al 2023; Kamal et al 2023; Mudian et al 2024). However, the data do not demonstrate a direct causal link between nutrient levels and terrestrial land cover alteration. The observed reduction in vegetative cover in certain areas with high nutrient loads may suggest localized environmental stress, though further spatial analysis is needed. The implementation of waste treatment systems such as biofloc or artificial wetlands may help mitigate nutrient pollution and indirectly support land conservation (Wu 2023; Yang et al 2024).

The results of the analysis showed that the total nitrogen (N) and phosphorus (P) loads in the coastal waters of Padang Pariaman Regency were 36.95 tons and 8.29 tons, respectively. The main source of nitrogen came from natural processes (in situ) which contributed 19.52 tons, while non-cultivation and cultivation activities contributed 14.03 tons and 3.40 tons, respectively. Meanwhile, phosphorus also mostly came from natural processes of 6.60 tons, followed by contributions from non-cultivation (1.11 tons) and cultivation (0.58 tons). The concentration of nitrogen in the waters was recorded at 0.72 mg L<sup>-1</sup>, while phosphorus was 0.16 mg L<sup>-1</sup>. This value reflects that, although cultivation activities contribute to increasing nutrient loads, the main source still comes from natural processes and other activities outside the fisheries sector.

In the context of environmental carrying capacity, the concentration of nitrogen and phosphorus in the waters must be compared to the recommended threshold limits for coastal water ecosystems. According to Wählström et al (2024), total nitrogen concentrations above 0.5 mg L<sup>-1</sup> and phosphorus above 0.1 mg L<sup>-1</sup> can increase the risk of eutrophication, especially in waters that receive continuous input of organic waste. Based on these results, the concentration of nitrogen in the waters of Padang Pariaman Regency has exceeded the safe limit, while phosphorus is approaching the threshold that can trigger excessive algae growth (Mangan et al 2022).

The contribution of cultivation activities to the increase in nitrogen and phosphorus is in line with the findings of Madjar et al (2024), who show that intensive ponds can increase the nutrient load in the surrounding waters, especially if the waste management system is not optimal. In a cultivation system that does not implement effective waste treatment, organic waste from uneaten feed and excretion of cultivated organisms can accumulate and increase nutrient concentrations in the surrounding waters (Martín-Hernández et al 2022; Xiao et al 2023; Wang et al 2024).

Shrimp pond expansion has been a major driver of land cover change. The conversion of coastal sand dunes into shrimp ponds is most prominent in Batang Anai and Sungai Limau districts, with a total conversion of 28 ha. This transformation poses ecological concerns, as sand dunes play a critical role in coastal protection and biodiversity conservation. Therefore, future aquaculture development in these areas should consider environmental safeguards, including buffer zones and sediment control measures (Anggriawan et al 2023). Land use classification accuracy in this study was high, with an overall accuracy of 94.81% and a kappa index of 0.93. However, some misclassifications occurred, particularly between moorlands and shrubs, due to similar spectral characteristics in remote sensing imagery (Aimé et al 2018; Li et al 2019). Field validation confirmed that certain areas previously classified as moorlands had transitioned into shrublands. Similarly, errors in distinguishing plantations from forests were observed, as tree crops often share visual similarities with natural forests. To address these classification challenges, the land cover map was refined to improve accuracy and reliability (Yuniarti et al 2020).

Statistical analysis using Spearman correlation revealed a strong negative relationship between vegetation cover and ammonia concentration ( $\rho=-0.88$ ), as well as with total suspended solids ( $\rho=-0.80$ ). This suggests that areas with reduced vegetative land are associated with increased nutrient and sediment loads, likely due to aquaculture effluents and land use pressures in coastal zones (Figure 3). Figure 8 shows the pathways of influence by which waste from shrimp farming and other sources of pollution can affect coastal ecosystems and their land cover. Waste from shrimp farms can have both positive and negative impacts. If managed properly, technologies such as biofloc systems and constructed wetlands can help filter waste before it reaches the water,

thereby reducing pollution and supporting land conservation such as mangrove forests and swamp ecosystems.

