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Adaptive Stilt Housing and Socio-Ecological Resilience in Coastal Settlements Under Urbanization Pressure

Idawarni Asmal [1, 2*], Arina Hayati [3], Sri Suryani [4], Nurul Nadjmi [1, 2]

[1] *Architecture Department, Engineering Faculty, Hasanuddin University, Gowa 92172, Indonesia.*

[2] *Infrastructure Planning Engineering, Postgraduate Hasanuddin University, Makassar 90245, Indonesia.*

[3] *Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia.*

[4] *Labtek UITB Jl. Ganesha No. 4 Bandung 40132, Indonesia.*

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Abstract

The water-based settlement of Cambayya, Makassar, represents a spatial adaptation by coastal communities facing urbanization, land scarcity, and dynamic marine conditions. High population density has driven the organic growth of informal stilt housing over coastal waters. This study examines spatial adaptation strategies that foster socio-ecological resilience in densely populated coastal environments. Utilizing a mixed-methods approach within a constructivist paradigm, the research combines spatial analysis, participatory observation, field surveys, interviews, and socio-ecological data interpretation. The findings reveal key adaptive responses, including the conversion of underfloor stilt areas into domestic space, the use of hybrid timber-concrete structures, and horizontal expansion into shallow waters. While adaptive, these practices exacerbate ecological degradation, such as tidal flooding, pollution, and inadequate sanitation. The study highlights the need for inclusive, sustainable spatial planning and proposes an innovative strategy: integrating stilt housing with waterfront development and cultural seascape tourism. This approach not only enhances resilience but also unlocks economic potential—estimated at over IDR 3.5 billion annually—through heritage-based ecotourism and creative industries. The study contributes a context-sensitive, community-driven spatial model for resilient coastal urbanism, positioning Cambayya as a reference for sustainable development in similar tropical coastal settlements.

Keywords: Spatial Adaptation; Water-Based Settlements; Socio-Ecological Resilience; Cambayya; Inclusive Spatial Strategies; Stilt Housing; Coastal Urbanization.

1. Introduction

Rapid urbanization in metropolitan regions has significantly increased population density and intensified land scarcity, particularly in coastal zones. According to Indonesia's Central Bureau of Statistics [1], the national urbanization rate reached 57% in 2021 and is projected to rise to 66% by 2045. Simultaneously, the *2023–2024 Statistics on Marine and Coastal Resources* [2] indicate that approximately 40% of Indonesia's population—over 110 million people—reside in coastal areas. This demographic shift underscores the mounting pressure on livable space and the ecological carrying capacity of coastal environments, particularly in major urban centers such as Makassar.

As a key coastal city in Eastern Indonesia, Makassar has undergone rapid urban expansion. This is marked by increasing residential demand driven by population growth and the spread of urban sprawl. Coastal zones have been

* Corresponding author: idawarni@unhas.ac.id

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progressively transformed into commercial hubs, port facilities, and reclamation projects, such as the Center Point of Indonesia (CPI) megaproject, significantly reducing land availability for housing—especially for low-income groups [3]. Rising land prices in central areas have forced these communities to relocate to marginal coastal spaces, where they remain close to informal livelihoods such as fishing, port labor, and micro-scale trading. However, financial constraints often compel them to occupy ecologically vulnerable zones, including riverbanks, tidal flats, and overwater settlements.

In response to increasing environmental and spatial pressures, low-income coastal communities in Makassar have developed distinctive and innovative spatial adaptation strategies. A notable example is the construction of two-story stilt houses, particularly prevalent in densely populated neighborhoods such as Cambayya, Gusung, and Ujung Tanah. These elevated dwellings, supported by wooden piles, utilize the underfloor space (*kolong*) for diverse functions, including household services, informal economic activities, and social interaction. However, the limited height of this space restricts its functionality for long-term use. This limitation stems from the structural capacity and availability of locally sourced timber, which remains the primary material for substructures. Moreover, vertical expansion toward the water surface increases exposure to tidal inundation and coastal flooding, especially during the rainy season [4].

Verticalization has emerged as both a response to land scarcity and a form of spatial zoning—where the lower level is designated for economic or semi-public use, while the upper level accommodates domestic functions. This vertical spatial arrangement illustrates the socio-economic resilience of these communities, allowing them to adapt to urbanization pressures while sustaining household livelihoods [5]. Horizontal adaptation is also evident through increased housing density and the subdivision of single housing units to accommodate extended families. Interstitial spaces—such as narrow alleys, underfloor zones, and wooden piers—are repurposed as kitchens, micro-enterprise areas, or communal interaction spaces [6]. While these practices demonstrate high socio-spatial adaptability, the informal and unregulated nature of such development increases the vulnerability of these areas to environmental and ecological hazards.

Most of these settlements lack basic infrastructure, including proper sanitation and drainage systems, making them highly susceptible to tidal flooding and coastal erosion. These issues are further intensified by climate change and the degradation of natural coastal ecosystems [7]. Environmental pollution caused by untreated grey water and black water is a persistent concern, exacerbated by the absence of wastewater treatment facilities. In addition, many households lack reliable access to clean and safe water, highlighting a critical infrastructure gap [8].

Despite these vulnerabilities, neighborhoods such as Cambayya possess considerable economic potential due to their strategic waterfront location and proximity to traditional harbors. These features offer opportunities for place-based tourism that highlights local culture and identity. The existing canals and water networks within the settlements could be optimized through integrated waterfront development, which blends housing, public spaces, tourism, and community-based economic activities. The implementation of a blue-green corridor—a multifunctional waterfront system—could enhance both ecological and social functions, serving as mobility infrastructure, recreational space, ecological buffer, and spatial connector [9].

1.1. Research Gaps

The spatial adaptations implemented by low-income coastal communities in Makassar reflect a dynamic interplay between social resilience and the pressures of complex ecological stressors. Local innovations—such as the development of vertical stilt housing and the creative utilization of constrained spaces—represent strategic responses to the structural challenges these communities face. As such, future spatial management strategies should prioritize inclusive planning policies, the enhancement of local adaptive capacity, and the participatory development of ecological infrastructure. These interventions are essential to ensure that coastal settlements remain sustainable, safe, and competitive in the context of accelerating urbanization.

Numerous studies have examined the adaptive strategies of coastal communities confronting urbanization and climate change, offering insights into both common patterns and research gaps. In Indonesia, previous research has focused on macro-level spatial planning (e.g., [10] in the context of Makassar) and retreat strategies from high-risk coastal zones. Internationally, studies have explored typological adaptations such as stilt housing in Bangladesh [11, 12] as flood mitigation measures. Contributions by Thanvisitthpon & Shrestha [13], as well as Nguyen et al. [14], have emphasized informal, community-based housing innovations in Bangkok and the Mekong Delta, illustrating bottom-up resilience among urban poor populations.

However, these studies tend to focus on rural or peri-urban settlements and rarely address hyper-dense, urbanized, water-based environments such as Cambayya, Makassar. While Nguyen et al. [14] provide valuable perspectives on community-led housing adaptation, they do not consider the compounded challenges of land scarcity, material limitations, and the need for multifunctional space characteristic of densely populated coastal zones. Similarly, Silva et al. [12] present typological insights into stilt housing but lack discussion on its integration with urban waterfront development and nature-based coastal protection strategies.

Complementing these findings, Sloey et al. [15] and Aghaloo et al. [16] underscore the increasing relevance of nature-based solutions (NbS), proposing frameworks such as hybrid green infrastructure and coastal corridors to enhance resilience. Research in Southkhali, Bangladesh, and by Kanan & Giupponi [17] emphasizes socio-ecological resilience through local participation and institutional engagement, while Gyucha et al. [18] advocate incorporating traditional knowledge and historical urban morphologies into contemporary resilience planning. However, few studies explicitly link socio-ecological resilience, stilt housing innovation, and the integration of NbS within hyper-dense, water-based settlements experiencing acute land scarcity—particularly in Southeast Asian contexts like Cambayya, Makassar. One promising approach is the integration of stilt housing with waterfront development and cultural seascape tourism as an adaptive and resilient urban strategy, offering a novel framework that aligns ecological conservation, spatial upgrading, and socio-economic empowerment.

Despite extensive research on coastal community adaptation to climate change and urbanization, critical gaps remain—especially regarding informal, water-based settlements in tropical urban zones. Existing literature tends to focus on rural areas or cities in the Global North, often overlooking the spatial and structural challenges in low-income, marginal urban contexts. Key issues—such as limitations in stilt construction due to the short length of wooden poles, which restrict usable underfloor space—are rarely addressed. Furthermore, few studies explore integrated micro-adaptive systems that combine housing, livelihoods, and community needs, or the spatial incorporation of NbS in response to environmental risk and land scarcity. The potential to merge adaptive housing design with cultural seascape tourism as a socio-ecological resilience strategy remains largely underutilized.

This study contributes new insights by analyzing two-story stilt house innovations developed by low-income communities in coastal Makassar as adaptive responses to spatial and ecological constraints. These grassroots adaptations represent a context-sensitive, participatory, and sustainability-oriented model of socio-spatial resilience. To address the gaps in current scholarship, the study proposes an integrative framework comprising: (1) a transformative spatial strategy based on the Eco Coastal Corridor (ECC), which combines adaptive stilt housing, waterfront development, productive green infrastructure, and multifunctional socio-ecological pathways to align coastal defense, ecological sustainability, and socio-economic vitality; (2) a constructivist, mixed-methods participatory approach—integrating field observation, spatial analysis, and community interviews—to explore local adaptation strategies; and (3) the incorporation of cultural seascape tourism to strengthen maritime identity and promote conservation-based economic development. Together, these elements offer a holistic, place-based framework for achieving resilience and inclusive sustainability in vulnerable coastal settlements such as Cambayya.

1.2. Research Problems, Research Objectives and Approaches

Research Problems are presented below:

- Inadequate access to habitable space
- Ecological vulnerability
- Pressures on spatial and socio-economic functions
- Need for context-based innovation
- Absence of inclusive and participatory spatial planning schemes

Based on the aforementioned background, this study aims to achieve the following objectives:

- To identify and analyze the limitations of habitable space in overwater settlements located in the coastal areas of Makassar, particularly those constructed by Low-Income Communities (LICs).
- To evaluate the ecological vulnerability of these settlements to tidal flooding, sea-level rise, and environmental pollution.
- To examine patterns of spatial use and socio-economic activities within the context of limited space availability.
- To develop an adaptive housing model grounded in locally available materials and the socio-cultural context of coastal communities.
- To formulate inclusive and sustainable spatial planning strategies that can enhance the socio-ecological resilience of overwater settlements.

The most pressing issue in Cambayya is the acute shortage of habitable space, which compels residents to convert the under-floor areas of stilt houses into living quarters, extend dwellings horizontally into shallow coastal waters, and utilize locally sourced timber whose limited span restricts vertical development. This spatial scarcity is not merely a physical constraint but is intricately linked to broader social and ecological vulnerabilities: increased exposure to tidal flooding, environmental degradation due to waste accumulation and inadequate drainage, and constrained informal economic activity due to the lack of multifunctional communal space.

Recognizing the centrality of spatial limitations, this study advocates for the implementation of adaptive two-storey stilt housing. Such designs encourage vertical densification, allowing domestic, economic, and social functions to be consolidated within a single unit while preserving ground-level semi-public space. This model facilitates a more inclusive, organized, and resilient waterfront, serving as a foundation for the upgrading of informal coastal settlements.

Comparable approaches, such as Chile's post-tsunami social housing program, demonstrate the value of co-designed elevated housing in flood-prone areas, preserving safety, cultural identity, and livelihoods. Similarly, recent studies on Indonesian coastal settlements emphasize the effectiveness of community-driven adaptation rooted in traditional spatial knowledge, especially in high-density, marginal urban environments. Prioritizing spatial adaptation ensures context-sensitive, resident-oriented, and ecologically responsive development pathways for vulnerable coastal communities.

2. Research Methodology

2.1. Research Paradigm

The research paradigm applied in this study is the constructivist paradigm with a mixed methods approach.

