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Ecological risk assessment for sustainable tourism on Saobi Island, Indonesia

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Abstract. *Romadhon A, Rini DAS, Hilyana S. 2025. Ecological risk assessment for sustainable tourism on Saobi Island, Indonesia. Asian J Ethnobiol 8: 291-300.* The complex interplay between growing tourism and ecological sustainability is investigated in vulnerable small island ecosystems, driven by the need to protect unique biodiversity amidst anthropogenic pressures. Therefore, this research aims to conduct a systematic ecological risk assessment on Saobi Island, Indonesia, to identify specific vulnerabilities and develop evidence-based recommendations for policymakers, tourism stakeholders, and local communities to implement sustainable tourism strategies. A robust composite Ecological Risk Index (ERI) framework was used and adapted explicitly for small island environments. This methodology integrated standardized and weighted indicators across four critical ecological parameters, namely marine water quality (fecal coliform concentrations), coral reef health (coral bleaching percentages), solid waste management efficiency (beach waste density), and tourism carrying capacity (tourism density). These indicators were quantitatively combined to obtain a single numerical score representing the overall ecological risk. The assessment suggested an overall ERI value of 0.78 for Saobi Island, classifying ecological risk as "low" (in the 0.67-1.00 range). The results showed that current tourism activities were largely sustainable. However, this research identified persistent localized concerns, reporting degradation in marine water quality, ongoing anthropogenic pressures impacting coral reefs, and inadequacies in current solid waste management systems. The results also indicated the necessity for implementing integrated, resilience-focused management strategies that balanced economic, environmental, and social factors. Implications included the urgent need for optimized ecological zoning, stricter regulation of tourism activities, and consistent application of Integrated Coastal Zone Management (ICZM). The framework incorporated precise spatial planning and robust community-based monitoring for mitigating ecological risks and improving long-term environmental stewardship.

Keywords: Ecological Risk Index, environmental management, Saobi Island, small islands, sustainable tourism

Abbreviations: ERI: Ecological Risk Index, ICZM: Integrated Coastal Zone Management

INTRODUCTION

Small islands are globally recognized tourist destinations for archipelagic economies (Romadhon et al. 2020; Zhang et al. 2023), face a critical challenge: the inherent tension between generating substantial revenue and employment from tourism and preserving their fragile ecological realities (Utami et al. 2023; Zhou et al. 2023). Uncontrolled growth often leads to habitat degradation, increased waste, water pollution, and resource overexploitation, fundamentally undermining local communities and the industry (Hampton and Jeyacheya 2020; Fernandez-abila et al. 2024). This inherent tension demands scientifically informed methods to manage ecological risks and achieve sustainable tourism.

Ecological risk assessment is indispensable tool for island tourism management. This variable provides a systematic framework to synthesize complex data, translating ecological dynamics into actionable insights for identifying threats and guiding conservation (Hernández et al. 2023). Ecological Risk Index (ERI) is a widely adopted composite metric for continuous environmental risk monitoring (Zhu and Cai 2023; Li et al. 2024; Wang and Zuo 2025) ERI converts diverse ecological parameters, such as water quality, coral reef health, waste management, and tourism carrying capacity, into a single composite score (Thompson et al. 2020; Tang et al. 2022). This aggregation simplifies the communication of complex ecological conditions, making ERI powerful for small island ecosystems (Huang et al. 2022; Lu et al. 2023; Sowrav et al. 2024). Even though numerous research has explored the environmental impacts of tourism on various islands, comprehensive ERI-based evaluations for integrated risk assessment remain scarce. This is particularly evident in Indonesian archipelagic destinations, with thousands of islands increasingly reliant on tourism. Several research reports economic benefits and environmental protection, but integrated ecological risk assessments using a composite index are relatively limited in the region. This represents a critical research gap, impeding precise, evidence-based sustainable management strategies for ecologically sensitive areas.

