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GAP ANALYSIS AND SANITARY LANDFILL DEVELOPMENT STRATEGY FOR COT PADANG NILA LANDFILL, PIDIE REGENCY

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ABSTRACT

Population growth and expanding socio-economic activities have significantly increased municipal solid waste (MSW) generation in Pidie Regency, Aceh Province, Indonesia. The Cot Padang Nila Final Disposal Site, the sole landfill facility serving the regency, currently processes approximately 45 tonnes of waste per day under an open dumping system. This study aims to quantify current and projected MSW generation over a 20-year planning horizon (2025–2045) and formulate a comprehensive and technically grounded optimization strategy. A quantitative evaluative research design was employed, integrating systematic field observations, institutional document analysis. Total MSW generation is projected to increase from approximately 317 tonnes/day in 2024 to 368 tonnes/day by 2045. The proposed optimization framework encompasses a transition to a cell-based sanitary landfill system with engineered composite liner, multi-stage leachate treatment, structured methane gas recovery, an aerobic composting facility (capacity: 128 t/day), a Material Recovery Facility (MRF) for inorganic fractions, and a comprehensive fleet depot. Implementation of these measures is projected to substantially improve waste management effectiveness, reduce environmental contamination risks, and extend the operational service life of the landfill.

Keywords : Municipal solid waste management, Landfill optimization, Sanitary landfill, Gap analysis

ABSTRAK

Pertumbuhan penduduk dan aktivitas sosial-ekonomi meningkatkan secara signifikan volume timbulan sampah di Kabupaten Pidie, Aceh, Indonesia. TPA Cot Padang Nila, merupakan satu-satunya fasilitas pembuangan akhir yang melayani kabupaten Pidie, saat ini menerima sekitar 45 ton sampah per hari dengan sistem open dumping. Penelitian ini bertujuan untuk memproyeksikan timbulan sampah selama 20 tahun perencanaan (2025–2045) dan merumuskan strategi optimalisasi yang komprehensif dan berbasis teknis. Total timbulan sampah diproyeksikan meningkat dari sekitar 317 ton/hari pada tahun 2024 menjadi 368 ton/hari pada tahun 2045. Kerangka optimalisasi yang diusulkan mencakup transisi ke sistem sanitary landfill berbasis sel dengan sistem liner komposit, instalasi pengolahan lindi multi-tahap, sistem pemulihan gas metana, fasilitas pengomposan aerob (kapasitas 128 ton/hari), Material Recovery Facility (MRF) untuk fraksi anorganik, dan depot armada operasional. Implementasi langkah-langkah tersebut diproyeksikan mampu meningkatkan efektivitas pengelolaan sampah, mengurangi risiko pencemaran, dan memperpanjang umur layanan TPA secara berkelanjutan.

Kata kunci : *Pengelolaan sampah perkotaan, Optimasi TPA, TPA landfill, Analisis Kesenjangan*

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Introduction

Municipal Solid Waste (MSW) management has emerged as a pressing global environmental and public health challenge, particularly in rapidly urbanising low- and middle-income countries where population growth, industrialisation, and shifting consumption patterns have outpaced the development of waste management infrastructure (Kaza et al., 2018). Global waste generation currently exceeds 2.01 billion tonnes per year and is projected to reach approximately 3.40 billion tonnes annually by 2050, with the majority of this increase anticipated in developing economies (Romianingsih, 2023). Beyond volume, the environmental significance of inadequate waste management is substantial: the waste sector contributes an estimated 1,580 billion tonnes of CO_2 equivalent (CO_2e) to global greenhouse gas emissions, representing approximately 3.2% of the global total (Aprilia, 2021). These figures underscore the urgent need for systemic improvements in waste collection, treatment, and final disposal practices.

In Indonesia, Law No. 18 of 2008 on Waste Management and Indonesian National Standard (SNI) 19-2454-2002 establish the legislative and technical framework for integrated MSW management, encompassing waste generation reduction at source, collection, transportation, treatment, and controlled final disposal. MSW is broadly classified into organic fractions primarily food waste, garden residues, and agricultural by-products and inorganic fractions, including plastics, metals, glass, paper, and textiles, each requiring differentiated collection and treatment approaches (Ambina, 2019). Population growth and evolving consumption behaviour have increased not only the absolute volume of MSW generated but also its compositional complexity, with inorganic materials constituting a growing proportion of the waste stream, particularly in peri-urban and secondary urban areas (Almeisa et al., 2024).

