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Research

Operational Performance of A Controlled Landfill In Bantaeng, Indonesia: Leachate Management, Odor Nuisance, and Institutional Constraints

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ABSTRACT

Municipal solid waste management studies increasingly emphasize landfill upgrading and environmental safeguards, yet limited empirical evidence remains on how controlled landfill operations perform under district-level resource constraints and fluctuating waste inflow, creating a gap in operationally grounded evaluations. This study assesses the operational system and environmental management of TPA Batu Terang, the main final disposal facility in Bantaeng Regency, Indonesia, focusing on daily waste inflow dynamics, leachate and landfill gas management, nuisance impacts, social dimensions, and institutional capacity. A qualitative descriptive case study design was applied using field observations and an in-depth semi-structured interview with the Head of the Environmental Agency. Reported waste inflow averaged 27.49 tons/day, periodically increasing to 30–32 tons/day due to routine clean-up programs and increased food and packaging residuals linked to the Free Nutritious Meal (MBG) initiative. The facility implements controlled landfill practices with periodic soil cover, supported by a weighbridge and computerized recording that enables semi-annual reporting and improves accountability. Environmental management is strengthened by a leachate collection system and staged multi-pond treatment (intake–facultative–maturation–biofilter), described as operating within capacity. However, methane utilization remains limited and odor persists as the most salient community concern, typically addressed through reactive covering. Key constraints include aging heavy equipment, limited budgets, human resource needs, and suboptimal source separation. Findings imply that phased improvements prioritizing routine cover discipline, equipment maintenance financing, incremental gas control and monitoring, and upstream waste diversion are essential to reduce impacts and support transition toward an integrated final processing facility (TPAS).

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1. Introduction

Solid waste management has emerged as a growing global environmental challenge driven by population growth, rapid urbanization, and shifting consumption patterns. Recent estimates indicate that municipal solid waste generation continues to rise and may substantially increase by mid-century if not matched by effective and sustainable management systems (Kaza et al., 2021). In many low- and middle-income contexts, limited infrastructure, financing constraints, and governance gaps mean that final disposal sites remain the dominant option for waste handling, often operating with minimal environmental controls (Ferronato & Torretta, 2022). This situation elevates risks of land degradation, surface- and groundwater contamination, greenhouse gas emissions, and nuisance impacts such as odor and vector proliferation, which collectively undermine environmental quality and public health.

Inadequate landfill operation is particularly associated with leachate release and uncontrolled gas generation, including methane, which contributes to climate forcing and can degrade local air quality when not captured or treated (Wilson et al., 2020). Nationally, Indonesia continues to face increasing waste pressures alongside expanding economic activity and urban development; reported national waste generation has reached tens of millions of tons annually, highlighting the urgency of strengthening local-level implementation capacity (Kementerian Lingkungan Hidup dan Kehutanan [KLHK], 2023). Although regulatory frameworks exist, practical implementation frequently remains challenged by insufficient facilities and limited source separation, with disposal still favored over reduction and recovery strategies (Guerreiro et al., 2021). Consequently, assessing real-world operational practices at disposal facilities is essential to identify priority risks, improvement opportunities, and feasible pathways toward more sustainable waste management.

Despite the availability of policy and technical guidance, many landfills in developing regions continue to operate below environmental performance standards, resulting in persistent pollution pathways (leachate and landfill gas), nuisance impacts (odor), and social concerns for nearby communities (Ferronato & Torretta, 2022; Wilson et al., 2020). In Indonesia, this implementation gap is amplified by rising waste volumes and uneven local capacity, which can lead to reliance on end-of-pipe disposal rather than integrated waste prevention and treatment approaches (KLHK, 2023; Guerreiro et al., 2021). A practical and evidence-based solution is to conduct systematic facility-level assessments that document operational systems, quantify incoming waste loads, and evaluate environmental and social impacts, thereby generating actionable recommendations to improve landfill management and support transition toward sustainable waste governance (Kaza et al., 2021).

Scientific literature emphasizes that improving landfill performance requires an integrated operational package that combines controlled disposal practices with pollution prevention measures. Key interventions include engineered leachate collection and treatment, stormwater separation, progressive cell development with compaction and daily cover, and routine monitoring of water and air quality to reduce contaminant migration and nuisance impacts (Wilson et al., 2020). In addition, landfill gas management—ranging from passive venting systems to active collection and utilization—has been highlighted as a critical pathway to reduce methane emissions and odor while supporting climate mitigation objectives (Kaza et al., 2021).