The research gap is addressed by meticulously applying ERI framework (Ma et al. 2020; Zhang et al. 2023; Zhou et al. 2023) adapted for small island ecosystems, to Saobi Island, Indonesia. Saobi Island is renowned for the natural beauty and rich biodiversity. However, rapid tourism growth has raised concerns among stakeholders about ecological integrity and long-term sustainability (Romadhon et al. 2020). The island's status as a conservation area since 1926, established to protect endemic bird species such as *Megapodius reinwardtii* (Dumont, 1823), shows the inherent ecological value and increased sensitivity to external pressures. The diverse marine and terrestrial ecosystems, including coral reefs, position Saobi Island as an ideal "natural laboratory" to investigate ecological risks. Tourism-environment dynamics are understood by evaluating key environmental parameters. These include marine water quality, coral reef health, and efficacy of solid waste management adopted from Romadhon et al. (2020), Hu et al. (2021), Rahmania et al. (2021), Shokri and Mohammadi (2021), Some et al. (2021), and Rahman (2024), respectively. Specifically, marine water quality and coral reef health serve as direct proxies for the impact of marine recreation and potential pollution on the highly sensitive coastal and marine ecosystems that attract tourism (Wakwella et al. 2023; Ji and Ding 2024). Solid waste management effectiveness directly reflects the capacity to handle increased anthropogenic waste from visitors, which impacts both aesthetics and ecological health (Obersteiner et al. 2021; Koiwanit and Filimonau 2023; Sakcharoen et al. 2023). Finally, tourism carrying capacity directly measures the intensity of human pressure on an ecosystem's finite resources (Utami et al. 2023; Zhang et al. 2023). The indicators were selected for the direct relevance to tourism impacts and the critical role in maintaining the island's ecosystem health and ecological integrity (Hung et al. 2021). While Saobi Island boasts diverse ecosystems including coral reefs, mangroves, coastal forests, and terrestrial wildlife habitats, the chosen indicators represent the most direct and measurable impacts related to the prevalent tourism activities and align with the adapted ERI framework's capacity for data consistency and interpretability. By integrating the concept into a comprehensive ERI, this research offers a novel method for assessing environmental pressures associated with tourism on small islands.

The overarching objective is to identify specific ecological vulnerabilities and develop evidence-based recommendations for policymakers, tourism stakeholders, and local communities in implementing sustainable tourism strategies. This research clearly states the contribution to a broader understanding of tourism for ecosystem services and community well-being in the unique, constrained context of small island environments. This integrated ecological risk analysis, with socio-economic considerations, offers an understanding critical for sustainable development (Zhang et al. 2021; Burbano et al. 2022; Nurhasanah and Van den Broeck 2022). The results serve as a crucial guide for promoting responsible tourism practices on Saobi Island, ensuring the safeguarding of invaluable ecological assets, and enhancing long-term environmental stewardship.

MATERIALS AND METHODS

Research area

This research was conducted on Saobi Island, Indonesia, an integral part of Kangean Archipelago in East Java, Indonesia. The area covered 424.83 hectares and was situated between 6°59′3.03″S-7°00′25.83″S and 115°26′45.59″E-115°28′35.25″E (Figure 1), supporting diverse terrestrial flora and fauna alongside the marine ecosystems. The vegetation consisted of coastal plants, reed communities, and herbaceous species. Dominant tree species included *Protium javanicum* Burm.fil., *Terminalia catappa* L., *Manilkara kauki* (L.) Dubard, and *Schleichera oleosa* (Lour.) Oken, contributing to ecological stability of the island. The species included the endemic *M. reinwardtii*, with *Cervus timoriensis* (de Blainville, 1822), *Macaca fascicularis* (Raffles, 1821), *Varanus salvator* (Laurenti, 1768), *Gallus varius* (Shaw, 1798), *Haliastur leucogaster*, and *Pteropus vampyrus* (Linnaeus, 1758). These species played key ecological roles, including seed dispersal and trophic regulation, emphasizing the importance of conserving biodiversity.

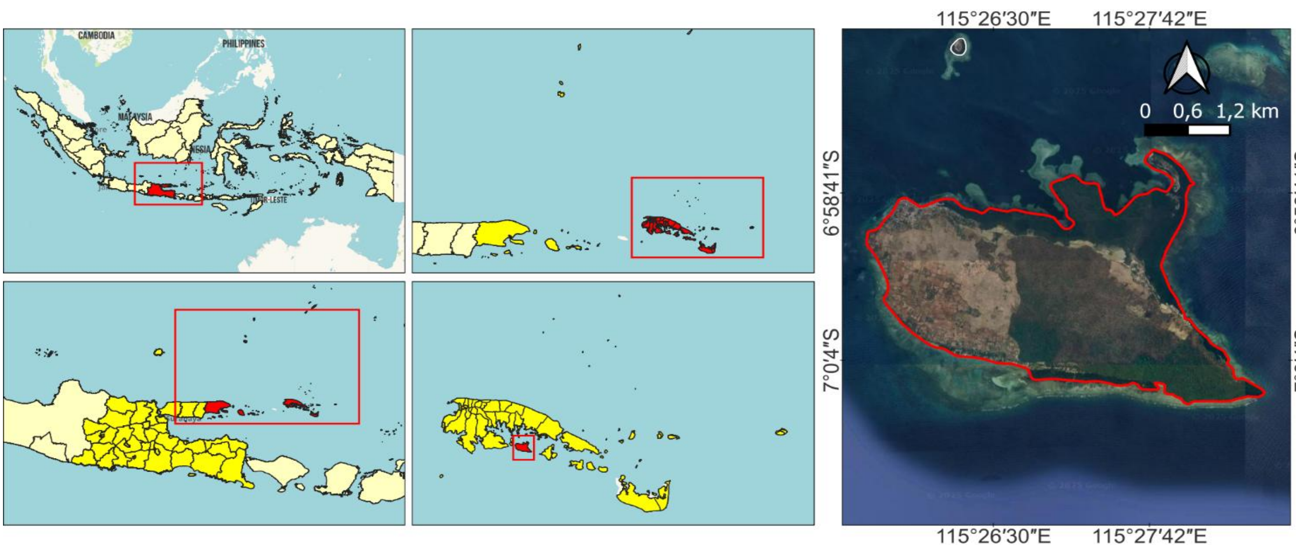

Figure 1. Location of Saobi Island in Kangean Islands, Sumenep District, East Java, Indonesia

