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Characteristics of Settlement on Water in Tobati Village, Papua: Challenges and Sustainability Strategies

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Abstract

This study analyzes the characteristics of the water settlement of Tobati Village, Papua, located in the Youtefa Bay conservation area, focusing on environmental, social, economic, and institutional challenges. The settlement faces various problems, such as water pollution, mangrove degradation, limited sanitation, and inadequate access to clean water, which threaten environmental sustainability and the community's quality of life. This study uses a qualitative case study approach to explore solutions based on an eco-settlement approach that integrates ecological, social, economic, technological, and architectural design sustainability. The results show that using passive design, such as cross ventilation and environmentally friendly building materials, can improve thermal comfort and energy efficiency in stilt houses. In addition, bio-digester technology for domestic waste treatment, rainwater harvesting systems, and mangrove rehabilitation supported by GIS mapping technology are proposed as key strategies to support sustainability. Collaboration between the government and local communities is also important to ensure inclusive and sustainable governance. This research significantly contributes to SDG 11 (Sustainable Cities and Human Settlements) and SDG 13 (Climate Action) by offering a holistic strategy for environmentally friendly and resilient coastal settlement management.

1.0 INTRODUCTION

Jayapura City, the capital of Papua Province, is a coastal city in Indonesia whose original residents are indigenous people who inhabit the coast of Jayapura City. One of the areas known as a coastal settlement located on the water and the oldest traditional village in Jayapura City is the Tobati Village settlement area. The residents of the Tobati Village area are the largest ethnic group in Jayapura City, namely the Tobati ethnic group, which has inhabited the village since 1908. This area is located within the Teluk Youtefa nature tourism park area. The legal status of the Teluk Youtefa area was strengthened by the issuance of the Decree of the Minister of Forestry of the Republic of Indonesia No. 714/KPTS-II/1996 concerning the determination of the Teluk Youtefa area as a conservation area (Sari et al., 2022). Tobati Village has an area of 1.42 hectares, a population of 402 people, a tropical climate with high humidity (83.70% -88.6%), an average temperature ranging from 28.8°C to 28.9°C (Badan Pusat Statistik Kota Jayapura, 2024), and rainfall reaching 3,164 mm based on 2019 data from the Dok 2 observation station. As is the characteristic of other settlements on water that adapt to geographical and climatic conditions, the houses in Tobati Village are stilt houses built from wood construction, either processed or sourced from the surrounding environment, especially mangrove forests.

The authors in articles (Elisabeth, 2019) and (Kadir et al., 2021) state that the Tobati indigenous people practice local wisdom in managing resources around Youtefa Bay, with women playing an important role in mangrove forest governance. The use of natural resources, including mangrove forests, fish, and other marine life, is managed based on strict customary laws. Likewise, as conveyed by the author in article (Mohamed et al., 2023), even though the community has extensive land, the Tobati community still maintains the tradition of building houses on water. The settlement pattern of the village reflects its socio-cultural identity, with houses arranged in family groups (Akram et al., 2023).

Researchers in (Iswanto et al., 2022) reported that the social structure of Tobati Village is governed by administrative and customary systems, with the ondoafi, or chief, holding authority over land and resources. Customary laws govern resource use, particularly in marine and mangrove ecosystems. These laws have helped maintain environmental balance for generations, but modern pressures such as urbanization and tourism have weakened the enforcement of these traditional governance systems. According to researchers in Ardi et al. (2022), this has led to significant environmental challenges, including the loss of mangroves and declining fish populations. In recent years, Youtefa Bay has experienced a decline in mangrove cover, with an estimated loss of 278.12 hectares between 1967 and 2017 due to land conversion for housing, roads, and other infrastructure. Other environmental issues that authors have studied (Sari et al., 2022) and (Thiagarajan & Devarajan, 2025) include coastal erosion, plastic waste pollution, and a decline in marine biodiversity, which have seriously impacted the local fishing industry. As a result, many residents have shifted their livelihoods to the tourism sector, renting or selling land along the coast for natural and culinary tourism attractions (Hosio & Aquarista, 2022).

The eco-settlement approach solves these environmental and socio-economic challenges by prioritizing sustainable development that combines ecological, social, and economic aspects (Farghali et al., 2023). This approach encourages the preservation of natural resources while improving residents' quality of life. Previous studies have shown that settlements built on water require a deep understanding of local wisdom and environmental adaptation to remain sustainable (Sindua et al., 2020);(Rahmah & Sulistyono, 2024), so this study is important to develop strategies that align with modern and traditional governance systems. Given the existing environmental challenges, this study aims to analyze the characteristics of the Tobati Village settlement environment and provide recommendations that support the sustainability of settlements with an eco-settlement approach. By examining the dynamics of the village's environment, society, and economy, this study is expected to provide a basis for strategies to improve the quality of the settlement environment while ensuring the long-term sustainability of the Tobati Village settlement environment. In addition, this research is relevant to efforts to achieve the Sustainable Development Goals (SDGs), especially SDG 11, which focuses on creating inclusive, safe, resilient, and sustainable cities and settlements, and SDG 13, which encourages action on climate change. By exploring the challenges and opportunities for sustainability in Tobati Village, this research contributes to preserving coastal ecosystems and sustainability-based settlement management.

2.0 LITERATURE REVIEW

2.1 Characteristics of Coastal Settlements

In the book Karim et al. (2023) it states that settlements are part of the residential environment, outside protected areas, which function as residential spaces that support the livelihoods of the population. The criteria for good settlements include physical and non-physical aspects, such as geographical location, environmental infrastructure, and the socio-economic activities of its residents. Social and economic factors influence the unique characteristics of each settlement. Good settlement development must ensure the availability of adequate infrastructure, utilities, and public services to support the livelihoods and quality of life of the community.

Coastal communities are defined by Indonesian Law No. 27 of 2007 as indigenous or local community groups living in coastal areas (Republic of Indonesia, 2007). These communities often rely on local wisdom and customary law to manage resources, such as fisheries and mangrove forests, sustainably. Researchers in Sabriani et al. (2023) stated that traditional fishing practices and community structures, such as the role of women in resource management, are integral to the community. The socio-cultural dynamics of coastal communities are shaped by their strong relationship with the marine environment and reliance on traditional ecological knowledge.

Researchers (Setiadi & Kusliansjah, 2021) and (Yodsurang, 2023) describe coastal settlements as having a combination of land-based and water-based buildings, with stilt houses built over the water to accommodate the geographical conditions of the area. These settlements are connected by wooden bridges and often rely on mangrove forests to protect against coastal erosion. The physical characteristics of these settlements, including the use of local materials such as wood and bamboo, reflect the environmental and cultural context of the community. Coastal settlements require adequate infrastructure, including sanitation systems, access to clean water, and public facilities, to support a healthy living environment.

