SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I5P105

Volume 12 Issue 5, 56-70, May 2025

Original Article

Optimizing Coastal Tourism Infrastructure: A Typology-Based Approach for Sustainable Development in Bontobahari, Indonesia

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Received: 05 March 2025 Revised: 06 April 2025 Accepted: 05 May 2025 Published: 31 May 2025

Abstract *- This research delves into the critical link between tourism infrastructure and regional development in Bontobahari, Indonesia, emphasizing the impact of coastal typologies on sustainable infrastructure planning. Recognizing the significant contribution of tourism to Indonesia's GDP and its role in the economy, the study underscores the need for improved infrastructure to bolster tourism growth and enhance visitor satisfaction, especially in coastal areas where infrastructure deficiencies are notable. The aim is to optimize infrastructure development through a coastal typology-based approach, fostering effective tourism resource management. Employing methodologies such as field observations, spatial data analysis, and infrastructure condition evaluations, the research identifies and assesses regional typologies, determining their suitability for tourism. Key findings reveal varied infrastructure conditions: some coastal areas suffer from poor roads and inadequate waste management, while others have satisfactory water systems. The study discusses sustainable tourism's alignment with Sustainable Development Goals, advocating for infrastructure that supports economic and ecological sustainability. A typology-based planning approach is used, tailored to address the specific needs of different coastal zones, enhancing disaster resilience and environmental sustainability. This study suggests significant infrastructure enhancements are necessary, particularly in roads and waste management, to improve the functionality and appeal of tourist destinations. The research also highlights the broader social benefits, such as increased local employment and improved resident life quality, underlining the comprehensive value of upgraded tourism infrastructure. This approach not only supports Bontobahari's economic growth but also promotes a sustainable, resilient tourism sector.*

Keywords *- Coastal typology, Infrastructure, Sustainable development, Tourism.*

1. Introduction

The tourism sector in Indonesia contributes approximately 4.7% to the overall global GDP [1]. Tourism is among the most influential economic and cultural sectors worldwide [2], and in certain countries, it also serves as a key economic driver [3]. Moreover, tourism substantially promotes infrastructure development in these countries [4]. Indonesia is recognized not only for its extraordinary natural resources but also for its diverse cultural heritage, making it one of the world's leading tourist destinations [5].

Tourism is a vital component of Indonesia's economic development, providing foreign exchange earnings, employment opportunities, and stimulating growth in other industries [6]. Further, a study has identified a two-way causal relationship between tourism and economic growth, involving several relevant variables such as exchange rates and inflation [6]. In marginal areas, however, tourism development frequently encounters challenges stemming from inadequate infrastructure despite the sector's significant potential to enhance community welfare [7].

Infrastructure is pivotal in both advancing tourism development and ensuring visitor satisfaction. Many studies indicate insufficient infrastructure can negatively affect tourists' experiences and comfort [6]. Consequently, expanding tourism infrastructure is essential for the sustainability and growth of tourist destinations, as it significantly impacts a destination's ability to attract and accommodate visitors [7]. The elements of tourism infrastructure represent critical aspects that underpin the sector's success. One of the principal components of any tourism infrastructure is its resources, including favorable features and a combination of natural and man-made attractions suited to establishing a robust tourism framework [7]. In addition, major infrastructure components include roads, clean water, waste management, and transportation facilities [8].

Sustainable tourism plays a crucial role in achieving numerous Sustainable Development Goals (SDGs), particularly those related to health (SDG 3), clean water (SDG 6), climate action (SDG 13), and infrastructure (SDG 9). Poor waste management can lead to pollution and environmental degradation, ultimately affecting both the tourism experience and public well-being. Therefore, it is vital to apply sustainable waste management principles, such as waste reduction, recycling, and efficient resource utilization, across the tourism sector. Furthermore, sustainable tourism bolsters SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), SDG 14 (Life Below Water), and SDG 9 (Infrastructure and Innovation) by encouraging eco-friendly infrastructure development and innovative resource management. Collaboration between the tourism sector and responsible waste management can foster a form of tourism that not only drives economic growth and alleviates poverty (SDG 1) but also safeguards public health and protects ecosystems, thereby contributing to the comprehensive achievement of the SDGs under the guidance of the World Tourism Organization (UNWTO) [9].

Marine tourism is one of the largest components of the tourism industry and continues to exhibit enormous potential, especially in developing countries [10]. Its substantial maritime opportunities necessitate comprehensive planning by regions with coastal and marine territories [11]. With its extensive waterways and abundant marine resources, Indonesia has significant prospects for further advancement in this sector. Consequently, it is imperative to manage these opportunities both optimally and sustainably, including those available in Bontobahari Bulukumba.

Table 1 indicates that over the past seven years, the locally generated revenue of Bulukumba Regency has fluctuated, with a significant decline in 2020 due to the pandemic, followed by a recovery in 2023. The tourism industry plays a crucial role in this economic growth, and the importance of sufficient infrastructure in attracting and retaining tourists cannot be underestimated. Inadequate development in this area may diminish the destination’s appeal and quality, ultimately hindering visitor arrivals. Therefore, a comprehensive understanding of regional typologies is essential for formulating more efficient and effective tourism development strategies.