The coexistence of multiple ecosystems, such as coral reefs, mangroves, coastal forests, and terrestrial wildlife habitats, made Saobi Island a unique natural laboratory. This ecological richness showed the uniqueness of the island as well as the vulnerability to human-induced pressures from tourism activities (Romadhon et al. 2020). Economically, the local community of Saobi Island relies heavily on tourism through various services, small businesses, and employment opportunities, a dependence that underscores the importance of balancing economic benefits with environmental preservation; the long-term sustainability of the community's well-being is intrinsically linked to the health of its natural resources. Therefore, local residents constitute a crucial stakeholder group whose active participation in and benefits from sustainable tourism practices are essential, providing an ideal environment to examine the ecological risks associated with tourism development and evaluate strategies to promote sustainable management (Hsiao et al. 2021; Yuxi et al. 2024)

Procedure

This research focused on four key environmental factors, namely water quality, coral reef condition, waste management, and tourism pressure. Data collection was carried out across two research stations, including two beaches with ten observation points, and was conducted twice to account for wet and dry seasons.

Water quality

In-situ measurements and water sampling were carried out at designated locations, referring to Some et al. (2021). Coliform bacteria concentrations were analyzed as the main indicator of environmental stress due to tourism activities. The method for detecting bacterial pollution parameters, with a particular focus on coliform bacteria, used the Plate Count.

Reef health

Based on Thompson et al. (2020), underwater visual surveys were conducted to show signs of bleaching or disease, providing a comprehensive overview of reef health.

Waste management

Data were collected by dividing each beach into 100-meter transects. Regular clean-ups were performed, and the quantity and types of waste were recorded to calculate average density (Garcés-ordóñez et al. 2020)

Potential carrying capacity

This variable directly determined tourism density by establishing the maximum sustainable number of visitors (Romadhon et al. 2020).

Data analysis

ERI system was developed to evaluate the sustainability of small island tourism. This adaptive framework incorporated measurable indicators and references specific to Saobi Island's characteristics and available data. A multi-criteria evaluation assigned each indicator a score reflecting the contribution to ecological risk. Water quality, coral reef health, waste management, and tourism pressure were selected for ecological relevance and data consistency.

Indicators were standardized using the extreme difference method to eliminate the influence of differing units and scales, ensuring consistent comparability before ERI calculation (Zhu and Cai 2023). The standardization equation was expressed as follows:

$$X'_{Ci} = \left(X_{Ci,\,max} - X_{Ci}\right) / \left(X_{Ci,\,max} - X_{Ci,\,min}\right)$$

Where, X'_{Ci}: Standardized score of ERI indicators (ranging from 0 to 1), X_{Ci}: Original score of ERI indicators, max X: Maximum value of the original score, min X: Minimum value of the original score

After standardization, indicator weighting was applied based on expert judgment and established guidelines (Nesticò and Maselli 2019; Shengrui et al. 2024). Indicator weightings were applied based on 15 expert judgments, which were based on a comprehensive review of relevant literature and established guidelines for ecological risk assessment. For each indicator, experts, leveraging their expertise in marine science, ecological assessment, and sustainable tourism, critically analyzed findings from previous studies on the impacts and relative significance of indicators (water quality, coral health, waste management, and potential carrying capacity) on small island ecosystems. These literature-based expert judgments allowed for the assignment of weights (water quality: 0.3, coral reef health: 0.4, waste management: 0.15, potential carrying capacity: 0.15), reflecting the importance of empirically established weights in determining ecological risk in a context similar to Saobi Island. The ERI matrix for small island as presented in Table 1. ERI was calculated by aggregating standardized and weighted indicator values to produce a single composite score, reflecting the overall ecological risk level using the formula:

$$ERI = \sum_{i=1}^{n} W_{Ci} \times X'_{Ci}$$

Where, ERI: ERI for Small Island Tourism, W_{Ci}: Weight assigned to each indicator (W1 = 0.3, W2 = 0.4, W3 = 0.15, W4 = 0.15), X'_{Ci}: Standardized score of ERI indicators (ranging from 0 to 1).