Beyond on-site engineering controls, researchers consistently argue that landfill improvements are most effective when embedded within broader municipal solid waste systems. This includes strengthening source separation, expanding recycling and organics diversion, and upgrading collection logistics to reduce the biodegradable fraction entering landfills and lower leachate and gas generation potential (Ferronato & Torretta, 2022). Governance and financing mechanisms—such as performance-based contracting, transparent reporting, and community engagement—are also identified as enabling factors for sustained operational compliance and social acceptability, especially in developing-country settings where resource constraints are pronounced (Guerreiro et al., 2021; KLHK, 2023).

Although global and national studies have clarified the magnitude of the waste challenge and the technical options available, empirical evidence from facility-level assessments in many Indonesian districts remains limited, particularly regarding how daily operational practices translate into observable environmental and social impacts (Ferronato & Torretta, 2022; KLHK, 2023). Prior work underscores that leachate and landfill gas are central risk pathways in inadequately managed sites, yet their local manifestation depends on site-specific conditions, incoming waste composition and volume, and operational consistency (Wilson et al., 2020). Consequently, localized case studies are needed to bridge the gap between policy aspirations and operational realities, while providing context-sensitive recommendations.

This study addresses that gap by presenting a field-based assessment of the operational system and management practices at TPA Batu Terang, located in Desa Bonto Salluang, Kecamatan Bissappu, Kabupaten Bantaeng (South Sulawesi, Indonesia), including documentation of incoming waste volumes (approximately 27.49 tons/day) and key environmental concerns (leachate, landfill gas, and odor) alongside social implications. The novelty lies in integrating a structured operational review with an impact-oriented appraisal tailored to a specific landfill setting, thereby producing implementable insights for local government and facility managers. Accordingly, the objective of this study is to (i) describe the operational and waste management system applied at TPA Batu Terang, (ii) evaluate environmental management related to leachate, landfill gas, and odor, (iii) identify environmental and social impacts arising from landfill operations, and (iv) outline the main challenges and future prospects for improving management at TPA Batu Terang in line with sustainable waste management priorities (Kaza et al., 2021; Wilson et al., 2020; KLHK, 2023; Guerreiro et al., 2021).

2. Method

This study employed a qualitative descriptive design using a case study approach to examine the operational system, environmental management practices, and socio-institutional dynamics of the Batu Terang Final Disposal Site (Tempat Pemrosesan Akhir/TPA Batu Terang) in Bonto Salluang Village, Bissappu Sub-district, Bantaeng Regency, Indonesia. The study was designed to generate an in-depth understanding of landfill practices under a controlled landfill scheme and to identify constraints and improvement prospects based on direct field evidence and stakeholder perspectives.

2.1 Study period and location

Fieldwork was conducted at TPA Batu Terang, Bantaeng Regency. Data collection was undertaken during a site visit period corresponding to the field observation and interview activities reported in this manuscript. The landfill was selected purposively because it functions as the main final disposal facility for municipal household waste and similar waste streams in the regency and therefore represents a critical node in local waste governance.

2.2 Study population, informants, and sampling technique

The study population comprised key stakeholders involved in, or responsible for, municipal solid waste management and landfill operation in Bantaeng Regency. The primary informant was the Head of the Environmental Agency of Bantaeng Regency, selected through purposive sampling based on institutional authority, knowledge of landfill operation and policy implementation, and direct responsibility for monitoring and responding to community concerns. Additional contextual information was obtained through on-site interactions with operational personnel encountered during field observation to support triangulation of operational descriptions when feasible.

2.3 Inclusion criteria

Informants were included if they (i) held formal responsibility for waste management and landfill oversight, or (ii) possessed direct operational knowledge of daily landfill activities and reporting. Informants were required to provide voluntary participation and consent for the interview.

2.4 Data collection methods and instruments

Data were collected using two principal techniques: Field observation, non-participant observation was conducted to document landfill setting and operational practices, including waste reception and placement, controlled landfill covering practices, visible nuisance conditions (especially odor), presence and function of weighbridge and recording systems, leachate collection and pond treatment configuration, and informal sector activities (waste picking and material recovery). Observation notes were recorded in a structured format covering site context, operational workflow, environmental control infrastructure, and community-interface conditions.