- The constructivist paradigm is chosen because this study focuses on how coastal communities (case studies in Cambayya-Makassar) construct understanding and adaptive strategies in response to urbanization pressures and spatial limitations through two-story stilt housing.
- The mixed methods approach is employed to provide a more comprehensive understanding by integrating quantitative data (e.g., housing distribution, settlement density, and economic factors) with qualitative data (such as community perceptions and adaptation experiences).
- This study also adopts the concept of settlement resilience, encompassing social, economic, infrastructural, and ecological resilience, to analyze community adaptation to changing environmental conditions.

Overall, this research utilizes a spatial-ecological and participatory mixed methods approach combining qualitative and quantitative analyses to examine the adaptive housing patterns of low-income coastal communities under urbanization pressures and spatial constraints. It integrates spatial analysis, physical building structure assessment, interviews, participatory observation, and socio-ecological data processing.

2.2. Data Collection

This study employs both primary and secondary data sources. Primary data will be collected through field surveys involving the physical measurement of stilt houses (e.g., clearance height, room dimensions, and types and lengths of timber columns), as well as environmental observations related to sanitation, drainage, and water quality. Additionally, daily activities of residents will be mapped using activity mapping and time-use diaries. In-depth interviews and Focus Group Discussions (FGDs) will be conducted with local residents, community leaders, and informal sector workers to explore spatial perceptions, adaptation strategies, and housing needs.

Secondary data will include spatial zoning maps (RTRW and RDTR), topographic data, demographic and socio-economic statistics from the Central Bureau of Statistics (BPS), and environmental and climatic data (such as tidal floods, sea level rise, and coastal erosion) sourced from technical agencies including the Meteorological, Climatological, and Geophysical Agency (BMKG) and the Environmental Agency. To ensure validity and reliability, this study applies data triangulation by integrating quantitative, qualitative, and spatial sources. Quantitative data from physical measurements of stilt houses and environmental surveys are cross-checked with official secondary data such as zoning maps (RTRW/RDTR), topography, and environmental statistics from BMKG and related agencies.

Qualitative insights from interviews and FGDs are triangulated with activity mapping and time-use diaries to verify consistency between residents' perceptions and actual daily practices. Field observations—such as drainage conditions or spatial constraints—are also used to validate interview findings. Additionally, spatial triangulation is performed by overlaying observed environmental risks with GIS-based risk maps to assess alignment between subjective experiences and objective spatial data. This integrated approach strengthens the study's methodological rigor and supports a holistic understanding of adaptation and resilience in water-based settlements.

2.3. Analytical Techniques

The analysis will be structured across four dimensions: spatial, structural, social, and strategic.

- Spatial analysis, using Geographic Information Systems (GIS), will map ecological vulnerability zones and spatial constraints, and visualize the distribution of housing adaptations.
- Space syntax and activity mapping will be applied to investigate spatial usage patterns and the configuration of socio-economic networks.

- Structural and morphological analysis will be used to classify stilt house typologies (particularly two-storey variants), measure subfloor clearances, and assess how local material constraints shape housing forms.
- Data from interviews and FGDs will be analyzed thematically to reveal meanings of adaptation, survival strategies, and the socio-economic functions of space.

Design and spatial strategies will be developed using a participatory co-design approach, and further evaluated through SWOT or TOWS analysis to generate inclusive and sustainable spatial planning recommendations.

2.4. Expected Outcomes

The key outputs of this research include:

- A spatial map of environmental vulnerability and spatial constraints in the coastal settlement;
- A typological classification of adaptive stilt houses based on local materials and spatial limitations;
- A design prototype for a two-storey stilt house tailored to the needs of low-income coastal communities;
- Strategic recommendations for community-based micro-scale spatial planning;
- A conceptual design of ecological-social corridors integrating housing and informal economic activities;
- And a policy brief directed at local government and stakeholders to promote adaptive and inclusive coastal spatial planning.

2.5. Study Area

The research will be conducted in Cambayya Sub-district, Makassar, South Sulawesi, Indonesia, a densely populated coastal settlement characterized by water-based housing and high exposure to tidal flooding, poor sanitation infrastructure, and socio-economic vulnerability. Most residents rely on informal livelihoods, including fishing, small-scale fish processing, and petty trade, making the site an ideal case for examining adaptive housing strategies in relation to both environmental pressures and socio-economic resilience. The research is conducted in Kelurahan Cambayya, Kecamatan Ujung Tanah, Kota Madya Makassar, South Sulawesi, Indonesia (Figure 1).

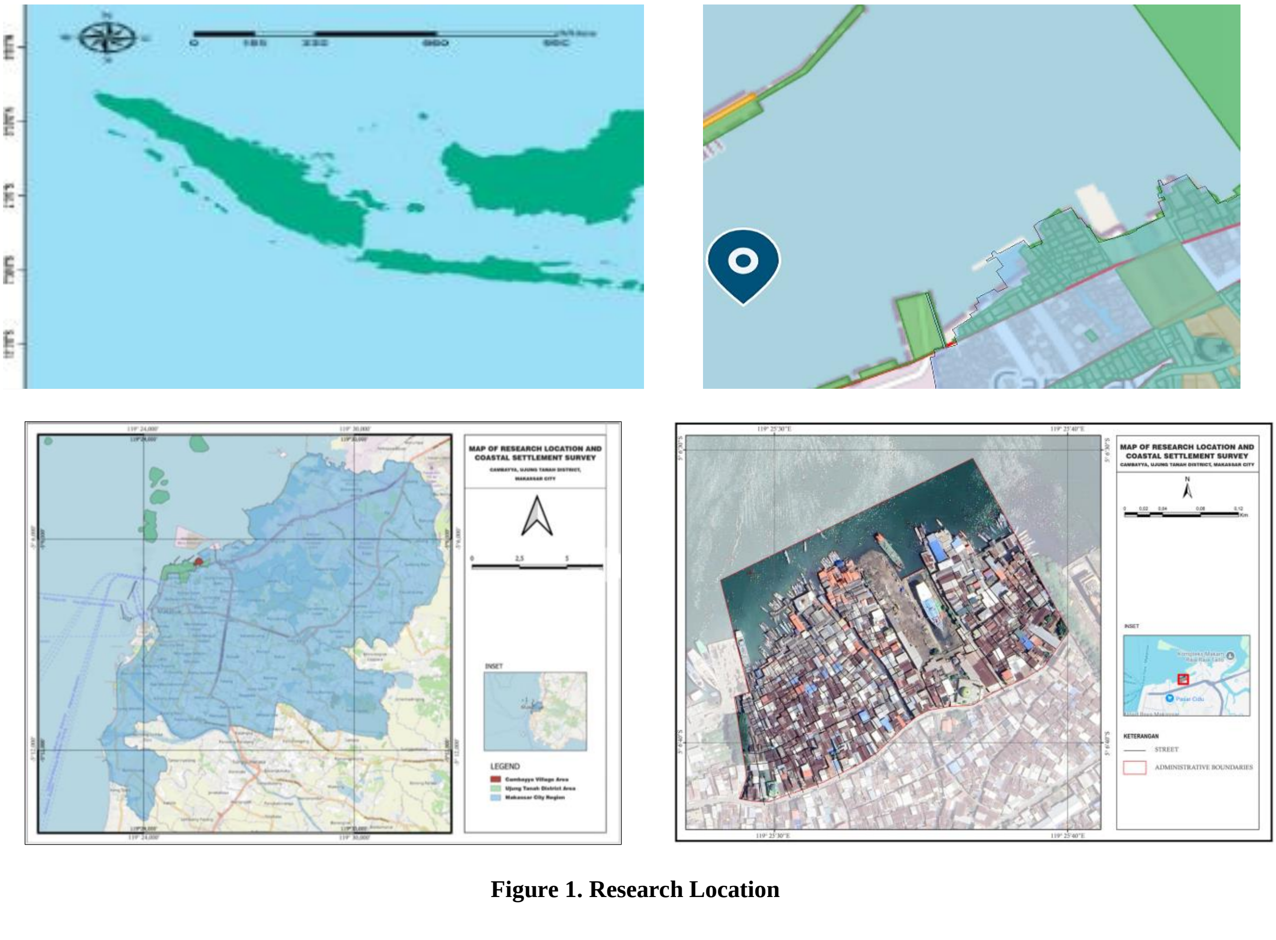


Figure 1. Research Location

3. Research Results and Analysis

3.1. Identifies and Analyzes the Spatial Limitations of Habitable Areas within the Waterfront Settlements in the Coastal Zone of Cambayya, Makassar

Figure 2 depicts the transformation of land use patterns and the spatial extent of the coastal zone in Cambayya.

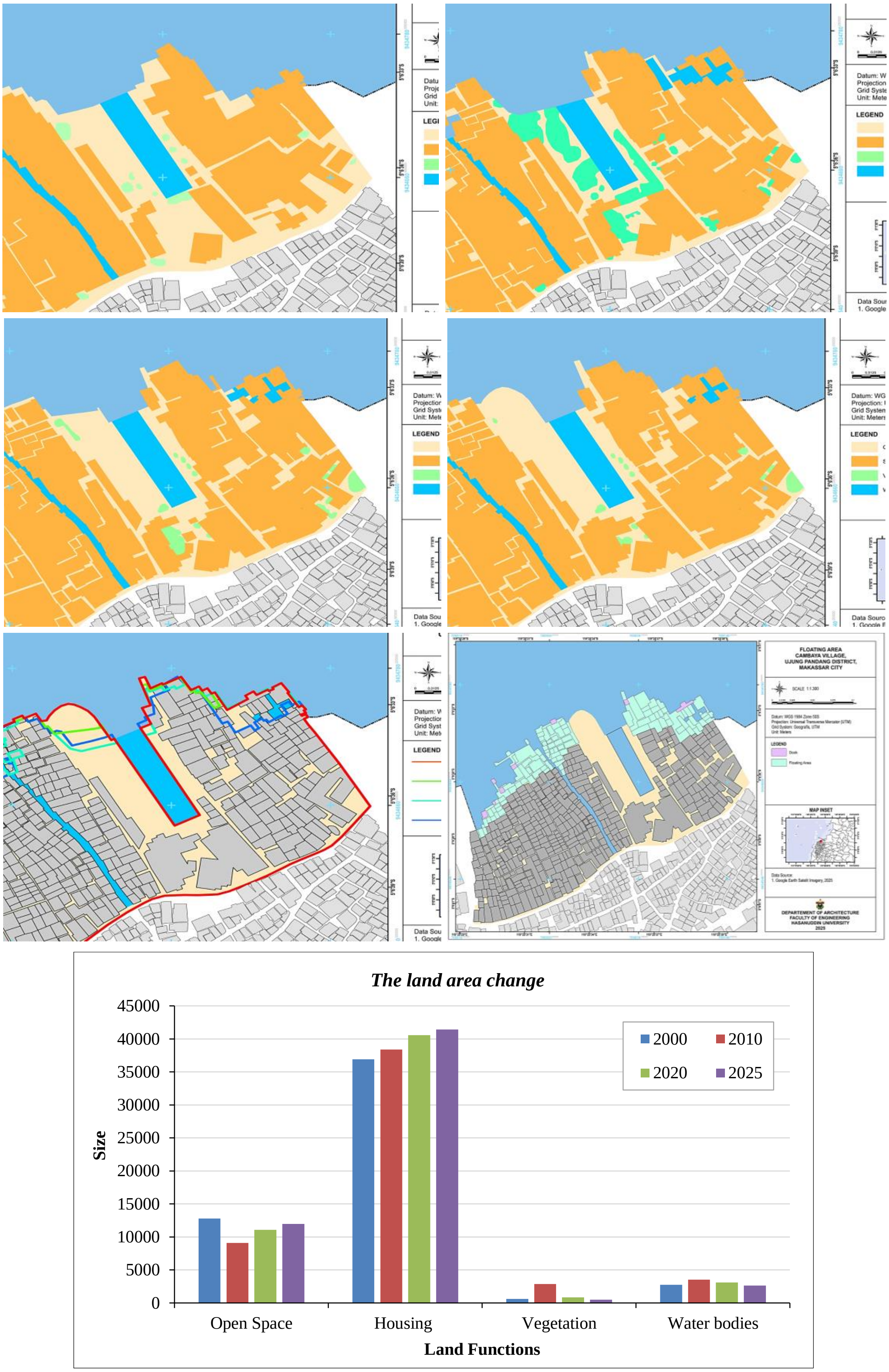
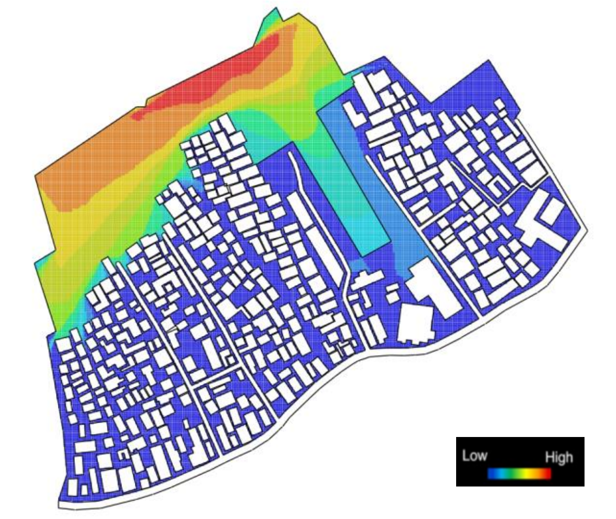