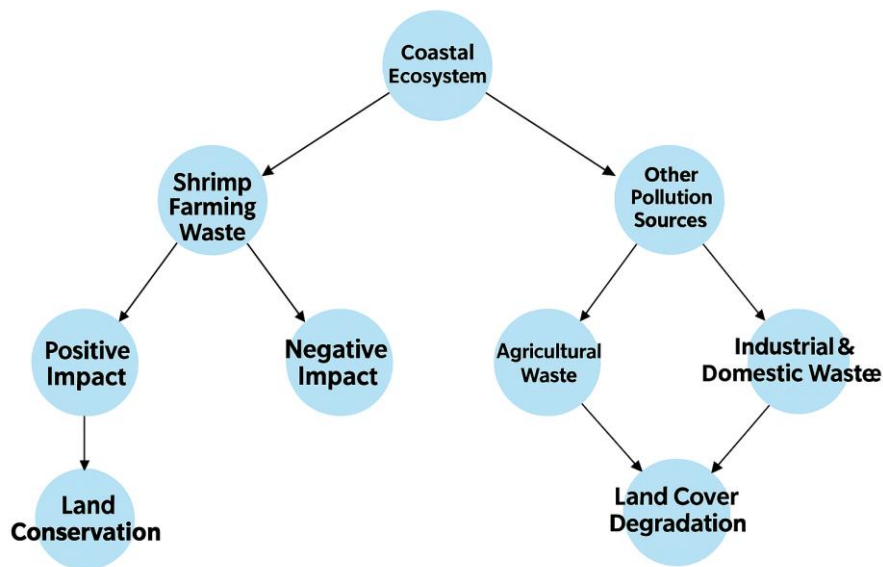


Figure 8. The impact of waste quantity on coastal ecosystem and land cover changes.

However, if waste is not managed properly, pollution from excess nutrients can cause eutrophication, which triggers excessive algae growth and reduces the quality of coastal ecosystems. In addition to waste from shrimp farming, coastal ecosystems are also affected by other sources of pollution such as agricultural waste and industrial or domestic waste. Agricultural waste containing fertilizers and pesticides can cause eutrophication, while industrial and domestic waste can increase the content of hazardous pollutants in the water. If this pollution is not controlled, land cover degradation will occur in the form of loss of mangrove ecosystems, increased sedimentation, and accumulation of pollutants in coastal waters. Conversely, if waste management is carried out properly, coastal ecosystems can be maintained, thus supporting the sustainability of coastal resources and maintaining environmental balance.

In addition to managing aquaculture waste, external factors such as domestic and industrial waste also contribute to changes in land cover in coastal areas. These findings support the hypothesis that shrimp pond development and associated waste contribute to water quality degradation. Although changes in land cover were not consistently detected at the regency level, statistical correlation shows a strong association between vegetative loss and elevated nutrient concentrations in coastal waters. Waste from shrimp farming activities that are rich in metals and pungent gases can accelerate coastal land degradation through the accumulation of toxic compounds in sediments and waters. Increased sedimentation due to land conversion and construction activities can also affect the carrying capacity of coastal ecosystems, especially in mangrove and wetland habitats that play an important role in filtering pollutants (Elvines et al 2023; Cebe et al 2024). If shrimp production was stopped, other sources of pollution can still cause significant changes in land cover in the coastal areas of Padang Pariaman. Unmanaged domestic waste can accelerate the degradation of coastal waters, while industrial and agricultural waste can continue to pollute soil and water, causing reduced land productivity and the loss of natural habitats such as mangrove forests and seagrass beds. In addition, without sustainable land use for cultivation, land conversion for other activities such as plantations or settlements can further accelerate the loss of important coastal ecosystems (Lu et al 2020; Kiran & Ramaraju 2022).