In-depth interview, Aasemi-structured in-depth interview was conducted with the Head of the Environmental Agency to elicit detailed explanations regarding: (i) landfill operational approach (controlled landfill rationale and practices), (ii) daily waste inflow patterns and drivers of inflow spikes, (iii) waste stream handling policies (including hazardous and toxic waste/B3 exclusion mechanisms), (iv) weighbridge use and reporting routines, (v) leachate management system design and perceived performance, (vi) landfill gas management priorities and limitations, (vii) dominant environmental and social impacts and complaint handling, (viii) institutional constraints (equipment, budget, human resources), and (ix) future plans toward an integrated final processing facility (TPAS) and phased improvement priorities. The interview guide was aligned with the study objectives and allowed probing for clarification and examples.

2.5 Data sources and documentation

Primary data consisted of observation records and interview transcripts/notes. Secondary data included operational figures and descriptions available at the site and from institutional reporting narratives provided by the informant (e.g., reported average daily waste inflow and periodic increases, and qualitative descriptions of semi-annual reporting through a national platform). Where accessible, supporting documents (internal reports or monitoring notes) were reviewed to corroborate statements; however, the analysis prioritized field-derived evidence.

2.6 Data analysis

All qualitative data were analyzed using thematic analysis. Observation notes and interview transcripts were compiled, coded, and categorized into major themes reflecting the structure of the results section, including: (1) site context and daily waste inflow dynamics, (2) controlled landfill operational practices and waste stream handling, (3) data governance and reporting (weighbridge), (4) leachate management infrastructure and perceived adequacy, (5) landfill gas management and safety priorities, (6) nuisance impacts (odor) and response measures, (7) social dynamics (informal sector involvement and complaint handling), (8) institutional constraints (equipment, budget, staffing), (9) policy–practice implementation gap (3R limitations), and (10) future prospects and phased improvement options. Triangulation between observation and interview findings was applied to enhance credibility, particularly for operational practices and perceived impact pathways. Findings were synthesized narratively to support interpretive discussion focused on operational implications and governance constraints. Results are presented in a qualitative narrative format organized into sub-sections that mirror the analytical themes. Descriptive statistics are included only where they were directly reported and relevant to operational interpretation (e.g., average daily inflow and peak ranges). Interpretive discussion is integrated to connect field findings with operational consequences (e.g., impacts of fluctuating inflow on compaction, cover scheduling, and odor control).

2.7 Research procedures and ethical considerations

The research was conducted through the following steps: (1) preparation of observation checklist and semi-structured interview guide; (2) coordination and access arrangement with relevant local authorities; (3) on-site reconnaissance and systematic observation of operational flow and environmental control units; (4) conduct of in-depth interview with the designated key informant; (5) consolidation of field notes and interview records; (6) coding and thematic analysis; and (7) synthesis of results and discussion aligned with the study objectives and the operational context of TPA Batu Terang.

3. Results & Discussion

3.1 Site Context and Daily Waste Inflow

Field observations and an in-depth interview with the Head of the Environmental Agency of Bantaeng Regency indicate that TPA Batu Terang functions as the main final disposal facility for household waste and similar municipal waste streams in Bantaeng. The landfill is located in Bonto

Salluang Village, Bissappu Sub-district, and is operated under the local government's authority. The facility applies a controlled landfill approach, reflecting practical adaptation to limited land availability and budget constraints.

Daily incoming waste is reported at an average of 27.49 tons/day, with periodic increases to 30–32 tons/day. These spikes are associated with routine local government environmental cleaning activities (e.g., "Friday Clean-Up" and weekend community clean-ups) as well as newly implemented programs such as the Free Nutritious Meal (MBG) initiative, which increases food residuals and packaging waste. This pattern demonstrates that waste loads are not only driven by population growth and economic activity, but also by institutional routines and service programs that shape waste generation peaks. In controlled landfill settings, fluctuating waste inflow may complicate compaction scheduling, cover application, and odor management, thereby increasing operational sensitivity to resource availability and workforce readiness.

3.2 Operational System: Controlled Landfill Practice and Handling of Waste Streams

Interview findings confirm that waste placement at TPA Batu Terang follows controlled disposal practices, including periodic soil covering (rather than daily cover typical of sanitary landfill systems). The informant emphasized that controlled landfill was selected as a feasible approach because sanitary landfill operation requires higher operational costs, daily cover, and more intensive technical maintenance. From an operational standpoint, this reflects a common "best achievable" approach in many resource-limited municipalities where landfill upgrades must be staged incrementally.