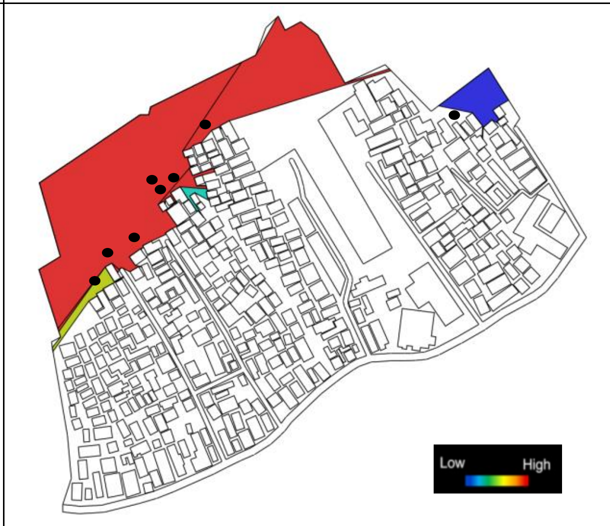
Figure 2. Images and Graphs Showing the Development of Settlement Areas from 2000, 2010, 2020, to 2025

From the land cover description and graphic images, it can be seen that the use of land for housing is decreasing from year to year. Open space decreased in 2010 and then increased slowly until 2025. Vegetation is decreasing, as is the water body. It can be observed that the settlement area has progressively expanded seaward, encroaching into shallow marine zones with depths reaching up to 3 meters.

The following data and analysis of Spatial Configuration shows the density of settlements, access and integration conditions and Isovist (see Figure 3).



Visibility Graph Analysis	**Axial Line Analysis**
Summary Value Minimum: 2 Average: 3211.99 Maximum: 11143	**Summary Value (Integration)** Minimum: 1.00841 Average: 1.77606 Maximum: 2.87839



Connectivity	**Isovist**
Summary Value (Connectivity) Minimum: 9 Average: 69.6335 Maximum: 162	**Isovist Analysis** Minimum: 15418.5 Average: 116277 Maximum: 165304

Figure 3. Visibility Graph Analysis, Axial Line Analysis and Isovist (Space syntax analysis)

Spatial Configuration and Visibility in Cambayya's Overwater Settlement, The results of the Visibility Graph Analysis (VGA) reveal an extremely low level of spatial visibility across the study area, indicative of a highly compact and densely developed urban fabric. The lack of open sightlines suggests limited visual permeability, which often correlates with constrained spatial mobility and fragmented public realm experiences. Despite this, integration values along the main pedestrian alleys are moderate, indicating their function as primary circulation routes. However, their connectivity to the broader neighborhood remains constrained, suggesting limited spatial integration at the settlement scale. Further connectivity analysis shows that several of these primary alleyways attain high connectivity values—illustrated in yellow and red on the analysis maps—marking their importance as key access nodes within the settlement structure. These paths serve multifunctional roles not only for circulation but also as communal spaces for social interaction and informal economic activity. The Isovist analysis, taken from communal spaces oriented toward the seafront, displays broad, unobstructed visual access to the ocean. This confirms the high potential of these visual corridors to enhance both the quality of public spaces and overall environmental comfort through improved openness and visual engagement with the surrounding coastal landscape.

Spatial configuration analyses using Visibility Graph Analysis (VGA) and Isovist techniques in the overwater settlement of Cambayya reveal a limited degree of visual openness and spatial connectivity. These conditions indicate socio-ecological vulnerability, as restricted visibility and circulation can hinder social interactions, reduce evacuation accessibility, and limit natural ventilation and daylight—factors essential for ecological comfort and safety during hazards such as fire or tidal flooding. However, the Isovist analysis indicates that communal spaces facing the seafront offer wide, unobstructed visual corridors. These seafront views present opportunities to enhance ecological resilience, improve microclimatic quality through sea breeze exposure and daylight access, and reinforce the identity of public spaces anchored in coastal culture.

In light of increasing urbanization pressure and land scarcity, innovative stilt house design emerges as a critical spatial adaptation strategy. The current spatial density and fragmentation of public space reflect constraints on horizontal land expansion. In this context, stilt houses can be reimagined not only as residential units but also as integral components of the spatial network, contributing to circulation systems, communal space formation, and enhanced visual orientation toward the coast. A two-story stilt house, when designed adaptively, can respond to spatial constraints by integrating semi-public functions on the ground level, optimizing visual corridors, and providing spaces that promote social interaction and spatial quality.

Furthermore, major pedestrian alleys with high connectivity values—highlighted in yellow and red on the VGA maps—function as essential access routes and multifunctional spaces for informal economic activities and social engagement. These routes serve as socio-economic lifelines and represent strategic spatial assets for reinforcing community resilience. Their role can be further enhanced by designing stilt houses that accommodate multifunctional spaces such as elevated verandas, shaded areas beneath houses, and shared communal platforms.

Although overall spatial integration remains limited across the settlement, moderately to highly integrated pathways may serve as the backbone for developing a more resilient spatial framework. Therefore, future spatial interventions should incorporate risk assessments for these pathways, ensuring that key corridors not only support daily socio-economic functions but also provide safe, navigable routes during emergency conditions. This aligns with the study's broader objective of promoting community-based soft infrastructure and ecologically oriented spatial planning as adaptive strategies for coping with socio-environmental pressures in tropical coastal settlements.

3.2. Spatial Planning Designation and Demographic Pressure

According to the Makassar City Spatial Planning Regulation (RTRW) for the 2015–2034 planning period and the Mayor's Decree No. 1301/050.13/2021 [19] on the Designation of Slum Areas, the Ujung Tanah District is categorized as a light-slum zone. This classification corresponds to the typical spatial characteristics of informal settlements along coastal and waterfront zones, such as irregular housing layouts, underdeveloped infrastructure, and high ecological vulnerability. Specifically, Cambayya Sub-district has been identified as a priority area for intervention through slum upgrading programs. At Figure 1, the officially designated slum area in Cambayya covers approximately 12.63 hectares and is inhabited by 4,875 residents, resulting in a population density of approximately 386 persons per hectare. The density image can also be seen in the Visibility Graph Analysis image (Figure 3) where the dark blue color represents the density of an area. According to the density classification provided by the Oversight and Control Team for Central Activity Areas – Directorate of Housing and Settlement Development (PKP) [20], this figure places Cambayya within the category of high-density settlements (defined as 201–400 persons/ha). Consequently, Cambayya warrants targeted spatial interventions to alleviate environmental stress, reduce spatial congestion, and upgrade basic infrastructure systems.

Pedestrian Circulation in Overwater Settlements

Pedestrian pathways in overwater settlements such as Cambayya, Makassar, are characterized by extreme variability in width and quality, heavily influenced by spatial constraints and self-built construction practices. Based on direct field observations and supporting empirical studies, the following typology of path widths is identified:

- Minimum width: approximately 60–80 cm, sufficient for single-person passage only.
- Moderate width: typically ranges from 1–1.2 meters, allowing two individuals to pass one another.
- Maximum width: up to 1.5 meters or more, though rarely found, and generally limited to main access routes or near communal docks.

These pedestrian pathways are typically constructed from wooden planks, many of which serve multiple functions such as informal motorcycle tracks, children's play areas, or semi-public gathering spots. As these pathways are predominantly self-built by residents without standardized regulation, their form, width, and construction quality vary significantly. Moreover, the circulation routes tend to be winding and narrow, contributing to both spatial disorientation and potential access issues during emergencies such as flooding or fire.

3.3. Typology and Condition of Overwater Housing

The settlement's housing typology, particularly those constructed along the seafront and canal edges, consists predominantly of structures built on wooden stilts or piles. These homes generally feature timber frame construction, with exterior cladding materials varying from wooden planks and plywood to corrugated metal sheets, or combinations thereof. Roofs are commonly of pitched (gable) design and utilize corrugated metal sheeting for covering.

During low tide, the supporting piles beneath these stilt houses become fully visible, especially for dwellings located along canal margins. Conversely, at high tide, water levels rise to the floor level of the houses, highlighting their vulnerability to tidal flooding and sea-level fluctuations. This architectural typology reflects a deeply adaptive response to the hydro-geographical context of Cambayya, though it simultaneously exposes residents to serious risks related to sanitation, structural integrity, and accessibility.

Figure 4 illustrates the variation in water levels within canal channels during low tide and high tide under normal conditions, specifically during the dry season when rainfall does not significantly influence tidal dynamics. These fluctuations are particularly relevant in evaluating the exposure and resilience of overwater housing structures, especially those constructed adjacent to open sea or along narrow waterways. Residences located along the seafront typically include expansive terraces or extended platforms, which serve as multifunctional spatial elements. These terraces not only support daily domestic activities but also act as critical communal interfaces between the private and public realms. Their usage includes:

- Docking and mooring boats, especially for fishing households;
- Recreational purposes, such as sitting and enjoying seascapes;
- Informal workspaces, including fish processing, net repair, or other livelihood activities;
- Sites of social interaction, where neighbors congregate or engage in conversation;
- Spaces for micro-enterprise, such as selling food, snacks, or household goods.