2.2 The Concept of Environmentally Friendly Settlements

The idea of eco-settlement started from a smaller scope in the form of a single building that micro-wise discusses in more detail aspects of technology or building engineering, such as the use of local materials or technologies related to building energy conservation (Ndlangamandla & Combrinck, 2020). From the idea of eco-building, it was developed into a wider scope of eco-settlement or eco-city. Several countries and cities have developed the concept of eco-settlements, which are associated with the concept of sustainable building, sustainable technologies, eco-towns, and eco-city (Zhang, 2020). Eco-settlements lead to the achievement of ecological values and can be expressed as the development of sustainable development. Eco-settlements are a concept of settlement arrangement that harmonizes ecological, social, and economic aspects towards ecosystem sustainability supported by a capable institutional system (Martono et al., 2022). In the Indonesian settlement-planning context, Pusat Penelitian dan Pengembangan Permukiman (Puslitbangkim), Ministry of Public Works, formulated eco-settlement criteria that group settlement quality into four main aspects: ecology, social, economy, and institutional capacity. These Puslitbangkim criteria are used as the analytical basis for identifying the sustainability characteristics of Tobati Village. As presented in Table 1, the criteria provide the reference framework for assessing ecological conditions, community capacity, local economic development, and stakeholder cooperation in the study area (Puslitbangkim, 2006).

Eco-settlement approach is one model that can be adapted to the scale of settlements, especially in coastal areas such as Tobati Village. As stated in previous studies, the term sustainable city development has emerged using the green city approach, namely a city designed by considering environmental impacts to reduce the need for energy, water, and food production inputs. In the context of village settlements, this principle can be adapted to create more sustainable settlements through energy, water management, and coastal ecosystem preservation.

Table 1. Eco-Settlement Criteria According to Puslitbangkim, Ministry of Public Works. (Source: Puslitbangkim, 2006).

Eco-settlement aspects	Criteria
Ecology	- Biodiversity - Air quality - Water quality and quantity - Healthy home - Land use - Climate change - Energy - Environmentally Friendly Technology
Social	- Community capacity (education, participation, habits) - community empowerment
Economy	- Technological innovation - Local economic development (employment opportunities, increased welfare/income) - Accessibility (transportation)
Institutional/institutional capacity	- Cooperation between stakeholders - Policy support

3.0 RESEARCH METHOD

3.1 Research Approach

This study uses a qualitative approach with a case study strategy (Creswell, 2017). This approach was chosen because it focuses on one specific location and explores a complex and unique case that occurred in Tobati Village, Jayapura City, namely a water settlement that faces ecological, social, economic, and institutional challenges in the context of eco-settlement. Tobati Village is located in Youtefa Bay, which is a mangrove conservation area, making it a significant location to study the interaction between humans and mangrove ecosystems in the context of eco-settlement. The case study method based on the framework (Abuhasel, 2023) was chosen because of its ability to investigate real-life phenomena in depth, especially in understanding how ecological knowledge and eco-settlement principles are reflected in the environmental characteristics and settlement management practices of Tobati Village.

3.2 Data Source

The data sources used are primary data and secondary data. Data sources in qualitative research are in the form of words and actions. Other data that can support this are documents and others (Nur'aini, 2020). Data sources are subjects from which data can be obtained. In this study, the data sources used are primary data and secondary data. Primary data sources, namely data directly collected by researchers from their first sources through in-depth interviews and observations. Secondary data sources, namely data collected by researchers as support from the first source, are arranged in the form of documents (Moleong, 2020).

3.3 Location and Subject of Research

The research location is Tobati Village, a coastal settlement in Youtefa Bay, Jayapura City, Papua Province, Indonesia. This location was chosen because of its unique characteristics, such as its settlement on water with a customary law background and the existence of a mangrove ecosystem. The research subjects consisted of local communities, village officials, and related stakeholders, who were selected through purposive sampling techniques based on their relevance and knowledge of the research issue (Mustafa et al., 2020).

3.4 Research Procedures

This research was conducted through the following stages:

i. *Case Identification and Selection:*

The researcher identified Tobati Village as a unique case due to its ecosystem dynamics, customary law, and urbanization challenges. The focus of the research was determined to understand the interaction between settlement characteristics and the eco-settlement approach (Abuhasel, 2023).

ii. *Data Collection:*

Data is collected through:

- In-depth Interviews: In-depth interviews were conducted with informants selected using purposive sampling and snowball sampling techniques. The selection of informants was based on stakeholder analysis, involving parties with in-depth knowledge or strategic positions, such as government officials, traditional leaders, and residents who have lived in Kampung Tobati for a long time (Sugiyono, 2019). A total of 9 key informants were interviewed, including 2 government officials, 2 traditional leaders, and 5 residents who have lived in Kampung Tobati for over 10 years. The informants involved provided valuable insights into the characteristics of the settlement on water. The process of selecting informants was carried out gradually until the number of informants was sufficient to obtain comprehensive data. The interviews were conducted with varying durations, recorded, and transcribed. The interviews were carried out by trained interviewers following a systematic procedure. If the interviews were conducted in a language other than English, translation was performed by a trained translator to ensure accuracy of meaning. The interview questions were tailored to the roles of each stakeholder within the context of the study. This process allowed the researchers to gather in-depth data on the characteristics of the settlement on water in Kampung Tobati and to comprehensively support the research objectives.
- Participatory Observation: Conducted to record the physical conditions of settlements, infrastructure, and daily community activities, using a checklist to ensure consistent documentation. The collected data were categorized into ecological, social, economic, and institutional themes and analyzed through triangulation by comparing results from interviews, observations, and documents. To support ecological analysis, the study used NDVI (Normalized Difference Vegetation Index) to examine changes in mangrove vegetation cover from satellite images (2014-2023). Microclimate data from stilt houses were collected using HOBO Data Loggers to record temperature, humidity, and wind speed, providing accurate thermal comfort measurements. Air quality data was obtained from IQAir, offering real-time and historical data on pollutants like PM2.5 and AQI. Secondary data were gathered from planning documents, environmental reports, and scientific literature on eco-settlements and coastal habitats.
- Document Study: Includes analysis of official documents, namely the Jayapura City RTRW, BPS data, as well as literature studies related to the mangrove ecosystem and customary law in Youtefa Bay (Sugiyono, 2019). The procedure for document study involved collecting secondary data from spatial planning documents, environmental reports, and scientific literature on eco-settlements and coastal settlements. The data were analyzed by reviewing and synthesizing the information in the context of the research objectives, particularly focusing on ecological, social, and legal aspects. The analytical method used included qualitative analysis to identify key themes, trends, and relationships between the documents, providing insights into the challenges and opportunities for sustainable settlement development in Tobati Village.
- Data Analysis: Data were analyzed with reference to the research objectives, namely to understand the characteristics of the Tobati Village settlement in terms of ecology, social, economic, and institutional aspects, and how the eco-settlement approach can be integrated into settlement management strategies. The analysis was carried out through the following steps:
- Data Organization: Grouping data based on main themes: ecological, social, economic, and institutional.
- Triangulation: Data validation is done by comparing the results of interviews, observations, and documents.