ERI provides a systematic and adaptable framework for assessing the environmental pressures associated with tourism on small islands. By integrating multiple indicators, the concept facilitates evidence-based decision-making, enabling policymakers and stakeholders to promote sustainable tourism practices. The flexibility allows adjustments based on data availability and the specific ecological conditions of each island, as a valuable tool for protecting ecosystems from the adverse impacts of tourism development. The calculated ERI values were classified into risk categories as presented in Table 2.

Table 1. ERI matrix for small island tourism

Environmental factor	Significance indicator	Quantification	Weight	Scoring	Reference
Water quality	Fecal coliform count	CFU/100 mL	0.3	1: < 276 2: 276-358 3: > 358	Some et al. (2021), Zhou et al. (2023)
Reef health	Coral bleaching	% Coral damaged	0.4	1: <25%; 2: 26-50%; 3: >50%	De et al. (2020), Thompson et al. (2020), Shokri and Mohammadi (2021), Zhu and Cai (2023)
Waste management	Beach waste density	Items/100 m²	0.15	1: < 20; 2: 20-40; 3: > 40	Garcés-ordóñez et al. (2020), Lee et al. (2021), Lukoseviciute and Panagopoulos (2021), Romadhon et al. (2024), Sempere-tortosa et al. (2024)
Potential carrying capacity	Tourism density	Number of tourists per day	0.15	1: < 100; 2: 100-200; 3: > 200	Romadhon et al. (2020), Tang et al. (2022), Li et al. (2024), Shengrui et al. (2024), Wang et al. (2024), Lu et al. (2025)

Table 2. ERI Classification

Classified risk	Index	Interpretation
Low risk	0.67-1.00	Indicates minimal ecological stress, suggesting that the island's current tourism activities exert limited negative impact on the environment and are relatively sustainable.
Moderate risk	0.33-0.66	Suggests that tourism is exerting a moderate influence on the island's natural resources and biodiversity. This level of risk requires careful management and preventive measures to avoid further degradation.
High risk	< 0.33	Reflects significant ecological stress, indicating that tourism has substantial adverse effects on the island's ecosystem and may lead to long-term environmental damage if not addressed.

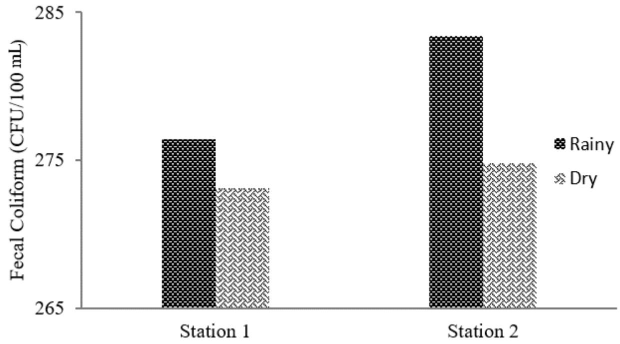

Figure 2. Mean fecal coliform count on Saobi Island by season

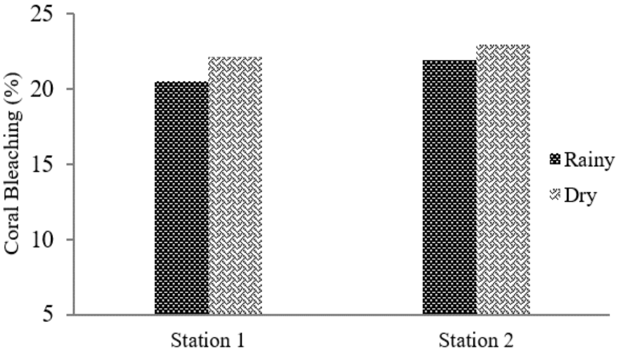

Figure 3. Observed coral bleaching percentages on Saobi Island, Indonesia

Table 3. ERI indicator score for fecal coliform count

Season	Count of fecal coliform
Rainy	281.40
Dry	273.95
Mean	277.68
X C1	2
X' C1	0.5

RESULTS AND DISCUSSION

Water quality

Water quality assessment is a critical component of ERI, focused on fecal coliform concentrations. During the rainy and dry seasons, the average fecal coliform count ranged from 279.4 to 283.4 CFU/100 mL and 273.1 to 274.8 CFU/100 mL, respectively (Figure 2).

The overall mean coliform count across all observation points was 277.68 CFU/100 mL. This value corresponded to a score of 2 in ERI framework, indicating a moderate level of ecological stress related to water quality. The standardized value for this indicator was 0.5 (Table 3)

Reef health

Coral reef health was assessed through bleaching observations, serving as a key indicator of marine ecosystem integrity. The average percentage of coral bleaching observed during the period ranged from 20% to 24% (Figure 3).