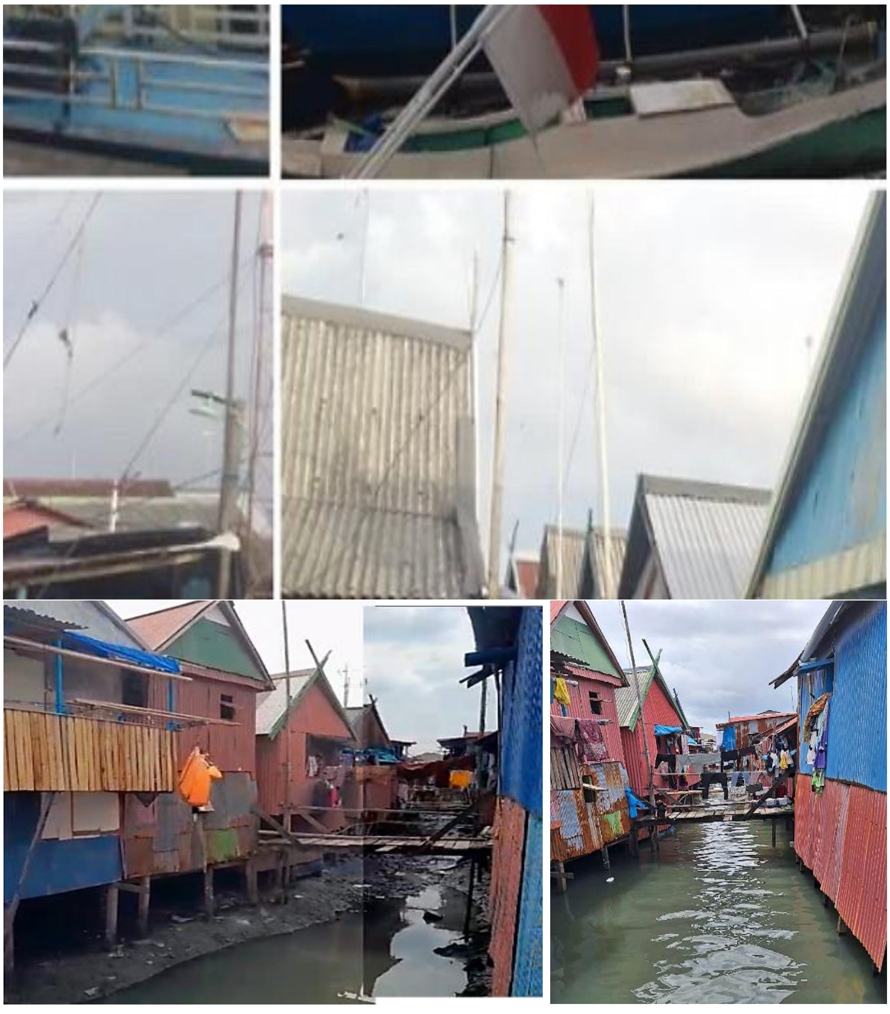


Figure 4. Water Levels in Canal Channels during Low Tide and High Tide under Normal

Such adaptive spatial practices reflect the community's capacity to optimize limited space in response to both ecological conditions and livelihood necessities, demonstrating a strong nexus between housing form, water dynamics, and social functionality.

3.4. Communal Spaces and Spatial Patterns of Socio-Economic Activities

The spatial distribution of communal spaces within the overwater settlement illustrates the dynamic interplay between physical layout and socio-economic behavior. Communal areas—such as widened alleys, small open decks, intersections of footbridges, and house-front platforms—are frequently transformed into multi-use spaces that accommodate a range of daily activities. These include:

- Economic transactions, such as informal vending or barter;
- Household-scale production, including drying fish or sewing nets;
- Child-friendly zones, for play and learning;
- Cultural practices, such as religious gatherings or community meetings;
- Social cohesion rituals, including mutual aid and neighborly exchanges.

The community's flexible use of space demonstrates how physical constraints are navigated through social adaptation strategies, reinforcing the resilience of local socio-spatial systems. The location and intensity of use within these communal zones often correlate with their spatial integration value, as revealed by visibility and connectivity analyses. Through these communal configurations, the settlement functions as a complex, adaptive system in which built form, social networks, and environmental constraints are negotiated through. Figure 5 illustrates the locations of communal spaces utilized by the community for various social and economic activities.

Figure 5. presents the spatial distribution and functions of public spaces within the coastal settlement of Cambayya

These areas are typically situated adjacent to the sea, leveraging their strategic position to serve as multifunctional nodes within the urban fabric of the community. While initially constructed to function as piers or docking platforms, these spaces have evolved to accommodate a broad range of community needs. These communal spaces are generally open, with only a roof, a plank floor, and a fence. A small portion is fenced in and used for sales.

3.5. Ecological Vulnerability to Tidal Flooding, Sea-Level Rise, and Pollution

The assessment of ecological vulnerability in Cambayya settlement focuses on the natural environmental characteristics that contribute to the settlement's exposure to risk. As illustrated in the topographic contour map of Cambayya Village, the area is characterized by low-lying coastal terrain, with minimal elevation difference between the land surface and mean sea level. This condition renders the settlement highly susceptible to several environmental hazards. Key vulnerabilities include:

- Tidal flooding, which occurs regularly due to the interaction between high tides and the low elevation of the settlement platform;
- Progressive sea-level rise, which threatens the long-term habitability and structural safety of overwater housing;
- Environmental pollution, particularly from inadequate waste management and greywater discharge, which exacerbates ecological degradation and undermines the health of both the marine ecosystem and local residents.

This ecological vulnerability is compounded by the informal nature of settlement development, lack of engineered protective infrastructure, and limited integration of environmental planning within local spatial governance. These factors collectively necessitate a resilience-oriented approach in future spatial interventions, including the use of nature-based solutions, adaptive architectural typologies, and community-based environmental stewardship.

3.6. Topographic Elevation and Rob Flood Vulnerability in Stilt Housing Areas

Topographic Elevation and Rob Flood Vulnerability in Stilt Housing Areas refers to the relationship between land elevation and the susceptibility of overwater or stilt housing communities to *rob* (tidal or coastal) flooding. In tropical coastal settlements, especially those built on low-lying or reclaimed areas, topographic elevation plays a critical role in determining the frequency, intensity, and duration of rob flood events. Thus, analyzing topographic elevation helps in understanding spatial risk patterns, guiding adaptive housing design, and informing resilient urban planning in coastal settlements (see Figure 6).

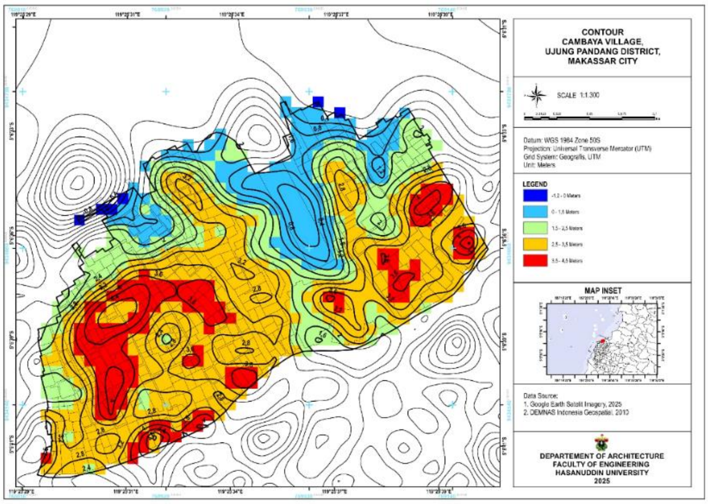


Figure 6. The contour map of the settlement, overlaid with housing density

The color-coded elevation gradient reveals that the light blue and light green zones represent areas situated at approximately 1 to 2 meters above the baseline coastal water level. These zones correspond to the dominant locations of stilt house construction, a vernacular architectural response to the challenges of living adjacent to shallow coastal waters. When this spatial information is cross-referenced with Table 1, which records peak tidal heights exceeding 1.6 meters, it becomes clear that the yellow elevation zones—within the 1 to 2 meter range—are highly susceptible to tidal inundation, commonly referred to as *rob* flooding.

This vulnerability is further exacerbated during the rainy season, particularly at its peak, when tidal surges coincide with heavy rainfall, leading to compounded flood risk. Under such conditions, backflow from drainage systems, elevated seawater levels, and runoff convergence converge to inundate ground-level and underfloor spaces, especially in houses where the clearance between the sea surface and the house floor is insufficient. The findings underscore the critical need for elevation-sensitive spatial planning, flood-resilient housing typologies, and integrated water management strategies. In particular, areas within the yellow flood-prone elevation band require targeted interventions, such as elevated access paths, water-sensitive infrastructure, and adaptive architectural designs, to ensure the long-term viability and resilience of the coastal settlement. Table 1 provides an overview of tidal water levels and rainfall intensity, which are critical contributors to coastal flood hazards.

Table 1. Highest tide period 1 January-21 April 2025 (BMKG-2025)

Date	Time	Altitude
01 Jan 2025	19:10 WITA	1.67 m
02 Jan 2025	19:40 WITA	1.64 m
12 Jan 2025	18:20 WITA	1.61 m
13 Jan 2025	18:30WITA	1.66 m
14 Jan 2025	18:50 WITA	1.68 m
15 Jan 2025	19:10 WITA	1.67 m
16 Jan 2025	19:30 WITA	1.64 m
28 Jan 2025	18:40 WITA	1.64 m
29 Jan 2025	19:00 WITA	1.67 m
30 Jan 2025	19:20 WITA	1.67 m
31 Jan 2025	19:40 WITA	1.61 m
11 Feb 2025	18:40 WITA	1.62 m
12 Feb 2025	18:50 WITA	1.62 m
13 Feb 2025	19:00 WITA	1.60 m
26 Feb 2025	18:40 WITA	1.61 m
27 Feb 2025	19:00 WITA	1.60 m
28 Feb 2025	06:30 WITA	1.68 m
03 Apr 2025	08:00 WITA	1.60 m

Sampling was conducted from January to April because these months are the peak of the rainy season, particularly from January to March, and the Meteorology, Climatology, and Geophysics Agency (BMKG) only provides data for months outside of these months. Furthermore, 1.6 m was chosen because this value represents the high tide threshold, which, when accompanied by heavy rainfall, can cause flooding.

Highest Risks in Disaster Combinations:

- When a combination of:
  - High tide >1.6 m (Table 1)
  - Heavy rainfall (peak rainy season: Dec–Feb) (Table 2)
  - Ineffective drainage channels (Figure 7)
- Then the possibility of tidal flooding + inundation of land runoff increases drastically (this phenomenon is called compound flooding).

Table 2. The highest rainfall when the peak of the rainy season begins (CHIRPS)

Moon-Years	Rainfall
December'20	720-800 mm/Month
January'21	***840-880 mm/Month***
February' 21	440-420 mm/Month
December'21	640-680 mm/Month
January'22	***660-680 mm/Month***
February'22	560-580 mm/Month
December' 22	***700-720 mm/month***
January'23	520-540 mm/Month
February'23	***700-720 mm/Month***
December'23	310-320 mm/Month
January '24	***760-800 mm/Month***
February'24	460-480 mm/Month
December'24	***920-960 mm/Month***
January'25	600-680 mm/Month
February'25	480-560 mm/Month

The interaction between high rainfall and tidal surges in amplifying coastal flood risks has been extensively discussed in several scholarly articles. For instance Pezzoli & Cartacho [21], Bennett et al. [22], Wahl et al. [23], Zscheischler et al. [24] underscore the increasing frequency and intensity of such compound climate extremes under global climate change scenarios. In Southeast Asian contexts, Nguyen et al. [14] emphasize the vulnerability of deltaic and urban coastal settlements, where poor drainage infrastructure and sea-level rise further exacerbate the impacts of concurrent extreme weather and oceanographic events. Table 3 presents the classification of tide height and its corresponding risk levels, offering a basis for evaluating coastal flood vulnerability.

Table 3. Classification of Tide Height and Risk

High Water Level	Risk Level	Main Impact
<1.4 m	Low	Light flooding in the lowest zone
<1.4 m	Low	Light flooding in the lowest zone
>1.6 m	High	Floods spread, houses are flooded, pedestrian paths are cut off
>2.0 m	Extreme Severe	Severe tidal flooding, structural damage, increased health risks

These studies collectively demonstrate that in densely populated coastal settlements like Cambayya, Makassar, the overlapping timing of heavy rainfall and high tides—particularly during the peak monsoon season—can lead to severe tidal flooding (locally known as *Banjir rob*), overwhelming limited drainage systems and threatening the habitability of overwater housing structures.

Figure 7. Environmental problems resulting from natural and anthropogenic factors

3.7. Environmental Problems

Other ecological vulnerabilities of settlements are caused by environmental problems that come from anthropogenic aspects. As one of the dense and irregular settlements, and one of the settlements categorized as slums according to the Mayor's Decree No. 1301/050.13/2021 [19]. Concerning the determination of locations for prevention and improvement of housing and slum settlements in the city of Makassar. As a slum settlement that is partly on water and partly on land (due to landfill by the community), this settlement has environmental and physical problems of housing and settlements as shown in the following picture.