The study also identifies that land cover transformation was more pronounced in the southern regions of Padang Pariaman Regency, including Lubuk Alung, Batang Anai, and Ulakan Tapakis. Large-scale changes were also noted in Sungai Limau and Batang Gasan districts. The most dominant transformation in Lubuk Alung involved the

conversion of agricultural fields into urban settlements and offices, reflecting ongoing regional development. Despite these changes, the total settlement area remained relatively stable between 2017 and 2021, indicating controlled urban expansion (Świtoniak 2014). Homer et al (2015) stated an important observation is the gradual reforestation in the eastern part of the regency, where former plantation lands have been restored as forests due to environmental and social considerations. Key informant interviews confirm that this land use reversal was driven by the negative impacts of plantation activities on local ecosystems and communities. Such reforestation efforts highlight the significance of sustainable land management policies in balancing economic development with ecological conservation (Ren et al 2019; Bui et al 2014). Topographically, Padang Pariaman Regency exhibits diverse landforms, including alluvial, andosol, latosol, and Mediterranean soil types. The landscape is characterized by flat areas covering 38% (51,378 ha), gentle slopes covering 28% (37,698 ha), steep slopes covering 21% (28,019 ha), and very steep slopes making up 3% (3,972 ha). This varied topography influences land use patterns, particularly in agricultural and aquaculture developments (Agustian et al 2019; Visa et al 2011). Overall, the study underscores the need for integrated coastal management strategies to ensure that shrimp farming and land use changes do not compromise the ecological balance of Padang Pariaman Regency. Sustainable shrimp farming practices, proper land use planning, and effective waste management systems should be prioritized to maintain the long-term productivity and health of coastal ecosystems.

**Conclusions.** This study shows that shrimp farming in Padang Pariaman's coastal areas contributes significantly to nutrient pollution, with TSS and ammonia concentrations often exceeding carrying capacity thresholds. Statistical analysis revealed a strong negative correlation between vegetation cover and both ammonia and TSS levels, indicating spatial associations between reduced vegetative land and degraded water quality. However, no direct causal relationship was established between pond waste and land cover change, as land use dynamics are also influenced by other factors such as settlement expansion. The findings highlight the importance of spatially targeted waste management and sustainable aquaculture practices to protect coastal ecosystem resilience.

**Acknowledgements.** The authors would like to thank the postgraduate director and head of the Environmental Sciences Department at Universitas Negeri Padang who have facilitated the authors in carrying out the research and also the extension and human resource development agency of the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia which has assisted researchers in carrying out this research.

**Conflict of interest.** The authors declare that there is no conflict of interest.

## References

- Agustian C. H., Kamal E., Mustapha M. A., Putra A., 2019 Land cover of mangrove ecosystem in marine tourism integrated Mandeh sub-district Koto Xi Tarusan, Pesisir Selatan Regency. *Sumatra Journal of Disaster, Geography and Geography Education* 3(2):191-195.
- Aimé J., Allenbach M., Bourgeois C., Léopold A., Jacotot A., Vinh T. V., Marchand C., 2018 Variability of CO<sub>2</sub> emissions during the rearing cycle of a semi-intensive shrimp farm in a mangrove coastal zone (New Caledonia). *Marine Pollution Bulletin* 129(1):194-206.
- Alauddin M. H. R., 2022 Analysis of organic waste loading (total suspended solid) from shrimp culture activity in Mangara Bombang coastal area – South Sulawesi Province. *IOP Conference Series Earth and Environmental Science* 1036(1):012094.
- Anggriawan R., Salsabilla N. A., Prahesti I. A., 2023 Volcanic soils: Their characteristics, management practices, and potential solution for water pollution. *SEAS (Sustainable Environment Agricultural Science)* 7(1):18-29.

