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Waste Characterization and Integrated Management Strategy for Small-Island Tourism in Derawan, Indonesia

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This study aims to evaluate the waste generation and composition characteristics as a technical basis for designing an Integrated Solid Waste Management (ISWM) strategy on Derawan Island, a small island tourism destination. By applying a quantitative method referring to the SNI 19-3964-1995 standard, data were collected over eight consecutive days from three different sources: households (stratified random sampling), the commercial sector (purposive sampling), and marine debris (transect method). The analysis results showed that total daily waste generation reached 2,810.05 kg/day. The specific generation rate of 1.652 kg/capita/day was far above the national average, indicating a "double burden" phenomenon due to high tourism activity. In terms of composition, the waste stream was dominated by organic material (53.99%), followed by inorganic waste (40.18%) and hazardous waste (5.83%). These findings prove that the conventional "collect-transport-dispose" model is highly vulnerable and uneconomical given the 1.5-hour sea transport distance to the final disposal site on the mainland. Therefore, this characterization data supports a decentralized ISWM framework that prioritizes on-site bioconversion of the organic fraction (e.g., composting and utilization of Local Microorganisms/MOL), complemented by high-value recycling recovery. This baseline data-driven approach can theoretically reduce the final residue that must be transported by sea to only 18.15% of its initial mass, thereby overcoming acute logistical constraints while ensuring environmental sustainability for coral reef-based ecotourism.

Keywords: Circular economy; Derawan Island; Organic waste bioconversion; Solid waste management; Waste characterization

INTRODUCTION

Solid waste management has become the most pressing environmental challenge in the archipelagic and coastal regions of Southeast Asia, particularly in destinations experiencing rapid tourism intensification (Ardiyanto et al., 2024; Dhokhikah et al., 2026; Johnson et al., 2014). A typical "double burden" phenomenon is experienced by small island destinations, namely the convergence of domestic waste streams from permanent residents with the much higher per capita waste production from seasonal tourists (Liu et al., 2023; Soria et al., 2015). Derawan Island, designated as a super-priority marine tourism destination in Berau Regency, East Kalimantan, serves as a concrete example of this crisis. With 1,505 permanent residents and 800±150 daily tourists on a limited land area of 44.6 hectares, this island generates 2,810.05 kg of waste every day. This burden is exacerbated by geographical isolation, requiring a 1.5-hour boat ride to reach disposal facilities on the mainland (Benuanta, 2026). Current management practices are still dominated by open dumping in coastal areas, posing serious risks of marine pollution and threatening the coral reef ecosystem, which is the main pillar of the local economy (Jambeck et al., 2015; Lamb et al., 2018).

Waste management in island regions requires a fundamentally different approach compared to urban systems on the mainland (Güereca et al., 2013; Johnson et al., 2014). The Integrated Solid Waste Management (ISWM) framework, which aligns waste reduction, reuse, recovery, and treatment, is an absolute necessity and is highly suitable for application in island areas with limited resources (Plachá et al., 2013; Wang et al., 2011). The Circular Economy concept further strengthens this approach by providing a framework to transform waste burdens into value-added resources, where organic fractions can be processed into compost or local animal feed, while recycled polymers and metals re-enter commercial supply chains (Patrício et al., 2015; Sultana et al., 2021). Nevertheless, the transition towards ISWM and circular systems in island regions is often hindered by the lack of accurate and context-specific baseline data on waste generation rates and compositional characteristics, as this information is highly dependent on local tourism dynamics, seasonal fluctuations, and supply chain dependencies (Cordova et al., 2022; Liu et al., 2015).

Although studies on solid waste management in small islands have been widely conducted, significant gaps still remain in the existing literature. Most previous research exhibits methodological fragmentation as it only focuses on household waste generation without considering the contribution of the commercial or tourism sectors (Lebreton et al., 2017). revealed that marine debris analysis is often carried out separately without integrating these findings into a comprehensive planning framework. Previous studies on Indonesian islands such as Karimunjawa, Labuan Bajo, and Wakatobi generally evaluated single waste streams in isolation, making their limited applicability for designing a holistic management system a major constraint. The novelty of this research lies in its integrated approach through the simultaneous evaluation of waste characteristics from three distinct main sources—domestic households, commercial accommodations and restaurants, and coastal marine debris—using a standardized quantitative methodology (Badan Standardisasi Nasional, 1995).