The mean coral bleaching recorded was 21.85%, which led to an indicator score of 1 in ERI framework. The standardized value for this indicator was 1 (Table 4)

Waste management

Waste management effectiveness was evaluated by quantifying solid waste accumulation on beaches. The density of solid waste on Saobi Island's beaches ranged between 35.1 and 38.2 items/100 m² (Figure 4).

The mean waste density recorded was 36.9 items/100m², which corresponded to ERI score of 2. This signified a moderate level of ecological stress, and the standardized value for this indicator was 0.5 (Table 5).

Potential carrying capacity

The potential carrying capacity of tourism density must be assessed to understand the extent of human activities and potential impacts on ecology. According to Romadhon et al. (2020), the island had a potential carrying capacity of 300 tourists per day (Figure 5), which corresponded to ERI score of 3. The standardized value for this indicator was 1 since the level of visitation did not exert excessive pressure on the natural resources (Table 6).

Ecological Risk Index (ERI)

The overall ERI for Saobi Island was calculated by integrating the standardized and weighted values of all four environmental indicators with an aggregated ERI score of 0.78 (Table 7).

Based on the classification (Table 2), ERI score of 0.78 falls in the 0.67-1.00 range, classifying Saobi Island as a "Low Risk" area. Therefore, current tourism activities are largely sustainable, exerting limited adverse impacts on the environment.

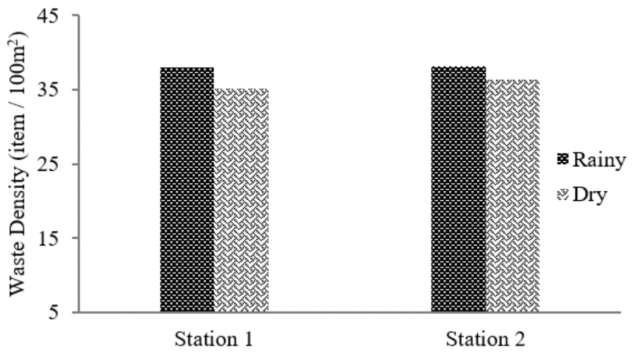

Figure 4. Beach waste density on Saobi Island, Indonesia

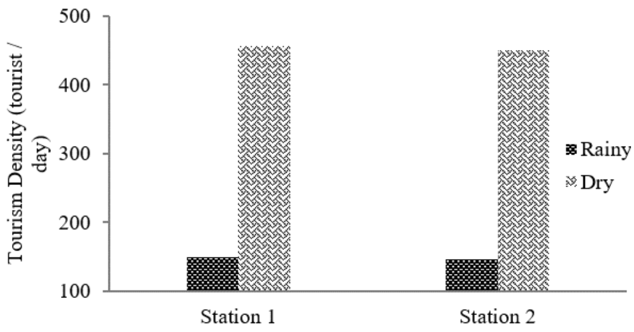

Figure 5. Tourism density on Saobi Island, Indonesia

Table 4. ERI indicator score for coral bleaching

Season	% coral affected
Rainy	21.20
Dry	22.50
Mean	21.85
X C2	1
X' C2	1

Table 5. ERI indicator score for waste density

Season	Waste density
Rainy	38.10
Dry	35.70
Mean	36.90
X C3	2
X' C3	0.5

Table 6. ERI indicator score for tourism density

Season	Tourism density
Rainy	453
Dry	147
Mean	300
X C4	3
X' C4	1

Table 7. ERI for Saobi Island, Indonesia

Environmental Component	Indicator	Weight	X' Ci	W x X' Ci
Water quality	Fecal coliform count	0.3	0.5	0.15
Reef health	Coral bleaching	0.4	1	0.4
Waste management	Beach waste density	0.15	0.5	0.08
Potential carrying capacity	Tourism density	0.15	1	0.15
Total				0.78
Classification			Low Risk	

Discussion

ERI framework applied to Saobi Island provides a comprehensive lens to examine the intricate relationship between tourism development and ecological health. The overall ERI score of 0.78, categorizing the island as "low risk," showed that ecosystem was not experiencing severe ecological stress from current tourism activities. This suggested a degree of ecological resilience since the existing management practices were relatively effective. However, a deeper, thematic analysis of individual indicators in ERI reported specific, localized vulnerabilities that necessitated proactive interventions to ensure long-term sustainability.

Water quality

On Saobi Island, the assessment of marine water quality showed a moderate level of ecological stress in ERI framework, scoring a standardized value of 0.5. The observed mean coliform count was 277.68 CFU/100 mL, corresponding to ERI indicator score of 2. Slightly higher counts were recorded during the rainy and dry seasons at an average of 281.40 CFU/100 mL and 273.95 CFU/100 mL, respectively. The elevation during the rainy season was attributed to increased surface runoff, which efficiently transported pollutants (Cabral et al. 2020). This issue was particularly pronounced in tourist-intensive areas, where existing wastewater treatment infrastructure might be insufficient to cope with seasonal runoff and the higher volume of waste generated during peak tourist periods (Utami et al. 2023; Fernandez-abila et al. 2024).

