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Optimizing Sustainable Tourism Capacity in Tanjung Bira: A Real-Time Environmental Management Dashboard Approach

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Abstract
Challenges in managing tourist visits and environmental quality in Bulukumba Regency. This study aims to examine the dynamics of tourism in Tanjung Bira and evaluate the carrying capacity of the area to support sustainable management strategies. This study uses a quantitative approach. Data collection techniques through literature studies and interviews. The results show a significant increase in domestic tourists and a sharp decrease in foreign tourists, which emphasizes the importance of sustainable strategies to balance growth and conservation. Therefore, the Real-Time Environmental Management Dashboard can be used as a solution to optimize environmental management in Tanjung Bira so that it can strengthen Bulukamba's position as an attractive tourist destination.
Keywords: *Bulukumba, Management, Real Time, Environmental Management Dashboard*

Abstrak
Tantangan dalam pengelolaan kunjungan wisatawan dan kualitas lingkungan di Kabupaten Bulukumba. Penelitian ini bertujuan untuk mengkaji dinamika pariwisata di Tanjung Bira serta mengevaluasi kapasitas daya dukung kawasan untuk mendukung strategi pengelolaan yang berkelanjutan. Penelitian ini menggunakan pendekatan kuantitatif. Teknik pengumpulan data melalui studi literatur dan wawancara. Hasil menunjukkan peningkatan signifikan pada wisatawan domestik dan penurunan tajam pada wisatawan mancanegara, yang menekankan pentingnya strategi berkelanjutan untuk menyeimbangkan pertumbuhan dan pelestarian. Oleh karena itu, Real-Time Environmental Management Dashboard dapat dijadikan sebagai solusi untuk mengoptimalkan pengelolaan lingkungan di Tanjung Bira sehingga dapat memperkuat posisi Bulukamba sebagai tujuan wisata yang menarik.
Kata kunci: Bulukumba, Pengelolaan, *Real-Time Environmental Management Dashboard*

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BACKGROUND

In recent years, the increase in tourist visits to beach destinations such as Tanjung Bira has created significant challenges regarding waste management. In 2018, Tanjung Bira welcomed approximately 238,810 visitors, and this number is expected to continue rising. The growing influx of visitors directly contributes to the accumulation of waste, which not only threatens environmental cleanliness but also diminishes the appeal of the tourist destination itself (Voukkali et al., 2021). This situation underscores the urgent need for effective and sustainable waste management to maintain environmental quality and enhance the tourist experience (Masri et al., 2020; Shen et al., 2021). This study aims to explore technological innovations in waste management at beach tourist destinations and assess how data-driven solutions can positively impact the minimization of these issues.

While various marketing aspects in the hospitality sector have been extensively researched, the focus on waste management as an integral part of the tourist experience remains limited. This study will highlight the role of web-based information systems in supporting operational management and waste management in tourist destinations (Maharani & Ulfa, 2022). Information technology enables managers to monitor the types and quantities of waste in real time, develop more effective management strategies, and identify the relationship between tourist activities and the increased volume of waste, which poses a significant challenge for environmental management (Martín-de Castro et al., 2016; Mihalič, 2000).

The potential waste generation at Tanjung Bira is estimated at 16,908.86 kg per year, with 87% originating from tourist waste, including plastics, cans, glass, paper, styrofoam, and organic materials. Additionally, 13% of the waste is produced by businesses, indicating the need for better management across the area (Inayah & Istiqomah, 2020). Implementing technological innovations in data-driven waste management is essential to support environmental sustainability at Tanjung Bira. The primary focus of this research is to analyze data obtained from web-based information systems capable of accurately measuring the volume and types of waste generated. Preliminary findings indicate a predominance of plastic and cans, reflecting consumption patterns that require better management (Pan et al., n.d.).

Furthermore, the collaboration among managers, government entities, and the community in utilizing data for decision-making will also be explored. Thus, technological innovations in waste management can be integrated into broader marketing strategies to enhance the positive image of the tourist destination and improve visitor satisfaction (Fuadi et al., 2021; Galati et al., 2023; Kusumawardhani, 2022). In this context, this research examines the significance of web-based information systems that not only enhance data accuracy related to waste management but also support evidence-based policy strategies in environmental management (Borchard et al., 2022; Setyawan et al., 2023).

