SUSTAINABLE STRATEGIES IN WASTE MANAGEMENT IN NUNUKAN REGENCY

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Abstract

Waste is one of the environmental issues that continues to pose a significant challenge for various regions in Indonesia, including Nunukan Regency. This regency, located in North Kalimantan Province, has unique geographical and demographic characteristics, with an area of 14,493 km² and a continuously growing population. This creates significant pressure in managing the waste generated from domestic, industrial, and commercial activities. The waste problem not only impacts the environment but also public health and the sustainability of regional development. Therefore, an effective and sustainable waste management system has become an urgent need to be implemented in Nunukan Regency. This research aims to understand the actual conditions of waste management, identify the factors affecting the effectiveness of waste management, and formulate strategies to improve infrastructure and community participation in waste management. The research method used is descriptive qualitative, with primary data obtained through in-depth interviews, observations, and focus group discussions, as well as secondary data from official documents. The research results show that Nunukan Regency still faces various challenges, such as limited infrastructure, low public awareness, and high volumes of plastic waste. To address this, a holistic approach involving the government, the community, and the private sector is needed, as well as the use of environmentally friendly technology and educational programs to raise public awareness. Thus, it is hoped that the waste management system in Nunukan Regency can become more effective and sustainable.

Keywords: Waste management, sustainability, environmentally friendly technology.

INTRODUCTION

Waste is one of the environmental issues that continues to pose a significant challenge for various regions in Indonesia, including Nunukan Regency. As a regency located in North Kalimantan Province, Nunukan has unique geographical and demographic characteristics that influence waste production and management patterns. With an area of 14,493 km² and a continuously growing population, Nunukan Regency faces significant pressure in managing waste generated from domestic, industrial, and commercial activities. The waste problem not only impacts the environment but also public health and the sustainability of regional development. Therefore, an effective and sustainable waste management system is urgently needed in Nunukan Regency.

Waste management encompasses a series of activities, including collection, transportation, processing, and final disposal of waste. According to Law No. 18 of 2008 on Waste Management, waste management must be conducted in an integrated and environmentally sound manner, involving active participation from the government, the community, and the private sector. However, the implementation of the waste management system in Nunukan Regency still faces various obstacles, such as inadequate infrastructure, low public awareness, and limited budget and human resources. This results in a significant amount of waste being improperly managed and ending up in inappropriate places, such as rivers, seas, and open land.

One of the main challenges in waste management in Nunukan Regency is the high volume of waste generated, especially plastic waste. According to data from the Nunukan Regency Environmental Agency, in 2022, the volume of waste generated reached around 150 tons per day, with plastic waste accounting for 20-30% of the total. Plastic waste is difficult to decompose and can have long-lasting negative impacts on the environment, such as soil, water, and air pollution. Additionally, plastic waste can threaten marine ecosystems, given that Nunukan Regency has extensive marine areas that are habitats for various marine species.

To address these issues, a holistic and integrated approach to waste management is needed. One concept that can be adopted is the waste hierarchy, which emphasizes the 3R principles (Reduce, Reuse, Recycle). These principles prioritize waste reduction at the source, reuse of waste that still has economic value, and recycling of waste into new products. Furthermore, waste management must consider technological, social, and economic aspects to ensure the sustainability of the system. The Nunukan Regency Government has made various efforts to improve the effectiveness of the waste management system, such as building a final disposal site (TPA) that meets environmental standards, promoting waste bank programs, and conducting socialization and education for the community. However, these efforts still need to be enhanced and supported by more comprehensive policies and active participation from all stakeholders. Additionally, collaboration between the government, private sector, and community is key to creating a sustainable waste management system.