The Regulation of the Ministry of Public Works and Housing (Permen PUPR) No. 3 of 2013 mandates local governments to establish a hierarchical waste management infrastructure encompassing source-reduction facilities, waste transfer stations, integrated waste treatment facilities (TPST), and final disposal sites (TPA). The regulation specifies detailed technical requirements for each infrastructure tier, including waste sorting and material recovery, composting of organic fractions, leachate collection and treatment, and landfill gas management. A sanitary landfill, where waste is systematically placed, compacted, and isolated within a lined, zoned cell structure before being progressively covered, represents the regulatory minimum standard for final disposal in Indonesia, replacing the environmentally unacceptable open dumping method (Izharsyah, 2020; Priatna et al., 2020).

Despite these regulatory requirements, a significant proportion of district- and municipal-level landfills across Indonesia continue to operate under open dumping conditions, characterised by the absence of engineered liner systems, leachate collection and treatment infrastructure, landfill gas management, and organised cell arrangement (Handriyani et al., 2020; Sukarmawati et al., 2023). These conditions generate wide-ranging adverse impacts, including groundwater and surface water contamination from uncontrolled leachate migration, unregulated methane gas emissions and associated explosion and fire risks, odour nuisance, proliferation of disease vectors, and degradation of surrounding land use (Yuliyanti et al., 2024).

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The Cot Padang Nila Final Disposal Site, located in Padang Tiji District, Pidie Regency, Aceh Province, is emblematic of these systemic challenges. As the sole waste disposal facility serving the entire regency, it currently receives approximately 45 tonnes of MSW per day and operates under an open dumping system, in clear non-compliance with applicable national technical standards. Although the landfill area has recently been expanded, no corresponding improvements to technical infrastructure or operational management protocols have been implemented. Prior studies in similar Indonesian contexts have documented the environmental consequences of comparable facilities (Handriyani et al., 2020; Sukarmawati et al., 2023; Manurung & Santoso, 2019); however, facility-specific gap analyses and structured optimization frameworks that can serve as direct inputs to local government decision-making remain limited in the peer-reviewed literature.

Against this backdrop, the present study aims to: (1) evaluate the existing operational conditions and infrastructure of the Cot Padang Nila landfill against applicable national standards using a structured gap analysis method; (2) project MSW generation for Pidie Regency over a 20-year planning horizon (2026-2045); and (3) formulate a technically grounded and contextually appropriate optimization strategy for landfill management. The study's findings are intended to provide an evidence-based planning reference for local government agencies and a replicable analytical framework applicable to comparable landfill optimization challenges across Indonesia.

Methods

Research Design

This study employed a quantitative evaluative research design to systematically assess the operational status of the Cot Padang Nila Landfill and develop an evidence-based optimization strategy. The research was conducted across two primary phases: (1) condition assessment through field-based data collection, facility documentation, and institutional document analysis; and (2) optimization planning through structured gap analysis, long-term waste generation projection, and technical specification of proposed facilities.

Study Area

The Cot Padang Nila Final Disposal Site is located in Padang Tiji District, Pidie Regency, Aceh Province, Indonesia. The facility covers a total area of 4.9 hectares and functions as the sole active landfill serving all waste generation sources in the regency, including residential, commercial, institutional, and market sources within its designated service coverage area.

Data analysis was conducted using a gap analysis method by comparing the existing conditions with applicable technical standards. The evaluation focused on key components, including landfill system design, leachate management, methane gas control, drainage systems, basic infrastructure, supporting facilities, and operational equipment. The findings served as the basis for formulating an optimization strategy oriented toward the implementation of a sanitary landfill system to improve operational efficiency and enhance environmental protection in a sustainable manner.

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Waste Generation Projection

To support long-term capacity planning, waste generation was projected over a 20-year period using the arithmetic, geometric, and least squares methods. The most appropriate method was selected based on the smallest deviation between the projected results and historical data. The formulas applied in the projection analysis are presented as follows:

$$\mathbf{P_n = P_0 + Ka\ (T_n - T_0)}$$

$$\mathbf{Ka} = \frac{(P2 - P1)}{(T2 - T1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Notes:
P_n = The projected population for the n-th year
P_0 = Population in the base year
Ka = Arithmetic growth constant
T_n = Projected year (*n*)
T_0 = Initial year (base year)
P1 = Population at the initial known year
P2 = Population at the final known year
T1 = Initial observation year
T2 = Final observation year

To obtain the projected waste generation, the following calculation formula was applied:

Waste Generation Projection = Population × Per Capita Waste Generation

Results and Discussion

Existing Conditions and Facility Gap Analysis

The Cot Padang Nila Final Disposal Site still operates under an open dumping system without an impermeable liner, 3R-based waste treatment, leachate collection systems, or methane gas capture facilities. Supporting infrastructure, such as a guard post, parking area, and weighbridge, is also unavailable. These conditions are not in accordance with the technical requirements stipulated in the Regulation of the Ministry of Public Works and Public Housing No. 03 of 2013 and the Indonesian National Standard SNI 19-3241-2008.