Global trends indicate that waste management is increasingly shifting towards digital solutions, including smart container technology. However, the adoption of these technologies remains limited and necessitates collaboration among stakeholders to maximize their effectiveness (Huang et al., 2024; Taufik et al., 2021). By studying best practices in sustainable waste management at beach tourist destinations, this research aims to provide recommendations for improving waste management effectiveness at Tanjung Bira and similar areas. Understanding the concept of physical carrying capacity is essential for sustainable tourism management (Darwis et al., 2024; Mc Cool & Lime, 2001; Musawantoro & Ridwan, 2020). Maintaining physical carrying capacity not only supports environmental preservation but also ensures visitor comfort through optimal capacity management (Jamin & Rahmafitria, 2022). With a data-driven approach derived from periodic environmental monitoring, it is hoped that preventive measures and visitor

restrictions during peak seasons can reduce pressure on natural resources, maintain environmental quality, and enhance the tourist experience (SHEN et al., 2023; Xu et al., 2023).

In today's digital age, implementing web-based information systems is crucial for waste management, especially in tourist areas. Research shows that efficient information systems can enhance data accuracy related to waste management and assist in formulating better policies (Setyawan et al., 2023; Tanveer et al., 2022) . By leveraging technology, managers can effectively collect and analyze data to support decision-making and optimize resources in waste management (Harahap, 2021; Harahap & Sumijan, 2020). This data-driven approach will contribute to the success of more targeted and sustainable waste management strategies.

Global trends reveal a growing shift in waste management towards more innovative digital solutions. Despite the significant potential for implementing technologies like smart waste containers, many managers have yet to fully capitalize on these opportunities (Borchard et al., 2022). This research will identify best practices in sustainable waste management at beach tourist destinations and emphasize the importance of collaboration among various stakeholders to promote technology adoption. By examining waste management practices in hotels and tourist destinations that have successfully implemented sustainable practices, this research aims to provide useful recommendations for enhancing waste management effectiveness at Tanjung Bira and similar destinations.

RESEARCH METHODS

This study employs a cross-sectional quantitative survey design to explore technological innovations in waste management at beach tourist destinations (Sugiyono, 2020). The primary objective of this research is to gather empirical data on the status of digitalization in waste management practices to support more targeted decision-making for future development (Borchard et al., 2022). The research is conducted through literature reviews, interviews with waste management practitioners, and direct interactions with local waste management entities in beach tourism areas to identify challenges and opportunities in implementing efficient technology in this field (Creswell., 2017).

The survey is structured around the value chain of waste management and relevant digital technologies to evaluate the level of technology adoption and its impact on the efficiency of waste management in beach areas. Data collection is scheduled to take place over three weeks, with response screening conducted to maintain the quality of the data obtained. The collected data will be analyzed using descriptive and inferential statistics, providing a comprehensive overview of the relationship between digital innovation and waste management practices in tourist areas. Below is the schedule for the research activities, which includes the stages of observation, design preparation, and final report drafting in Tanjung Bira. Observation 1 will be conducted in March, Observation 2 in April, design preparation in May, and report drafting from June to July. This research will be conducted in Tanjung Bira, located in Bonto Bahari District, Bulukumba Regency, South Sulawesi, which is renowned for its soft white sands and stunning ocean views. The tools and materials used in this study include Web Hosting from Hostinger for storing and managing the research website, Corel Draw for graphic design in data visualization and infographics, ArcGIS 10.8 for spatial analysis and mapping of waste management locations in the beach tourism area, and Microsoft Excel for processing and analyzing descriptive and inferential statistical data, as well as presenting data in tables and graphs. Descriptive analysis is data that has been collected with the aim of only explaining (Riyanto dan Arini, 2021).