In a global context, waste management has become a serious issue, especially in efforts to achieve the Sustainable Development Goals (SDGs) set by the United Nations (UN). Goal 12 of the SDGs, "Responsible Consumption and Production," emphasizes the importance of environmentally friendly and sustainable waste management. As part of the global community, Nunukan Regency has a responsibility to contribute to achieving this goal through the implementation of an effective waste management system. According to Herianingrum, Sri (2016), waste management is part of nature conservation and the economy of natural resources. Additionally, waste management has an economic dimension that cannot be ignored. If managed properly, waste can become a resource with economic value. For example, organic waste can be processed into compost or biogas, while inorganic waste such as plastic and metal can be recycled into industrial raw materials. By leveraging the economic potential of waste, Nunukan Regency can not only reduce environmental burdens but also create jobs and increase community income.

According to Indrawanto, Denny (2025), in site planning for industrial and commercial areas, sanitation planning (waste management in households or industries) must be prioritized. However, to realize an effective and sustainable waste management system, support from various parties, including the central government, local government, private sector, and community, is needed. The central government can provide support through supportive policies and regulations, as well as adequate budget allocation. The local government, in this case, the Nunukan Regency Government, needs to improve its capacity and capability in waste management, including through infrastructure and human resource development. The private sector can contribute through investment in environmentally friendly waste management technology, while the community needs to be encouraged to actively participate in waste reduction and management efforts.

In a local context, culture and local wisdom can also be utilized to support the waste management system. For example, indigenous communities in Nunukan Regency have traditions and local knowledge in managing natural resources sustainably, which can be integrated into modern waste management systems. By combining modern and traditional approaches, it is hoped that a more effective and locally appropriate waste management system can be created. Furthermore, environmental education and awareness also play a crucial role in supporting the waste management system. Through integrated environmental education programs in school curricula, the younger generation can be equipped with the knowledge and skills to manage waste responsibly. Continuous environmental awareness campaigns are also needed to change community behavior in producing and managing waste.

Problem Formulation

The waste management system in Nunukan Regency faces various complex challenges, both from technical, social, economic, and environmental aspects. Although the local government has made various efforts to improve the effectiveness of waste management, waste remains a critical issue that requires serious attention. Based on the background described, several problem formulations that can be identified in the waste management system in Nunukan Regency are as follows:

1. Limited Waste Management Infrastructure: Nunukan Regency still faces limitations in waste management infrastructure, such as temporary waste disposal sites (TPS), final disposal sites (TPA), and waste transportation fleets. According to data from the Nunukan Regency Environmental Agency (2022), only about 60% of the regency has access to regular waste collection services. This results in a significant amount of waste not being collected and ending up in open environments, rivers, or the sea. The question that arises is: How to improve the availability and quality of waste management infrastructure in Nunukan Regency.

2. Low Community Awareness in Waste Management: Community awareness about the importance of waste management is still low, leading many residents to dispose of waste carelessly or fail to segregate waste by type. According to research by the Ministry of Environment and Forestry (2020), community participation in

waste management programs is still suboptimal. The question that arises is: How to increase community awareness and participation in waste management in Nunukan Regency.

3. High Volume of Plastic Waste: Plastic waste is one of the main issues in waste management in Nunukan Regency. Data from the Nunukan Regency Environmental Agency (2022) shows that plastic waste accounts for 20-30% of the total waste generated. Plastic waste is difficult to decompose and can have long-lasting negative impacts on the environment. The question that arises is: How to reduce the volume of plastic waste and improve its management in Nunukan Regency.

4. Limited Waste Processing Technology: The waste processing technology used in Nunukan Regency is still limited to conventional methods, such as open burning and composting. These methods have negative environmental impacts, such as greenhouse gas emissions and air pollution. The question that arises is: How to adopt more environmentally friendly and efficient waste processing technology in Nunukan Regency.

5. Challenges in Waste Management in Island Areas: Nunukan Regency has island areas that require a specific approach to waste management. The main challenge in island areas is limited transportation access and infrastructure. The question that arises is: How to design an effective and sustainable waste management system for island areas in Nunukan Regency.

6. Limited Budget and Human Resources: Waste management requires adequate budget and human resources. However, Nunukan Regency still faces limitations in this regard, hindering the implementation of waste management programs. The question that arises is: How to optimize budget allocation and improve human resource capacity in waste management in Nunukan Regency.