Coastal regions are multifunctional zones that serve a wide range of purposes. Indonesia’s coastal areas exhibit diverse typologies, influencing infrastructure planning and management strategies. This diversity often leads to new challenges, particularly those related to infrastructure and land requirements [12]. Infrastructure facilities constitute a critical pillar for attracting investment and developing the tourism sector [13]. In this context, typology data and information provide a vital foundation for effective coastal zone management planning [14]. Studies on coastal physical typology and suitability analysis for coastal tourism development [15] highlight multiple factors, including relief, major components, landscapes, coastal physical typology, and land use [13].

Table 1. Tourism growth in bulukumba

Year	Local Revenue (million Rupiah)	Economic Growth (%)
2017	106.037	6.77
2018	200.080	6.89
2019	188.708	5.05
2020	168.422	0.43
2021	153.236	0.76
2022	168.703	3.81
2023	185.964	5.21

Research on coastal typologies in Indonesia generally emphasizes physical characteristics, coastal dynamics, and management strategies [14]. While several studies have explored marine tourism potential through typological lenses [15], most focus narrowly on physical infrastructure without integrating local contextual planning [16]. Ignoring local conditions in infrastructure projects can harm both communities and ecosystems—for instance, and road construction has been linked to significant landscape changes and biodiversity loss, prompting calls for a more equitable, multispecies perspective [17]. This multidimensional approach is increasingly vital to sustainable development frameworks [18]. Infrastructure planning should be rooted in integrated regional strategies [19], supported by frameworks that align infrastructure needs with regional characteristics [20]. In coastal areas, such integration is essential for addressing site-specific conflicts and complexities [21], enabling tailored solutions based on regional typologies [22].

In developing infrastructure for marine tourism areas through a typology-based approach, understanding the coastal typology, grounded in an analysis of physical coastal characteristics, is of paramount importance. Geomorphological processes, including the uplift of karst hills and wave action, create distinct coastal types [23]. Geomorphology greatly contributes to examining changes in the Earth’s surface, where soil properties and composition significantly affect human activities and the distribution of life in the area [24]. Morphological occurrences in sediment deposits, which have been uplifted several hundred meters above sea level, also serve as key indicators of relief changes over millions of years [25]. These relief features ultimately establish the foundation for human habitats and activities [26], while topography influences water flow and distribution, vital to coastal ecosystems [27]. Consequently, a thorough understanding of coastal geomorphology and physical characteristics is vital for identifying specific typologies and designing sustainable, context-appropriate infrastructure development.

Coastal typology is shaped by geological processes, topography, and human activities [15]. Research carried out in Bontobahari identified various coastal types—such as land-deposition beaches, marine-deposition beaches, and structural beaches—to assess their suitability as coastal tourism destinations [16]. In this area, coastal typology was analyzed through the collection of morphological data, examination of coastal materials, and investigation of existing coastal issues [13]. Observations and spatial data show that the coastal zone in Bontobahari District falls into the category of secondary coasts, namely beaches formed by marine deposition, characterized by hydrodynamic coastal processes such as erosion, beach accretion, and the potential risk of tsunamis. Meanwhile, the other coastal type in the region is a primary coast, which is structurally formed [16].

Bontobahari District holds considerable potential for tourism development, particularly in its coastal areas, which are well-suited for marine tourism. Effective planning should begin with an overview of the region's physical characteristics [28] and strategies to address coastal settlement challenges [29]. Like many coastal regions in Indonesia, Bontobahari faces infrastructure-related constraints [30], and sustainable tourism requires adequate infrastructure that accounts for environmental impacts and climate change [31]. A typology-based approach is thus essential, as it helps align infrastructure initiatives with regional characteristics [32]. Coastal typology informs strategies for development, including infrastructure provision, waste management, and disaster mitigation [33], making it critical for sustainable coastal management [34]. Previous typology-based studies have largely remained conceptual without translating typological classification into zone-specific infrastructure recommendations. This study addresses that limitation by developing a practical framework that aligns physical coastal features with tailored infrastructure planning in Bontobahari.

This study fills that gap by proposing a typology-based infrastructure development framework tailored specifically for marine tourism zones in Bontobahari. While prior research has addressed coastal tourism potential and geomorphological mapping, few have operationalized these typologies into actionable infrastructure strategies considering local disaster risk, ecological constraints, and sustainability objectives.

The novelty of this work lies in its application of typology-based planning-grounded in geomorphological analysis-to develop practical, zone-specific recommendations for roads, clean water, waste management, and pier systems. This integrated approach provides a new perspective that combines spatial planning with sustainable infrastructure policy in coastal tourism development.

2. Methodology

2.1. Site Location

This research was conducted in Bontobahari District, which serves as the focal area for marine tourism in Bulukumba Regency (Figure 1).