- Interpretation: Data were analyzed in depth to understand the patterns of interaction between aspects and the dynamics of settlement characteristics in Tobati Village (Sugiyono, 2019).
- Validation of Findings: Validity of findings was maintained through data triangulation, member checking, and consultation with experts to ensure consistency and accuracy of interpretation (Sugiyono, 2019).
- Analysis Method: The analysis approach was carried out by referring to the qualitative data analysis model (Sugiyono, 2019) which includes data reduction, data presentation, and conclusion. This analysis is adjusted to the research objectives, namely, to identify the characteristics of the Tobati Village settlement through the eco-settlement concept which includes ecological, social, economic, and institutional aspects, to produce a sustainable management strategy.

4.0 RESULTS AND DISCUSSION

Tobati Village, located in the Youtefa Bay nature conservation area, Papua, is a traditional settlement on the sea. The village is deeply rooted in its natural environment, with its main livelihoods dependent on marine resources and mangrove forests in the bay. The rapid development of Jayapura as a coastal city, such as the construction of infrastructure such as bridges and ring roads in the area, has created ecological challenges for the village. These changes combined with shifts in social and institutional aspects, pose significant challenges for sustainable living in Tobati Village. An eco-settlement approach that combines ecological conservation with sustainable economic and social development, provides a framework to analyze the current condition of Tobati Village and identify solutions to the challenges faced.

4.1 Ecological Aspects

Mangrove Vegetation Cover

Mangrove vegetation cover in the Tobati Bay area was obtained from USGS Landsat 8 imagery in 2019, Hill shade Ina Geoportal in 2024, and ArcGIS 10.4 processing results in 2024. Meanwhile, to obtain the mangrove density value, the Normalized Difference Vegetation Index (NDVI) analysis was used. The resulting vegetation density maps for the Youtefa Bay area are presented in Figure 1 for 2014, Figure 2 for 2019, and Figure 3 for 2023.

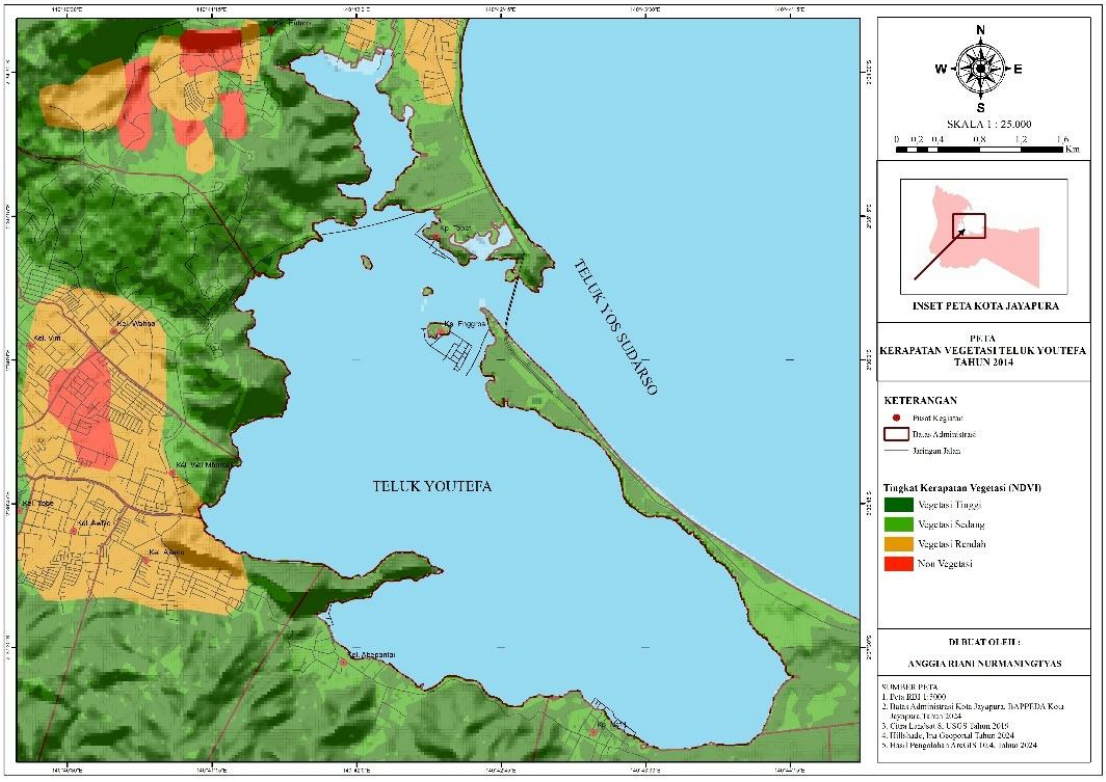

Figure 1. Mangrove Vegetation Density Map 2014.

