

Analysis Of Environmental Quality Of Settlements On Water Based On Eco-Settlement With Fuzzy Delphi, Case Study Of Tobati Village, Papua

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Abstract

Settlements on water represent coastal communities' adaptation to ecological conditions, yet they are vulnerable to environmental degradation, limited infrastructure, and the pressures of climate change. This study aims to evaluate the environmental quality of settlements on water in Tobati Village, Papua, using eco-settlement indicators to identify priority aspects that influence sustainability. This research applies a constructivist paradigm with a qualitative case study approach, combined with the Fuzzy Delphi Method (FDM) to achieve expert consensus. Data were obtained through field observations, in-depth interviews with traditional leaders, village heads, and stakeholders, and supported by literature studies. Analysis was conducted through thematic coding with NVivo, then validated using FDM to ensure the relevance and priority of the identified aspects. The results indicate six main dimensions that influence the environmental quality of settlements: ecology, economy, socio-culture, institutions, infrastructure, and technology. The dominant ecological factor is the role of mangroves as a natural buffer, while socio-culturally, local wisdom such as "women's forests" and mutual cooperation support conservation. Conversely, weak institutional synergy, limited sanitation, and a lack of appropriate technology are the main obstacles. This study confirms that the FDM-based eco-settlement approach is capable of producing priority aspects that are both contextual and strategic, with implications for sustainable coastal settlement management policies in Papua and similar coastal areas.

Keywords: environmental quality, settlements on water, eco-settlement, Tobati Village, Papua.

INTRODUCTION

Environmental quality is the ability of an environment to meet the criteria for good housing so that it is suitable for its residents to live in (Ridwan & Giyarsih, 2012). The quality of a residential environment reflects the conditions of survival and well-being of the community, which are influenced by objects, conditions, living things, and their behaviour. According to Setiawan, D., et al., (2017), environmental quality can be reviewed from several aspects, namely contextual (natural characteristics, comfort, security, location, accessibility), spatial (architectural, building size, spatial organization), social (community profile and interaction, social integration, socio-administrative organization), and economic (ability to own a residence, permanent ownership, and residential preferences). Thus, the quality of a residential environment is determined by aspects of comfort, security, accessibility, spatial, social, and economic.

The underdevelopment of coastal communities contrasts with the vast potential of coastal resources they possess, reflected in the behaviour of fishermen in managing these resources. Utilisation based on the principle of sustainability is expected to ensure the availability of resources for current and future generations (Huda & Sari, 2017). However, resource management often faces a gap between long-term conservation and the interests of exploitation by powerful investors. Fishermen's behaviour is influenced by internal and external factors; positive behaviour tends to follow economic and conservation principles, while negative behaviour involves destructive activities that damage the environment. The potential of the marine sector should be able to improve people's welfare, but in reality, coastal communities are still trapped in poverty, both culturally and structurally (Kusnadi et al., 2008), partly due to the low responsibility of those exploiting marine resources. On the other hand, degradation of coastal ecosystems due to environmentally unfriendly fisheries exploitation also worsens the situation. Coastal communities, especially fishermen, continue to face ecological, social, and economic problems that cause them to be left behind (Hasbiah, 2023). Mangrove

ecosystems and coastal areas are even targeted for resource extraction by economically driven development projects, which increase financial benefits while increasing damage. Therefore, the use of natural resources must be in accordance with local laws and customary laws to ensure equitable development and improve the quality of life for communities.

The mangroves around Tobati Village, Youtefa Bay, continue to degrade, with a loss of 278.12 hectares between 1967 and 2017. This demands stricter law enforcement, given that the area is a Nature Tourism Park (Hamuna & Tanjung, 2018). Furthermore, plastic pollution and declining fish diversity have led to reduced catches and increasingly remote fishing grounds, increasing operational costs (Kalor et al., 2021); (Indrayani et al., 2023). Other environmental damage includes coastal abrasion, mangrove forest destruction, water pollution, coral reef damage, and housing and air quality issues (Alfons, 2018). This damage is triggered by natural factors such as wind, waves, and soil structure, as well as human activities such as landfilling, deforestation, the use of destructive fishing gear, and domestic waste disposal. Aspects influencing the quality of the residential environment in Tobati include ecological, socio-cultural, economic, and institutional dimensions as indicators of eco-settlement (Dewi et al., 2019). The ecological dimension encompasses air quality, water quality, healthy housing, land use, and environmentally friendly technology; the social dimension highlights community capacity and empowerment; the cultural dimension emphasizes local wisdom in resource management; the economic dimension relates to welfare, housing affordability, and a healthy environment; while the institutional dimension encompasses institutional capacity, policy support, and the role of customs. Various studies show that indicators of residential environmental quality vary, encompassing socio-economic, cultural, political, climate, health and housing conditions, market value, resident experience, and infrastructure availability (Krisandriyana et al., 2019 ; Murtiono et al., 2021 ; Septanti, 2023 ; Muthmainah et al., 2019 ; Fitri, 2021). Local wisdom and the existence of customary law in Tobati are important additional indicators. The aim of this research is to evaluate these aspects to understand the factors that influence the environmental quality of settlements above water, so that they can form the basis for sustainable settlement development and management strategies.