Tabel 1. Carrying Capacity Components in Tourism Management

Component	Definition	Formula	Variables	Evaluation Method	Reference
Physical Carrying Capacity (PCC)	Maximum capacity of visitors that the destination can physically accommodate at a given time, ensuring environmental sustainability and comfort.	$PCC = A \times V/a \times Rf$	**A** : Area size **V/a** : Area required per visitor **Rf** : Daily rotation factor	Observation, Area Measurement, Daily Capacity Calculation	(Fandeli, 2002; Tokarchuk et al., 2021)
Real Carrying Capacity (RCC)	Capacity that accounts for correction factors, including environmental variables affecting physical capacity.	$RCC = PCC - CF1 - CF2 - CF3 - CF4$	**CF1** : Rainfall **CF2** : Fishing activity **CF3** : Water quality **CF4** : Waste management	Observation, Interviews, Environmental Data Collection, Statistical Analysis	(Da Silva, 2002;
Effective Carrying Capacity (ECC)	Maximum number of visitors that can be sustained while considering management capacity within the tourism area.	$ECC = RCC \times MC$	**MC** : Management capacity (ratio of available staff to needed staff)	Capacity Analysis, Literature Review, Interviews, Observation	Zekan et al., 2022)
Waste Management Component	Processes and practices for waste management, including waste reduction, recycling, and disposal within the tourist area to support environmental carrying capacity.	No specific formula, but it influences **CF4** in RCC	No specific mathematical variables, but includes types, volume, and frequency of waste management	Observation, Identification, Literature Review, Interviews	(Borchard et al., 2022; Tanveer et al., 2022)

Additionally, the Waste Management Component plays a crucial role in supporting the overall carrying capacity by implementing processes for waste reduction, recycling, and disposal. While it does not have a specific formula, it impacts the waste management

factor in RCC, and its evaluation relies on observations, identifications, literature reviews, and interviews.

The Input-Process-Output (IPO) model is a foundational framework in systems theory that effectively illustrates how information systems operate by transforming raw data into meaningful information. In this model, inputs refer to the data and resources fed into the system, processes involve the manipulation and analysis of this data, and outputs are the actionable insights generated for decision-making. This structured approach not only aids in understanding the functionality of information systems but also enhances the evaluation of their efficiency and effectiveness. As noted by (Galais et al., 2021; Puad et al., 2016; Syam et al., 2021) , "The IPO model provides a structured way of understanding how information systems convert data into useful information by outlining the inputs, processes, and outputs involved" (Management Information Systems: Managing the Digital Firm). Thus, employing the IPO model facilitates better data visualization and process comprehension, ultimately supporting improved strategic decision-making within organizations.

Table 2. Framework The Input-Process-Output (IPO)

Input	Process	Output
1. Area Data	Overlay area data with existing maps	Existing Conditions of tourism areas
- Area for tourism	Apply spatial analysis methods	Trends in tourism capacity
2. Environmental Data	Map rainfall and water quality data	Existing Conditions of environmental factors
- Rainfall, water quality	Perform spatial analysis on biodiversity and waste	Trends in environmental conditions
3. Staffing Information	Analyze staff distribution on maps	Existing Conditions of staffing levels
- Number of staff, required staff	Assess management capacity through mapping	Trends in staffing needs
4. Visitor Data	Overlay visitor flow data onto maps	Existing Conditions of visitor flow
- Duration of tourist visits	Conduct spatial analysis of visitor data	Trends in visitor behavior

Source: (Fandeli, 2002; Galais et al., 2021; Lelloltery et al., 2018; Syam et al., 2021)

The table 2 for carrying capacity assessment outlines the key components involved in evaluating tourism sustainability in a specified area. It categorizes inputs such as area data, environmental data, staffing information, and visitor data, along with the corresponding processes, including overlay analysis and spatial mapping. The outputs highlight both existing conditions and trends, providing valuable insights for effective tourism management and decision-making.

RESULTS AND DISCUSSION

The results of this study show that Bulukumba Regency, which has topographic variations from lowlands to mountains with altitudes reaching 1,000 meters above sea level, has developed into one of the main tourist destinations in South Sulawesi. Administratively, Bulukumba Regency is divided into 10 sub-districts covering 129 villages and 27 urban villages with a total area of approximately 1,154.7 square kilometers, or 2.5% of the total area of South Sulawesi. Based on data on the number of tourist visits from 2018 to 2022, there was a significant increase in domestic tourist visits,

especially after the end of the COVID-19 pandemic restrictions. However, the number of foreign tourist arrivals experienced sharp fluctuations, with a drastic decline in 2021 due to the international travel restriction policy.