2.2. Data Types and Sources

2.2.1. Primary Data

Primary data refers to information obtained directly from the study site. Such data are generally used to generate information that accurately reflects real-world conditions, thereby providing a sound basis for decision-making [35]. In this research, primary data include environmental conditions, physical characteristics, and the availability of infrastructure.

2.2.2. Secondary Data

Secondary data were acquired through a literature review of relevant resources derived from books, geographical data, or previous research for this study. These sources serve as complementary references for the primary data collected [36].

2.3. Data Analysis Techniques

2.3.1. Determination of Coastal Region Typology

The determination of coastal physical typology in this study refers to a morphological system aligned with the guidelines for integrated rapid coastal surveys [37]. Grouping coastal areas by considering three fundamental physical components (Figure 2): relief, genetic processes, and primary surface materials, sequentially plays a central role in defining coastal relief types [16]. The stages for determining regional typology are summarized in Table 2.

2.3.2. Data Interpretation Analysis

Interpretation in this study involves the process of assigning meaning and significance to the conducted analysis, explaining descriptive patterns, and examining relationships and interconnections among existing data [38].

In this research, determining the physical infrastructure conditions aims to evaluate the quality and feasibility of infrastructure within the marine tourism area. The study not only describes the current state of infrastructure but also assesses its viability through indicators tailored to each infrastructure type. Consequently, this interpretive process enables researchers to discern relationships within the data and identify both strengths and weaknesses of the area's infrastructure.

The steps for data interpretation analysis include the following:

1) Gathering Existing Data from the Study Site
2) Analyzing the Condition Index of Each Infrastructure. To determine the condition index, each infrastructure

component is assessed using a set of predefined indicators. Each indicator receives a score reflecting its current state-ranging from very poor to excellent-based on observed or measured conditions. Once all indicators have been evaluated, the total score is compared against the number of indicators used. The resulting figure represents the condition index, providing an overall assessment of the infrastructure's status.

3) Interpreting Index Values Based on Defined Ranges. Using the calculated condition index, researchers then interpret the resulting scores. The index ranges facilitate categorizing infrastructure conditions by their respective feasibility levels. The explanation of how index values are interpreted within the established ranges is summarized in Table 3.

2.3.3. Formulating Recommendations for Infrastructure Improvement and Enhancement

Recommendations are formulated by first examining the typology of the area through its physical attributes. This approach clarifies the fundamental characteristics and potential of the region, highlighting specific limitations, particularly concerning roads, clean water, and pier waste management. An evaluation of the existing infrastructure is then conducted to determine whether improvements or upgrades are needed. Incorporating a typology-based approach, which merges the region's physical characteristics with perspectives derived from relevant literature and previous studies, the resulting recommendations for infrastructure development are grounded in these combined insights.

This approach is based on tailoring design solutions that align with the region's typology, enhancing comfort and accessibility, and creating sustainable outcomes that positively influence the advancement of the tourism sector in Bonto Bahari.

The assessment of existing infrastructure and the evaluation rubric used to provide ratings and obtain a condition index are detailed below:

1) Roads. The assessment of road conditions is conducted using criteria set by the World Road Association (PIARC), which provides standards for systematically evaluating road infrastructure quality [39]. The assessment table for determining the existing condition of roads is summarized in Table 4.
2) Clean Water. The assessment table for determining the quality of clean water is summarized in Table 5.
3) Piers. The assessment of piers includes several important elements that must be checked to ensure that the pier structures remain safe and functional. The explanation for each pier assessment aspect is summarized in Table 6.
4) Waste Management. The assessment table for waste management in the area is summarized in Table 7.