THEORETICAL REVIEW

a) Residential Environmental Quality

Environmental quality is the ability of an environment to meet the criteria for good housing so that it is habitable (Ridwan & Giyarsih, 2012 ; Kurniadi, 2014) . According to (Hamidah et al., 2017) , the quality of a residential environment can be seen from contextual aspects (comfort, security, location, accessibility), spatial (architecture, size, spatial organisation), social (community profile and interaction, social integration, social organization), and economic (housing ownership, affordability, housing preferences). In general, environmental quality is influenced by physical factors (air, water, land, houses, roads, vehicles) and non-physical (social, economic, cultural, political). However, population growth and living needs often reduce the quality of settlements due to limited land.

In coastal areas, community underdevelopment contrasts with the vast potential of their resources. Fishermen's behaviour in managing coastal resources is key; sustainable utilisation is expected to ensure sustainability. However, there is a gap between long-term conservation interests and exploitation by powerful investors. Fishermen's behavior is influenced by internal and external factors: positive behaviour follows conservation principles, while negative behavior damages the environment. Although the marine sector has the potential to improve welfare, coastal communities remain trapped in structural and cultural poverty (Gustika et al., 2023) , exacerbated by marine ecosystem degradation and low accountability from exploiters. Community ignorance also poses a challenge to strengthening local livelihood strategies and wisdom. This condition leads to ecological, social, and economic underdevelopment (Mulyati et al., 2024) . Furthermore, economically oriented development projects also put pressure on coastal and mangrove ecosystems, so natural resource utilisation must be accompanied by local regulations and customary laws for more equitable and sustainable development. *Eco-settlement criteria*.

This research draws on studies of *eco-settlement indicators* established by the Housing and Settlement Law and research conducted in several cities and countries. This concept is also linked to environmental quality factors in coastal settlements, resulting in the removal of several criteria and the addition of others. A more detailed summary of the indicators used in the research is presented in Table 1 below:

Table 1 Synthesis of Eco-settlements Criteria

No	Eco-settlement aspects	Criteria
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1.	Ecology	- Environmental Quality - Healthy home - Land use - Infrastructure
2.	Socio-cultural	- Community capacity (education, participation, habits, customs) - community empowerment
3.	Economy	- Technological innovation - Local economic development (employment opportunities, increased welfare/income) - Accessibility (transportation)
4.	Institutional/institutional capacity	- Cooperation between stakeholders - Support for government policies and customary institutions

Source: summarised from Puslitbangkim, 2006

RESEARCH METHODS

1. Research Approach

The approach used was a qualitative one with an instrumental case study to explore in depth the aspects that influence the environmental quality of the settlements above the water in Tobati Village based on eco-settlement indicators. This approach was chosen because it is suitable for understanding contextual phenomena comprehensively by considering social, ecological, and institutional aspects in the actual conditions of the community (Yin, 2018).

Qualitative research, as a *human instrument*, functions to determine the focus of the research, select informants as data sources, assess data quality, analyse data, interpret data and draw conclusions from the findings (Sugiyono, 2013). Research requires several instruments to obtain valid data. In this research, the researcher acts as both a data collector and an active instrument in the field. In qualitative research, the researcher holds a unique role: as planner, data collector, analyst, data interpreter, and reporter of research results (LJ Moleong, 2010).

2. Determination of Informants

The informant selection technique used purposive sampling, which selects informants based on specific considerations, such as those considered to be the most knowledgeable or authoritative, thus facilitating researchers' understanding of the social situation (Sugiyono, 2013). Informant selection also utilizes stakeholder analysis to understand the social and institutional context of a policy or program (Rietbergen-McCracken & Narayan, 1998). This analysis helps identify influential stakeholders relevant to the research field.

In this study, the evaluation of aspects affecting the environmental quality of settlements in Tobati Village involved stakeholders from the government and academia. From the government side, informants included the Jayapura City Environmental Agency and Housing and Settlement Agency. From the academic side, they included experts in traditional settlements, environmental engineering, urban design, environmental management, environmental chemistry, sanitation infrastructure, indigenous planning, and government and public policy. The stages of *stakeholder analysis* can be seen in the figure below:

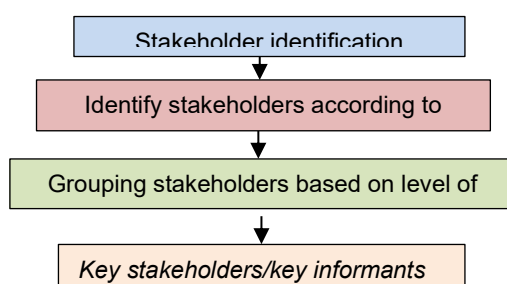


Figure 1. Stakeholder Analysis Stages

Source: Jaya et al., 2015

3. Research Location

The location of this research is in the Tobati Village settlement, which is located in the Youtefa Bay area, Jayapura City, Papua Province.