The data obtained shows that from 2018 to 2021, domestic tourist arrivals have increased by 65.52%. This positive trend continued from 2021 to 2022 with a further increase of 5.36%. In contrast, foreign tourists showed a very significant decline, reaching 99.05% between 2018 and 2021. This indicates a strong influence of the pandemic on foreign tourist visitation patterns in the Bira Beach area. This data provides a clear view of the changing dynamics of tourism in Bulukumba Regency over the past few years as well as the challenges in attracting foreign tourists post-pandemic.

The findings regarding Physical Carrying Capacity (PCC) indicate that Pantai Bira has a maximum capacity of accommodating 341,504 tourists. This figure is derived from calculations of the area size, assuming each tourist requires 15 square meters of space, while also considering the rotation factor for visits. The importance of this calculation lies in the effort to maintain a balance between managing visitor numbers and preserving the environment, which poses a significant challenge for tourism operators in the area.

Table 3. Environmental Carrying Capacity at Pantai Bira

No	Carrying Capacity Type	Value/Estimate	Explanation
1	Physical Carrying Capacity (PCC)	341,504 Tourists	The maximum capacity of Pantai Bira to accommodate tourists is 341,504 individuals, calculated based on the area size, space requirement per tourist, and rotation factor. This calculation is crucial to ensure that the number of visitors does not exceed the threshold that can be accommodated without harming the environment.
2	Real Carrying Capacity (RCC)	222,319 Tourists	After considering correction factors such as rainfall, water quality, and waste management, the real carrying capacity (RCC) decreases to 222,319 tourists. This indicates that environmental factors significantly influence the area's ability to sustainably accommodate visitors.
3	Effective Carrying Capacity (ECC)	80%	The effective carrying capacity (ECC) for managing the Pantai Bira area is 80%, with 28 available staff out of the needed 35. This reflects that the current human resources are sufficient for effective management of the area, although there is still room for improvement in management capacity.

Source: Data Analysis, 2024

Furthermore, the Real Carrying Capacity (RCC) provides a more realistic picture by considering various environmental factors that can affect the accommodation capacity. After adjustments for the impacts of rainfall, water quality, and waste management, the actual capacity drops to 222,319 tourists. This finding emphasizes that effective environmental management is crucial to maintaining the area’s carrying capacity and preventing ecosystem damage that could arise from overcapacity.

Finally, the Effective Carrying Capacity (ECC) shows that Tanjung Bira has adequate human resources to manage the area with an effective capacity of 80%. While the current number of staff meets the requirements, there is still a shortfall compared to the ideal staff number needed. This highlights the need for greater attention to human resource management to ensure that the area can be managed effectively and sustainably, in line with efforts to maintain overall environmental carrying capacity.

Apart from the aspect of tourist visits, a major challenge also arises in waste management in the Bira Beach tourism area. Based on the results of the study, the volume of waste in this area increased dramatically during weekends and holidays, with glass waste being the largest composition, at 3,761 kg, followed by canned and plastic waste. This shows that the waste generated is dominated by non-organic materials that are difficult to decompose. This significant accumulation of waste has the potential to pollute the environment and reduce the attractiveness of Bira Beach, so more effective waste management measures are needed to support the sustainability of the tourist area.

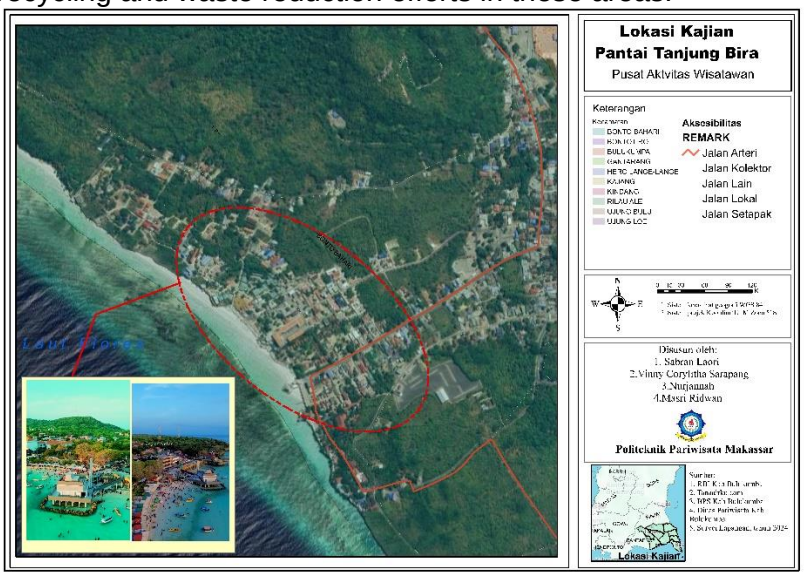
Tabel 4. Categorizes various types of waste in Bira Beach