This study aims to comprehensively evaluate the generation and compositional characteristics of waste originating from domestic, commercial, and marine sources on Derawan Island as a basis for formulating an appropriate Integrated Solid Waste Management (ISWM) strategy. These empirical findings are contextualized within the ISWM and Circular Economy frameworks, thereby establishing a fundamental technical foundation for designing an economically viable and environmentally sustainable management system, particularly for small island tourism destinations. This integrated evaluation provides strong quantitative evidence to guide infrastructure planning decisions and policy recommendations for coastal areas facing similar ecological and logistical challenges.

METHODS

Study Area and Period

This research was conducted on Derawan Island, Berau Regency, East Kalimantan, Indonesia (02.005°S, 118.650°E) from February 6–14, 2025. The eight-day sampling period was strategically chosen to capture waste generation during the transitional season (early dry season), coinciding with increased tourist visits and representing typical operational conditions. To account for the temporal variability of marine debris, coastal sampling was specifically carried out during the highest high tide and lowest low tide cycles, thereby capturing the maximum accumulation of waterborne waste driven by ocean currents and tidal dynamics. Derawan Island is inhabited by approximately 1,505 permanent residents and hosts over 80 commercial establishments (hotels, restaurants, dive centers) serving an average of 800±150 daily tourists, making it a representative case study for sustainable tourism management on small islands.

Figure 1. Map of the Study Location

Research Design, Sampling, and Population

The determination of the domestic sample size refers to the Indonesian National Standard (Badan Standardisasi Nasional, 1995) through the application of the formula $S = 0.5\sqrt{P}$, where P represents the total population. Based on a permanent population of 1,598 individuals, a theoretical sample size of 5 households, equivalent to 20 individuals, was obtained. Stratification based on housing durability was applied using stratified random sampling to optimize representativeness despite the limited numerical sample size: 25% permanent structures with one sample, 35% semi-permanent structures with two samples, and 40% non-permanent structures with two samples. This stratification strategy captures the diversity of household consumption patterns and waste generation volumes across different socioeconomic groups.

Samples in the accommodation sector included six hotels or inns purposively selected based on two explicit criteria: a minimum room capacity of 15 units and an occupancy rate above 60 percent. Meanwhile, four restaurants were selected based on criteria of a minimum daily visitor count of 100 people and leftover food production exceeding 20 kilograms per day. This purposive selection ensures that the sampled facilities represent the spectrum of actual business scales operating on the island. A comprehensive summary of the sampling design is presented in Table 1.

Data Collection and Analysis

Daily waste measurement and collection were conducted for eight consecutive days using a calibrated digital scale. Quantification of marine debris followed the transect method based on standard coastal monitoring protocols (Lippiatt, S., Opfer, S., & Arthur, C., 2013). Four separate beach segments, each measuring 200 meters in length and 50 meters in landward depth—equivalent to 10,000 square meters per transect—were systematically established to capture spatial variations in waste accumulation. Transect placement was deliberately determined at (1) locations representing main tourist landing zones, (2) points prone to residential waste disposal, (3) areas where debris predominantly accumulates due to wind and current direction, and (4) protected zones near coral reefs.

Based on historical records from the Berau Regency of Statistics, the geometric growth method using the formula $P_t = P_0(1+r)^n$ was chosen to project the ISWM planning capacity until 2035. The high correlation coefficient (R2 ≥ 0.92) served as the basis for selecting this method, as it mathematically provides a reliable foundation for long-term infrastructure design in the region. The collected waste samples were classified according to SNI 19-3964-1995 into three categories: (1) organic waste, (2) inorganic waste, which is further divided into recyclable and non-recyclable materials, and (3) hazardous B3 waste. All data were then analyzed using descriptive statistics.

Table 1.