Fecal coliform observations supported the assertion that sewage was released into watersheds without adequate treatment (Verga et al. 2020). Additionally, intensive rain leads to a high input of nutrients into coastal aquatic environments, promoting the proliferation of bacteria, including coliforms (Seo et al. 2019; Aram et al. 2021). The persistent presence of coliform bacteria at moderate levels signifies potential public health hazards for visitors and residents, posing risks such as waterborne illnesses (Garcés-ordóñez et al. 2020). Moreover, coliform contamination frequently indicates broader environmental challenges, such as inadequate waste management and insufficient sanitation, which intensifies ecological risks in tourism-dependent regions (Maliga et al. 2025). The contamination severely undermines the island's reputation as a safe and pristine tourist destination, directly impacting tourism economy and recreational value (Hampton and Jeyacheya 2020). This shows an urgent need for continuous monitoring and significant enhancements in wastewater management strategies during periods of high rainfall and peak tourist activity (Yang et al. 2025).

Reef health

The observation shows a slightly higher prevalence during the dry and rainy seasons at 22.50% and 21.20% respectively. This indicates the need for a comprehensive investigation into the specific factors influencing coral reef health (Table 4). Even though elevated Sea Surface Temperatures (SST) are a primary catalyst for coral bleaching, with a 1°C increase above optimal conditions capable of inducing stress (Ardis et al. 2019), the seasonal patterns in tropical Indonesian regions are complex and do not uniformly characterize warmer dry seasons (Pathak et al. 2021). For instance, research in Karimunjawa National Park suggests that the east monsoon associated with the dry season can exhibit lower SST values than others (Ardis et al. 2019). This nuance shows that thermal stress may not fully account for the observed seasonal disparity in coral bleaching.

Since the dry season on Saobi Island is consistent with peak tourist periods, the increased incidence of coral bleaching can be attributed to the synergistic impact of intensified anthropogenic pressures on a temperature-sensitive ecosystem (Utami et al. 2023). During the periods of increased tourism, human activities substantially generate various stressors that increase coral susceptibility to bleaching (Fernandez-abila et al. 2024). These stressors include direct physical damage inflicted by marine recreational activities such as diving, snorkeling, and boating, which can harm coral structures and impede natural recovery processes (De et al. 2020). Corals physically damaged or chronically stressed by human activities exhibit reduced resilience, increasing vulnerability to environmental fluctuations (Hafezi et al. 2020). Moreover, elevated tourist numbers are frequently associated with increased waste generation and potential pollution, including untreated sewage and intensified surface runoff. The influx of contaminants decreases water quality, placing additional strain on coral ecosystems and impairing general health (Fernandez-abila et al. 2024). The underscored concerns regarding "inadequate waste management systems" and "anthropogenic pressures on coral reefs" contribute to ecological vulnerability. Therefore, the aggregated impact of intensified human-induced pressures during periods of peak tourism in the absence of seasonal thermal stress can surpass the intrinsic resilience of coral, leading to a greater frequency of bleaching during Saobi Island's dry season.

Waste management

Waste management proved to be an area requiring significant attention and presented a clear challenge for environmental sustainability. The observed beach waste density, averaging 36.9 items/m², led to a moderate ecological stress and ERI indicator scores of 0.5 and 2, respectively (Table 5). Small island areas, such as Saobi Island, exhibit complex patterns where beach waste density during the dry season can appear lower. The average beach waste density during the dry and rainy seasons was 35.70 and 38.10, respectively. This apparent paradox is driven by the dynamic interplay of waste management practices and natural environmental factors. During the dry season, intensified human activities lead to an increased generation of waste (Diaz-Farina et al. 2020; Grelaud and Ziveri 2020). However, the lower observed beach waste density is largely a direct outcome of enhanced cleanup efforts and strategic waste management, implemented to preserve the aesthetic appeal crucial for tourism industry (Battisti et al. 2020). These proactive measures aim to mitigate the immediate visual impact of waste as the overall volume rises (Andolina et al. 2021). Conversely, the rainy season often experiences higher beach waste density despite potentially lower tourist numbers. This is primarily due to natural hydrological processes, where increased rainfall and storm events significantly amplify the transport of land-based litter and pollutants into coastal environments through surface runoff (Hitchcock 2020). The natural flushing mechanisms deposit substantial quantities of debris onto beaches, contributing to higher observed waste accumulation (Bui et al. 2021; Okuku et al. 2021). Even though tourist-generated waste undeniably increases during the dry season, effective localized management and reduced land-to-sea transport of debris contribute to the lower measured density.