	Waste Type					
	Plastic Waste	**Glass Waste**	**Metal Waste**	**Paper Waste**	**Styrofoam Waste**	**Organic Waste**
	a. Plastic bottles (drinking water, soft drinks)	a. Glass bottles	a. Beverage cans (soda, beer)	a. Wrapping paper (fast food)	a. Food containers (rice boxes, soup bowls)	a. Food scraps (rice, vegetables, fruits)
	b. Plastic bags	b. Glass containers (jars)	b. Food cans (sardines, corned beef)	b. Tissues (wet and dry)	b. Single-use styrofoam cups	b. Fruit and vegetable peels
	c. Food packaging (instant noodle packs, snacks)	c. Cosmetic glass bottles	c. Can lids	c. Cardboard (food and drink packaging)		c. Small branches
	d. Plastic straws		d. Aerosol cans (deodorant, hairspray)	d. Brochures and pamphlets		
	e. Single-use plastic cups					
	f. Plastic spoons and forks					
	g. Plastic wraps (cling film)					
Total Weight	1,980 Kg (20.2%)	3,761 Kg (38.4%)	2,457 Kg (25.1%)	291 Kg (3.0%)	826 Kg (8.4%)	473 Kg (4.8%)

(Kg)/ Percentage (%)					

Source: Processed Data, 2024

The table categorizes various types of waste by material, providing insights into the composition of waste generated in a specific context. Plastic waste, which includes items such as plastic bottles, bags, food packaging, straws, and single-use utensils, amounts to 1,980 kg, representing 20.2% of the total waste. Glass waste dominates the category with 3,761 kg, accounting for 38.4% of the total, primarily due to the frequent disposal of heavy items like glass bottles and jars. Metal waste, which includes beverage and food cans, contributes 2,457 kg, making up 25.1% of the total waste. In contrast, paper waste, consisting of wrapping paper, tissues, and brochures, accounts for only 291 kg or 3.0%, indicating a lower reliance on paper products. Styrofoam waste, which includes disposable food containers and cups, totals 826 kg, representing 8.4% of the waste, reflecting the prevalence of single-use items. Lastly, organic waste, comprising food scraps and plant materials, amounts to 473 kg, or 4.8% of the total waste. This data highlights the significant presence of glass and plastic waste, suggesting opportunities for targeted recycling and waste reduction efforts in these areas.



Picture 1. Map of Study Location as the center of visitor activity in Bira Beach Area

Picture 1, Map of Study Location showcases central visitor activity points in the Bira Beach Area, highlighting key areas along the coastline where tourist activity, accommodations, and waste generation are concentrated. Key locations include Jalan Tanaberu-Bira, known for its high visitor traffic, and Pantai Pasir Putih, a pristine white sand beach attracting numerous tourists. The map also marks the area around Alun-alun near Masjid Thalhah Ubaidillah and Tanjung Bira, popular gathering spots close to important religious sites. In addition, the map pinpoints high-density areas for accommodations, such as near the Mess Pemda and Jalan Pasir Putih Bira, where notable hotels like Same Resort Bira Beach and Anda Beach Hotel are situated. These areas see significant waste accumulation due to heavy tourist flow, particularly plastic waste, which affects the local environment. By identifying these central points, the map underscores areas with increased waste challenges, emphasizing the importance of waste management strategies in tourist hotspots of Bira Beach.