Summary of sampling design and criteria

Sector / Source	Sampling Method	Stratification Parameter / Criteria	Sample Size
Domestic (Households)	*Stratified Random Sampling* (SNI 19-3964-1995)	Permanent (25%) Semi-Permanent (35%) Non-Permanent (40%)	5 Households (20 Capital)
Commercial (Accommodation)	*Purposive Sampling*	Capacity >15 rooms & high occupancy rate	6 Inns/Hotels
Commercial (Culinary)	*Purposive Sampling*	High daily tourist visit volume	4 Restaurants
Marine Debris	*Transect Method* (200 m × 50 m)	Peak high and low tide zones	4 Beach Segments

Data Quality Assurance

The entire weighing process was conducted using a calibrated Kern EFS digital scale with a precision level of ±0.5 kg. This measuring instrument was permanently placed at a designated measurement station. Consistency of measurement results was ensured through a daily calibration procedure utilizing a set of standard weights. To minimize potential recording errors, each measurement data point was recorded independently by two observers. All raw data were then systematically entered into a worksheet format equipped with columns for date, source, weight, and category, in preparation for further statistical analysis and quality verification.

RESULTS AND DISCUSSION

Waste Generation Rates and the Double-Burden Phenomenon

A quantitative evaluation of accumulated waste over an eight-day sampling period, covering 2,025 person-days from permanent residents and daily tourists, revealed a total waste of 22,480.42 kg, equivalent to 2,810.05 kg per day. Considering the aggregate daily population of 1,505 permanent residents and approximately 800 floating tourists, the specific per capita waste generation rate was calculated to be 1.652 kg per capita per day.

This generation rate is nearly double the standard reference for ordinary households set by the (Badan Standardisasi Nasional, 1995) which ranges from 0.5 to 0.8 kg/capita/day. This increase illustrates the well-documented phenomenon of a "double burden" in small island destinations, where baseline residential waste coincides with much higher consumptive waste from the seasonal tourist population (Ardiyanto et al., 2024; Güereca et al., 2013; Manomaivibool, 2018). Cross-regional comparisons show that the generation rate on Derawan Island is very similar to other major marine tourism centers such as Labuan Bajo (1.62 kg/capita/day), Karimunjawa (1.45 kg/capita/day), and the Gili Islands (1.78 kg/capita/day), but exceeds islands with low tourist visitation such as the Banda Islands (0.65 kg/capita/day) (Cordova et al., 2022; Liu et al., 2023; Manomaivibool, 2018).

The high per capita consumption of tourists and the absolute dependence on packaged mainland supply chains are direct causes of this increased generation. To ensure high data granularity for engineering purposes, the weight distribution by source is systematically organized in Table 2.

Table 2.

Waste Weight Distribution by Source (8-day sampling period)

Waste Stream Source	Organic (kg/day)	Inorganic (kg/day)	Hazardous / B3 (kg/day)	Total Weight (kg/day)	Proportion (%)
Domestic Households (5 HH)	528.76	263.81	15.06	807.63	28.73%
Commercial (Hotels/Inns)	765.06	667.60	101.28	1,533.94	54.57%
Commercial (Restaurants)	222.55	152.52	5.62	380.69	13.54%
Marine Debris (Coastline)	1.53	81.25	5.00	87.78	3.12%
Total Daily Accumulation	1,517.15	1,165.18	126.96	2,810.05	100%

Table 2 shows that although household waste remains significant in quantity, tourism-related commercial waste dominates the island's waste stream significantly (68.11% of daily production). Potential misinterpretation regarding storage space requirements can be avoided by presenting daily volume fluctuations in Liters in Table 3. This detailed volume data becomes crucial in determining the dimensions of receiving bins and manual sorting stations in the proposed strategy.

Table 3.

Daily Volumetric Waste Projections for Sorting Station Sizing

Source Category	Daily Volume (Liters/day)	Bulk Density (kg/m^3)	Peak Hour Multiplier
Domestic	1,615.26	250.40	1.2
Commercial Sector	4,050.00	180.25	1.5
Coastal Marine Debris	850.50	95.10	2.1

Compositional Analysis and Plastic Vulnerability

Physical characterization analysis indicates that from the total daily waste stream of 2,810.05 kg, the composition consists of organic waste at 1,517.15 kg/day (53.99%), inorganic waste at 1,129.43 kg/day (40.18%), and hazardous waste (B3) at 163.97 kg/day (5.83%). The inorganic fraction is further divided into high-value recyclable materials (10.04%) such as HDPE, PET, and aluminum, and non-recyclable inorganic materials (30.14%) in the form of low-density films and contaminated packaging.