Table 1. Gap Analysis of Existing Facilities and Infrastructure at the Cot Padang Nila Final Disposal Site Based on the Regulation of the Ministry of Public Works No. 3 of 2013

Component	Existing	Standard	Description
Operational System	Open dumping	Sanitary landfill	No zoning arrangement has been implemented
Leachate Treatment	Not available	Complete leachate treatment plant (IPLT)	Potential to contaminate groundwater
Methane Gas Management	Not available	HDPE ventilation pipe system	No methane gas ventilation system installed
Composting Facility	Not available	Mandatory facility	High volume of organic waste
Drainage System	Not optimal	Closed drainage system	Rainwater mixes with leachate
Supporting Facilities	Limited	Complete facilities	No weighbridge, vehicle pool, or control post

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Operational Road	Narrow and damaged	Asphalted road, ≥ 8 m wide	Road surface is partly unpaved and damaged
Waste Sorting	Informal scavengers	Standard MRF (Material Recovery Facility)	Sorting conducted manually by scavengers for resale
Personal Protective Equipment (PPE)	Limited	Mandatory occupational safety standards	Only basic equipment available
Transportation Fleet	17 units	42 units (based on needs analysis)	Insufficient waste transportation fleet

Waste Generation and Compostional Analysis

The analysis indicates that waste generation in Pidie Regency in 2024 reached 0.7 kg/person/day, or approximately 316,782 kg/day, and is projected to increase to 368,032 kg/day by 2045. However, only around 45 tons/day of waste are transported to the Cot Padang Nila landfill, suggesting limited coverage of centralized waste management services. The waste stream is dominated by inorganic waste (65%), while organic waste accounts for 35%.

Table 2. Waste Composition at the Cot Padang Nila Final Disposal Site

Waste Type	Volume (kg/day)	Percentage (%)	Description
Organic Waste	128.811,2	35	Food waste, leaves, and kitchen residues
Inorganic Waste	239.220,8	65	Plastics, metals, glass, and paper
Total	368.032	**100**	

The population projection up to the year 2045 was calculated using the arithmetic growth method, with 2025 serving as the baseline year. This projection was employed as the basis for estimating future waste generation and determining the required landfill capacity and service life. At the Cot Padang Nila Landfill, the projected population data were utilized to formulate optimization strategies for landfill capacity and to support sustainable waste management planning. Referring to Indonesian National Standard SNI 19-3983-1995, Pidie Regency is classified as a medium-sized city, with a waste generation rate of 0.7 kg/person/day or 3.5 L/person/day. The existing waste inflow to the landfill is approximately 30–45 tons/day. Based on these parameters, the waste generation projection for the period 2025–2045 was calculated using the arithmetic projection method and is presented in the following table.

Waste Generation Projection

Table 3. Population and Waste Generation Projection for Pidie Regency Over the Next 20 Years

No.	Year	Population	Waste Generation (kg/person/day)	Waste Generation (L/person/day)	Total Waste (kg/day)	Total Waste (L/day)
1.	2026	460.383	0.7	3.5	322.268	1.611.340
2.	2027	463.824			324.677	1.623.383
3.	2028	467.265			327.085	1.635.426
4.	2029	470.706			329.494	1.647.469
5.	2030	474.146			331.903	1.659.513
6.	2031	477.587			334.311	1.671.556
7.	2032	481.028			336.720	1.683.599
8.	2033	484.469			339.128	1.695.642

No.	Year	Population	Waste Generation (kg/person/day)	Waste Generation (L/person/day)	Total Waste (kg/day)	Total Waste (L/day)
9.	2034	487.910			341.537	1.707.685
10.	2035	491.351			343.946	1.719.728
11.	2036	494.792			346.354	1.731.771
12.	2037	498.233			348.763	1.743.814
13.	2038	501.674			351.171	1.755.857
14.	2039	505.114			353.580	1.767.901
15.	2040	508.555			355.989	1.779.944
16.	2041	511.996			358.397	1.791.987
17.	2042	515.437			360.806	1.804.030
18.	2043	518.878			363.215	1.816.073
19.	2044	522.319			365.623	1.828.116
20.	2045	525.760			368.032	1.840.159