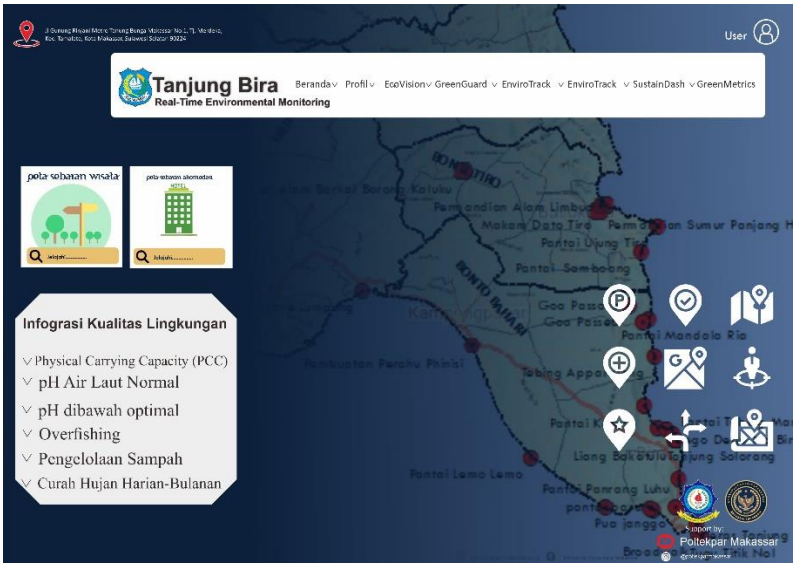
a. Plastic waste from visitor food and drink at Pasir Putih Beach

b. Waste disposal along the roadside path of Jalan Pasir Putih Bira

Picture 2. Plastic Waste from Visitor Food and Drinks at Pasir Putih Beach

Based on picture 2, a. Plastic waste from visitor food and drink at Pasir Putih Beach, At Pasir Putih Beach, a significant amount of plastic waste is left behind by visitors, primarily consisting of food and drink packaging such as plastic bottles, bags, and wrappers. This litter is often scattered across the beach, polluting the white sand, which is the main attraction of the area. The discarded food and drink plastics not only detract from the natural beauty but also pose a potential threat to the nearby marine ecosystem. b. Waste disposal along the roadside path of Jalan Pasir Putih Bira, Along the tourist pathway at Jalan Pasir Putih Bira, litter is often discarded along the roadside by visitors or vendors operating nearby. Piles of waste, mainly plastic and other packaging, make the area look unclean and disorganized. Despite being a pathway leading to popular tourist spots, the lack of adequate waste bins has led many people to dispose of litter along the roadside, which pollutes the surrounding environment and diminishes the experience for tourists visiting Bira.

The Real-Time Environmental Management Dashboard for waste management in Tanjung Bira is designed to streamline waste data management and provide users with intuitive access to relevant information. In the Header, the system logo and title, "Tanjung Bira Waste Management Dashboard," serve as key identifiers, offering a professional and structured interface. The main navigation menu includes links to essential pages such as Map, Reports, Feedback, and User Profile, enabling quick access to various features. An account settings icon on the right side of the header allows users to manage their profiles and preferences easily, enhancing the overall user experience. The Sidebar on the left provides additional navigation options for expedited access to specific functions. Users can return to the Home page, access the Interactive Map that displays the locations of trash bins, or view Waste Data for real-time information on waste types and quantities generated. An Upload Image feature allows users to submit photos related to the condition of waste bins or accumulation, crucial for verification purposes. The Reports section presents various analytical graphics, while the Feedback menu collects user input for continuous service improvement. In the main dashboard area, Real-Time Statistics provide up-to-date information on total accumulated waste, indicators for full bins, and pie or bar charts showing waste types by percentage. The Interactive Map visualizes trash bin conditions in Tanjung Bira with color-coded indicators: green for empty, yellow for half-full, and red for full bins. Waste hotspots are marked to highlight areas with high waste generation, enabling the management team to respond more swiftly.



Picture 3. Real-Time Statistics at Pasir Putih Beach

Source: Researcher, 2024

Based on picture 3, below this section, Reports and Analysis include daily, weekly, and monthly waste trends, along with feedback analysis to identify key issues frequently reported by the public. The Footer area contains contact information, links to relevant environmental policies, and copyright information, providing transparency and easy access to additional support services. The following table 5 presents a comprehensive overview of the Real-Time Environmental Management Dashboard for Tanjung Bira, highlighting its key features, processes, and the relationship between its components and research findings.