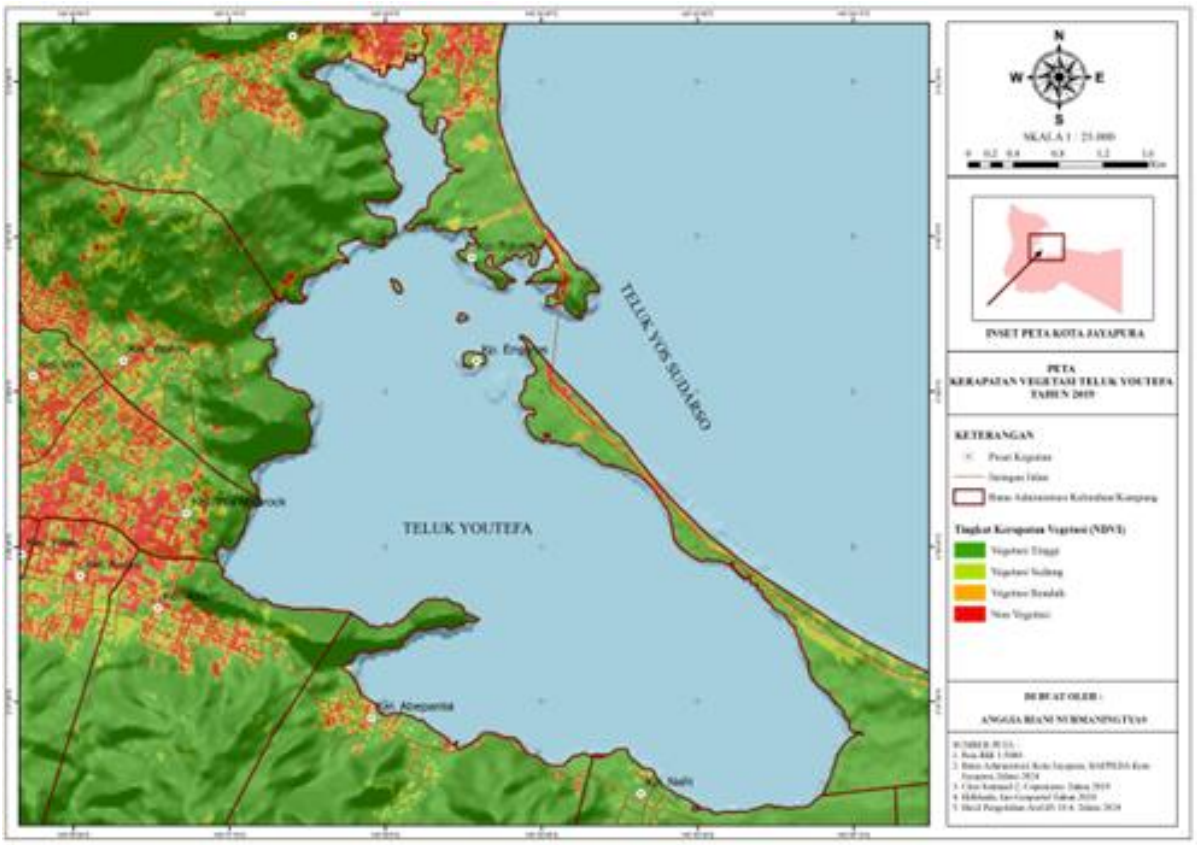

Figure 2. Mangrove Vegetation Density Map 2019.

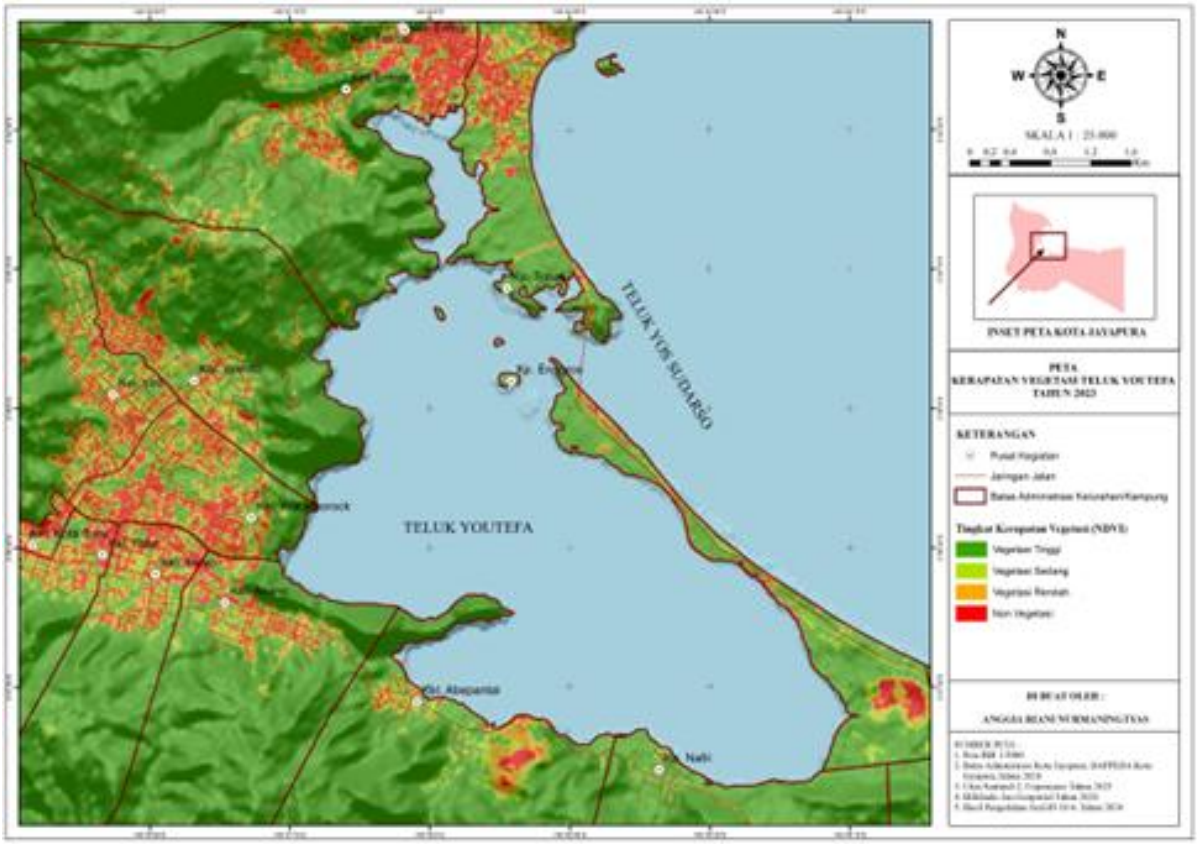

Figure 3. Mangrove Vegetation Density Map 2023.

The decline in vegetation area from 18,048,892.03 m² in 2014 to 16,128,263.27 m² in 2019 indicates significant pressure from development and land conversion in Youtefa Bay. Infrastructure development, uncontrolled urbanization, and economic development are the main factors contributing to this decline. The visual comparison between Figure 1 and Figure 2 suggests that mangrove vegetation cover was more extensive in 2014 than in 2019, while Figure 3 shows the vegetation condition in 2023 after the rate of decline had slowed. However, from 2019 to 2023, the decline in vegetation area slowed down slightly, with only a decrease of 46,052.53 m². This indicates that while development pressure still exists, rehabilitation and conservation efforts have succeeded in slowing the rate of vegetation loss. The detailed mangrove vegetation density level by ward and year is summarized in Table 2.