7. Environmental and Health Impacts of Suboptimal Waste Management: Suboptimal waste management can have negative impacts on the environment and public health, such as soil, water, and air pollution, as well as the spread of diseases. The question that arises is: How to reduce the environmental and health impacts of suboptimal waste management in Nunukan Regency.

8. Lack of Collaboration Among Stakeholders: Waste management requires collaboration between the government, private sector, and community. However, this collaboration is still suboptimal in Nunukan Regency. The question that arises is: How to improve collaboration among stakeholders in waste management in Nunukan Regency.

9. Utilization of Economic Potential from Waste: If managed properly, waste can become a resource with economic value. However, this potential has not been optimally utilized in Nunukan Regency. The question that arises is: How to utilize the economic potential of waste to support sustainable development in Nunukan Regency.

10. Alignment of Waste Management Policies and Regulations: Waste management policies and regulations need to be aligned with local conditions and current developments. However, the implementation of these policies and regulations still faces various obstacles. The question that arises is: How to improve the alignment and effectiveness of waste management policies and regulations in Nunukan Regency.

Research Objectives

The research on the waste management system in Nunukan Regency aims to achieve several practical and academic objectives. These objectives are formulated to address the identified problems and provide tangible contributions to improving the effectiveness and sustainability of the waste management system in the region. The research objectives are as follows:

1. To understand the actual conditions of waste management in Nunukan Regency.
2. To identify the factors affecting the effectiveness of waste management.
3. To formulate strategies to improve waste management infrastructure.
4. To reduce the volume of plastic waste through recycling and plastic reduction programs.
5. To increase community participation in waste management.
6. To adopt environmentally friendly waste processing technology.
7. To improve environmental and public health awareness.
8. To encourage collaboration among stakeholders.
9. To provide academic and practical contributions.

METHOD

This research uses a descriptive qualitative research method. The qualitative approach is used to understand the perceptions, attitudes, and behaviors of the community and stakeholders regarding waste management. This qualitative approach is expected to provide a holistic picture of the waste management system in Nunukan Regency.

The data sources in this research consist of:

- Primary Data: Data obtained through in-depth interviews, observations, and focus group discussions (FGD) with various stakeholders, such as government officials, community leaders, business actors, and community members.
- Secondary Data: Data obtained from official documents, such as annual reports from the Nunukan Regency Environmental Agency, local regulations, and publications related to waste management.

Data collection techniques used include:

- In-Depth Interviews: Interviews conducted with government officials, community leaders, and business actors to gather information on policies, programs, and challenges in waste management. Interview questions were prepared based on a pre-designed interview guide.
- Observation: Observations conducted at waste management locations, such as final disposal sites (TPA), waste banks, and illegal waste disposal sites, to observe the actual conditions of waste management.

Table 1 Current Population and Head of Household Numbers and Projections for 5 Years in Nunukan Regency