Tabel 5. Tanjung Bira Management Dashboard: Features and Functions

Dashboard	Description	Relation to Research Findings	Input	Process	Output
Header	Displays the logo and the title "Tanjung Bira Waste Management Dashboard."	Provides a clear and professional identity, raising awareness about waste management's importance in tourist areas. This aligns with findings indicating increased waste volume during weekends and holidays.	Dashboard logo, title	User navigates to different sections of the dashboard	Clear branding and professional interface

Main Navigation	Links to “Map,” “Reports,” “Feedback,” and “User Profile” pages.	Facilitates access to information related to waste volume and types, identifying peak visitor times, supporting more effective management efforts. This relates to findings on fluctuations in tourist visits impacting waste generation.	Navigation links	Users click on links to access various pages	Quick access to essential features
Sidebar	Provides additional navigation such as “Interactive Map” for trash can locations and an “Upload Image” feature.	The interactive map can show waste hotspot locations, assisting management teams in responding quickly. The image upload feature allows users to report trash bin conditions, improving management in high waste areas.	Interactive map, user-uploaded images	Users interact with the map and upload images	Enhanced navigation and user feedback
Real-Time Statistics	Displays up-to-date information on total accumulated waste, indicators for full trash bins, and pie or bar charts showing types of waste.	Supports quick decision-making in waste management, vital due to increasing waste volume, particularly from plastics and glass. Monitoring	Waste data inputs (e.g., bin statuses, types)	System processes data to generate statistics	Up-to-date visual statistics

		waste types in real-time directs recycling and waste reduction programs.			
Interactive Map	Shows the condition of trash bins with color indicators: green for empty, yellow for half-full, and red for full.	Helps managers visualize waste disposal issues in areas like Pasir Putih Bira Road, facilitating prompt action to address accumulation.	Location data, bin status information	Mapping software displays data on the interactive map	Visual representation of bin conditions
Reports and Analysis	Provides daily, weekly, and monthly waste trends and feedback analysis.	Enables understanding of waste generation patterns over time, allowing better planning according to tourist visit patterns, particularly during weekends and holidays.	Historical waste data, user feedback	System analyzes trends and compiles reports	Detailed analytical reports
Feedback	Gathers input from users for continuous improvement.	User feedback helps assess the effectiveness of waste management strategies and identifies recurring issues, such as visitor awareness regarding waste	User input through feedback forms	Collection and analysis of user feedback	Actionable insights for service improvement

		disposal challenges.			
Footer	Provides contact information, links to relevant environmental policies, and copyright information.	Offers transparency and easy access for further support, essential for building public trust and enhancing community engagement in environmental management, aligned with maintaining Bira Beach's appeal.	Contact details, policy links	Information is displayed at the footer	Transparency and access to support resources

Source: Researcher Data Analysis, 2024

The findings of this study clearly show that Bulukumba Regency has emerged as a prominent tourist destination in South Sulawesi, characterized by diverse topographical features ranging from lowlands to mountainous areas, with elevations reaching 1,000 meters above sea level. The region comprises 10 sub-districts and a total area of approximately 1,154.7 square kilometers, representing 2.5% of South Sulawesi. Data from 2018 to 2022 indicates a substantial increase in domestic tourist visits, particularly following the easing of COVID-19 restrictions, with domestic arrivals rising by 65.52% from 2018 to 2021 and continuing to grow by 5.36% in 2022. In contrast, foreign tourist numbers plummeted by 99.05% during the same period, highlighting the significant impact of the pandemic on international travel. This trend emphasizes the urgent need for targeted strategies to reinvigorate foreign tourist interest in the region, particularly in light of the changing dynamics of post-pandemic travel patterns (Guedes & Jiménez, 2015).

Furthermore, the assessment of carrying capacity reveals critical insights into managing tourism sustainably in the Pantai Bira area. The Physical Carrying Capacity (PCC) is estimated at 341,504 tourists; however, the Real Carrying Capacity (RCC) drops to 222,319 when accounting for environmental factors such as rainfall and waste management. This decline underscores the importance of effective environmental management to sustain tourism without compromising the ecosystem (Martín-de Castro et al., 2016; Mihalič, 2000). Additionally, the Effective Carrying Capacity (ECC) indicates that, while human resources are currently adequate to manage the area at an 80% capacity, there remains a gap in staffing that must be addressed to enhance operational efficiency. The waste management findings reveal a pressing challenge, with plastic waste accounting for 20.2% of total waste generated, primarily during peak tourist periods. This situation necessitates improved waste management strategies focused on reducing plastic waste to ensure the long-term sustainability and attractiveness of Bira Beach as a tourist destination.