Figure 2. Administrative Map of Tobati Village

Source: 2023 village boundaries, 2024 ARCGIS data processing

4. Data collection technique.

Data collection was conducted based on its *setting*, namely the natural setting in the study area of the Tobati Village settlement. The data collection techniques in this study were:

- Observation. Observation is used to study human behavior, work processes, and natural phenomena through direct observation without standard tools (Sugiyono, 2013). Observations were conducted in a structured manner according to the research objective of determining the characteristics of the water settlements in Tobati Village based on eco-settlement criteria. Data were obtained through visualization of physical conditions such as roads, environmental infrastructure, drainage, and waste with the aid of a camera.
- *In-depth interviews*: The interview method used was a semi-structured interview to explore the issues more openly, using an interview guide as a reference (Sugiyono, 2013). Discussions were conducted with experts and relevant stakeholders to obtain empirical information regarding aspects that influence the environmental quality of the settlements above the water in Tobati Village according to eco-settlement indicators. The tools used included a question guide, a voice recorder, and written notes.
- Literature study, data derived from literature surveys or bibliography, including those relevant to water settlements with the *eco-settlement concept*. Literature sources include journals, books, research results, and spatial planning documents.

5. Data Analysis Techniques

The analysis was conducted in two stages. First, data from observations, interviews, and literature were analyzed using NVivo through open coding, axial coding, and selective coding to generate thematic categories. These categories were mapped into ecological, social, economic, and institutional dimensions according to eco-settlement indicators, resulting in settlement characteristics. In the second stage, the obtained characteristics were formulated into a Fuzzy Delphi Method (FDM) instrument. FDM is a collective decision-making method (Habibi et al., 2015) with the advantages of time efficiency, guaranteed consensus results, and reduced bias. Its main principles include anonymity, feedback, statistical analysis, and convergence of expert opinion. In this study, FDM was used to identify and validate aspects that influence the environmental quality of settlements above the water in Tobati Village based on eco-settlement indicators.

Data analysis using the Fuzzy Delphi Method (FDM) was carried out in several stages ((Alqahtani et al., 2023)

- 1) Analyze the characteristics of settlements in Tobati Village from observations, interviews, and literature to formulate an expert response form.
- 2) Conduct initial iterations by removing duplications, combining similar findings, and adding relevant aspects from the literature.
- 3) Determine expert panelists through stakeholder analysis.
- 4) Formulate a Delphi instrument in the form of a list of statements of aspects that influence the environmental quality of settlements above water.
- 5) Distribute the instrument to experts (first round) via WhatsApp or in person, then analyze the responses based on a five-point rating scale (strongly agree–strongly disagree) to determine the initial consensus and statements that need revision.

Table 2. Fuzzy Scale of the Likert Scale 5

Scale of approval	Fuzzy Scale		
5	0.6	0.8	1
4	0.4	0.6	0.8
3	0.2	0.4	0.6
2	0	0.2	0.4
1	0	0	0.2

Source: Habibi et al., 2015

6) In the FDM analysis stage, expert answers were tabulated and calculated using an Excel formula to obtain the average value of m_1 , m_2 , m_3 , m_1 , m_2 , m_3 . The results were used in the **defuzzification (Si) process**, which averaged the three values to produce a single score compared to a *threshold* of 0.5. Factors with $S_i < 0.5$ were eliminated, while $S_i \geq 0.5$ were accepted as expert consensus. Next, a **second round of Delphi was conducted** with a revised instrument to test consistency and strengthen opinion convergence. The assessment used a **5-point fuzzy scale (Likert)** from strongly agree to strongly disagree.

RESULTS AND DISCUSSION

The initial stage of the research identified the characteristics of the Tobati Village water settlement based on eco-settlement criteria, which were grouped into main, strong, and weak characteristics based on observations and literature. These characteristics were compiled in a Delphi instrument containing closed-ended questions and open-ended responses to validate expert views and explore new aspects. Data were analyzed using the Fuzzy Delphi Method to gauge consensus and rank the importance of aspects, resulting in a list of validated aspects as the basis for settlement management strategies.