The lack of awareness regarding domestic waste disposal (both solid and liquid), coupled with a highly inadequate drainage network and the encroachment of canal areas for housing expansion along riverbanks and shallow coastal zones, has led to the narrowing of canals and reduced water flow capacity.

Canal and river silting and narrowing are increasingly caused by unregulated informal housing development and the accumulation of solid waste beneath stilt houses. The piped water supply system is disorganized, and the greywater drainage network is shallow—some segments are covered with concrete, while others remain open. In addition, many walkways and bridges built over water are deteriorated, posing safety hazards to users.

These anthropogenic activities have significantly degraded the aquatic environment, resulting in water pollution. Based on in-situ measurements using a Yinmik multi-parameter water quality tester (EZ9908 model), parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, and temperature indicate declining water quality conditions (see Table 4).

Table 4. The results of the equipment tests in the field found that the water content under the houses was

	The outermost part of the settlement (sea)	Middle part	The part that borders the mainland
Salinity NaCl (mg/L)	58,5	2.866	2.720
Temperature (ºC)	26	25.9	26.1
TDS	15.250	16.510	16.010
PH	6,29	6.77	7.98
BOD (mg/L)	40	85.5	160.0
COD (mg/L)	84.0	188.1	216.4
Ammonia NH_4 (mg/L)	0.05	0.25	3.60
Phosphate ($P0_4$) (mg/L)	94.9	220.0	189.8

For total Coliform content: 2.260.000 (MPN/100 ml- SM2017.9223).

For E. coli content: 435,000 (MPN/100 ml - SM2017.9223) in the densely populated area. For E. coli content in areas closer to the sea: 140 (MPN/100 ml). Data on water pollution due to anthropogenic activities are relevant to this research title because they reflect ecological pressures that threaten the resilience of coastal communities. In the context of stilt house innovation, this pollution requires adaptation of design and environmental management strategies to maintain the sustainability of community life amidst land limitations and urbanization. Adger [25], Strengthening Community and Ecological Resilience to Address Waterborne Contamination in Dense Coastal Settlements. According to the Indonesian Ministry of Health Regulation No. 492/2010 on Drinking Water Quality, the permissible level of *Escherichia coli* (E. coli) in drinking water is 0 MPN/100 mL. However, in highly populated and dense coastal settlements, such as Cambayya in Makassar, excessive E. coli contamination has been observed, reflecting a direct correlation between population density and the deterioration of water quality.

This situation underscores the critical intersection of social and ecological resilience. Social resilience, in this context, involves building local capacity, fostering collective action, and strengthening community ownership over environmental change. Ecological resilience, meanwhile, pertains to the community's ability to restore and maintain healthy environmental conditions amid ongoing stressors.

A set of immediate, participatory actions is proposed as a foundational response while longer-term infrastructure—such as decentralized sanitation and wetland systems—is being developed:

- Water Safety Education and Provision. Raise awareness about the importance of using clean water and boiling it before consumption or cooking. Provide access to safe water through communal tanks and distribute simple purification tools, such as sand filters or chlorine tablets.
- Promotion of Clean and Healthy Living Behaviors (PHBS). Implement handwashing programs with soap (CTPS) at key communal locations such as docks and places of worship. Deliver health messages through visual media and live demonstrations by trained environmental volunteers.
- Emergency Sanitation Solutions. Install micro septic tanks or temporary containment units to minimize open defecation and prevent direct discharge of fecal matter into surrounding waters. Promote greywater separation to reduce contamination loads.
- Early Detection of Waterborne Diseases. Empower local health cadres to monitor community health, distribute oral rehydration salts (ORS), and refer suspected cases of diarrheal diseases to nearby health facilities.
- Community Sanitation Education. Establish sanitation learning hubs targeting children and families to cultivate long-term environmental hygiene practices.

These actions are rapid, low-cost, and community-driven. They form a critical transitional strategy that enhances both social cohesion and ecological stewardship while awaiting the implementation of permanent sanitation infrastructure.

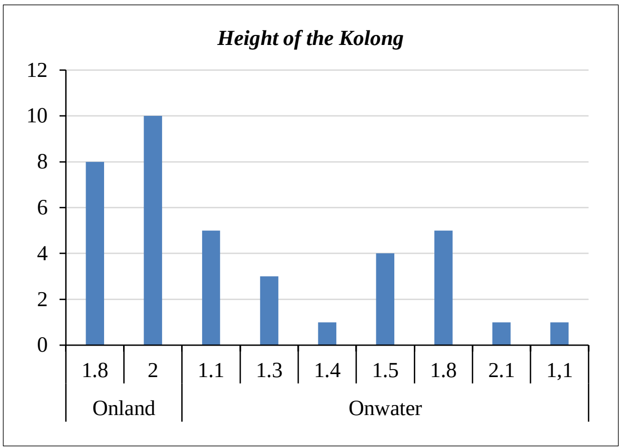
3.8. Transformation of Underspace *(kolong)* into Functional Family Area

Figure 8 illustrates how the space beneath stilt houses—originally intended for air circulation—has been converted into living areas. Despite the limited dimensions, residents continue to utilize this space for various domestic activities.

Figure 8. Change in function of the space under the house (kolong), the floor from a transitional space to a residential space

Limited Kolong Height Due to Market Constraints on Timber Size. The limited height of the kolong is primarily caused by the restricted availability of timber columns in the local market, typically no longer than 5 meters. Originally conceived as a transitional zone between the water surface and the upper dwelling, the *kolong*—the underfloor space of stilt houses—was traditionally used for storage and utility functions. However, its role has evolved significantly; it is now frequently utilized as an extension of the living area, accommodating various daily activities such as cooking, sleeping, and religious study (e.g., Qur'anic recitation).

Interviews with residents indicate that the *kolong* is perceived as thermally more comfortable than the upper floors. This enhanced thermal comfort can be attributed to two primary factors: (1) the shading effect provided by the elevated main structure, which reduces solar heat gain, and (2) the proximity to water beneath the floor, which facilitates evaporative cooling. These conditions collectively create a microclimate that is cooler and more humid, offering passive thermal relief in a tropical coastal environment. However, this spatial adaptation is not without challenges. During peak rainy seasons, especially when coinciding with tidal surges, the *kolong* floor often becomes inundated. Residents report that water can rise to submerge the entire area, compromising its usability and posing health and safety risks. This seasonal flooding underscores the need for adaptive design strategies that respond to both climatic and tidal variability, particularly in the context of informal overwater settlements vulnerable to climate-induced sea level rise (see Figure 9).



Correlations

		On water	On Land
On water	Pearson Correlation	1	0.812**
	Sig. (2-tailed)		0.000
	N	38	38
On Land	Pearson Correlation	0.812**	1
	Sig. (2-tailed)	0.000	
	N	38	38

** Correlation is significant at the 0.01 level (2-tailed).

Figure 9. The size of the space used for domestic activities and the correlation between the height of the space and the function of the space

There is a significant correlation between the height of the stilted space beneath the houses (locally known as *kolong*) and its associated functional use on buildings that are on water and on land (bordering water)). In the coastal settlements of Makassar, particularly among houses built above water, *kolong* spaces with a height ranging from 1.1 to 1.8 meters are commonly used for domestic activities such as bathing, washing, cooking, and, in some cases, habitation. For buildings located on reclaimed land—originally shallow coastal waters filled by residents—the average height of the *kolong* ranges between 1.5 and 2 meters. Measurements were conducted using a Leica Geosystems laser distance meter for accuracy.

Not all *kolong* spaces are fully utilized, especially in structures directly above water, where a portion of the space remains submerged. Based on residents' testimonies, approximately 1.5 meters of the *kolong* is typically submerged during high tide, leaving only the upper portion usable for additional spatial functions. Structures with lower clearance (between 1.1 to 1.4 meters) are predominantly used for service-oriented domestic activities such as washing and cooking, rather than habitation.

Interestingly, residents also report that during periods of high temperature—especially midday when ambient temperatures can reach up to 31°C—the *kolong* provides a cooler microclimate, and becomes a preferred space for daily activities. In situ environmental measurements confirm this observation, revealing that humidity levels in stilted homes above water exceed 80%, contributing to the cooler sensation and perceived thermal comfort within the *kolong* compared to upper floors. Stilt-house settlements in coastal areas like Cambayya experience distinctive microclimatic conditions, marked by high daytime temperatures and humidity. These are primarily caused by proximity to seawater, intense solar radiation, limited vegetation, and dense housing, which collectively reduce ventilation and elevate heat stress. Midday conditions are especially severe due to heat absorption and reflection from water surfaces, compounded by obstructed airflow. The resulting high humidity impairs the body's cooling ability through sweat evaporation, leading to thermal discomfort. In response, residents seek relief in the *kolong* which serves as a natural thermal refuge. This space remains cooler due to:

- Evaporative cooling from the water below
- Protection from direct sunlight, and
- Thermal buffering from the water's heat inertia.

These features make the *kolong* an effective passive cooling zone, supporting both rest and daily activities under extreme heat conditions—highlighting the climatic responsiveness of traditional stilt-house architecture (see Figure 10).

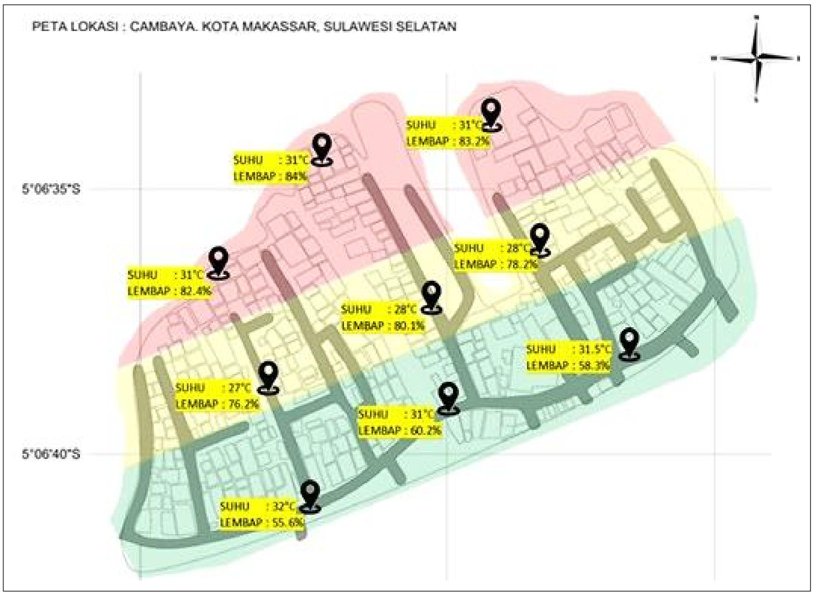


Figure 10. Temperature and Humidity Conditions in the Cambayya Waterfront Settlement

3.9. Conventional Adaptation to Structural Limitations

In response to constraints on the height of wooden columns and the limited availability of suitable materials, local residents often adopt conventional adaptation strategies. In several overwater settlements, such as those inhabited by the Bajau people in Bone and on Bokori Island in Kendari, structural innovations have emerged. These include the use of composite columns made of stone, reinforced concrete, and wood to increase the structural height and resilience of stilt houses. Figure 11 illustrates such adaptive construction practices.

Figure 11. (a) Bajoe-Bone Settlement: Hybrid house pillars with concrete pillars at the bottom

Figure 11. (b) Stilt Housing on Bokori Island, Kendari

The settlement employs a modular concrete frame upon which the main housing structures are placed. In several coastal communities built over water, such as those in Bajoe (South Sulawesi) and Kendari, there has been a gradual material transition from traditional wooden stilts to more durable supports made of reinforced concrete or natural stone. Despite these improvements, the construction techniques remain largely conventional. This material shift is driven by several factors, including the high cost and limited availability of premium-grade hardwoods (Class I). Some structures utilize circular or square concrete columns, while others incorporate natural river stones as foundational supports.