- Bhuiyan M. A. E., Witharana C., Liljedahl A. K., Jones B. M., Daanen R., Epstein H. E., Agnew A., 2020 Understanding the effects of optimal combination of spectral bands on deep learning model predictions: A case study based on permafrost tundra landform mapping using high resolution multispectral satellite imagery. *Journal of Imaging* 6:1-16.
- Bui T. D., Maier S. W., Austin C. M., 2014 Land cover and land use change related to shrimp farming in coastal areas of Quang Ninh, Vietnam using remotely sensed data. *Environmental Earth Sciences* 72:441-455.
- Cebe K., Balas L., Yıldırım P. F., 2024 Assessment and mitigation of Land-Based pollutants and climate change impacts on coastal water quality. *Journal of Coastal Research* 113:402-406.
- Damastuti E., Groot R., 2017 Effectiveness of community-based mangrove management for sustainable resource use and livelihood support: A case study of four villages in Central Java, Indonesia. *Journal of Environmental Management* 203:510-521.
- Dauda A. B., Ajadi A., Tola-Fabunmi A. S., Akinwole A. O., 2018 Waste production in aquaculture: Sources, components and managements in different culture systems. *Aquaculture and Fisheries* 4:81-88.
- Elvines D. M., MacLeod C. K., Ross D. J., Hopkins G. A., White C. A., 2023 Fate and effects of fish farm organic waste in marine systems: Advances in understanding using biochemical approaches with implications for environmental management. *Reviews in Aquaculture* 16(1):66-85.
- Fadhilah L. T., Kamal E., Mustapha M. A., Putra A., 2019 Land cover change mangrove ecosystem in the coastal area of Bungus Teluk Kabung Padang City. *Sumatra Journal of Disaster, Geography and Geography Education* 3(2):165-169.
- Fallati L., Savini A., Sterlacchini S., Galli P., 2017 Land use and land cover (LULC) of the Republic of the Maldives: first national map and LULC change analysis using remote-sensing data. *Environmental Monitoring and Assessment* 189(8):1-15.
- Garcia L. C., Fonseca A., 2018 The use of administrative sanctions to prevent environmental damage in impact assessment follow-ups. *Journal of Environmental Management* 219:46-55.
- Gonzalez P., Tucker C. J., Sy H., 2012 Tree density and species decline in the African Sahel attributable to climate. *Journal of Arid Environments* 78:55-64.
- Grêt-Regamey A., Sirén E., Brunner S. H., Weibel B. 2017 Review of decision support tools to operationalize the ecosystem services concept. *Ecosystem Services* 26:306-315.
- Homer C. G., Dewitz J., Yang L., Jin S., Danielson P., Xian G. Z., Coulston J., Herold N., Wickham J., Megown K., 2015 Completion of the 2011 National Land Cover Database for the Conterminous United States – representing a decade of land cover change information. *Photogrammetric Engineering & Remote Sensing* 81(5):345-354.
- Kalantzi I., Karakassis I., 2006 Benthic impacts of fish farming: Meta-analysis of community and geochemical data. *Marine Pollution Bulletin* 52(5):484-493.
- Kamal E., Yeka A., Berlian E., Sarianto D., Lubis A. S., 2023 Analysis of water quality in the coastal area of Padang Pariaman Regency, West Sumatra, Indonesia. *AACL Bioflux* 16(6):3407-3415.
- Kiran D., Ramaraju H., 2022 Integrative study of coastal land-based pollution and effects: Focus on soil properties. *Indian Journal of Ecology* 49(2):440-445.
- Li F., Feng J., Zhou X., Xu C., Haissam-Jijakli M., Zhang W., Fang F., 2019 Impact of rice-fish/shrimp co-culture on the N<sub>2</sub>O emission and NH<sub>3</sub> volatilization in intensive aquaculture ponds. *Science of The Total Environment* 655:284-291.
- Li H., Wang J., Fan Y., Han J., 2018 High-fidelity inhomogeneous ground clutter simulation of airborne phased array PD radar aided by digital elevation model and digital land classification data. *Sensors* 18:1-16.
- Long H., Liu Y., Hou X., Li T., Li Y., 2014 Effects of land use transitions due to rapid urbanization on ecosystem services: Implications for urban planning in the new developing area of China. *Habitat International* 44:536-544.