Primary data were obtained through observations of physical conditions, spatial planning, infrastructure, and social interactions; interviews with traditional leaders, village heads, and residents; and literature studies to strengthen the findings. Analysis was conducted using NVivo through open coding (meaning units), axial coding (theme relationships), and selective coding (final categories). All results were mapped into ecological, economic, social, and institutional dimensions according to eco-settlement indicators. The results of the analysis using NVivo produced three categories of settlement characteristics above the water in Tobati Village, namely:

1) **Key Characteristics.** The Tobati Village water settlement is a traditional area deeply tied to the coastal ecosystem and socio-customary order. Its main characteristics are evident in the connection of community life practices to ecological (especially mangrove) and socio-cultural conditions: there is a tradition of "women's forests" and customary prohibitions on the use of marine resources; air quality is relatively good; local materials are used in house construction; and women play a role in the household economy. On the other hand, clean water distribution is uneven, sanitation is inadequate, and environmentally friendly technologies have not been implemented, thus remaining a challenge to ecological sustainability. From a socio-economic perspective, the community remains dependent on marine resources through a diversification of jobs (fishermen, sea taxis, craftsmen, tourism businesses), supported by social capital (mutual cooperation, religious activities), and the role of traditional leaders and village heads. However, participation in planning is uneven, cooperatives/local economic institutions do not exist, and traditional knowledge has not been systematically documented. Customary institutions are recognized and functioning, but have not been fully integrated into formal laws and spatial planning policies, so management strategies need to be holistic-participatory, based on local wisdom, and adaptive to environmental and climate change.



Figure 3. Existing settlements above the water in Tobati Village

Source: documentation, 2025

2) Strong Characteristics (Supporting Eco-Settlement Principles), consisting of:

- Ecological aspects. The existence of "women's forests" and customary maritime prohibitions maintain coastal ecosystems; air quality is good; the use of local materials and customary practices is still maintained; garbage collection boats are available, and recycling training has been conducted, albeit limited.

- Economic aspects. There is diversification of livelihoods based on local resources, as well as the utilization of local potential and sea access for economic activities (e.g., seafood, parking businesses, small-scale coastal land rentals).

- Social aspects. Strong social capital (mutual cooperation, customary participation); the inheritance of local knowledge is still alive; women are active in household businesses; and empowerment occurs informally.

- Institutional aspects. There is awareness of inheritance rights and customary land management; women's role in resource management is recognized; regular musrembang (development planning meetings) are held; collaboration between village heads and Ondoafi (village leaders) in decision-making; top-down financial support is available; and women play a significant role in "women's forests" through the transmission of oral knowledge.

2) Weak Characteristics (Requires Intervention), consisting of:

- Ecological aspects. There has been a decline in mangrove area ($\pm 209,000 \text{ m}^2$) due to development and climate change; limited PDAM water distribution; domestic waste is dumped directly into the sea, resulting in poor sanitation; low building insulation with high daytime temperatures and low wind speeds; no sustainable waste management system; no environmentally friendly technology (dependence on PLN); and waste from rivers pollutes the village's waters.

- Economic aspects. Income is unstable; sea transportation, as the primary mode of transportation, is not yet supported by adequate infrastructure (high fuel costs, inadequate docks); and access to skills training remains limited.

- Social aspects. Young people's involvement in traditional customs is low; participation in musrembang (development planning meetings) is uneven (community involvement is still elitist); social inclusion and education based on local socio-cultural principles are needed.

- Institutional aspects. There is no formal recognition of customary territories; there is a lack of synergy between customary and formal leadership; there is overlap between customary rules and formal regulations; the implementation of the RTRW and Perdasi is not yet in sync with the reality on the ground; the inheritance of knowledge is not documented (still oral); and there is minimal legal protection for indigenous communities in spatial planning and there is no clear collaboration mechanism between parties.

The next research stage is iteration, where researchers conduct initial iterations of all the characteristics obtained from field observations, in-depth interviews, and literature reviews. This process aims to produce a more structured list of aspects ready for validation by a panel of experts. The initial iteration steps include:

- Comprehensive Characteristics Review. Researchers re-examine all characteristics that have been categorized into ecological, economic, social, and institutional dimensions.

- Duplication Removal. Characteristics that have identical meanings are removed to avoid unnecessary repetition.

- Combining Similar Findings. Characteristics that have a substantive relationship are combined into one more comprehensive aspect.

- Eliminate Irrelevant Aspects. Aspects that do not support the research focus or are not verified from primary or secondary sources are removed from the list.

- Additional Aspects Based on Academic Literature. Researchers added aspects that are theoretically important for eco-settlement-based water settlement management but have not been explicitly identified in the field. These additions are supported by valid academic sources, thus enriching the initial list of aspects.

The results of this initial iteration are a list of selected aspects that represent the actual conditions of Tobati Village while meeting theoretical criteria. This list will then be used to develop a Delphi instrument for validation by a panel of experts in the next stage.