3.10. Cultural Seascape Tourism Potential

As a coastal settlement directly bordering the sea, Cambayya possesses significant potential for "blue tourism," particularly cultural seascape tourism. Public spaces adjacent to the waterfront can be transformed into attractive destinations that highlight the cultural, ecological, and social uniqueness of the community (see Figure 12). These include opportunities for community-based coastal tourism involving canal tours, local seafood gastronomy, artisanal craft markets, and waterfront recreational areas.

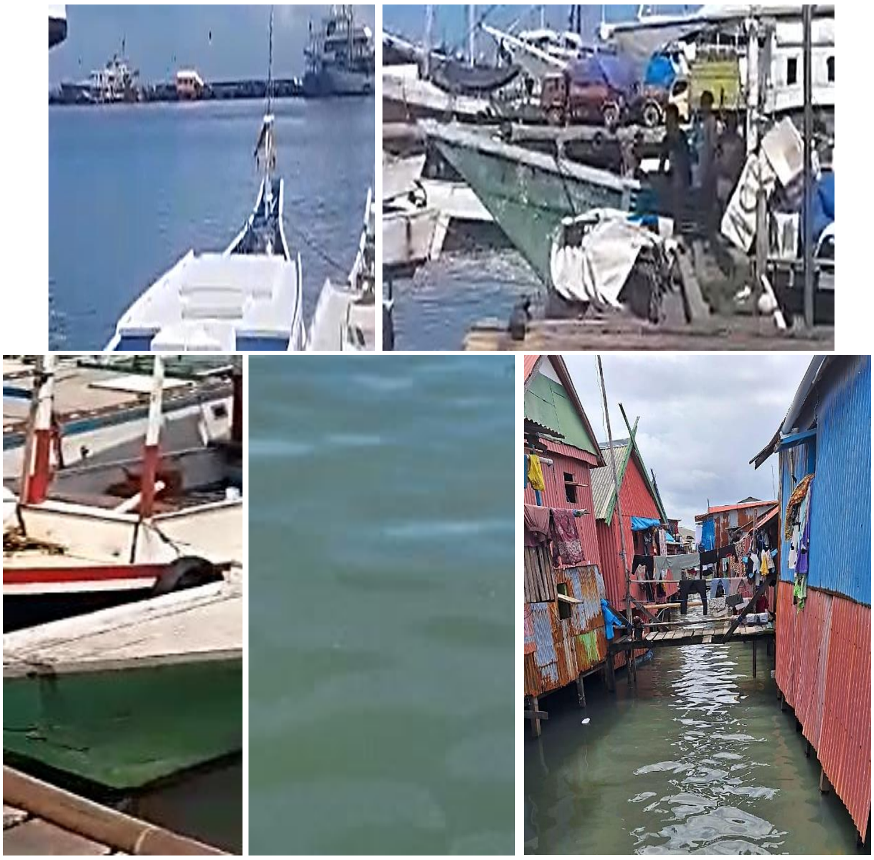


Figure 12. Natural Coastal Views and Socio-Cultural Activities in Cambayya Coastal Settlement

The coastal landscape of Cambayya presents a unique environmental and socio-cultural setting, characterized by expansive seascapes, distinctive coastal ecosystems, and direct access to natural light and ventilation—conditions often superior to those in densely built urban environments. These physical attributes are complemented by rich intangible heritage, including deep-rooted maritime traditions, community-based livelihoods, and strong social cohesion. Such qualities form a valuable cultural seascape that holds significant potential for development as a niche tourism model—***Cultural Seascape Tourism***—which integrates ecological appreciation with the preservation and celebration of coastal community identity. This model not only offers visitors an immersive cultural experience but also empowers local residents through inclusive, heritage-based economic participation.

***Cultural Seascape Tourism*,** refers to a form of tourism that integrates the natural beauty of the seascape with the cultural and maritime life of the community. In the context of Cambayya, this includes:

- Experiencing scenic sunrise and sunset views from stilt houses or coastal piers
- Exploring traditional wooden piers, local fish markets, and daily maritime economic activities
- Enjoying floating seafood culinary experiences rooted in local traditions

This tourism model fosters not only environmental awareness but also the preservation of cultural heritage, while creating alternative livelihood opportunities for coastal communities, such as local tour guiding and homestay services [26]. Living in overwater homestays offers more than just accommodation; it can serve as a form of therapeutic experience. The combination of panoramic sea views, the rhythmic sound of waves, and the refreshing ocean breeze contributes to psychological well-being by reducing stress, enhancing mood, and promoting mental relaxation. Such immersive natural environments are increasingly recognized in environmental psychology for their restorative effects. Therefore, integrating ecotourism with traditional coastal living can simultaneously support community-based economies, reinforce cultural identity, and improve the overall quality of life for both visitors and residents.

4. Discussion

4.1. Spatial Adaptation Patterns of Stilt Settlements in Response to Urbanization and Land Pressure in Cambayya Sub-District, Makassar

Rapid urbanization in Makassar has created significant spatial pressure on coastal zones, particularly in Cambayya Subdistrict, Ujung Tanah District (Figure 1). Strategically located near the city port, fishing centers, and distribution routes, this area has attracted low-income communities (MBR), especially fishermen and informal workers, to settle in close proximity to their livelihoods. However, limited access to legal land and the high cost of property in central Makassar have forced communities to occupy marginal zones, especially above coastal waters, through the construction of stilt houses based on local adaptive knowledge. The evolution of these overwater dwellings is illustrated in Figure 2.

The emergence of stilt settlements in Cambayya has been shaped by the absence of formal coastal zoning regulations and weak spatial governance. Houses are typically constructed using makeshift timber and recycled materials, resulting in highly dense and irregular spatial patterns that develop organically, without technical planning. Based on official documentation from the Makassar City Government (2022) [19], settlements in RW 02 and RW 04—both directly adjacent to coastal waters and serving as the study area—have been categorized as “severely slum” areas, with housing densities exceeding 500 people per hectare. This figure far surpasses the ideal density threshold for urban housing recommended by Indonesia’s Ministry of Public Works and Housing Regulation No. 14 of 2018. As a result, these settlements face critical shortages of open space, poor air ventilation, and high risks related to fire hazards and substandard sanitation systems.

Urbanization-driven land scarcity has triggered extreme spatial adaptation strategies. Residents have creatively utilized the substructure space—referred to locally as *kolong*—to add usable areas beneath the main dwelling, creating the appearance of two-story houses suspended over water. This vertical adaptation is accompanied by horizontal expansion toward the sea through pier-like structures, as shown in Figure 8. In many cases, expansions involve anchoring additional stilts into shallow waters or reclaiming land using waste and debris. This pattern of adaptation reflects a survivalist response to spatial constraints but simultaneously increases ecological vulnerability, especially in relation to tidal flows and sedimentation processes.

A major fire incident in September 2023 further exposed the structural and environmental vulnerabilities of these overwater communities. The fire destroyed dozens of homes in the densest sectors of the settlement, revealing poor construction practices involving flammable materials such as salvaged wood and plywood. Post-disaster adaptation involved using rubble and debris from the destroyed houses to create reclaimed land. These informal land-making practices disrupted tidal movements, contributed to artificial sedimentation, and created unstable land masses lacking legal recognition. This phenomenon illustrates a form of disaster-induced spatial transformation that is unregulated and ecologically precarious, yet perceived by residents as a necessary response to survival [27, 28].

Slum conditions in Cambayya are further intensified by natural population growth and the increasing number of nuclear families occupying a single housing lot. Many families have resorted to constructing new dwellings atop older ones or horizontally expanding into narrow spaces using supplementary structures. This intensifies overcrowding and results in almost no access to natural lighting or ventilation, as captured in Figure 3. The built environment thus manifests severe symptoms of spatial saturation, with extremely limited environmental resilience.

Collectively, the combination of rapid urbanization and land scarcity in Cambayya has given rise to informal, survival-oriented spatial adaptations. These adaptive responses demonstrate the social resilience and ingenuity of the community, but they pose long-term challenges to habitability, environmental sustainability, and formal urban integration. Therefore, targeted interventions—such as participatory incremental upgrading, coastal ecosystem-based zoning, and the implementation of ecological sanitation infrastructure—are crucial in building spatial resilience. Evidence from global case studies underscores that participatory urban upgrading initiatives lead to improved living conditions and stronger institutional inclusion when residents are actively involved [29-31].

4.2. Ecological Vulnerability of Settlements to Tidal Flooding, Sea-Level Rise, and Environmental Pollution

Settlements on water in Cambayya Sub-district, Makassar, exhibit a high degree of ecological vulnerability due to a combination of urbanization pressures, infrastructural disparities, and low environmental awareness. These settlements have developed on shallow waters through stilt housing systems constructed without formal technical planning. According to local residents, the foremost houses extend approximately 3.5 to 4 meters seaward from the original coastline. The densely packed houses lack any formal drainage or sanitation infrastructure, resulting in the direct discharge of all domestic waste—including grey water, black water, and household refuse—into the water beneath the stilt structures. This practice has caused the adjacent seawater to discolor to black and emit foul odors. And according to Asmal et al. (2022) [32], there are 4 factors that contribute significantly to influencing the community towards the management or attitude towards wastewater, namely the physical condition of the built environment, the natural environment, community activities, and government involvement, and this is an obstacle to changing the community's attitudes and views towards wastewater. And according to Asmal et al. [32], there are 4 factors that contribute significantly to influencing the community towards the management or attitude towards wastewater, namely the physical condition of the built environment, the natural environment, community activities, and government involvement, and this is an obstacle to changing the community's attitudes and views towards wastewater. During low tides, residual sludge accumulates, forming chronic waste layers beneath the settlements, as illustrated in Figures 4, 7, and 8.

In-situ water quality testing across three locations revealed extreme pollution levels. Total dissolved solids (TDS) ranged from 15,250 to 16,510 mg/L, far exceeding safe water quality thresholds. pH values fluctuated between 6.29 and 7.98, with relatively stable temperatures from 25.9°C to 26.1°C. BOD 160.0 ml/L, COD 216.4 ml/L, Ammonia 3.60 ml/L, and Phosphate 189.8 ml/L. More concerning were the microbiological parameters: total coliform levels reached 2,260,000 MPN/100 ml, and Escherichia coli concentrations were as high as 435,000 MPN/100 ml, indicating severe fecal contamination (Table 4). These results align with French et al. [33], who documented high microbiological contamination in informal coastal settlements across Indonesia, primarily due to open sanitation systems. Such contamination significantly increases the risk of waterborne diseases, including diarrhea, dermatological infections, and gastrointestinal illnesses.

In Cambayya, Makassar, extreme levels of water contamination—recorded at 2,260,000 MPN/100 mL for total coliform and 435,000 MPN/100 mL for *Escherichia coli*—significantly exceed safety thresholds set by the WHO and Indonesia's Ministry of Health Regulation No. 32/2017. This alarming condition necessitates immediate short-term public health interventions alongside the planning of long-term infrastructure solutions, such as wetland-based sanitation and bio-reactor systems.

Several urgent mitigation measures are recommended:

- **Provision of Safe Water**: Establish clean water access through mobile tank distribution, certified refill stations, or subsidized PDAM (local water utility) connections. Community outreach should discourage the use of contaminated seawater, especially for children.
- **Promotion of Hygiene and Sanitation**: Intensify hygiene campaigns promoting handwashing and waterborne disease prevention (e.g., diarrhea, hepatitis A), and distribute emergency sanitation kits containing soap, disinfectant, and hand sanitizer.
- **Temporary Sanitation Facilities**: Deploy mobile toilets and emergency latrines designed to prevent further contamination of coastal waters.
- **Community Health Surveillance**: Conduct routine health monitoring through mobile medical teams and provide supplementary immunization for vulnerable populations.
- **Participatory Risk Management**: Engage residents in mapping sanitation risks and strengthening local volunteer groups for environmental education and monitoring.

These interventions are low-cost, rapid, risk-based, and can be implemented independently of large-scale infrastructure. However, their effectiveness depends on strong support from local governments and public health institutions. A community-based approach is essential to ensure both immediate impact and long-term sustainability during the transition to comprehensive sanitation systems.