Table 2. Mangrove Vegetation Density Level in The Youtefa Bay Area.

No.	Ward	Density Level	Year		
			2014	2019	2023
1.	Enggros	Tall	21,761.53	1,792,074.63	1,577,773.31
		Currently	887,320.62	200,680.42	250,344.81
		Low	1,243,049.94	82,190.10	145,205.80
		Total Vegetation	2,152,132.09	2,074,945.15	1,973,323.92
		Non Vegetation	-	83,761.40	186,411.62
2.	Tobati	Tall	43,235.73	1,360,359.19	1,423,281.39
		Currently	1,323,312.19	361,776.46	325,916.86
		Low	806,198.45	246,035.66	214,588.62
		Total Vegetation	2,172,746.37	1,968,171.31	1,963,786.86
		Non Vegetation	-	307,934.09	312,968.71
3.	Entrop	Tall	127,084.59	6,831,382.19	7,145,874.72
		Currently	3,656,130.63	753,569.50	680,197.67
		Low	5,142,139.66	562,736.19	414,982.31
		Total Vegetation	8,925,354.89	8,147,687.89	8,241,054.70
		Non Vegetation	-	772,815.64	897,630.33
4.	Abe Pantai	Tall	1,192.55	3,630,731.62	3,350,432.21
		Currently	628,209.71	199,404.06	294,003.29
		Low	4,095,662.93	62,836.87	214,799.80
		Total Vegetation	4,725,065.19	3,892,972.54	3,859,235.30
		Non Vegetation	-	49,854.17	83,822.20
5.	Holtekamp	Tall		39,024.39	40,835.33
		Currently	1,224.37	3,328.26	3,325.69
		Low	72,369.12	2,133.72	648.94
		Total Vegetation	73,593.49	44,486.38	44,809.96
		Non Vegetation	-	414.77	956.89
Total Vegetation Area			18,048,892.03	16,128,263.27	16,082,210.74
Total Non-Vegetation Area			-	1,214,780.06	1,481,789.75

Source: NDVI data processing, 2024

Between 2014 and 2019, some areas showed an increase in high and medium vegetation density, particularly in locations farther from settlement centers. However, the total vegetation area in Youtefa Bay continued to decline during the same period. This indicates ecosystem recovery in some areas, especially in areas far from settlement centers. However, after 2019, although high and medium density persisted in some areas, there were signs of degradation in other areas, especially around settlements and development areas. The stabilization of vegetation density in certain areas indicates that some areas have reached their optimal capacity to restore ecosystems, but areas closer to urbanization still face serious challenges. Non-vegetated areas tend to increase in coastal areas experiencing settlement expansion and infrastructure development. In

2023, it can be seen that areas that had previously begun to recover are being converted back to non-vegetated areas, especially in the areas around Entrop, Enggros, Tobati, and Holtekamp Sub-districts.

Ecologically, Tobati Village is highly dependent on natural resources, especially mangrove forests, which play an important role in supporting coastal ecosystems. However, infrastructure development around the village has contributed to significant environmental degradation. The construction of traditional houses in Tobati, which are built on stilts, predominantly uses processed wood materials. The average service life of these houses varies depending on factors such as the type of wood used, the quality of construction, and the local environmental conditions, including humidity, rainfall, and exposure to coastal elements. Generally, buildings constructed with processed wood in tropical coastal environments like Tobati have a service life of 20 to 50 years. Similarly, processed wood materials dominate the construction of village roads, and some houses also use mangrove wood as foundation pillars. The use of mangrove wood is strictly regulated by customary rules, ensuring a balance between the needs of the local community and their responsibility to protect the surrounding environment.

Mangrove forests in this area play a very important ecological role in maintaining coastline stability, supporting biodiversity, and providing natural habitats for various marine species, including fish that are the main source of livelihood for local fishermen. However, the decline in vegetation cover between 2014 and 2023, especially in Tobati Village, indicates that pressure on the mangrove ecosystem is increasing. This decline is caused by major infrastructure developments, such as the ring road and bridge construction projects connecting Muara Tami and Abepura, which have resulted in the loss of most of the mangrove forests.

The reduction in mangrove cover has not only resulted in the degradation of local ecosystems but has also disrupted the sustainability of fish stocks, which are vital to the livelihoods of fishermen in Tobati. Data shows that vegetation density in Tobati has changed from year to year, with increases in vegetation in some areas offset by significant decreases in other areas due to uncontrolled development. This degradation ultimately threatens marine biodiversity and reduces the quality of habitat for fish species that have long been the mainstay of the local economy. This condition requires efforts to rehabilitate mangrove forests that can help restore local ecosystems and increase fish stocks, in addition to the government ensuring that every new infrastructure project in coastal areas is carried out after going through a strict environmental impact assessment. The implementation of regulations related to Environmental Impact Analysis (AMDAL) must be strengthened and supervision must be increased to minimize land conversion and further ecosystem damage.

4.2 Waste and Sanitation

The waste disposal system in the Tobati Village residential area is by having a boat from the sanitation department that comes every two days to collect waste, but the bay area is still polluted by waste brought by the river from other settlements. This pollution worsens the degradation of the marine environment, which is already problematic with the decreasing area of mangrove areas. Meanwhile, the clean water and drinking water system for daily use of the community comes from the PDAM network. However, service disruptions often force residents to buy water to meet their needs. The lack of reliable access to clean water increases the vulnerability of communities to environmental and health risks. This condition worsens the economic burden on the community, especially for families with limited income. The uncertainty of clean water supply not only impacts health but also hampers the productivity of residents who depend on clean water for daily activities, such as cooking, washing, and sanitation. In the long term, dependence on alternative water sources such as buying water can trigger social instability and deepen the inequality of access to basic resources in Tobati Village. Therefore, improving clean water infrastructure is an urgent need for environmental sustainability and the social welfare of the Tobati community. The observed condition of sanitation and clean water facilities in Tobati Village is shown in Figure 4.

Figure 4. Condition of sanitation and clean water facilities in Tobati Village, 2024.