The next stage was to formulate the Delphi instrument. After the list of selected aspects was obtained through initial iterations and the selection of panelists, the next stage was to formulate the Delphi instrument in the form of an expert response form. This instrument contained statements representing aspects that influence the environmental quality of the settlements above the water in Tobati Village, which had previously been compiled based on the results of field characteristic analysis and strengthening of academic literature. The expert response form was designed to facilitate panelists in providing assessments, views, and input on each

In the first round of Fuzzy Delphi Method (FDM) analysis, the panellists' assessment of the list of environmental quality aspects of the Tobati Village water settlements showed that most aspects had reached sufficient consensus, both based on the threshold value (d) and the recommended consensus percentage ($\geq 75\%$). However, the panellists' assessment of the environmental quality aspects of the Tobati Village water settlements showed that aspects coded E12 and EM2 had not yet reached consensus. Aspect E12 is part of the ecological dimension with the statement: "Experience and risk of disasters such as tsunamis influence the vulnerability of the settlement environment and the need for adaptation of environmental design and planning." This aspect emphasises how previous disaster events—such as the 2011 tsunami—and the potential for future disasters can affect the environmental vulnerability of settlements above water, and encourage the implementation of adaptive design and planning. Based on the FDM results, the threshold value (d) for E12 is 0.388889, exceeding the established limit (≤ 0.2), and the consensus percentage is only 21.931%, far below the minimum agreement limit ($\geq 75\%$). This indicates a significant difference of opinion among the panellists, both in assessing the urgency and relevance of this aspect to the context of settlement management in Tobati Village. Some panellists considered that the urgency of this aspect was still relatively low when compared to other environmental issues that were more directly felt by the community, while other panellists emphasised the importance of this aspect because past disasters had had a significant impact on the physical condition of settlements.

Meanwhile, aspect EM2 is included in the economic dimension with the statement: "Limited market access for capture fishery products affects the income of fishing communities and the sustainability of the local economy." This aspect highlights barriers to distribution and market access for seafood as one of the issues that can affect the economic sustainability of fishing communities in Tobati Village. The FDM results show that EM2 has a threshold value (d) of 0.805556, which also exceeds the agreement limit, and the consensus percentage is only 15.9571%. Several panellists considered that the capture fisheries sector is no longer the main livelihood for most residents, so limited market access is no longer a strategic issue. Conversely, other panellists argued that although its contribution has decreased, this sector is still relevant for certain community groups, especially traditional fishermen.

The failure of these two aspects to reach consensus in the first round was the basis for proceeding to the second round of the Delphi questionnaire. The goal was to provide the panellists with an opportunity to review their assessments after receiving feedback on the distribution of assessments in the first round, thus hopefully achieving a higher level of understanding. Furthermore, the panellists provided input that can be used as a basis for developing a management strategy for the Tobati Village water settlement. The panellists' input in this round provided a more comprehensive picture of field conditions and potential instrument improvements. Some key points from the input contained in the first round's statement form include:

- Pollution in Youtefa Bay does not solely originate from residential activities on the water, but is also influenced by waste from the surrounding land areas.
- *Rainwater harvesting* technology to overcome limited access to clean water.
- The existence of citizen communication forums is informal in nature, but has the potential to be strengthened to become part of formal environmental management institutions.
- The low level of community participation in environmental activities is thought to be influenced by minimal outreach from relevant parties.
- The need for the separation of waste and liquid waste management indicators to facilitate evaluation.
- Addition of indicators of public awareness and compliance with environmental regulations.
- The importance of maintaining the sustainability of mangrove vegetation as a natural barrier against abrasion and seawater intrusion.
- Proposal for the development of a communal sanitation system that is appropriate to the characteristics of settlements on water.

2. Second round of the Delphi process

The second round of Delphi analysis was conducted as a follow-up to the results of the first round, where most aspects had achieved an adequate level of consensus according to the Fuzzy Delphi Method (FDM) criteria. However, there were two aspects, namely E12 and EM2, which had not met the consensus threshold (threshold ≤ 0.2 and consensus percentage $\geq 75\%$). The threshold value for E12 was 0.388889 and for EM2 was 0.805556, while the consensus percentages only reached 21.93% and 15.96%, respectively. This indicates that there are quite significant differences in views among the panellists regarding the relevance or urgency of

these two aspects in the framework of improving the environmental quality of settlements above the water in Tobati Village.

In the second round, statements E12 and EM2 were sent back to the panellists for re-evaluation. The panellists were given the opportunity to consider the aggregate results of the first round of assessments, input from other panellists, and supporting academic references. The goal was to achieve alignment of views, thereby achieving a higher level of consensus, or at least narrowing the range of differences in assessments among the experts and stakeholders involved.