Furthermore, the area serves as a docking point for fishermen's boats and small cargo vessels, where loading and unloading activities frequently result in fuel and oil spills. These chemical pollutants exacerbate the environmental degradation. Evidence of oil slicks and diesel odors has been reported at several points, accompanied by the decline of aquatic fauna such as fish and mollusks previously abundant under the houses. Tosepu & Nasibah [34] emphasize that oil pollution from small-scale maritime activities significantly contributes to shallow coastal ecosystem degradation in urban Makassar.

Ecological vulnerability is further amplified by tidal flooding and seawater intrusion during rainy seasons coinciding with high tides. Residents frequently report seawater entering homes up to ankle height, carrying domestic waste and debris. The absence of drainage systems and non-waterproof housing foundations accelerates structural damage and increases local contamination loads. Figures 6 (land contour), Tables 1 and 2 (highest tides and high rainfall), and Figure 7 (accumulation of garbage and narrowing of canal channels) are the causes of the settlements being exposed to ROB flooding. This phenomenon echoes findings by Sofiyah & Suryawan [35], who highlight similar challenges in informal coastal settlements in Jakarta, where regular seawater intrusion exacerbates sanitation problems and health risks.

Water supply for Cambayya residents is sourced from the municipal water company (PAM) and bore wells located near main roads, with water distributed through piped systems to overwater houses. Although direct evidence of contamination in these water sources is lacking, the presence of environmental waste and potential leachate infiltration raises concerns regarding drinking water safety. Wulandari et al. [36] underscores the critical importance of protecting clean water sources and maintaining closed distribution systems in areas with poor sanitation to prevent cross-contamination.

Solid waste management is severely deficient. There is no formal waste collection or segregation system, resulting in all solid waste—plastic debris, food scraps, and construction materials—being dumped directly into the sea. Accumulations of trash beneath houses and around foundation piles cause artificial sedimentation, which may accelerate coastal shallowing. Werorilangi et al. [37] identify household waste disposal into marine environments as a primary factor in ecosystem pollution and substrate degradation in Makassar's coastal areas.

In summary, the ecological vulnerability of Cambayya's overwater settlements stems from spatial constraints, weak spatial governance, and a lack of sanitation and environmental infrastructure. Massive water pollution, solid waste accumulation, seawater intrusion, and unregulated maritime activities have collectively rendered this area environmentally unhealthy and unsafe. These findings corroborate national and international research demonstrating that informal coastal settlements in developing countries commonly face analogous challenges. Consequently, ecological and participatory interventions are urgently needed, including the development of waste treatment systems, zoning for maritime activities, and community-focused environmental education programs.

4.3. Integrating Stilt Housing and Waterfront Development: An Adaptive and Resilient Approach for Coastal Water Settlements in Cambayya, Makassar

The stilt housing settlement in Cambayya, Ujung Tanah District, Makassar City, exemplifies the intricate dynamics of coastal urbanization. This area is subject to multiple ecological stressors, including tidal inundation, recurrent coastal flooding (locally known as *rob*), water pollution, and socio-economic challenges driven by limited spatial capacity and inadequate infrastructure. Consequently, a design approach that emphasizes adaptability and resilience is essential to enhance the quality of life and strengthen the community's capacity to withstand environmental hazards.

In response to these conditions, several substructures within the area—particularly in low-lying and wetland zones—have adopted hybrid construction techniques (Figure 11). Informal settlements typically employ concrete and natural stone foundations, often shaped according to the economic means and practical knowledge of local builders. In contrast, formal housing developments, particularly those initiated by government programs, incorporate modular concrete substructures that offer uniformity, structural reliability, and ease of replication.

A forward-looking strategy involves the integration of stilt housing with waterfront development, guided by principles of modularity, multifunctionality, and sustainability. This approach not only enhances spatial organization but also supports climate-adaptive infrastructure, encourages eco-friendly practices, and fosters socio-economic resilience in vulnerable coastal communities.

4.3.1. Linear Stilt Housing Rows as Integrated Canal System

The existing unplanned, high-density settlement, compounded by poor drainage systems and building encroachments into the canal body, has resulted in unhealthy conditions, frequent flooding, fire hazards, and the loss of aesthetic values. A proposed solution involves transforming the scattered stilt housing pattern into an organized linear row system aligned with the canal edge.

This concept incorporates a modular rear terrace functioning as a pedestrian pathway with a minimum width of 1.8 meters, serving as a transitional zone between private and public spaces. This configuration promotes social interaction and enhances community surveillance through the principle of *eyes on the water* [38]. The proposed width adheres to international standards for pedestrian comfort established by the Americans with Disabilities Act [39], the American Association of State Highway and Transportation Officials, and the Federal Highway Administration [40, 41].

4.3.2. Modular Wetland Systems as Domestic Wastewater Biofilters

Beneath the rear terrace, a horizontal subsurface flow constructed wetland (HSSF-CW) is proposed to serve as a biofiltration system for greywater before discharge into coastal waters. Such systems have proven effective in reducing turbidity, total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5), as demonstrated by Collivignarelli et al. [42] and Suleman et al. [43]. Field assessments reveal high pollutant concentrations in household wastewater in this area, underscoring the strategic relevance of integrating horizontal biofilters into the stilt housing system.

4.3.3. Optimization of Underfloor Spaces for Functional Activities

The space beneath the houses, currently ranging from 1.1 to 1.8 meters in height (Figure 9), is often used for domestic functions such as cooking, laundry, and bathing. The height of the underpass utilized for domestic activities is very appropriate to its intended use, the lower the height of the underpass utilized, the less its function, and vice versa. However, this height is inadequate in terms of ergonomic and sanitary standards. According to SNI 03-1733-2004 [44], the ideal minimum height for service areas is 2.4 meters. Suriandjo et al. [45] suggests the following stilt height standards:

- Minimum of 1.5–2.0 meters from the highest tidal point;
- Ideally 2.5–3.0 meters for semi-functional space;
- An additional 0.5 meters to accommodate tidal surges and flooding.

Given the availability of local materials (e.g., wooden stilts of ~5 meters in length), the optimal height of the underfloor space is between 2.2–2.5 meters. This elevation supports cross-ventilation, domestic utility, and mitigates inundation and sanitary issues. Prior studies [46-49] emphasize the relevance of multifunctional underfloor usage in high-density coastal zones without requiring horizontal expansion.

4.3.4. Utilization and Structural Comparison of Underfloor Space in Coastal Stilt Houses

In densely populated coastal settlements, the development of underfloor space in stilt houses serves not only domestic needs but also thermal comfort. During the daytime, residents often retreat to the shaded area beneath their homes due to elevated ambient temperatures exceeding 31°C, making upper levels uncomfortably hot. This has led to the widespread adaptation of the underfloor area as a livable, cooler zone.

A structural comparison of Type-36 stilt houses (6×6 m) highlights the differences between fully wooden designs and hybrid systems combining concrete and wood.

Table 5. The difference between the use of wooden structures and hybrid structures (wood and concrete) lies in their structural performance, durability, and environmental impact

Aspect	Full Wood	Hybrid Concrete-Wood
Underfloor Structure	All columns and beams made of wood	Concrete modular piers (submerged), wooden upper frame
Cost Estimate	± IDR 17 million	± IDR 25–30 million (based on height and number of modules)
Primary Material	Ulin/Bangkirai wood	Precast concrete (bottom) + Ulin/Bangkirai wood (top)
Seawater Resistance	Moderate; requires protective treatment	High; submerged concrete is more durable
Durability	5–10 years with maintenance	15–25 years with minimal degradation
Maintenance Needs	High; anti-termite/fungus coating required	Low; concrete base requires minimal upkeep
Construction Ease	Simple and faster	Requires lifting equipment for concrete modules
Suitability	Small-scale, community-driven projects	Long-term, high-tide coastal areas, community-scale

The hybrid construction model—using concrete for the lower structure and wood for the upper portion—is slightly more expensive than conventional wooden stilt houses. However, it offers several long-term advantages that justify the investment. The use of reinforced concrete at the base enhances seawater resistance, making the structure more resilient against tidal forces, saltwater corrosion, and wave impacts. Concrete also provides greater durability and structural stability, particularly in high-density settlements exposed to frequent tidal inundation.

Meanwhile, wood remains the preferred material for the upper levels due to its thermal comfort, aesthetic integration with local architectural traditions, and lightweight nature, which minimizes structural stress. This hybrid design requires low maintenance compared to fully wooden structures, which are more prone to decay, termites, and moisture damage. In the long term, it reduces lifecycle costs and improves safety.

Importantly, this model aligns with sustainable construction principles, utilizing locally available materials, reducing frequent repairs, and supporting climate-resilient housing. It also opens possibilities for modular upgrades and integration with solar energy systems, rooftop rainwater harvesting, and other eco-friendly technologies—making it an adaptable solution for coastal urban settlements.

4.3.5. Multifunctional Jetty as Adaptive-Ecological Infrastructure

To address spatial limitations and maximize waterfront access, a multifunctional modular jetty is introduced. This infrastructure functions not only as a boat docking point but also as a public space, seafood transaction area, and social interaction hub. Some jetty modules are equipped with floating constructed wetlands (FCWs) that use native vegetation such as *Typha*, *Cyperus*, and *Vetiver* to treat grey and black water [50]. Due to their floating nature, FCWs are ideal for stilt settlements with limited land and unstable ground conditions.

4.3.6. Structural Materials and Technical Specifications for Durability

The primary building structure is designed to withstand coastal environmental conditions. Lightweight precast concrete with corrosion-resistant piles is recommended. In areas with local material potential, reclaimed *ulin* wood is used for flooring and wall panels, while Portland Composite Cement (PCC) is selected for its superior sulfate and corrosion resistance and environmental friendliness [51]. Micro-drainage systems and protective rails using galvanized steel or local bamboo are included. The two-story housing model with cross ventilation improves thermal comfort and energy efficiency [52].

4.3.7. Visual Harmonization and Strengthening of Maritime Cultural Identity

Waterfront design also embodies cultural identity. Architectural elements such as gabled roofs, Bugis-Makassar wooden ornaments, and traditional jetty forms foster visual continuity and reinforce local coastal character. Contextual visual design offers potential for the development of environmentally based community tourism [53], categorized as coastal-based marine ecotourism. However, successful implementation requires adequate basic infrastructure and active community involvement (Figure 12 illustrating scenic views and culturally engaging activities).

4.3.8. Spatial Integration of Social, Economic, and Ecological Dimensions

This integrative approach yields cross-sectoral benefits. Socially, fragmented spaces become interconnected, reinforcing community interaction. Economically, new productive spaces emerge, such as kiosks, informal trading zones, and homestays. Ecologically, modular infrastructure prevents waterlogging, introduces vegetative buffers such as vertical gardens, and enhances air quality and neighborhood aesthetics [12, 54].

4.3.9. Policy Direction: Incremental and Participatory Upgrading

The most feasible development model is incremental upgrading—phased, adaptive, and community-driven. This approach has been proven effective in upgrading informal coastal settlements in Southeast Asia [55]. Active community participation from the planning through implementation phases is essential to ensure long-term success and ownership.

Integrating stilt housing with waterfront development presents a comprehensive response to the ecological, spatial, and socio-economic challenges of coastal settlements like Cambayya. This approach not only improves housing quality but also strengthens ecological and social resilience. With proper technical implementation and active community engagement, this area could become a prototype for sustainable coastal settlement transformation in Indonesia.

4.4. Inclusive and Sustainable Spatial Strategies to Enhance Socio-Ecological Resilience in Water-Based Settlements

1. Functional Zoning: Vertical and Horizontal Integration

- Vertical Zoning: Functions are stratified by level to maximize efficiency and environmental adaptation. The underfloor space is designated for service activities (e.g., washing, sanitation, kitchen); the main floor functions as living space; and the roof accommodates rainwater tanks and vertical garden systems [55].
- Horizontal Zoning: A linear row housing configuration is applied along canal corridors or water routes. Rear-access pedestrian paths and public corridors serve as social connectors and transitional zones between private and public spaces [56].