The lack of adequate sanitation infrastructure is a critical issue, as household waste from toilets is disposed of directly into the sea. This not only causes marine pollution but also affects public health. The disposal of waste without adequate treatment contributes to the increased risk of spreading waterborne diseases, such as diarrhea and skin infections, especially among children. In addition, this pollution also has a negative impact on the marine ecosystem, destroying fish habitats and reducing the quality of fishermen's catches, which are one of the main sources of livelihood for the Tobati community. In the long term, continued damage to the marine environment will worsen the social and economic crisis in this village, so immediate efforts are needed to build an environmentally friendly and sustainable sanitation system to protect public health and maintain the sustainability of the surrounding aquatic ecosystem. The separation of liquid and solid waste allows for more targeted and efficient management and is consistent with sanitation planning principles (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2022; Spuhler et al., 2020). This approach can be implemented by providing communal septic tank facilities to treat domestic liquid waste so that it is not directly discharged into the sea, as well as developing a solid waste management system through recycling or composting for organic waste, while non-organic waste is processed through waste banks or recycling facilities. In addition, it is important to encourage waste separation systems at the household level by educating the community and providing separation tools such as separate tubs or channels, so that waste management can start from the source more effectively and sustainably.

Researchers in the article (Lamdjad & Khalfallah, 2022) stated that efforts to produce sustainable settlements include increasing rainwater infiltration. Rainwater Harvesting System (RHS) is used as an effort to overcome water shortages in a particular area and can be designed for household or community-based use, allowing significant water savings, as well as addressing existing and future water crises (Kumar et al., 2022; Mukarram et al., 2023).

4.3 Quality of Space in a Residence

The existing condition of houses in the Tobati settlement does not meet the thermal comfort standards set by ASHRAE and SNI. Based on temperature measurements using the Hobo Data Logger, the air temperature in the house ranges from 31.89°C to 32.20°C with humidity reaching 69%, which is far above the optimal thermal comfort range according to ASHRAE (26.2°C–26.8°C) with a relative humidity of approximately 70% and SNI standards (24°C–26°C) with a relative humidity of approximately 60% (Nasrullah & Hamdy, 2024). Temperatures that are too high and excessive humidity can reduce the quality of life of residents, cause heat stress, and increase the risk of health problems such as respiratory disorders and mold growth. This condition is also exacerbated by the low wind speed, only 0.09 m/s, which indicates inadequate natural ventilation so that fresh air circulation is not optimal.

The integration of thermal comfort standards emphasizes the importance of improving thermal conditions and air quality in Tobati settlements. Cross ventilation, increasing openings, and using building materials that can reflect heat are important steps to maintain temperature and humidity within comfortable limits according to ASHRAE and SNI standards. In addition, low natural lighting (only 11.8 lux) also needs to be improved to meet healthy lighting standards, thus supporting the productivity and health of residents. With these improvements, houses in Tobati can meet healthy home standards that support thermal comfort, as well as improve the quality of life and well-being of their residents.

The stilt house is designed to utilize natural air ventilation by integrating cross ventilation. Cross ventilation is achieved by installing windows and ventilation holes on opposite sides of the house, to allow air to enter from one side and exit through the other (Jimin et al., 2020). Increasing the elevation of the stilt house by about 1.5 meters above the water surface will be able to create space under the floor of the house that encourages airflow and reduces heat that spreads from below, thus keeping the indoor temperature cool without the need for artificial air conditioning. In hot and humid tropical contexts, adequate outside air ventilation is one of the main parameters in reducing energy consumption while maintaining thermal comfort (Nasrullah & Hamdy, 2024).

Building materials can play an important role in ensuring optimal air circulation. The use of porous materials such as woven bamboo or wood with small gaps allows air to flow freely. Passive roof design with ventilation (ridge or clerestory ventilation) helps to channel hot air out of the house. The orientation of the building facing the dominant local wind and the arrangement of vegetation around the house can guide the natural flow of wind into the house. The optimal cooling set point at 26°C provides the most comfortable thermal conditions, with a thermal sensation close to neutral, which can be achieved through these steps without the need for artificial cooling (Medina et al., 2022). With a combination of these steps, the stilt houses in Kampung Tobati can utilize natural ventilation to reduce energy consumption while maintaining thermal comfort for its occupants.

4.4 Environmental Sanitation

The sanitation conditions in the waterborne settlement of Tobati Village is poor and inadequate. Field observations and interviews with the Village Head revealed that most houses do not have septic tanks or proper waste treatment systems, leading to domestic waste (including faeces) being directly disposed of into the sea through the house foundations or simple open channels. This practice has been ongoing for a long time and is not considered a serious issue by some residents. Qualitative analysis (NVivo coding) confirms this finding: nearly all informants stated that household waste is discarded into the sea, with only a few mentioning the presence of communal or individual septic tanks. This waste disposal practice without treatment is classified as inadequate sanitation according to the Jayapura City Spatial Planning standards (RTRW Kota Jayapura, 2008) and national sanitation guidelines (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2022). As a result, coastal ecosystem pollution occurs, increasing the risk of diseases, and clearly contradicting the principles of environmentally friendly housing.

Efforts to improve sanitation are urgently needed, and one recommended solution is the use of sealed septic tanks specifically designed for stilt houses over water. This system should be designed with sealed compartments, equipped with an anaerobic baffled reactor (ABR), and have proper maintenance access. For locations without regular sludge suction services, the use of waste-degrading bioenzymes or other biological active materials can help reduce sludge accumulation and extend the tank's lifespan (Spuhler et al., 2020; UPM GmbH, 2021).

Access to clean water in Tobati Village is still very limited; PDAM water is only supplied twice a week to a communal storage tank at the village's edge, without piped connections to homes, forcing residents to fetch water by boat or purchase bottled water for consumption. This infrastructure limitation not only burdens household economies but also hinders the creation of a hygienic settlement environment. In this situation, a Community-Based Rainwater Harvesting System (CBRWHS) becomes a potential alternative. A study Mukarram et al. (2023) demonstrated the effectiveness of this collective system in improving water resilience in coastal areas of Bangladesh, although challenges such as financial limitations and low technical literacy still need to be addressed. The implementation of the CBRWHS in Tobati Village should be accompanied by community education, technical training, and the development of pilot models to ensure sustainability and suitability within the local context.