To address these challenges, the implementation of a Real-Time Environmental Management Dashboard for waste management in Tanjung Bira has been proposed. This dashboard is designed to streamline waste data management, providing users with intuitive access to relevant information (Galais et al., 2021; Syam et al., 2021). The system features a professional interface, including the "Tanjung Bira Waste Management Dashboard" title and a navigation menu for essential pages like Map, Reports, Feedback, and User Profile. An Interactive Map visually represents the conditions of trash bins using color-coded indicators to quickly identify full, half-full, and empty bins, while also highlighting waste hotspots in the area. This functionality allows the management team to respond swiftly to waste accumulation issues.

Real-Time Environmental Management Dashboards have been shown to enhance operational efficiency in waste management by enabling timely decision-making and improving resource allocation (Filho et al., 2024). By integrating real-time statistics, interactive mapping, and user feedback mechanisms, the dashboard empowers stakeholders to address environmental challenges proactively. Such structured approaches not only aid in effective waste management but also foster community engagement and awareness regarding environmental stewardship (Moric et al., 2021; Pramanik & Ingkadijaya, 2018; Sharpley, 2000) , ultimately enhancing the overall sustainability and appeal of Tanjung Bira as a tourist destination. Implementing such systems has been proven effective in other contexts, suggesting a strong potential for positive outcomes in Tanjung Bira.

The findings of this study have important implications for policymakers and tourism stakeholders in Bulukumba Regency. The rise in domestic tourist arrivals post-COVID-19 signals the need for strategies to attract foreign visitors through better marketing and infrastructure. The assessment of carrying capacity emphasizes the necessity of sustainable tourism practices that balance economic growth with environmental conservation. Implementing the Real-Time Environmental Management Dashboard can enhance waste management and promote responsible tourism behaviors. Additionally, engaging the community in sustainability initiatives will empower locals and strengthen the tourism sector’s resilience, ensuring Bulukumba remains an attractive destination for future visitors.

This study has notable limitations. Firstly, it relies on secondary data for tourist arrivals, which may not fully reflect visitor experiences. The assessment of carrying capacity is based on estimations that could vary due to changing environmental conditions and tourist behaviors. Additionally, the focus is primarily on the Pantai Bira area, which may not capture the broader tourism landscape in Bulukumba Regency. Furthermore, the proposed Real-Time Environmental Management Dashboard is still in the design phase and has not been tested in real-world conditions, raising concerns about its effectiveness and user acceptance. Future research should incorporate primary data collection, explore other tourist areas, and evaluate the dashboard's impact on waste management to enhance understanding of sustainable tourism in the region. This approach will provide a more comprehensive view of the challenges and opportunities for sustainable tourism development in Bulukumba

CONCLUSION

This study underscores the critical tourism dynamics in Bulukumba Regency, particularly in the Pantai Bira area. The findings reveal three key types of carrying capacity vital for sustainable tourism management. Firstly, the Physical Carrying Capacity (PCC) is estimated at 341,504 tourists, derived from calculations based on area size, space requirements per tourist, and a rotation factor. This understanding is essential to prevent overcrowding and ensure visitor numbers remain within limits that protect the environment. Secondly, after accounting for environmental correction factors

such as rainfall, water quality, and waste management, the Real Carrying Capacity (RCC) significantly decreases to 222,319 tourists, highlighting the substantial impact of environmental conditions on the area's ability to sustainably host visitors. This finding stresses the need for enhanced environmental management practices to maintain the region's ecological integrity. Lastly, the Effective Carrying Capacity (ECC) for managing Pantai Bira is set at 80%, with 28 staff members currently available out of a necessary 35, indicating that while human resources are adequate for effective management, there remains a need for capacity building to improve operational efficiency. Additionally, the proposed Real-Time Environmental Management Dashboard offers a proactive approach to enhance waste management practices. By facilitating real-time monitoring and engaging local communities, this dashboard can play a pivotal role in fostering environmental stewardship and ensuring the long-term sustainability of Bulukumba's tourism sector. Collaborative efforts among stakeholders will be crucial in reinforcing Bulukumba's position as an attractive and sustainable tourist destination for the future.

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