The arithmetic method was selected because it produced the lowest deviation from historical population growth data among the three methods evaluated. However, it is acknowledged that this method assumes a constant absolute increment in population per year and may therefore underestimate actual growth rates if urbanisation dynamics accelerate over the projection period. The projected waste generation trajectory underscores the urgency of transitioning to a sanitary landfill system with planned cell-based capacity management: at the current rate of waste receipt (45 tonnes/day), centralised waste management covers only approximately 14% of total waste generated, leaving the vast majority of MSW unmanaged by formal systems a significant environmental and public health concern that must be addressed through parallel improvements in collection coverage and service delivery.

Proposed Optimization Framework

Table 4. Optimization Plan for the Management of Cot Padang Nila Landfill

Aspek	Existing Condition	Optimization Plan
Landfill	Open Dumping	Implementation of sanitary landfill system
Organic waste	Not available	Construction of composting facility
Inorganic waste	Not available	Development of inorganic waste processing facility
Waste segregation	Not available	Establishment of a Material Recovery Facility (MRF)
Collection fleet	Insufficient	Addition of 20–28 collection vehicles
Fleet depot	Not available	Construction of a vehicle depot
Leachate management	Simple leachate pond	Capacity improvement of leachate treatment plant and additional filtration system
Methane gas	Passive venting	Installation of gas ventilation system and methane utilization
Operational roads	Partially damaged	Road reconstruction and widening using concrete pavement

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Sanitary Landfill Cell Zoning and Composite Linear System

To enhance operational efficiency, the 4.9 hectare landfill area is planned to be divided into 4-5 cells, each with an effective area of approximately 1 ha and a depth of 10 m. This division allows each cell to accommodate waste for roughly two years. The effective area calculation is as follows:

$$\text{Lsel} = 49.000 \text{ m}^2 / 5$$
$$= 9.800 \text{ m}^2$$

Each cell is equipped with a clay liner or geomembrane as an impermeable base layer, a leachate collection piping system, gas ventilation, and daily and final cover to control leachate, gas emissions, and environmental impacts.

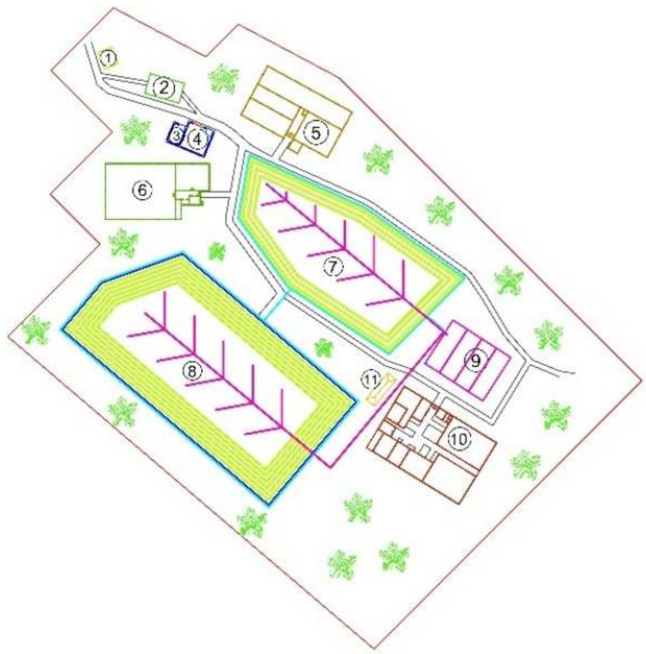

Figure 1. Planning Layout of Cot Padang Nila Landfill

Legend:
1. Guard Post
2. Weighbridge
3. Toilet / WC
4. Office
5. Inorganic Waste Processing Building
6. Compost House
7. Landfill
8. Planned Landfill
9. Leachate Treatment Pond
10. Fleet and Heavy Equipment Pool
11. Methane Gas Processing