Waste entering the facility consists of organic and inorganic fractions, while hazardous and toxic waste (B3) is not handled directly at the landfill. Instead, B3 waste generators (healthcare facilities, workshops, electronics stores) are required to use temporary storage and scheduled collection by licensed transporters. This separation reduces high-risk contamination at the landfill level, yet it also implies the need for strong compliance monitoring beyond the landfill boundary (generator responsibility and transport integrity). In practice, controlled landfill performance depends not only on site practices but also on upstream enforcement and the extent to which mixed waste still dominates municipal collection.

3.3 Weighbridge and Reporting System as an Operational Strength

A notable operational feature observed at the site is the existence of a weighbridge integrated with computerized recording, used for mandatory weighing of incoming municipal waste trucks. The operator records daily inflow and reports it semi-annually through the national reporting platform. In qualitative terms, this system represents a governance and accountability asset: reliable inflow data helps local government quantify service demand, track seasonal fluctuations, and justify resource allocation.

In many low- and middle-income settings, landfill management is undermined by poor data systems; therefore, the weighbridge at TPA Batu Terang can be interpreted as an enabling condition for evidence-based planning. However, data utility depends on how consistently it is used for operational decision-making (e.g., adjusting cover frequency during high-load periods, planning equipment maintenance schedules, estimating leachate production, and forecasting remaining landfill lifespan).

3.4 Environmental Management: Leachate Collection and Multi-Pond Treatment

Observation and informant description indicate that the landfill has an installed leachate collection pipe network located approximately three meters beneath the landfill base, directing leachate to a staged pond treatment system. The leachate ponds consist of intake ponds (ponds 1–5), facultative ponds (ponds 6–8), a maturation pond (pond 9), and a biofilter pond (pond 10). Importantly, the final storage pond has reportedly never been filled since operation, which was interpreted by the informant as a sign that the leachate management system is still functioning within planned capacity.

From an environmental health perspective, the presence of a structured leachate management train suggests an intentional mitigation of groundwater and surface-water risk pathways—often critical weaknesses in inadequately operated disposal sites. The staged pond configuration (intake–facultative–maturation–biofilter) is generally consistent with decentralized treatment logic, where sequential biological processes reduce pollutant loads before release. Nevertheless, field-based qualitative appraisal also implies that functional adequacy should ideally be supported by routine water quality monitoring (e.g., COD/BOD, ammonia, pH, conductivity, and indicator organisms) and inspection of pipes and liners to detect early-stage failures. Thus, while leachate infrastructure appears robust, sustaining performance requires continuous monitoring, maintenance, and enforcement of stormwater separation to avoid hydraulic overload.

3.5 Landfill Gas (Methane) Management: Safety Priorities and Limited Utilization

The informant noted that methane generation occurs from organic waste decomposition, but energy utilization is limited due to the relatively low and variable waste inflow. Landfill gas capture and energy recovery is typically more feasible for larger landfills with stable, high volumes. At TPA Batu Terang, gas is predominantly released to reduce accumulation and lower fire risk, while a small portion has been utilized for practical operational needs (e.g., cooking) in a limited manner.

This finding highlights a common operational trade-off in small to medium landfills: risk management and immediate safety may take precedence over climate mitigation and energy recovery. Nonetheless, uncontrolled methane release remains environmentally significant and may also exacerbate odor complaints. A feasible intermediate pathway in such settings is staged gas management—starting with passive venting and basic flare systems and progressing to active collection if volumes increase (Elgarahy et al., 2024) . The site's experience suggests that improving gas control could be linked to upstream waste diversion strategies, especially organics reduction, which would lower methane generation potential and improve odor conditions.

3.6 Dominant Nuisance Impact: Odor as the Most Salient Community Concern

Both observation and interview data consistently identify odor as the most dominant environmental impact associated with the active landfill cell. While water and soil impacts are perceived to be controlled through leachate systems, odor remains a frequent source of community concern. Management action typically includes applying soil cover when complaints arise, indicating a responsive but potentially reactive approach.

In qualitative interpretation, this suggests that odor is not merely a technical issue but also a social interface: it shapes community acceptance and trust in local environmental governance. Odor control effectiveness strongly depends on cover frequency, compaction quality, exposed waste surface area, and timing during high inflow days. Therefore, the recurring odor issue may reflect operational constraints—such as equipment availability, cover material access, and staffing—rather than an absence of awareness. In controlled landfill systems, enhancing routine cover and cell discipline is among the most cost-effective strategies to reduce odor, vectors, and visible litter.