The underlying increase in tourism-generated waste and associated anthropogenic pressures during the dry season continues to exert significant stress on coral reefs, contributing to bleaching events. The elevated tourist activity with potentially inadequate waste management infrastructure often leads to increased marine pollution from untreated wastewater, sewage discharge, and runoff containing various contaminants into coastal waters (Prouty et al. 2020; Rodríguez et al. 2024). This degradation of water quality, characterized by nutrient enrichment and the introduction of harmful substances, directly compromises coral health and impairs physiological functions (Donovan et al. 2020).

Marine debris poses direct threats to corals, causing physical damage, increasing susceptibility to diseases, and directly contributing to coral bleaching through abrasion, smothering, or pathogen transfer (Ying et al. 2021; Bove et al. 2023). This chronic stress from diverse tourism-related pollutants can collectively exceed the corals' intrinsic resilience, leading to an increased incidence of bleaching during the dry season.

Potential carrying capacity

The higher tourism density observed (Andolina et al. 2021) is evident from the data reported, which shows a significantly higher tourist count of 453 and 147 during the dry and rainy seasons, respectively. This increase in visitor numbers intensifies anthropogenic pressures on the fragile ecosystems and small island resources (Romadhon et al. 2020; Utami et al. 2023; Fernandez-abila et al. 2024) since excessive visitation can strain water, energy, and infrastructure. An interesting paradox is reported in the beach waste density data (Table 5) with an average of 35.70 items/m² and 38.10 items/m² during the dry and rainy seasons, respectively. This phenomenon can be attributed to more rigorous and frequent beach cleanup efforts and improved waste management strategies implemented during peak tourism to maintain the aesthetic appeal crucial for the industry (Battisti et al. 2020; Grelaud and Ziveri 2020). Conversely, the rainy season significantly amplifies the transport of land-based litter and pollutants into coastal environments through surface runoff (Yu et al. 2019; Hitchcock 2020), acting as a natural flushing mechanism (Okuku et al. 2021), thereby contributing to higher observed waste accumulation, as previously discussed in the "Waste Management" section.

The increased tourism density and associated waste generation during the dry season impact coral reef health and contribute to bleaching events, exerting considerable pressure on small island resources. The overall rise in waste generation leads to increased marine pollution, including untreated wastewater, sewage discharge, and runoff containing various contaminants into coastal waters (Prouty et al. 2020; Rodríguez et al. 2024). This degrades water quality, introduces excess nutrients, and induces stress on coral ecosystems (Donovan et al. 2020). Therefore, "inadequate waste management systems" and "anthropogenic pressures on coral reefs" contribute to ecological vulnerability. As detailed in the "Reef Health" and "Waste Management" discussions, these factors degrade water quality, introduce excess nutrients, and induce stress on coral ecosystems. Marine debris also directly impacts coral reefs by causing physical damage, increasing disease susceptibility, and directly contributing to bleaching through abrasion, smothering, or pathogen transfer (Chi et al. 2021; Ying et al. 2021; Bove et al. 2023). Physical damage from recreational activities such as diving, snorkeling, and boating increases with higher tourist numbers, harming coral structures and impeding natural recovery (De et al. 2020). Corals compromised by physical damage or chronic stress from pollution exhibit reduced resilience and are susceptible to environmental fluctuations (Hafezi et al. 2020). In this context, higher tourism density during the dry season contributes synergistically to the observed incidence of coral bleaching, surpassing the intrinsic resilience.

Management implications

The low ERI score of 0.78 for Saobi Island indicates that current environmental pressures are relatively well-managed. This shows the critical need for a proactive and integrated management approach to ensure long-term sustainability. Several integrated strategies should be prioritized to enable the long-term sustainability of Saobi Island as a tourism destination. First, continuous monitoring and management of coliform bacteria levels in water are essential, particularly in high-traffic tourist zones. Effective sewage treatment systems must be implemented to safeguard public health and maintain the reputation of the island since the systems significantly reduce faecal contamination (Aram et al. 2021; Rahmania et al. 2021). These treatments may reduce coliform levels in recreational waters by approximately 30% (Aram et al. 2021; De Giglio et al. 2022; Wakwella et al. 2023). This directly contributes to SDG 6: Clean Water and Sanitation, which aims to ensure availability and sustainable management of water and sanitation for all. Second, proactive measures to maintain coral reef health should focus on mitigating pollution, preventing destructive fishing practices, and addressing climate-related impacts. Furthermore, the promotion of responsible diving and snorkeling practices is equally critical. Evidence shows that coral reefs in marine protected areas tend to exhibit better ecological conditions (Romadhon et al. 2020, 2024). These measures can improve coral reef health by 20-50% over several years when consistently implemented (Hammerton 2018; Ardis et al. 2019; De et al. 2020). Adaptive management and continuous monitoring remain crucial to optimizing the outcomes (Thompson et al. 2020). Adaptive management and continuous monitoring remain crucial to optimizing these outcomes, contributing directly to SDG 14: Life Below Water, which aims to conserve and sustainably use the oceans, seas, and marine resources for sustainable development. Third, improved waste management practices are required to preserve aesthetic appeal and reduce coastal litter, supporting SDG 11: Sustainable Cities and Communities (which advocates for making cities and human settlements inclusive, safe, resilient, and sustainable) and SDG 12: Responsible Consumption and Production (which promotes sustainable consumption and production patterns). Integrated programs should include recycling, sustainable waste disposal, community-based clean-up initiatives, composting, and environmental awareness campaigns.