4.5 Thermal Comfort of Housing

The Tobati settlement is located in a humid tropical climate with an average daily temperature ranging from 26º-32°C and humidity between 75%-82%. Microclimate measurements within the stilt houses using a

Hobo Data Logger show typical daily temperature and humidity patterns for tropical coastal environments. In the morning (around 06:00-09:00), the air temperature is relatively cool, around ~29°C, with high relative humidity of ~76%-79%. As midday approaches, the temperature rises quickly above 30°C, accompanied by a decrease in humidity to ~70%. The peak conditions occur around 13:00, when the temperature inside the house reaches ~33.9°C, with humidity dropping to ~62%. After this, the temperature decreases slightly to ~32.5°C in the afternoon (around 15:00), while humidity increases back to ~65% as the intensity of sunlight decreases. The wind blows very gently (~0.1-0.13 m/s) throughout the day, so it has little effect on cooling. The combination of high temperatures, low relative humidity, intense sunlight, and minimal natural ventilation during midday creates an uncomfortable thermal condition, particularly in houses without cross-ventilation or adequate roof insulation. The thin tin roof material commonly used exacerbates the heat inside. In terms of thermal comfort, Tobati's stilt houses require passive design interventions such as improved ventilation, the use of cooler building materials, and shading to better adapt to the hot tropical coastal climate.

Despite facing ecological pressures, the ambient air quality in Tobati Village is relatively good. Monitoring via the online platform IQAir from June 25 to 30, 2025, showed $PM_{2.5}$ concentrations ranging from 7-26 µg/m³ and PM_{10} concentrations between 2-6 µg/m³, which fall within the "good" to "moderate" category according to international standards (IQAir, 2020). This is supported by the village's open coastal geographical characteristics and the dominance of sea winds with speeds of 1-4 m/s, which effectively disperse local pollutants. The daily meteorological parameters during this period showed air temperatures ranging from 24º-29°C and high relative humidity (72%-94%), reflecting the typical humid tropical climate found in coastal areas. While humidity does not directly affect the chemical composition of the air, it does influence thermal comfort. Overall, air quality in Tobati still supports outdoor activities and does not indicate serious pollution. However, mitigation of potential increases in emissions, such as from vehicles or waste burning, remains necessary. The preservation of mangrove ecosystems as natural pollutant absorbers is a key strategy in maintaining air quality and supporting the sustainability of coastal settlement environments. The main elements of the stilt-house construction observed in Tobati Village are summarized in Table 3 and illustrated in Figure 5.

Table 3. House Construction.

Element	Classification/Features
Foundation Type	Pile foundation made of wood (commonly ironwood or mangrove wood), driven directly into shallow seabed or coastal mud.
Floor Structure	Wooden planks or beams arranged horizontally on transverse reinforcing beams, using matoa wood planks.
Wall Structure	Wooden planks or a combination of plywood.
Roof Structure	Generally, uses a corrugated iron roof.
Construction System	The building structure is made of wooden frames, with connections using nails.

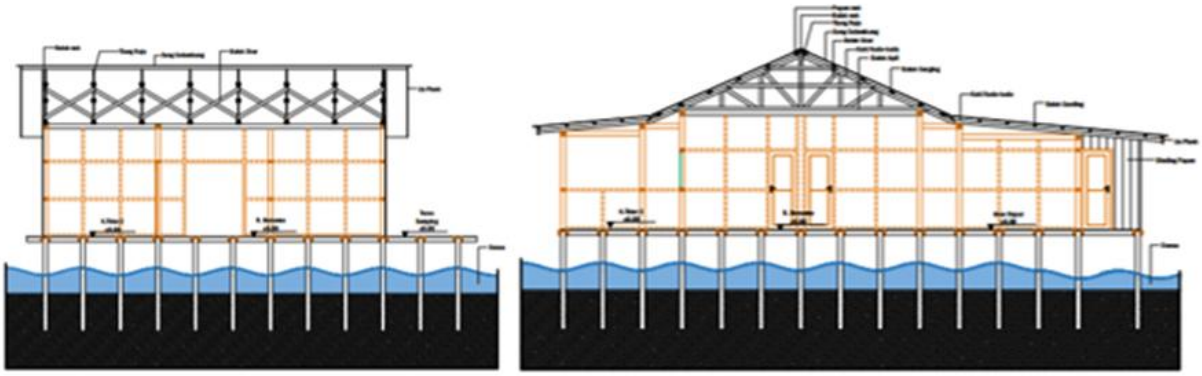

Figure 5. House Construction.

4.6 Economic Aspects

The economy of the Tobati Village community is partly dependent on marine resources. Approximately 60% of the population works as traditional fishermen in Youtefa Bay, with the main catch being fish, shrimp, and crab. The fisheries sector is the backbone of the local economy, where the catch is sold directly to the local market or processed into ready-to-eat products. In addition, the community has also begun to utilize the potential of culture-based tourism as an alternative source of income. The uniqueness of local traditions, such as the existence of a "hutan perempuan" protected by customary law, is a tourist attraction that can be further developed. Some communities also manage handicraft businesses using local raw materials, such as wood and seafood. This potential shows great opportunities for economic diversification, although this sector still requires better infrastructure and marketing support. With this diversity of economic activities, the Tobati Village community can create a diverse economic foundation, although most still depend on the primary sector.

The supporting economic infrastructure in Tobati Village has made a positive contribution to community activities. The wooden walkway above the water, with a partial foundation of concrete and wood, extends for 145.69 meters and serves as the main connection between houses, facilitating community mobility and economic activities. A stable electricity network also allows small business operations to run smoothly. In terms of water sources, the community utilizes the network from the Regional Drinking Water Company (PDAM) and rainwater reservoirs for daily needs. However, the limited services of the PDAM network force the community to rely on rainwater that is only collected as needed or to buy clean water for daily activities such as cooking or processing seafood. In addition, access to local markets in Jayapura City via sea transportation allows the community to sell their products more widely. However, fluctuations in seafood catches due to the degradation of the mangrove ecosystem are a challenge that affects the stability of the community's economy. To improve economic sustainability, efforts are needed to diversify businesses, increase community capacity through entrepreneurship training, and support infrastructure such as more adequate docks to support the fisheries and tourism sectors.

4.7 Social Aspects

The Tobati Village community has a unique social structure, formed through a combination of tradition and adaptation to the dynamics of modernization. Social solidarity, which is one of the main strengths, is reflected in the culture of cooperation for activities such as building houses and repairing roads. Religious celebrations that are routinely held are important moments to strengthen relationships between residents and maintain social cohesion amidst changing times. One of the traditional traditions that is still maintained is the existence of a "hutan perempuan" (mangrove), which can only be entered by women (Elisabeth, 2019; Kadir et al., 2021; Hosio & Aquarista, 2022). This forest functions as an exclusive area for women to harvest marine products, with customary rules that protect the mangrove ecosystem and ensure the sustainability of marine resources. This tradition shows the important role of women in the village's social and economic systems while reflecting the harmony between local culture and environmental conservation. The Tobati local language is now used mainly by older community members. However, efforts to preserve the language have been carried out through the involvement of language translators, whose work has been documented and compiled into a book.