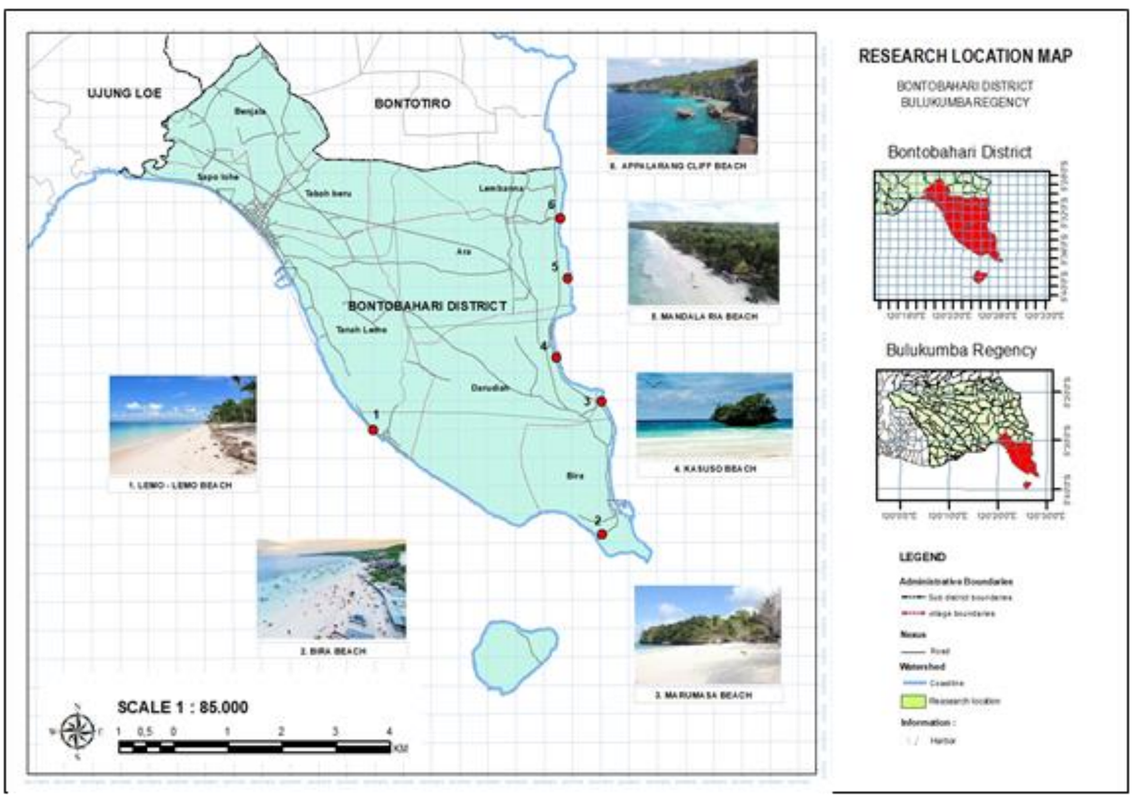

Fig. 1 Research Site

3. Results and Discussion

3.1. Coastal Area Typology

Physical data for each coastal area were obtained through observation and spatial analysis. As summarized in Table 8, the coastal regions in the Bontobahari Sub-district are predominantly classified as secondary coastal types (marine deposition beaches) with hydrodynamic coastal dynamics. These areas exhibit potential hazards such as tsunamis, beach erosion, and accretion.

3.2. Existing Infrastructure Conditions

3.2.1. Roads

Road conditions in coastal areas play a crucial role in maintaining mobility and ensuring the safety of road users, including tourists, local residents, and passing vehicles.

Good road conditions not only contribute to a comfortable driving experience but are also closely related to safety factors, transportation efficiency, and environmental preservation. Therefore, it is essential to evaluate the quality of road infrastructure in coastal areas to identify which aspects need improvement or upgrades.

Table 9, Figures 3 and 4 provide data on road conditions in various tourist areas of Bontobahari, covering road length, road area, average road condition scores, and road condition categories.

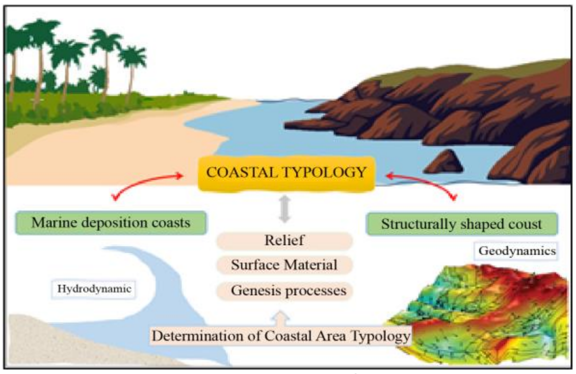

Fig. 2 Grouping Coastal Areas by Relief, Genetic Processes, and Primary Surface Materials

Fig. 3 View of a Road Classified as Fairly Good in Bontobahari

Fig. 4 View of a Road Classified as Poor in Bontobahari

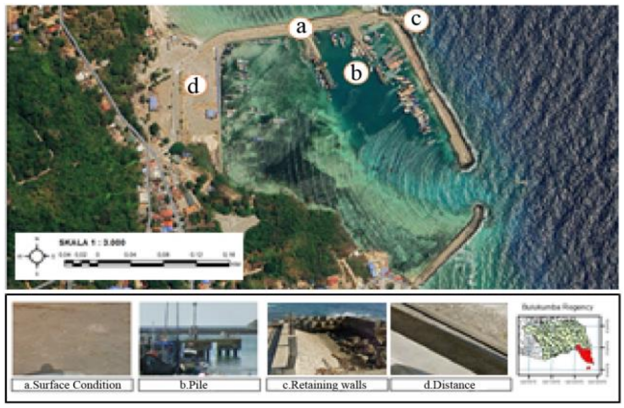

Fig. 5 Map of the Tourist Area Displaying Pier Locations, Distances, and Structural Conditions