2. Environmentally Adaptive Infrastructure

- Construct modular, multifunctional piers that are resistant to tidal fluctuations, serving as social spaces, docking areas, and platforms for microeconomic activities [57].
- Integrate Floating Constructed Wetlands (FCWs) using native plant species such as Typha, Vetiver, and Pontederia to treat greywater through natural biofiltration processes [50].
- Utilize locally available, salt-resistant materials (e.g., recycled ulin hardwood and lightweight precast concrete) to ensure structural durability under coastal conditions [58].

3. Inclusive and Community-Based Public Spaces

- Design shared open spaces such as floating plazas, communal docks, and vertical gardens to encourage social interaction [59].
- Ensure universal accessibility through pedestrian paths with a minimum width of 1.8 meters, non-slip surfaces, and adequate lighting [60].
- Activate participatory programs including community murals, educational gardens, and collective sanitation efforts [61].

4. Economic Diversification and Livelihood Enhancement

- Encourage the use of residential units for home-based enterprises such as food stalls, seafood processing, and homestay accommodations [62].

- Promote coastal-based marine ecotourism that highlights local wisdom through canal tours, seafood-based culinary experiences, and traditional handicrafts [63]. This is greatly supported by the potential of marine eco-tourism owned by settlements such as Figure 12 and Figure 5.

The development of coastal-based ecotourism holds significant potential for strengthening local cultural identity but may also present risks if not managed inclusively.

Positive Impacts: Ecotourism can revitalize traditional practices by transforming them into cultural attractions, fostering community pride and heritage preservation. Newly developed tourism infrastructure may also create expanded communal spaces, encouraging local social interaction. Moreover, inclusive economic opportunities allow residents to actively participate as tourism entrepreneurs. Heightened environmental awareness is another benefit, often emerging through increased community engagement in marine conservation.

Negative Risks: Unregulated tourism development can lead to the privatization of public coastal spaces, displacing local social activities. Cultural practices risk being commodified, potentially eroding their meaning and authenticity. Additionally, a surge in visitor numbers may intensify environmental degradation, including pollution and habitat disruption.

Preventive Strategies: To mitigate these risks, a community-based tourism (CBT) approach is essential, placing local residents at the center of tourism governance. Co-designed spatial planning processes must be employed to ensure residents contribute directly to the design of tourism infrastructure. Socio-economic zoning can safeguard public spaces as community assets, while collective benefit-sharing mechanisms should be instituted, allocating tourism revenue for local social programs.

Conclusion. When implemented through participatory, community-led, and spatially just frameworks, coastal ecotourism can support long-term socio-economic sustainability while preserving the integrity of communal spaces.

5. Adaptive Information Systems and Early Warning Mechanisms

- Integrate community-based flood and tidal risk mapping into local planning [64].
- Install early warning systems using sensor-based technology or locally developed applications to monitor tidal flooding and extreme weather events [65].

6. Community-Based Management Models

- Establish inclusive local management bodies (e.g., environmental committees) composed of residents, women, fishers, youth, and traditional leaders [66].
- Implement an incremental upgrading model that is flexible, phased, and responsive to the socio-economic capacity of local communities [55, 67].

7. Ecological Education and Environmental Awareness

- Conduct regular environmental education programs such as waste banks, sanitation training, and organic/inorganic waste separation workshops [68].
- Incorporate local ecological and climate adaptation content into school curricula to strengthen environmental literacy among youth [69].

4.4.1. Summary

These strategies provide a replicable planning model for inclusive coastal settlements that not only improve the physical conditions of water-based communities but also enhance social cohesion, economic empowerment, and long-term ecological resilience.

Table 6. SWOT analysis table for arranging settlement above water

Strengths	Weaknesses
Local wisdom of stilt houses that are adaptive to high tides	Basic sanitation, clean water, and drainage infrastructure are inadequate
Community solidarity and mutual cooperation are still strong	High housing density results in limited open space and air circulation
Strategic location near the coast and maritime economic routes	Economic dependence on the informal sector and minimal livelihood diversification
Strong maritime traditions and local culture	Many buildings do not meet environmental safety and health standards
Opportunities	**Threats**
Government program for upgrading coastal slums	Climate change: sea level rise, extreme weather, tidal flooding
Potential for developing culture-based tourism and coastal tourism	Coastal land conversion for industrial or reclamation purposes
Environmentally friendly technology (floating biofilters, floating compost)	Climate change: sea level rise, extreme weather, tidal Social inequality and risk of local eviction
Access to funding and international cooperation for climate	Marine pollution from domestic waste and shipping activities

4.5.1. Matrix Based Development Strategy SWOT

Opportunities: Government Support for Coastal Slum Upgrading

Although not directly assessed within this study, Indonesian government policies signal strong political feasibility and funding potential for spatial interventions—such as double-story stilt housing and adaptive coastal corridors—in dense coastal urban zones like Cambayya.

- Housing Finance Liquidity Facility (FLPP) Since 2010, FLPP has disbursed over IDR 111 trillion to support more than 1.26 million low-income households (MBR), demonstrating enduring state commitment to affordable housing finance. Evidence also indicates a negative correlation between FLPP-supported housing and community morbidity, suggesting positive public health outcomes
- Subsidized Homeownership and Tax Relief Regulations such as Permen PUPR (Minister of Public Works and Public Housing Regulation) No. 242/KPTS/M/2020 and PMK No. 60/2023 include provisions on income thresholds, capped selling prices, and government-covered VAT, expanding access to formal, decent housing for MBR (low-income communities).
- Streamlined Permitting Process Government Regulation No. 64/2016 simplifies licensing for MBR housing development, facilitating faster project realization and potentially reducing bureaucratic barriers to adaptive housing initiatives.
- Land Provision Mechanisms Government Regulation No. 19/2021 formalizes land acquisition for public interest—including affordable housing—which may support land-for-intervention strategies in waterfront zones like Cambayya.
- Targeted Housing Assistance Regulations such as Permen PUPR No. 7/2022 and No. 35/2021 establish technical and administrative channels for special housing grants and subsidies, offering avenues for financing community-scale spatial upgrades.

These national-level housing policies offer a robust structural basis and political support for implementing innovative spatial adaptations in coastal slums. The alignment of FLPP, subsidy schemes, permission easing, and land acquisition mechanisms provides a favourable environment to pilot and scale up spatial strategies like two-story stilt housing integrated with waterfront corridors. This policy climate enhances both financial feasibility and institutional legitimacy of such interventions in Cambayya and analogous contexts.

Table 7. Matrix based development strategy SWOT

Strategi Streng-Opportunity (Maxi-Maxi)	Strategi Weaknesses-Opportunity (Mini-Maxi)
Develop adaptive stilt houses and modular waterfronts based on local culture (strength + ecotourism opportunities)	Improve sanitation infrastructure using floating domestic waste biofilters (weaknesses + technological opportunities)
Integrate community-based tourism activities with public open space systems (local culture + tourism programs).	Facilitate creative economic business training for residents to diversify income (informal economy + livelihood opportunities).
Build a multifunctional pier that supports micro-economy and waste processing (strategic location + access to funding).	Collaborate with academics and NGOs to improve uninhabitable houses (non-standard buildings + climate financing opportunities).
Strategy S-T (Maxi-Mini)	Strategy W-T (Mini-Mini)
Strengthen ecological resilience through modular-elevative design based on local wisdom (house structure + tidal flood threat).	Design a policy of protection against eviction and land conversion (minimal legality + threat of reclamation).
Utilize community solidarity for early warning and disaster response systems (mutual cooperation + climate risk). strategy	Prioritize gradual upgrading based on citizen participation so as not to cause social conflict (poverty + threat of inequality).

4.5.2. Strategic Conclusion

By adopting a comprehensive SWOT approach, strategies for managing coastal water settlements such as Cambayya can be directed at strengthening local capacity, using environmentally friendly technologies, improving community-based economies, and mitigating ecological and social risks.

5. Conclusions

The water-based settlement in Cambayya, Makassar, represents a spatial adaptation strategy developed by coastal communities in response to urbanization pressures, land scarcity, and dynamic aquatic environments. This adaptation is evident in the transformation of stilt-house understructures into domestic spaces, the use of timber and hybrid timber-concrete stilts, and the horizontal expansion of settlements into shallow marine areas. These spatial responses are organic and need-based, demonstrating both social and technical flexibility in managing limited space.

Nevertheless, these settlements face significant ecological vulnerabilities, including tidal flooding (rob), marine water intrusion, and environmental pollution. These challenges are exacerbated by canal narrowing, waste accumulation beneath houses, inadequate drainage systems, and poor sanitation infrastructure. Despite these vulnerabilities, the settlement exhibits considerable potential for economic improvement through the development of cultural seascape tourism—a form of tourism that integrates maritime heritage and natural coastal landscapes—which could enhance both local livelihoods and environmental quality.

The increasing ecological degradation due to anthropogenic activities reinforces the urgency of implementing more inclusive and sustainable spatial strategies. In this context, the approach of Inclusive and Sustainable Spatial Strategies to Enhance Socio-Ecological Resilience in Water-Based Settlements is essential. This strategy emphasizes the importance of strengthening multifunctional public spaces, enhancing community-based infrastructure, and preserving coastal ecosystems as integral components of settlement sustainability.

Furthermore, this study highlights the necessity of Integrating Stilt Housing and Waterfront Development: An Adaptive and Resilient Approach for Coastal Water Settlements in Cambayya, Makassar. This integration provides opportunities for adaptive spatial design that not only addresses structural resilience against tidal fluctuations but also supports socio-economic activities and promotes ecological connectivity across coastal landscapes.

Adopting a constructivist paradigm and a mixed-methods approach, this study concludes that the spatial adaptation of the Cambayya community is dynamic and multifaceted. It reflects socio-ecological resilience shaped by the interplay between local cultural practices, environmental pressures, and socio-economic conditions. To ensure the long-term sustainability of such coastal settlements, planning and design interventions must be community-based, context-sensitive, and aligned with the principles of resilient and environmentally conscious development.

Our findings reveal that spatial adaptation in Cambayya, Makassar, has emerged as a dynamic, organically-grown response to urbanization pressure, limited land availability, and a shifting coastal environment. This study emphasizes the integration of stilt housing and waterfront development as a resilient, adaptive strategy: not only does it enhance resistance to tidal fluctuations, but it also enables socio-economic activity and ecological connectivity. A novel contribution is the identification of “cultural seascape tourism” as a promising pathway that aligns maritime heritage with environmental preservation.

Compared to prior research, which often focuses on macro-level planning or typological House on Stilts studies in contexts like Bangladesh, Brazil, or the Mekong Delta, our study provides a context-specific analysis of densely populated water-based settlements in Southeast Asia—a topic still underexplored. While many studies underscore the importance of nature-based solutions (NbS) and community participation for socio-ecological resilience, few explicitly examine how stilt housing innovation and NbS integration intersect under conditions of acute land scarcity.

Recent high-impact research supports this approach. A systematic review of NbS projects in informal settlements across Southeast Asia and the Pacific highlights the efficacy of constructed wetlands and community-driven green infrastructure for sanitation and resilience enhancement. Additionally, studies exploring coastal adaptation in Southeast Asian cities emphasize the paradoxes and transformative possibilities of integrating Blue Urbanism and NbS in urban coastal planning. This study contributes to scholarly discourse by filling an important gap: the demand for micro adaptive spatial strategies that seamlessly integrate housing, livelihood, and communal functions in compact, informal coastal settlements. By centering a participatory, context-sensitive, and sustainability-oriented framework, the research offers a locally grounded model of resilient coastal urbanism appropriate for similarly vulnerable environments in tropical Southeast Asia.

6. Declarations

6.1. Author Contributions

Conceptualization, I.A.; methodology, A.H. and S.S.; software, I.A.; formal analysis, I.A.; data curation, I.A.; writing—original draft preparation, I.A.; writing—review and editing, I.A., A.H., S.S., and N.N.; visualization, I.A.; project administration, N.N.; funding acquisition, I.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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