The dominance of organic waste at 53.99% aligns with empirical findings on global tropical tourism islands such as Palau (49.5%) and the Maldives resorts (54.1%) (Hakika et al., 2024; Johnson et al., 2014; Wang et al., 2011). The inorganic fraction on Derawan Island, however, shows an increase in typical low-density single-use rigid plastics. This plastic dominance driven by supply chains represents a critical vulnerability, as it reflects the island's dependence on mainland networks for consumer goods, significantly worsening the risk of marine pollution and coral reef degradation(Chen et al., 2020; Lamb et al., 2018; Lebreton et al., 2017).

Mass Balance and Integrated Solid Waste Management Framework

This material composition directly determines the shift in Integrated Solid Waste Management (ISWM) strategies. The conventional linear model of collect-transport-dispose is fundamentally inadequate, economically costly, and highly environmentally vulnerable for small island destinations requiring 1.5 hours of sea transportation (Adalya & Mutaqin, 2022; Al-Salem et al., 2019). The dominance of organic waste is the primary reason for this incompatibility. Instead, a decentralized ISWM framework based on a Circular Economy is recommended, prioritizing local bioconversion and material recovery (Fan et al., 2019; Patrício et al., 2015).

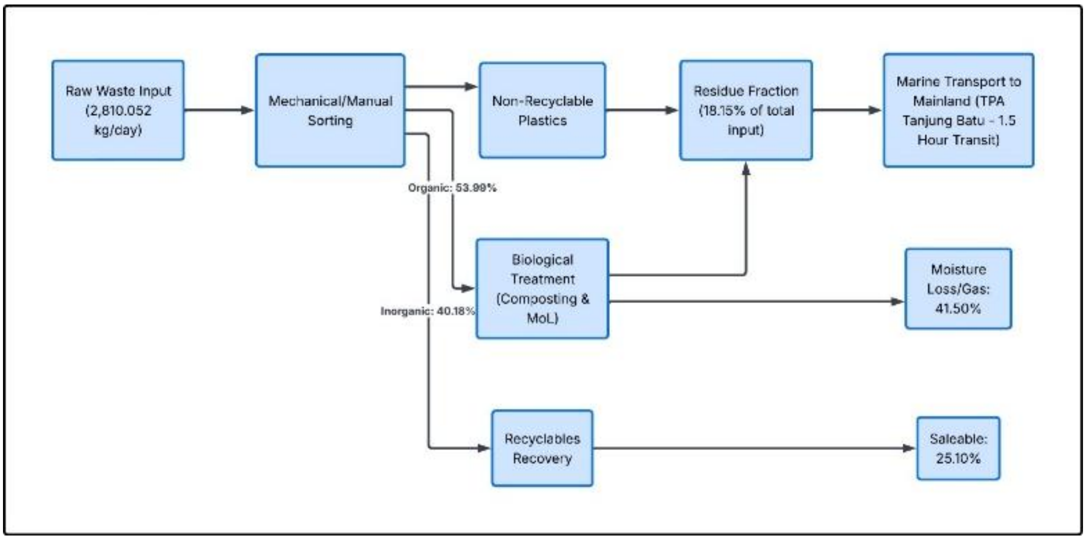

Figure 2. Conceptual mass balance and material flow within the proposed Derawan Island ISWM framework

Table 4.