- Lu Y., Yuan J., Lu X., Su C., Zhang Y., Quan Y., Xie W., 2020 Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability. *Environmental Pollution* 239:670-680.
- Madjar R. M., Scăețeanu G. V., Sandu M. A., 2024 Nutrient water pollution from unsustainable patterns of agricultural systems, effects and measures of integrated farming. *Water* 16(21):1-25.
- Mangan S., Lohrer A. M., Thrush S. F., Ellis J. I., Pilditch C. A., 2022 The effects of long-term nitrogen enrichment on estuarine benthic-pelagic coupling. *Journal of Marine Science and Engineering* 10(12):1-18.
- Martín-Hernández E., Taifouris M., Martín M., 2022 Addressing the contribution of agricultural systems to the phosphorus pollution challenge: a multi-dimensional perspective. *Frontiers in Chemical Engineering* 4:1-8.
- Mudian P., Mustafa A., Asaf R., Akmal A., Hamzah H., Tarunamulia T., Syaichudin M., Albasri H., Kamariah K., Ratnawati E., Athirah A., Makmur M., Tauhid I., Tahe S., 2024 Water quality changes in the coastal area of intensive whiteleg shrimp brackish water pond aquaculture. *Journal of Water and Land Development* 61:130-142.
- Mukhtar E., Raynaldo A., Novarino W., 2021 Carbon stock mapping using mangrove discrimination indices in Mandeh Bay, West Sumatra. *AAFL Bioflux* 14(1):430-440.
- Pratiwi R. K., Mahmudi M., Faqih A. R., Arfiati D., 2023 Dynamics of water quality for vannamei shrimp cultivation in intensive ponds in coastal areas. *Jurnal Penelitian Pendidikan IPA* 9(10):8656-8664.
- Putra A., Dewata I., Hermon D., Barlian E., Umar G., Widodo T., Damanhuri H., 2023 Activity Recommendations Based on an Environmental Approach in Zoning of Marine Protected Areas (MAPS) Pariaman City – Indonesia. *Environment Asia* 16(3):57-67.
- Raynaldo A., Mukhtar E., Novarino W., 2020 Mapping and change analysis of mangrove forest by using Landsat imagery in Mandeh Bay, West Sumatra, Indonesia. *AAFL Bioflux* 13(4):2144-2151.
- Ren C., Wang Z., Zhang B., Li L., Chen L., Song K., Jia M., 2018 Remote monitoring of expansion of aquaculture ponds along coastal region of the Yellow River Delta from 1983 to 2015. *Chinese Geographical Science* 28:430-442.
- Schulp C. J. E., Burkhard B., Maes J., Van-Vliet J., Verburg P. H., 2014 Uncertainties in Ecosystem Service Maps: A Comparison on the European Scale. *PLoS ONE* 9(10):1-11.
- Seto K. C., Guneralp B., Hutyrá L. R., 2012 Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences* 109(40):16083-16088.
- Sfez S., Van D. H. S., Taelman S. E., Meester S., Dewulf J., 2015 Environmental sustainability assessment of a microalgae raceway pond treating aquaculture wastewater: From up-scaling to system integration. *Bioresource Technology* 190:321-331.
- Song X., Chang K., Yang L., Scheffran J., 2016 Change in environmental benefits of urban land use and its drivers in Chinese cities, 2000–2010. *International Journal of Environmental Research and Public Health* 13:1-21.
- Świtoniak M., 2014 Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland. *Catena* 116:173-184.
- Taranger G. L., Karlsen Ø., Bannister R. J., Glover K. A., Husa V., Karlsbakk E., Svåsand T., 2014 Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. *ICES Journal of Marine Science* 72(3):997-1021.
- Torun F., Hostins B., Schryver P., Boon N., Vrieze J., 2022 Molybdate effectively controls sulphide production in a shrimp pond model. *Environmental Research* 203:1-9.
- Visa S., Ramsay B., Ralescu A. L., Knaap E., 2011 Confusion matrix-based feature selection. *Maics* 710(1):120-127.