The appearance of Saobi Island can be significantly improved through reduced litter and the safeguarding of the environment through sustainable recycling and waste management initiatives, supported by enhanced public awareness and education programs. A reasonable assessment suggests that effective waste management strategies enhance the appearance of the island by 30% to 60% (Fuldauer et al. 2019; Mestanza et al. 2019; Wang et al. 2021; Rahmania et al. 2021). In addition, zoning regulations, promoting off-season tourism, and diversifying activities regulate visitor numbers. These solutions may provide outcomes ranging from 30% to 60%, alleviating resource strain (Torres-delgado et al. 2023; Zhang et al. 2023; Zhou et al. 2023). In tourist-dependent regions, elevated tourism levels may alter ERI by increasing waste and pollution, exerting additional pressure on natural resources (Long et al. 2022; Tang et al. 2022; Ćulibrk et al. 2025). These impacts deteriorate the environment by damaging ecosystems, reducing air and water quality, and increasing habitat destruction (Long et al. 2022; Lin et al. 2024). Social, environmental, and economic considerations must be integrated in developing ecotourism programs. This method ensures local community participation in monitoring and managing sustainable tourism initiatives. The quality of the workforce and the development of supporting infrastructure play crucial roles. By combining the strategies, ecological risk factors can be effectively mitigated. Therefore, a multidimensional perspective is necessary for balancing economic, environmental, and social factors to guarantee sustainable tourism and the long-term ecological resilience of small islands as tourist destinations.

A broader perspective is required when considering the implications of island tourism for environmental sustainability. This includes evaluating the unique conditions of each island, engaging with local communities, and balancing policies with broader frameworks such as ICZM. Ecological Risk Assessment shows the importance of Ecological Function Zoning since small islands facilitate efficient spatial planning (Zhou et al. 2023). Zoning is a fundamental component of coastal management, optimizing land use and sensitive ecosystems. Community-based monitoring has proven highly effective when residents directly participate in conservation efforts, reinforcing the emphasis of ICZM on stakeholder inclusion (Chi et al. 2020; Van Cong 2020).

ICZM is a holistic strategy for managing coastal resources to balance competing stakeholder interests and safeguard fragile ecosystems (Pathak et al. 2021). This method requires integrated planning that considers all interrelated components of the coastal zone, including tourism's impacts on water quality (Dreizis 2020; Shengrui et al. 2024). Furthermore, stakeholder inclusion promotes collective responsibility and ensures that management decisions are adaptive and participatory. Adaptive management allows continuous monitoring and modification of plans in response to new data and changing circumstances (Pathak et al. 2021). In practice, small islands such as Pulo Aceh, Seribu, Karimunjawa, and Wakatobi show that waste management is significantly improved through ICZM frameworks by integrating strategies for the reduction, recycling, and proper disposal (Rahmania et al. 2021). For Saobi Island, the adaptation of ICZM minimizes the negative environmental impacts of tourism and promotes the long-term conservation of natural resources. For Saobi Island, the adaptation of ICZM minimizes the negative environmental impacts of tourism and promotes the long-term conservation of natural resources, contributing to SDG 13: Climate Action (which calls for urgent action to combat climate change and its impacts) and broader environmental stewardship.

In conclusion, despite its current classification as a low-risk area with an ERI value of 0.78, the long-term sustainability of Saobi Island necessitates a proactive and integrated management approach, especially given that water quality, coral health, waste management, and tourism density individually show varying degrees of pressure, with localized concerns and seasonal exceedances of carrying capacity signaling the need for targeted interventions. In this context, future strategies must emphasize an Integrated Coastal Zone Management framework that prioritizes robust wastewater management improvements, dedicated coral reef conservation efforts, and comprehensive waste reduction measures, which are crucial for safeguarding the natural environment and ensuring continued attractiveness for responsible tourism development. To further enhance the understanding and management of ecological risks in small island tourism, future research should integrate socio-economic indicators into the ERI framework to provide a more holistic assessment of sustainability; this can be complemented by the application of remote sensing technologies, enabling more frequent and broader spatial monitoring of key environmental parameters, and by establishing longer time-series monitoring programs for all indicators, which would allow for the detection of subtle trends, seasonal variations, and the effectiveness of implemented management strategies over extended periods, thus providing invaluable data for adaptive management and policy refinement.

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