The Second Delphi Round was conducted to re-evaluate two aspects that had not reached consensus in the first round, namely E12 (Potential tsunami disaster risk on settlement sustainability) and EM2 (Community access to markets for economic activities). This re-evaluation was conducted to clarify differences in views among panellists and ensure understanding of the urgency of each aspect in the context of the environmental quality of settlements above the water in Tobati Village. The results of the analysis showed that in the second round, aspect E12 had a \bar{d} value of 0.18416 and a defuzzification value of 0.74074, which means it had met the consensus limit and was agreed upon as an important aspect. Has reached a positive consensus, which means the majority of panellists agreed that the potential tsunami disaster risk is an important aspect that needs to be considered in settlement management and planning. This view strengthens awareness of the importance of disaster mitigation and community preparedness, even though tsunami events are rare, because of their very large impact on settlement sustainability.

Aspect EM2 has also reached consensus; the calculation of the EM2 aspect shows a \bar{d} value of 0.19853 and a defuzzification value of 0.49074. However, a negative consensus was formed. This means that most panellists agreed that community access to markets is not a top priority in influencing the quality of residential environments. This assessment is based on the view that community economic constraints are more influenced by other factors, such as limited capital, skills, and business opportunities, rather than solely by proximity or connection to markets. Thus, the results of the second round confirmed that of the two aspects that initially lacked consensus, only E12 is considered a high priority, while EM2 is considered less urgent to be included in the main strategy for improving the quality of residential environments in Tobati Village.

Aspect E12 will be a key component of the threats component of the AWOT analysis phase, focusing on disaster mitigation and adaptation. Conversely, EM2 (market access), although consensus has been reached, was agreed to be negative and therefore not included in the list of strategic priority aspects. However, this aspect remains relevant for consideration in long-term supporting policies, particularly if a more comprehensive local economic strengthening program is implemented in the future.

The following is the second round of the Delphi analysis table :

Table 4. Results of the Second Round of Calculations of the Fuzzy Delphi Method (FDM) for the Assessment of Environmental Quality Aspects of Settlements Above Water in Tobati Village