Fig. 6 Waste Management in Fair Condition at Appalarang Beach

Fig. 7 Waste Management in Poor Condition at Mandalaria Beach

Table 2. Determination of Regional Typology

Step	Title	Description
1	Relief Identification	Relief identification was performed by extracting contour line data from the 2024 Bulukumba Regency spatial planning map.
2	Identification of Main Materials	Materials used for determining coastal physical typology are divided into four primary categories: solid material, soft or muddy material, clastic or loose material (e.g., sand), and organic material [16]. The type of material was determined through field observation.
3	Identification of Formation Processes	The formation process was identified by interpreting geological maps and landform information to determine whether the coastal area was formed by structural, volcanic, solutional, marine, fluvio-marine, or bio-marine processes [16].
4	Analysis of Coastal Physical Typology	After identifying the relief, primary constituent materials, and dominant formation processes, each dataset was converted into a digital format using on-screen digitizing methods within ArcMap software. These three parameters were then overlaid and analyzed, followed by additional digitizing to delineate the boundaries of the coastal physical typologies within the study area [16].

Table 3. Interpretation of condition index value

Condition Index Range	Category	Description
4.5 – 5	Excellent	Infrastructure in the tourism area is in excellent condition; all components function properly and meet established quality standards.
3.5 – 4.4	Good	Infrastructure is in good condition. While some aspects may require minor improvements or maintenance, the primary functionality remains unaffected.
2.5 – 3.4	Fair	Infrastructure is in fair condition, although certain components may need more attention—such as repairs or replacements to address damage or substandard conditions. Enhancements are needed for optimal performance.
1.5 – 2.4	Poor	Infrastructure is in poor condition, with multiple elements not functioning properly or already damaged. This compromises visitor comfort and safety, necessitating urgent repairs to restore feasibility.
1 – 1.4	Very Poor	Infrastructure is in very poor condition, nearly failing to meet minimum standards for tourism use. This may include severe damage, breakdown of essential functions, or potential hazards to users. Major, immediate repairs are crucial.

Table 4. Road condition assessment (existing)

Assessment Category	Scale	Description
Road Surface Condition	1	Road surface is extremely damaged (large holes, severe cracks).
	2	Road surface is damaged (small holes, visible cracks).
	3	Road surface is fairly good (minor damage).
	4	Road surface is good (almost no damage).
	5	Road surface is excellent (no damage).
Road Structure	1	Road structure is inadequate and often suffers structural damage.
	2	Road structure is fairly strong but has minor damage.
	3	Road structure is adequate and stable.

	4	Road structure is very good and can withstand heavy loads without problems.
	5	Road structure is optimal and durable against extreme loads and weather.
Drainage Capability	1	No drainage or very poor drainage.
	2	Drainage is inadequate and often results in water accumulation.
	3	Drainage is sufficient, but some areas still experience water accumulation.
	4	Drainage is good, with minimal water accumulation.
	5	Drainage is excellent, with no water accumulation after heavy rains.
Road Markings and Traffic Signs	1	No road markings or traffic signs.
	2	Road markings and traffic signs are unclear and incomplete.
	3	Road markings and traffic signs are fairly clear, though some are still in need of repair.
	4	Road markings and traffic signs are clear and complete.
	5	Road markings and traffic signs are very clear, complete, and function well.
Safety and Facilities for Road Users	1	No safety facilities, and it is very dangerous.
	2	Safety facilities are very limited.
	3	Safety facilities are sufficient, though improvements are needed.
	4	Safety facilities are good and meet standards.
	5	Safety facilities are excellent and conform to international standards.

Table 5. Clean water quality assessment

Assessment Category	Scale	Description
Color	1	Does not meet criteria: Water is clear, may be warm, or contains many suspended particles over 100-TCU.
	2	Does not meet criteria: Water is visibly colored, possibly indicating contamination; has a color index of 51–100 TCU.
	3	Meets criteria: Water color is slightly cloudy and somewhat transparent, with minimal suspended particles but does not exceed 26–50 TCU.
	4	Meets criteria: Water with slight color, almost transparent, safe from heavy metals, with color index 6–25 TCU.
	5	Fully meets criteria: Water is very clear and colorless, indicating no significant contamination, 0–5 TCU.
Odor	1	Does not meet criteria: Water has a strong, unpleasant odor; shows signs of chemical or organic pollution.
	2	Does not meet criteria: Water has a distinct odor, such as metallic, fishy, or musty, indicating possible contamination by organisms or chemicals.
	3	Meets criteria: Water has a mild scent, clear but still detectable, indicating slight but non-threatening contamination.
	4	Meets criteria: Water has a very mild odor, suggesting a safe relief from contamination.
	5	Fully meets criteria: Water is odorless, indicating no contamination.
Taste	1	Does not meet criteria: Water has a strong taste, like acid or salt, and is clearly unpleasant, indicating significant contamination.
	2	Does not meet criteria: Water has an obvious taste, such as metallic, salty, or another noticeable flavor, indicating potential contamination.
	3	Meets criteria: Water has a slight taste, is acceptable but still noticeable, and has no significant contamination.
	4	Meets criteria: Water has a very slight taste or just a hint of flavor; safe for consumption.
	5	Fully meets criteria: Water tastes normal, is not overpowering, and is free from noticeable contamination.

pH Level	1	Does not meet criteria: pH is very high (above 8.5) or very low (below 6.5), causing potential health issues if consumed regularly.
	2	Does not meet criteria: pH moderately high (7.5–8.5) or moderately low (6.5–7.5), better than extremes but still off ideal.
	3	Meets criteria: pH slightly off (6.5–7.5); manageable and typically safe for regular consumption.
	4	Meets criteria: pH balanced, slight deviation (6.8–7.4) within ideal drinking range.
	5	Fully meets criteria: Perfect pH level (7), ideal for consumption without any risk.