3.7 Social Dynamics: Informal Sector Contribution and Complaint Handling

The landfill's relationship with surrounding communities is described as "manageable," supported by complaint follow-up by the Environmental Agency. Another key social dimension is the presence of informal waste pickers, who recover economically valuable materials such as plastics and metals and channel them to waste banks or recycling pathways. This activity indirectly reduces the volume of waste placed in the landfill.

From a systems perspective, the informal sector functions as a practical resource for material recovery in contexts where formal separation and recycling are limited. However, their involvement also requires attention to occupational health risks (injuries, exposure to pathogens, smoke, and chemical residues) and the need for basic protections and site rules (Maalouf et al., 2020). Qualitatively, the results indicate that sustainable landfill governance should integrate technical improvements with social protections and recognition mechanisms for informal actors to enhance both recovery performance and social equity.

3.8 Management and Institutional Constraints: Equipment, Budget, and Human Resources

A central theme emerging from the interview is the interdependence of technical operation and institutional capacity. The informant emphasized constraints related to aging heavy equipment (bulldozers/excavators), which are critical for waste movement, compaction, and cover application. Equipment failure can disrupt the entire operational chain, amplifying odor, safety hazards, and potential slope instability.

Budget limitations also shape the choice of controlled landfill over sanitary landfill and restrict upgrades and maintenance. Human resources are described as another key factor: staff must not only manage daily operations but also monitor risks such as fire, slope failure, and environmental contamination. The findings reinforce that landfill performance is fundamentally a governance issue: without stable financing, trained personnel, and scheduled maintenance, even available infrastructure can degrade over time (Escamilla-García, 2024).

3.9 Policy Framework and Implementation Gap in Local Practice

The landfill operates under national and local regulations on waste and environmental management, including waste management law and local bylaws and regent regulations. Yet, the informant described that the 3R (reduce, reuse, recycle) approach is not optimal due to rising waste quantities, increasing plastic fractions, and limited collection systems that are not designed for separated waste streams. This creates a structural barrier: mixed collection reduces the feasibility of effective downstream sorting and increases the residual fraction requiring disposal.

This reflects a typical policy–practice gap: regulations and strategies exist, but implementation is constrained by infrastructure readiness, logistics, and public participation in source separation. The qualitative evidence suggests that improving TPA performance cannot be isolated from broader municipal solid waste improvements (collection redesign, transfer stations, organics diversion, and community behavior change).

3.10 Future Prospects: Toward TPAS and Priority Actions for Incremental Improvement

The informant reported that the landfill is operating as a temporary solution while a longer-term transition toward a TPAS (integrated final processing facility) is being prepared, supported by scientific studies and plans for environmentally friendly technologies aimed at reducing landfill residues. In the near term, the most urgent needs include improved landfill cell arrangement and maximizing soil cover to reduce odor and minimize environmental risk exposure.

Routine monitoring and multi-agency inspection every six months (local environmental agency, public works, and relevant central government units) were described as a mechanism to maintain operational safety and continuity. In qualitative synthesis, future improvement pathways can be framed as phased interventions: (i) strengthen daily operational discipline (cover, compaction, slope control), (ii) stabilize equipment and maintenance budgeting, (iii) enhance leachate and gas monitoring and incremental gas control, and (iv) integrate upstream interventions (source separation, organics diversion, and recycling strengthening). Such sequencing is realistic for district-level governance contexts and aligns with sustainable waste management priorities.

4. Conclusion

This qualitative case study indicates that TPA Batu Terang is a critical component of municipal waste management in Bantaeng Regency, operating as the main final disposal facility and applying a controlled landfill system as an adaptive response to land and budget limitations. Operational capacity is strengthened by the presence of a weighbridge with computerized recording and by environmental infrastructure, particularly the leachate collection network and multi-pond treatment system, which—based on field observations and informant accounts—continues to function effectively under current loading conditions.

Nevertheless, key challenges remain, notably the limited optimization of landfill gas (methane) management and persistent odor as the most salient community concern. Performance is further constrained by institutional limitations, including restricted budgets, aging heavy equipment, and human resource needs, alongside the continued dominance of mixed waste and suboptimal source separation despite regulatory alignment. Priority actions should therefore be pursued in phases, focusing on improved daily operational discipline (compaction and routine cover), stabilization of equipment and maintenance financing, incremental strengthening of gas control and environmental monitoring, and upstream interventions (source separation and organics diversion) to reduce residual waste and support the planned transition toward an integrated final processing facility (TPAS).

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