- Wählström I., Almroth-Rosell E., Edman M., Olofsson M., Eilola K., Fleming V., Gröger M., Arneborg L., Meier H. M., 2024 Increased nutrient retention and cyanobacterial blooms in a future coastal zone. *Estuarine Coastal and Shelf Science* 301:1-11.
- Wang Y., Guo X., Wang G., Wang L., Huang T., Li Y., Wang Z., Dai M., 2024 Assessment of nutrient cycling in an intensive mariculture system. *Marine Pollution Bulletin* 209:1-13.
- Wu B., Yang Z., 2018 The impact of moral identity on consumers' green consumption tendency: The role of perceived responsibility for environmental damage. *Journal of Environmental Psychology* 59:74-84.
- Wu Y., 2023 Mechanism and application of constructed wetlands in sewage treatment. *Highlights in Science Engineering and Technology* 73:179-185.
- Xiao H., Jiang M., Su R., Luo Y., Jiang Y., Hu R., 2023 Fertilization intensities at the buffer zones of ponds regulate nitrogen and phosphorus pollution in an agricultural watershed. *Water Research* 250:1-11.
- Yang Z., Zou Y., Zhu X., Yu X., 2024 Promoting aquatic health in constructed wetlands: removal of pathogens and nitrogen. *Water* 16(917):1-14.
- Yuniarti E., Indika P. M., Dewata I., Heldi, Barlia E., 2020 Comorbidity mapping of covid-19 events in west Sumatera. *Sumatra Journal of Disaster, Geography and Geography Education* 4(1):11-16.
- Yusoff F. M., Umi W. A. D., Ramli N. M., Harun R., 2024 Water quality management in aquaculture. *Cambridge Prisms: Water* 2:1-22.
- Zhou J., Tu T., Wang H., Kitazawa D., 2024 Modeling environmental impacts of intensive shrimp aquaculture: A three-dimensional hydrodynamic ecosystem approach. *Fishes* 9(4):1-13.
- \*\*\* GEBCO Compilation Group, 2021 The GEBCO\_2021 grid – A global bathymetric grid at 15 arc-second resolutions. <https://www.gebco.net/>
- \*\*\* Ministry of Marine Affairs and Fisheries, MMAF 2021 Marine spatial plan for coastal zones of West Sumatra Province. Ministry of Marine Affairs and Fisheries, Republic of Indonesia, <https://jdih.kkp.go.id/Homedev/DetailPeraturan/3096>
- \*\*\* US Geological Survey, 2022 Landsat 8 surface reflectance data (Level-2). <https://www.usgs.gov/landsat-missions/landsat-8>.

Received: 16 December 2024. Accepted: 14 August 2025. Published online: 30 August 2025.

Authors:

Adnal Yeka, Doctoral Program of Environmental Science, Postgraduate School, Universitas Negeri Padang, Indonesia; Polytechnic AUP, Jakarta, Indonesia, e-mail: [adnal.yeka@kkp.go.id](mailto:adnal.yeka@kkp.go.id)

Eri Barlian, Environmental Science, School of Graduate, Universitas Negeri Padang, Indonesia, e-mail: [e.barlian@fik.unp.ac.id](mailto:e.barlian@fik.unp.ac.id)

Eni Kamal, Marine, Coastal and Aquatic Resources, Bung Hatta University, Indonesia, e-mail: [ekamal898@bunghatta.ac.id](mailto:ekamal898@bunghatta.ac.id)

Deni Sarianto, Polytechnic of Marine and Fisheries, Dumai, Indonesia, e-mail: [denisarianto@gmail.com](mailto:denisarianto@gmail.com)

Amelia Sriwahyuni Lubis, Biology Department of Andalas University, Padang, West Sumatra, Indonesia, e-mail: [amelialubis@bunghatta.ac.id](mailto:amelialubis@bunghatta.ac.id)

This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

How to cite this article:

Yeka A., Barlian E., Kamal E., Sarianto D., Lubis A. S., 2025 Coastal ecosystem carrying capacity and shrimp farming in Padang Pariaman, West Sumatra, Indonesia. *AAFL Bioflux* 18(4):1952-1969.