Table 6. Pier condition assessment (existing)

Assessment Category	Scale	Description
Pier Condition	1	Pier surface is extremely damaged, and significant cracks or deformations are present.
	2	Pier surface shows moderate damage and deformation.
	3	Pier surface is moderately good, with minor cracks or deformations.
	4	Pier surface is flat and free from any cracks or deformations.
	5	Pier surface is in perfect condition, without any cracks, deformations, or damage.
Pile Condition	1	Piles show severe corrosion, damage, or loss; immediate replacement is required to maintain stability.
	2	Piles show significant signs of corrosion or damage affecting stability.
	3	Some piles show minor corrosion or damage; however, overall structural integrity is maintained.
	4	Piles are in good condition with only tolerable minor corrosion or damage.
	5	Piles are in excellent condition with no signs of corrosion or damage.
Sheet Piling Condition	1	Sheet piling experiences major cracks, deformations, and structural weakening, affecting stability.
	2	Sheet piling shows minor cracks or deformations.
	3	Sheet piling is mostly good, but minor deformations are present that require attention.
	4	Sheet piling is in good condition with minor issues that do not affect performance.
	5	Sheet piling is in excellent condition and stable with no cracks or deformations.
Drainage System	1	Drainage system is non-functional and completely blocked, causing significant water stagnation.
	2	Drainage is largely obstructed or damaged, leading to operational issues due to water stagnation.
	3	Drainage system functions but not optimally; small obstructions affect performance.
	4	Drainage system works well; only slight water retention issues.
	5	Drainage system is in excellent condition, free-flowing without any obstructions, allowing rainwater to drain efficiently without issues.

Table 7. Waste management condition assessment

Assessment Category	Scale	Description
Cleanliness of Waste Area	1	Very poor cleanliness: no maintenance and contains heavy litter.
	2	Poor cleanliness: infrequent cleaning, the area is still cluttered with waste.
	3	Moderate cleanliness: Some waste is present but minimal.
	4	Good cleanliness: regular cleaning and maintenance, no visible litter.
	5	Optimal cleanliness: perfectly maintained, no litter or debris.
Odor Control	1	No effort to control odor; very unpleasant with possible health risks.
	2	Ineffective odor control; noticeable odor affecting area usability.

	3	Adequate odor control; some odor present but not overpowering.
	4	Good odor control; minor smells effectively managed.
	5	Excellent and effective odor control; no perceivable odor.
Waste Disposal Site Location	1	Not strategically located; causes inconvenience, no consideration for accessibility.
	2	Poorly located; some areas lack accessibility or convenience.
	3	Adequately located in strategic areas but has some accessibility issues.
	4	Well-placed; considers user convenience and accessibility, near waste sources.
	5	Ideally located; it perfectly suits area needs and maximizes convenience and accessibility.
Waste Separation	1	No waste separation; all types are mixed without any separation or sorting.
	2	Inconsistent waste separation; limited facilities; not all waste types properly sorted.
	3	Basic waste separation is generally sorted, but some categories are mixed.
	4	Good waste separation; clear categories, minor mixing, well-managed.
	5	Excellent waste separation; perfectly sorted, labeled, and managed, with high-quality facilities.

Table 8. Geomorphological characteristics and disaster potential of coastal areas

Tourism Area	Relief Topography (Meters)	Surface Material	Genesis Processes	Coastal Typology	Disaster Potential
Bira	0–20	Sandy Alluvium	Marine Activity	Secondary Coastal (Marine deposition)	Tsunami and Accretion
Appalarang	0–200	Solid Material	Structurally-Active	Primary Coastal (Structurally shaped coast)	Erosion and Landslides
Mandalika	0–75	Alluvial Deposits and Sand	Marine Activity	Secondary Coastal (Marine deposition)	Tsunami and Abrasion
Marumasa	0–25	Alluvium and Solid Material	Marine Activity and Structurally Active	Primary Coastal (Structurally shaped coast)	Tsunami and Abrasion
Lemo-Lemo	0–2	Alluvial Deposits and Sand	Marine Activity	Secondary Coastal (Marine deposition)	Tsunami and Accretion
Kasuso	0–100	Alluvial Deposits and Sand	Marine Activity	Primary Coastal (Structurally-shaped coast)	Tsunami and Accretion

Table 9. Road condition assessment (proposed)