Access to education in Tobati Village is relatively adequate. Tobati State Elementary School, which is equipped with sea transportation to reach students, supports the community's basic education without significant obstacles. This school has eight teachers and 56 students who meet the educational needs according to the village's capacity. In terms of health, the available facilities are also considered adequate. One integrated health service post unit, according to the standards for one village, provides basic health services that operate routinely. For more complex health service needs, the community can access the health center outside Tobati Village using sea transportation, which allows them to get more complete services. This support provides a solid foundation for improving community welfare. With a combination of strong traditions and adequate social infrastructure support, the social aspects of Tobati Village show great potential to develop sustainably without losing their cultural identity.

4.8 Institutional Aspects

Institutions in Tobati Village play an important role in supporting community life, managing natural resources, and maintaining social and cultural sustainability. The institutional system in this village consists of two main elements: formal institutions and customary institutions, each of which has a significant role in managing community life and resources.

Formal Institution

Formal institutions in Tobati Village are represented by village government apparatus, such as the Village Head and the Village Consultative Body (Bamuskam). The Village Head is responsible for implementing local government policies, ensuring basic community services, and managing village development. Bamuskam functions as a community representative institution that provides input and control over village policies.

Tobati Village has two official administrative offices used for government activities and community meetings. In addition, several development programs, such as increasing access to clean water through PDAM, health services through integrated health service post, and education through Tobati State Elementary School, have had a positive impact on the community.

Customary Institutions

The customary institution in Tobati Village is led by Ondoafi, who has the authority to manage the social, cultural, and environmental aspects of the community. Ondoafi is responsible for maintaining customary law and preserving community traditions. One tradition that reflects the role of customary institutions is the existence of a "hutan perempuan", a mangrove area that can only be accessed by women to harvest marine products. This tradition not only reflects the value of local wisdom but also supports the sustainability of the ecosystem and strengthens the role of women in resource management.

Tobati Village is known for its customary rules, such as the Manjo Law (Tebaiy & Manan, 2018) which regulates the sustainable use of natural resources. However, the results of interviews with the community and village head in 2024 revealed that customary rules such as the Manjo Law are no longer applied or known. Most people only remember the practice of local wisdom that is not formalized as customary law, while the village head emphasized that there are no more customary rules applied in everyday life in the community. The loss of recognition of customary law is largely due to changes in community life patterns and the reduced influence of customary institutions in everyday practice. However, traditional values are still maintained through other customary practices, such as restrictions on the use of certain resources through informal community agreements.

Formal and customary institutions in Tobati Village make a significant contribution to supporting locally-based governance. The synergy between these two institutional systems enables resource management that is in line with local cultural values and modern needs. With close collaboration, Tobati Village can utilize the potential of tradition and customary law as part of sustainable governance policies. There is a great opportunity to formalize several relevant customary practices into formal policies, such as mangrove and marine product management based on community agreements. This approach can strengthen traditional values while supporting the environmental, social, and economic sustainability of the village.

This gap indicates a shift from customary-based governance to a formal system that has not been fully integrated. Papua Provincial Regulation No. 5 of 2022 does recognize the rights of indigenous peoples, but its implementation in Tobati Village is still limited (Kuddy & Lamba, 2022). To overcome this challenge, it is necessary to integrate local wisdom with formal governance through collaboration between indigenous peoples and government authorities. This step not only ensures environmental sustainability but also preserves the cultural values of Tobati Village amidst modernization.

5.0 CONCLUSIONS

This study evaluates the characteristics of settlements on water in Tobati Village, Papua, using an eco-settlement approach that includes ecological, social, economic, and institutional aspects. The results show that Tobati Village faces significant sustainability challenges, but also has great potential to become a model for sustainable coastal settlements by utilizing renewable technologies, strengthening local wisdom, and encouraging institutional collaboration.

Ecologically, Tobati Village relies on the mangrove ecosystem which is the main support for community life. However, land conversion, domestic waste pollution, and solid waste have caused serious environmental degradation. Technologies such as drones and GIS offer solutions to monitor mangrove conditions in real time so that rehabilitation steps can be carried out timelier. Rainwater harvesting technology has also made an important contribution to meeting the community's clean water needs, given the limited access to groundwater sources. In addition, domestic waste management through bio-digesters can reduce pollution and produce biogas and organic fertilizer, which have economic and ecological value.

From a social perspective, the Tobati Village community demonstrates the strength of solidarity through cooperation practices and traditions such as the “hutan perempuan”, where women play an important role in environmental conservation and natural resource management. Social infrastructure, such as schools and integrated health service post, have helped improve the quality of life of the community. However, further education on the importance of protecting the environment and efficient waste management is needed to raise community awareness of sustainability.

Economically, the majority of the Tobati Village community relies on the traditional fisheries sector. However, pressure from environmental degradation has affected the productivity of this sector. Economic diversification through the development of culture-based ecotourism is a promising solution. This potential can be supported by infrastructure such as piers and tourist facilities, as well as entrepreneurship training to develop craft products based on recycled waste. In addition, simple technologies such as solar-powered seafood dryers can increase the efficiency and income of fishermen.

The Tobati Village institution consists of complementary formal and customary systems. The formal system, led by the Village Head and Bamuskam, supports basic community administration and services, while the customary system led by the Ondoafi plays an important role in preserving traditions and managing resources based on local wisdom. Collaboration between these two systems can be strengthened by formalizing some relevant customary practices into formal policies, such as the management of “women’s forests” as a model for locally-based conservation. Ondoafi participation in formal decision-making can also strengthen more inclusive and sustainable governance.

To support the sustainability of Tobati Village, several strategic recommendations can be implemented. First, in the ecological aspect, the use of drones and GIS technology to monitor mangroves, expansion of rainwater harvesting systems, and implementation of bio-digesters for domestic waste management should be top priorities. Second, in the social aspect, community-based environmental education programs need to be improved, while cooperation practices can be directed to build integrated sanitation infrastructure. Third, in the economic aspect, the development of culture-based ecotourism and entrepreneurship training to utilize recycled waste can help diversify community income. Finally, in the institutional aspect, collaboration between formal and customary systems should be strengthened through the integration of traditions into formal policies.

This research contributes to the achievement of SDGs 6, 11, 12, and 13, by supporting efficient water and sanitation management, inclusive and sustainable settlement development, waste reduction, and climate change mitigation through mangrove ecosystem conservation. With this holistic approach, Tobati Village can become a model for resilient coastal settlements, improving the quality of life of the community, and protecting coastal ecosystems as a foundation for sustainability.

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