Proposed Integrated Solid Waste Management Mass Balance (Daily Basis)

Treatment Pathway	Input (kg/day)	Process Mechanism	Output (kg/day)	Final % of Total
Organic Bioconversion	1,517.15	Composting & MoL Bioreactors (41.5% mass reduction)	887.53 (Compost)	31.56%
High-Value Recycling	282.35	Dry-waste sorting & sale to mainland supply chains	0 (Exported/Sold)	0.00%
Energy Recovery (Potential)	212.54	Co-combustion/Plastic energy-recovery	0 (Exported)	0.00%
Non-recyclable Residue	634.54	Maritime transport to mainland landfill	510.45	18.15%
Hazardous / B3 Waste	163.97	Specialized containment & handling	163.97	5.83%
TOTAL DAILY WASTE	2,810.05		2,810.05	100%

Based on data in Table 4 and the conceptual framework in Figure 2, the organic fraction of 1,517.15 kg/day is processed in a decentralized manner through Local Microorganism (MoL) bioreactors and composting. This process successfully reduces organic mass by approximately 41.50% through moisture evaporation and stabilization of volatile organic compounds, with a reduction coefficient consistent with operations in tropical island regions (Materazzi et al., 2016; Sultana et al., 2021). Additionally, high-value recyclable materials are recovered and channeled into the circular economy supply chain on the mainland through informal intermediaries (scavengers/collectors).

The final residual waste that cannot be recycled and is transported by sea to the mainland was structurally reduced to only 510.45 kg per day. This figure is equivalent to 18.15% of the total initial flow of 2,810.05 kg. 81.85% reduction in maritime shipping mass directly addresses various critical constraints through lower annual transportation costs, reduced vessel frequency, and decreased CO_2 emissions from fuel (Kaza et al., 2018).

Comparative Discussion and Management Implications

The decentralized approach relying on community-based sorting and on-site biological processing is currently a global best practice for geographically isolated island destinations. Dependence on mainland landfills has become ecologically and economically unfeasible for island regions, making upstream reduction interventions essentia (Jambeck et al., 2015). This is reinforced by various case studies highlighting the urgency of independent waste management in remote areas.

The current eight-day sampling protocol only captures transitional dry season conditions. Daily fluctuations in waste production can be triggered by seasonal variations due to peak tourist visit surges or monsoon weather patterns. Although the number of household samples is mathematically limited, strict stratification has been applied to ensure fundamental representativeness (Cordova et al., 2022). Continuous multi-season monitoring is recommended moving forward to refine the long-term capacity design of ISWM infrastructure on Derawan Island.

CONCLUSIONS

Evaluating waste patterns on Derawan Island highlights a clear "double burden," where tourism-driven commercial activities heavily overload the limited municipal infrastructure. The empirical data confirms that relying on the traditional, transport-heavy "collect-transport-dispose" model is both ecologically risky and financially unsustainable for such an isolated geographic setting.

To address this, small-island destinations must pivot toward a decentralized Integrated Solid Waste Management (ISWM) framework. By prioritizing on site biological processing, specifically through composting and bioconversion using salt-tolerant Local Microorganisms (MoL), combined with recycling high-value polymers, these fragile ecosystems can drastically cut down their reliance on mainland landfills. This structural shift bypasses complex maritime logistics while directly shielding sensitive marine ecotourism corridors from debris pollution. Ultimately, these findings offer a practical, evidence-based roadmap for other small islands striving to build ecological and economic resilience through localized resource recovery.

SUGGESTION

For Further Research: Continuous twelve-month monitoring across seasons is necessary to measure waste generation fluctuations influenced by monsoon patterns and peak tourist visits. A detailed economic analysis comparing the costs of decentralized Integrated Solid Waste Management infrastructure with mainland landfill transportation needs to be implemented. The technical feasibility of a composting system using Local Microorganisms adapted to marine environments must be evaluated under tropical island climate conditions.

For Policy and Infrastructure Planning: The implementation of a decentralized ISWM framework needs to be mandated in the waste management master plan of Berau Regency for policy and infrastructure planning. A regulatory framework requiring tourism businesses to contribute to local ISWM infrastructure based on their waste generation proportion must be established. Waste characterization data should also be integrated into spatial planning codes to prevent coastal development in zones vulnerable to waste dumping.

For Operational Practice: Operational practices can begin with source sorting training for all tourism businesses, emphasizing the separation of organic and inorganic waste. Community-based waste management cooperatives need to be established to handle collection, sorting, and composting processes. Tourism industry certification standards mandating on-site waste reduction targets, such as a 10% annual decrease in single-use packaging usage, should also be developed.

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