Tourism Area	Total Length (m)	Basic Road Width (m)	Average Road Condition Rating	Remarks
Pantai Bira	3712.26	142.65	3.06	Good
Pantai Appalarang	1423.85	626.94	2.23	Poor
Lemo-Lemo	1394.64	599.95	3.1	Good
Kasuso	752.07	470.68	3.1	Good
Mandalika Ria	864.41	870.54	2.3	Poor
Marumasa	358.32	1870.43	1.8	Poor
Average Road Condition			2.59	Poor

Table 10. Clean water condition assessment

Tourism Area	Average Water Condition Rating	Description
Pantai Bira	5	Excellent
Pantai Appalarang	4.75	Excellent
Lemo-Lemo	4.5	Excellent
Kasuso	4.25	Good
Mandalika Ria	4.25	Good
Marumasa	4.25	Good
Average for Clean Water	4.5	Excellent

Table 11. Pier condition assessment (proposed)

Existing Infrastructure	Assessment Score	Average
Surface Condition	3	3.5
Pile	4	
Sheet Piling	4	
Drainage System	3	

Table 12. Waste management condition assessment (proposed)

Tourism Area	Average Waste Management Rating	Description
Pantai Bira	2.1	Poor
Pantai Appalarang	3.5	Average
Lemo-Lemo	1	Poor
Kasuso	1.5	Poor
Mandalika Ria	1.5	Poor
Marumasa	2	Poor
Average for the Region	1.9	Poor

From the analysis, the Bira Beach area has the longest road (3,712.26 m) with a road condition score of 3.06, categorized as “Fair.” Meanwhile, Appalarang Beach (1,423.85 m in length) has the worst road condition, scoring 2.2. Lemo-Lemo and Kasuso, although having shorter road lengths, both fall into the “Fair” category with scores of 3.1. Mandala Ria (864.41 m) and Marumasa (358.32 m) have very poor road conditions, scoring 2.3 and 1.8, respectively, indicating a need for significant improvements. Overall, the average road condition score for tourist areas in Bontobahari is 2.59, which is classified as “Poor,” suggesting that road infrastructure in these tourist sites requires attention and rehabilitation to enhance accessibility and visitor comfort.

3.2.2. Clean Water

Table 10 presents information on the average water condition in various tourist areas in Bontobahari. The water condition is assessed based on the cleanliness and suitability of the available water for visitors. According to Table 10, Bira Beach has the highest average water condition score of 5, indicating excellent water quality. Other areas, such as Appalarang Beach (4.75), Lemo-Lemo (4.5), Kasuso, Mandala Ria, and Marumasa (all scoring 4.25), also demonstrate good water quality. Overall, the average water condition score in the Bontobahari tourist areas is 4.59, categorized as “Good,” suggesting that water quality in most of these tourist destinations is adequate and safe for visitors.

3.2.3. Piers

Summarized in Table 11 and Figure 5, the average pier condition score is 3.5, which indicates that, overall, piers in the area are in a “Fairly Good” condition. Although some indicators-such as surface conditions and drainage systems-require attention, the piers generally remain structurally sound, with high piling and retaining wall scores. Nonetheless, regular maintenance and repairs are necessary to ensure these piers' sustainability and operational safety.

3.2.4. Waste Management

Waste management is a critical aspect of tourism development and maintenance. Table 12 and Figures 6-7 summarise the waste management conditions in the study locations. According to Table 12, Bira Beach has an average waste management score of 2.1, categorized as “Poor.” Likewise, other areas such as Appalarang Beach (3.5, Fair), Lemo-Lemo (1, Poor), Kasuso (1.5, Poor), Mandala Ria (1.5, Poor), and Marumasa (2, Poor) also show predominantly poor waste management conditions. Overall, the average waste management score in the Bontobahari tourist areas is 1.9, which is categorized as “Poor.” This finding indicates an urgent need to improve waste management practices to provide visitors with a cleaner and more comfortable environment.

3.3. Recommendations for Infrastructure Improvement

3.3.1. Roads

Previous studies have shown that sandy alluvial deposits are vulnerable to natural disasters. Regions with varied topography have a higher risk of landslides [40]. Areas characterized by secondary coastal typologies, such as Bira, Lemo, Mandala Ria, Marumasa, and Kasuso, feature surface materials of sandy alluvium and alluvial deposits susceptible to erosion and abrasion due to marine activities. Hence, a comprehensive approach to infrastructure development that accounts for geological factors and disaster potential is essential [41]. It is, therefore, important to improve drainage systems, reinforce road structures, and install additional safety features such as road markings, pedestrian walkways, and street lighting. These measures would enhance accessibility and safety for tourists, particularly in disaster-prone areas.