Q	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	(mean a)	(mean b)	(mean c)	d_P1	d_P2	d_P3	d_P4	d_P5	d_P6	d_P7	d_P8	d_P9	d_P10	d_P11	avg distan	Konsensus (<0.2)					
E1	5	4	5	5	3	5	5	5	5	5	5	0,681818	0,916667	0,972222	0,0642	0,143303	0,0642	0,0642	0,369441	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,09914	Konsensus	
E2	5	5	5	5	5	3	3	5	5	5	5	0,659091	0,888889	0,944444	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,088875	0,135384	Konsensus
E3	5	3	5	5	4	5	5	5	5	5	5	0,681818	0,916667	0,972222	0,0642	0,369441	0,0642	0,0642	0,143303	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,0642	0,09914	Konsensus	
E4	5	4	5	5	4	4	5	5	5	5	5	0,659091	0,888889	1	0,082886	0,121929	0,082886	0,082886	0,121929	0,082886	0,121929	0,082886	0,121929	0,082886	0,121929	0,082886	0,082886	0,082886	0,097083	Konsensus		
E5	4	4	5	4	4	5	5	5	5	5	4	0,613636	0,861111	1	0,091759	0,091759	0,112376	0,091759	0,091759	0,112376	0,091759	0,112376	0,112376	0,112376	0,112376	0,091759	0,10113	Konsensus				
E6	4	3	4	4	3	4	4	5	5	5	4	0,5	0,75	0,944444	0,032075	0,232958	0,032075	0,032075	0,232958	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,100336	Konsensus		
E7	4	3	3	5	4	4	4	4	5	5	4	0,5	0,75	0,944444	0,032075	0,232958	0,032075	0,032075	0,232958	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,032075	0,116205	Konsensus			
E8	5	4	5	5	4	5	4	5	5	5	5	0,666667	0,916667	1	0,068041	0,136083	0,068041	0,068041	0,136083	0,068041	0,136083	0,068041	0,068041	0,068041	0,068041	0,068041	0,068041	0,068041	0,086598	Konsensus		
E9	4	2	5	5	3	3	4	5	5	5	4	0,522727	0,772727	0,909091	0,05567	0,487799	0,192847	0,192847	0,240881	0,240881	0,05567	0,192847	0,192847	0,192847	0,192847	0,192847	0,05567	0,190982	Konsensus			
E10	5	3	5	5	4	3	4	5	5	5	5	0,583333	0,833333	0,944444	0,139812	0,29441	0,139812	0,139812	0,075223	0,29441	0,075223	0,139812	0,139812	0,139812	0,139812	0,139812	0,139812	0,139812	0,156177	Konsensus		
E11	3	2	5	5	4	4	5	5	5	5	5	0,555556	0,805556	0,916667	0,267399	0,513451	0,165893	0,165893	0,066124	0,066124	0,165893	0,165893	0,165893	0,165893	0,165893	0,165893	0,165893	0,165893	0,188577	Konsensus		
E12	4	2	5	5	3	4	4	5	5	5	5	0,527778	0,777778	0,916667	0,05319	0,493528	0,187714	0,187714	0,246373	0,05319	0,05319	0,187714	0,187714	0,187714	0,187714	0,187714	0,187714	0,187714	0,18416	Konsensus		
EM1	3	3	4	4	3	4	4	5	5	5	5	0,444444	0,694444	0,916667	0,185648	0,185648	0,066124	0,066124	0,066124	0,185648	0,066124	0,066124	0,066124	0,254082	0,254082	0,254082	0,254082	0,149983	Konsensus			
EM2	3	2	3	3	2	3	2	4	5	5	4	0,225	0,5	0,722222	0,016038	0,241097	0,016038	0,016038	0,241097	0,016038	0,241097	0,25959	0,438619	0,438619	0,25959	0,25959	0,198533	Konsensus				
EM3	3	4	4	4	3	4	3	5	5	5	4	0,472222	0,722222	0,916667	0,20538	0,05319	0,05319	0,05319	0,20538	0,05319	0,20538	0,231852	0,231852	0,231852	0,05319	0,143423	Konsensus					
EM4	4	3	4	4	4	4	3	3	5	5	4	0,444444	0,694444	0,916667	0,066124	0,185648	0,066124	0,066124	0,066124	0,185648	0,066124	0,185648	0,254082	0,254082	0,066124	0,132896	Konsensus					
S1	5	5	5	5	5	3	3	5	5	5	4	0,611111	0,861111	0,944444	0,117851	0,117851	0,096225	0,117851	0,117851	0,315495	0,315495	0,117851	0,117851	0,117851	0,117851	0,117851	0,096225	0,149854	Konsensus			
S2	5	5	5	5	4	5	3	4	5	5	4	0,638889	0,888889	0,972222	0,092128	0,092128	0,092128	0,092128	0,114531	0,092128	0,342467	0,092128	0,092128	0,092128	0,092128	0,092128	0,114531	0,120996	Konsensus			
S3	5	4	4	4	4	3	4	5	5	5	4	0,555556	0,805556	0,972222	0,159571	0,048113	0,048113	0,048113	0,048113	0,280542	0,048113	0,159571	0,159571	0,159571	0,159571	0,048113	0,109773	Konsensus				
S4	5	4	4	5	2	4	5	5	5	5	4	0,583333	0,833333	0,944444	0,139812	0,075223	0,075223	0,139812	0,541013	0,139812	0,075223	0,139812	0,139812	0,139812	0,139812	0,075223	0,152798	Konsensus				
S5	5	3	5	5	5	4	4	5	5	5	5	0,583333	0,833333	0,944444	0,139812	0,29441	0,139812	0,139812	0,29441	0,139812	0,075223	0,075223	0,139812	0,139812	0,139812	0,139812	0,156177	Konsensus				
S6	5	4	5	4	4	4	5	5	5	5	5	0,638889	0,888889	1	0,090722	0,113402	0,090722	0,113402	0,113402	0,090722	0,113402	0,090722	0,090722	0,090722	0,090722	0,090722	0,113402	0,098969	Konsensus			
S7	5	5	5	5	4	4	4	5	5	5	4	0,638889	0,888889	1	0,090722	0,090722	0,090722	0,113402	0,090722	0,113402	0,113402	0,113402	0,113402	0,090722	0,090722	0,113402	0,101031	Konsensus				
S8	5	3	5	4	4	4	3	5	5	5	5	0,555556	0,805556	0,944444	0,161971	0,273579	0,055556	0,161971	0,055556	0,161971	0,055556	0,273579	0,161971	0,161971	0,161971	0,161971	0,152421	Konsensus				
L2	5	5	5	5	4	4	5	5	5	5	5	0,611111	0,861111	0,972222	0,114531	0,321551	0,114531	0,092128	0,114531	0,092128	0,092128	0,114531	0,114531	0,114531	0,114531	0,114531	0,127241	Konsensus				
L3	5	5	5	2	3	4	5	5	5	5	4	0,583333	0,833333	0,944444	0,144338	0,144338	0,144338	0,144338	0,533594	0,288675	0,083333	0,144338	0,144338	0,083333	0,083333	0,181754	Konsensus					
L4	4	3	4	5	3	4	4	5	5	5	4	0,472222	0,722222	0,916667	0,05319	0,20538	0,05319	0,231852	0,20538	0,05319	0,05319	0,231852	0,231852	0,05319	0,143423	Konsensus						
L5	5	4	5	4	5	4	4	5	5	5	4	0,638889	0,888889	1	0,090722	0,113402	0,090722	0,113402	0,090722	0,113402	0,090722	0,113402	0,090722	0,113402	0,113402	0,113402	0,101031	Konsensus				
L6	4	2	5	4	4	4	5	5	5	5	5	0,527778	0,777778	0,944444	0,039284	0,501541	0,184257	0,039284	0,039284	0,039284	0,039284	0,184257	0,184257	0,184257	0,184257	0,184257	0,147204	Konsensus				
L7	4	3	5	5	2	4	4	5	5	5	5	0,527778	0,777778	0,916667	0,05319	0,246373	0,187714	0,187714	0,493528	0,05319	0,05319	0,187714	0,187714	0,187714	0,187714	0,18416	Konsensus					
L8	4	4	5	3	4	4	4	5	5	5	4	0,555556	0,805556	0,972222	0,048113	0,048113	0,159571	0,159571	0,280542	0,048113	0,048113	0,048113	0,048113	0,159571	0,159571	0,048113	0,109773	Konsensus				
HL1	4	3	4	5	2	4	4	5	5	5	4	0,5	0,75	0,916667	0,048113	0,225668	0,048113	0,209718	0,473853	0,048113	0,048113	0,048113	0,209718	0,209718	0,048113	0,048113	0,147032	Konsensus				
HL2	5	5	5	5	3	4	5	5	5	5	5	0,666667	0,916667	0,972222	0,069066	0,069066	0,069066	0,069066	0,363595	0,069066	0,137025	0,069066	0,069066	0,363595	0,069066	0,129406	Konsensus					
HL3	3	3	4	4	4	4	5	5	5	5	4	0,555556	0,805556	0,972222	0,048113	0,280542	0,159571	0,048113	0,048113	0,048113												