Buffer Zone
Leachate Channel
Drainage
Road

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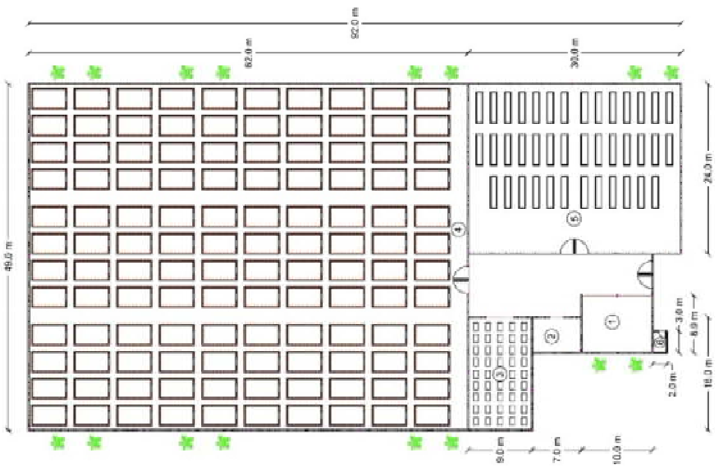
Inorganic Waste Material Recovery Facility (MRF)

The composting facility, with a capacity of approximately 6 tons/day, is designed as a semi-permanent structure with partially open walls. It includes dedicated areas for waste reception, shredding, composting, drying, and compost storage.

Table 5. Technical Specifications of the Organic Waste Composting Facility

Room/Unit	Dimensions (P × L)	Area (m²)	Function
Waste Reception Area	10 m × 8 m	80	Reception and weighing of organic waste
Temporary Storage Area	7 m × 5 m	35	Temporary storage of organic waste
Shredding Area	16 m × 9 m	144	Shredding of organic materials using a mechanical shredder
Composting Area	62 m × 49 m	3.038	Aerobic decomposition process
Sieving and Packaging Room	24 m × 30 m	720	Sieving and packaging of finished compost
Total Area		**4.017 m²**	

The inorganic waste processing facility is designed to handle 65% of the total waste generation (239,220.8 kg/day), primarily consisting of plastic, paper, and metal fractions.



Notes:
Reception Area
Storage Area
Shredding Area
Composting Area
Compost Sieving and Packaging Room
WC/Toilet

Figure 1. Design of the Organic Waste Composting Facility

The facility operates through manual sorting, shredding, packing, and storaging of recyclable materials.

Table 6. Technical Specifications of the Inorganic Waste Processing Facility

Room/Unit	Dimensions (P × L)	Area (m²)	Function
Storage and Collection Room	16 m × 20 m	320	Reception and initial sorting of plastics, metals, and paper
Washing Area	25 m × 10 m	250	Washing of plastic materials prior to shredding
Drying Area	25 m × 8 m	200	Drying of plastic materials before shredding
Shredding Area	49,5 m × 10,5 m	519,75	Processing plastics using a shredding machine
Plastic Waste Processing into Products (Plastic Art)	5,5 m × 5,5 m	30,25	Utilization of recycled plastics to create art or marketable products
Operator and Office Room	4 m × 4 m	16	Administration and activity supervision
Total Building Area		**1.336 m²**	

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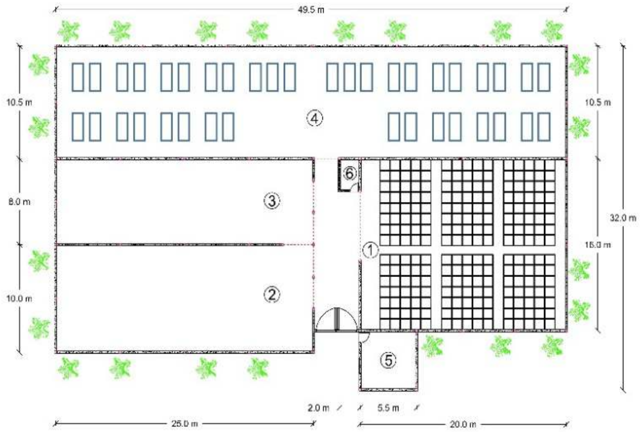

Notes:
1. Waste Reception Area
2. Waste Storage Area
3. Shredding Area
4. Composting Area
5. Compost Sieving and Packaging Room
6. WC/Toilet

Figure 2. Design of the Inorganic Waste Processing Facility

Vehicle and Heavy Equipment Fleet Depot

Supporting operational facilities plays a crucial role in ensuring the effective functioning of landfill waste management systems.