3.3.2. Clean Water

The distribution of groundwater and surface runoff is influenced by various hydrogeological factors. Studies in Indonesia indicate groundwater flow patterns generally follow topographical contours, moving from higher to lower elevations [42]. Land cover changes significantly affect surface runoff, with built-up areas increasing runoff coefficients [43]. Geomorphological conditions are vital in determining springs' location, distribution, and hydrological characteristics [44]. Groundwater levels vary across landscapes [42], and the spatial distribution of springs often clusters, controlled by topographical intersections, fault structures, and the confluence of hydraulic heads in groundwater basins [45]. Therefore, previous research indicates that alluvial and sandy alluvial deposits significantly affect groundwater availability and quality, whereby complex and unique geological processes indirectly influence local aquifer conditions and groundwater potential [46].

Areas characterized by alluvial deposits and sandy alluvium, such as Bira, Lemo–Lemo, Mandala Ria, Marumasa, and Kasuso, face challenges in providing clean water due to limited clean water sources and the potential for groundwater contamination resulting from erosion. Consequently, improving and developing efficient, clean water supply systems is crucial, especially in tourist-heavy regions like Bira Beach. Implementing water treatment technologies capable of filtering seawater or contaminated water would be highly beneficial in meeting clean water needs.

Several water treatment technologies can be utilized to meet clean water demands, particularly in areas with limited water sources. Reverse osmosis is an efficient method for seawater desalination [47-48]. Additionally, water distillation can be carried out using multi-media filter (MMF) technology, employing two-stage filtration with materials such as anthracite, sand, gravel, palm fiber, and charcoal to produce clean water [49]. For structural coastal areas like the cliff coast of Appalarang, a staged pumping technique can channel water from the source to higher elevations [50], or a full conventional treatment system encompassing coagulation, flocculation, sedimentation, filtration, and disinfection can effectively turn turbid water into clear water [51]. Beyond addressing the increased demand for clean water due to the number of visitors, coastal areas are also susceptible to natural disasters such as earthquakes and tsunamis, necessitating resilient water supply systems [52].

3.3.3. Piers

To mitigate disaster risks, it is essential to adopt disaster-responsive construction and environmental planning in coastal areas [53]. Ports are critical infrastructures that support economic and industrial development [54]. Besides Bira, other tourist destinations in the region also have a strong potential for attracting visitors and, therefore, require comfortable pier facilities. Adequate facilities support tourism activities and enhance the overall visitor experience. However, developing optimal pier infrastructure must consider factors such as tidal ranges and water depth [55].

Coastal regions encounter various challenges in infrastructure development, including insufficient supporting facilities [56]. Another study indicates that areas with predominantly alluvial soils—such as many of the sites in this research—pose challenges for infrastructure projects due to the physical characteristics of alluvial deposits. These deposits generally exhibit low to moderate bearing capacity, high water absorption potential, and susceptibility to changes in pore composition, all of which necessitate careful consideration in construction projects [57]. Coastal protection structures like groins are crucial for reducing erosion but require maintenance to remain effective [58].

3.3.4. Waste Management

Coastal waste management is becoming increasingly important due to the high volume of waste produced by tourists and local communities. A previous study examined the effectiveness of Integrated Waste Management Facilities, emphasizing the need for improved infrastructure and operational strategies [59]. Several efforts to enhance waste management facilities can be pursued, including educating the public on waste segregation to reduce marine pollution [59]. Additional strategies involve promoting the 3Rs (Reduce, Reuse, Recycle), training on waste management with economic value, improving human resources, and increasing waste management fleets and infrastructure [60].

Marine tourism areas dominated by secondary coasts with alluvial and sandy materials face unique waste and sanitation management challenges, as the geological, hydrological, and hydrogeological factors must be carefully considered. Applying appropriate technology to anticipate geological, hydrogeological, and hydrological hazards is essential [61]. Preventive measures to improve sanitation can include implementing biopores and integrated waste management systems [62].

4. Conclusion

Infrastructure in several tourist areas in Bontobahari requires special attention, particularly on road conditions, piers, and waste management. Although clean water quality in most locations is already satisfactory, many areas still face poor road conditions that necessitate improvements to ensure smoother accessibility. Waste management also remains a major concern, as numerous sites exhibit substandard practices, highlighting the need for more efficient systems and adequate facilities. In addition, certain areas must be evaluated for their pier requirements, ensuring that future pier construction is both environmentally friendly and safe.

The coastal typology, predominantly secondary beaches formed by marine sediment deposition and marked by hydrodynamic processes, poses unique challenges for infrastructure development due to tsunamis, erosion, and accretion risks. Consequently, infrastructure projects in the tourist areas of Bontobahari must be adapted to the specific characteristics of coastal regions, employing approaches that account for local disaster potential and geographical conditions. Improvements in infrastructure and environmental management are thus essential not only to enhance the quality of tourist destinations in Bontobahari but also to ensure visitor safety and long-term sustainability.

Acknowledgments

We would like to express our sincere gratitude to The Graduate School, Universitas Hasanuddin for the facilities and support provided throughout this study. We also appreciate the local government and the various experts whose valuable input and insights have greatly contributed to our understanding and approach to tourism infrastructure development.

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