Conclusion

Based on two rounds of Delphi analysis, all aspects of the environmental quality of the Tobati Village water settlement were validated by cross-disciplinary experts. The majority of aspects received positive consensus as priority components, except for market access for seafood, which was eliminated. Tsunami risk only reached consensus in the second round. This final list of aspects served as the basis for formulating a sustainable settlement management strategy using an eco-settlement approach. The following is a synthesis of the analysed aspects per dimension:

1) Ecological Dimension

The environmental quality of Tobati's waterfront settlements is influenced by the natural ecosystem and surrounding environmental pressures. Mangrove forests act as a natural buffer, but pollution from waste, poor sanitation (domestic waste discharged directly into the sea), and limited access to clean water degrade the ecological quality and public health. Coral reefs are damaged, stilt houses with minimal ventilation and zinc roofs reduce thermal comfort, while the construction of a ring road exacerbates mangrove degradation.

Local initiatives like "women's forests" support conservation, but climate change increases the risk of tidal flooding and sea level rise, threatening the resilience of settlements. The threat of tsunamis also increases vulnerability, making adaptations to building design and disaster-resilient planning essential to ensure the sustainability of settlements.

2) Economic Dimension.

Economically, the main challenge in Tobati is the low business capacity of residents due to a lack of training and limited transportation access to the main market. Despite this, the community has developed informal economic diversification, such as motorcycle taxis, food stalls, and tourist lodges, which support economic resilience while preserving environmental quality. However, limited market access and transportation continue to limit income growth and investment in residential improvements.

3) Socio-Cultural Dimensions

The socio-cultural dimension of Tobati is determined by community awareness, customary practices, and environmental education. Ecological awareness, the role of the younger generation, documentation of local wisdom, and women's involvement strengthen the effectiveness of environmental management. The culture of mutual cooperation and environmental education enhances collective participation, while the customary inheritance rights system provides certainty of living space and influences the direction of settlement development.

4) Institutional and Leadership Dimensions

The institutional dimension in Tobati is characterised by weak synergy between village heads and ondoafi, minimal enforcement of regulations, and the absence of specific customary regulations related to the environment. Coordination between stakeholders is low due to the lack of regular communication forums, while community participation in development decisions is also limited. The lack of synchronisation between government agencies and the unrecognised status of customary villages weakens the protection of local wisdom. Overlapping customary and formal regulations further diminish the effectiveness of environmental management.

5) Infrastructure and Environmental Dimensions

Tobati's infrastructure and facilities influence the quality of settlements through the physical condition of dwellings and basic facilities. Concrete foundations increase stability but reduce flexibility and potentially damage aquatic ecosystems. Low-quality house construction with minimal ventilation and lighting, coupled with the use of less adaptable modern materials, makes housing uncomfortable and less durable. The absence of floating landfills (TPS), waste banks, and communal sanitation facilities causes household waste to pollute the sea and pose health risks. Conversely, the adaptation of stilt houses to the tides supports environmental resilience and housing quality. Technology and Innovation Dimension

In terms of technology, the low level of adoption of appropriate innovation in environmental management is a major concern. The application of appropriate technology in Tobati Village is still minimal, resulting in suboptimal efforts to improve energy efficiency, water conservation, and residential sustainability. The lack of local innovation in domestic and household waste management also contributes to the ongoing high level of environmental pollution and the low effectiveness of the current waste management system. This underscores the need for further support and development in technology and environmental innovation to ensure sustainable and resilient management of the Tobati waterfront settlements in the future.

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