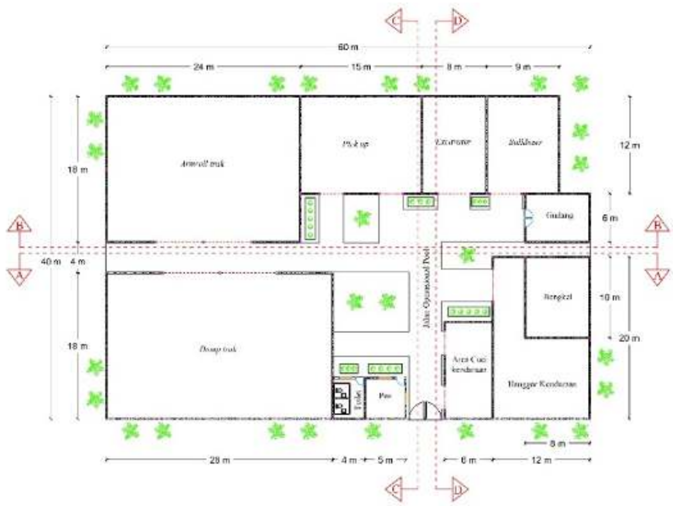

Figure 3. Landfill Fleet and Heavy Equipment Pool Design

One key aspect that requires particular attention is the availability of a vehicle and heavy equipment depot, which serves as a parking area, maintenance facility, and traffic control center for waste collection vehicles and heavy equipment operating within the landfill area.

Table 7. Technical Specifications of the TPA Fleet Pool

Facility	Unit	Dimensions (P × L)	Area (m²)	Description
Dump Truck	18 unit	28 × 18	504	Dump truck parking
Armroll Truck	10 unit	24 × 18	432	Parking *armroll truck*
Pick Up	14 unit	15 × 12	180	Pick up Area parking
Excavator	2 unit	8 × 12	96	*Excavator* Parking
Bulldozer	2 unit	9 × 12	108	*bulldozer* Parking
Circulation Road	-	16 × 12	192	Internal vehicle routes
Vehicle Washing	2 slot	6 × 12	72	Washing of trucks and heavy equipment

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Facility	Unit	Dimensions (P × L)	Area (m²)	Description
Warehouse	1 unit	6 × 8	48	Storage for tools and spare parts
Light Workshop	1 unit	8 × 10	80	Light maintenance and fleet servicing
Hangar	±20 unit	20 × 12	240	Covered area for vehicles
Administration Office	1 unit	5 × 5	25	Control and supervision room
Toilet	1 unit	4 × 5	20	Sanitation facilities for staff
Buffer zone	-	-	223	Open area
Total			**2.220 m²**	

Conclusion

Waste generation in Pidie Regency is projected to increase from approximately 317 tonnes/day in 2024 to 368 tonnes/day by 2045, while the landfill currently receives only approximately 45 tonnes/day, indicating that formal centralized waste management covers less than 15% of total MSW generated. This coverage deficit, along with limited collection fleet capacity, reflects a significant limitation in current waste management service coverage delivery failure that must be addressed concurrently with infrastructure upgrades.

The proposed optimization framework centred on a transition to an engineered, cell-based sanitary landfill system, complemented by an aerobic composting facility, an inorganic waste MRF, a multi-stage leachate treatment plant, landfill gas control system, and an expanded and properly maintained collection fleet, provides an integrated, technically grounded, and standards-compliant pathway to substantially improve landfill performance, environmental protection, and waste management service coverage. The phased, cell-based landfill design offers an implementation approach compatible with the typical capital investment constraints of district-level government agencies in Indonesia.

Several limitations of this study should be acknowledged. First, waste generation projections rely on arithmetic extrapolation of population data with a constant per capita waste generation rate, which may not capture non-linear growth dynamics associated with accelerating urbanisation or changing consumption patterns. Second, the absence of detailed hydrogeological surveys and leachate quality characterisation data in the current study limited quantitative assessment of existing groundwater contamination impacts. Third, a detailed cost-benefit analysis of the proposed optimization measures, which would be essential for informing budget allocation decisions, was beyond the scope of this work.

Further studies and detailed engineering design are required before implementation of hydrogeological and groundwater quality monitoring surveys, leachate characterisation studies, techno-economic feasibility assessments of the proposed facility components, and social impact analyses of increased formal waste management service coverage. The structured gap analysis and optimization design framework presented in this study may be applicable to other district-level landfills across Indonesia that face comparable operational and infrastructure challenges.

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