NO	District Name	Number of Urban Villages/Villages (according to RTRW)	2024 Soul	2024 Head of the Family	2025 Soul	2025 Head of the Family	2026 Soul	2026 Head of the Family	2027 Soul	2027 Head of the Family	2028 Soul	2028 Head of the Family	2029 Soul	2029 Head of the Family
1	SEBATIK	4	7.364	29.456	8.375	33.408	9.524	38.006	10.831	43.324	12.317	49.240	14.008	56.031
2	NUNUKAN	5	72.925	291.700	85.510	342.039	100.266	401.066	117.570	470.279	137.859	551.486	161.650	646.599
3	SEMBAKUNG	10	6.798	27.192	7.428	29.711	8.116	32.464	8.868	35.471	9.689	38.757	10.587	42.348
4	LUMBIS	28	6.735	26.940	7.175	28.700	7.644	30.576	8.143	32.574	8.676	34.703	9.243	36.970
5	KRAYAN	23	3.547	14.188	3.640	14.562	3.736	14.945	3.885	15.389	3.936	15.748	4.089	16.158
6	SEBUKU	10	12.071	48.284	15.029	60.117	18.713	74.851	23.299	93.196	29.009	116.086	36.129	144.474
7	KRAYAN SELATAN	13	1.452	5.808	1.484	5.936	1.517	6.067	1.560	6.201	1.584	6.337	1.619	6.477
8	SEBATIK BARAT	4	12.888	51.552	15.920	63.681	19.666	78.664	24.293	97.173	30.009	120.086	37.070	148.278
9	NUNUKAN SELATAN	4	25.547	102.188	31.238	124.950	38.196	152.782	46.704	186.814	57.107	228.426	69.827	279.308
10	SEBATIK TIMUR	4	15.030	60.120	16.429	65.716	17.958	71.833	19.630	78.519	21.457	85.828	23.454	93.817
11	SEBATIK UTARA	3	8.278	33.112	8.978	35.913	9.738	38.951	10.561	42.245	11.455	45.819	12.424	49.695
12	SEBATIK TENGAH	4	8.988	35.952	10.209	40.837	11.596	46.385	13.172	52.688	14.962	59.847	16.995	67.978
13	SEI MANGGARIS	4	10.795	43.180	12.365	49.461	14.164	56.655	16.224	64.805	18.584	74.335	21.287	85.147
14	TULIN ONSOI	12	11.262	45.048	15.096	60.384	20.235	80.942	27.124	108.498	36.359	145.485	48.737	194.947
15	LUMBIS OGONG	26	2.989	11.956	3.541	14.163	4.194	16.777	4.969	19.874	5.886	23.548	6.972	27.889
16	SEBAKUNG ATULAI	10	3.281	13.124	3.989	15.955	4.849	19.396	5.895	23.579	7.166	28.664	8.712	34.846
17	KRAYAN TIMUR	17	1.558	6.232	1.613	6.451	1.669	6.677	1.728	6.912	1.789	7.154	1.851	7.405
18	KRAYAN BARAT	25	3.028	12.112	3.270	13.079	3.531	14.123	3.813	15.250	4.117	16.468	4.446	17.782
19	KRAYAN TENGAH	11	1.063	4.252	1.106	4.426	1.152	4.607	1.199	4.796	1.248	4.992	1.299	5.196
20	LUMBIS PANSIANGAN	13	1.514	6.056	3.553	14.213	8.339	33.356	19.571	78.284	45.932	183.727	107.798	431.190
21	LUMBIS HULU	10	810	3.240	1.870	7.480	4.318	17.270	9.968	39.872	23.013	92.054	53.132	212.528
	Amount	240	217.923	871.692	257.818	1.081.275	309.121	1.236.488	378.946	1.515.782	482.152	1.928.608	651.266	2.605.062

Source: Analyze, 2025

Table 2 Current Population Growth Rate and Density and Projections for 5 Years in Nunukan Regency

NO	District Name	Number of Urban Villages/Villages (according to RTRW)	2024 Soul	2024 Head of the Family	2025 Soul	2025 Head of the Family	2026 Soul	2026 Head of the Family	2027 Soul	2027 Head of the Family	2028 Soul	2028 Head of the Family	2029 Soul	2029 Head of the Family
1	SEBATIK	4	7.364	29.456	7.617	29.456	7.879	31.516	8.150	32.600	8.430	33.720	8.720	34.879
2	NUNUKAN	5	72.925	291.700	101.904	291.700	13.274	53.097	198.985	795.942	278.058	1.112.234	388.554	1.554.215
3	SEMBAKUNG	10	6.798	27.192	7.013	27.192	7.236	28.943	7.465	29.860	7.702	30.806	7.946	31.783
4	LUMBIS	28	6.735	26.940	6.946	26.940	7.164	28.657	7.389	29.557	7.621	30.484	7.860	31.441
5	KRAYAN	23	3.547	14.188	3.605	14.188	14.658	58.633	3.725	14.899	3.786	15.144	3.848	15.393
6	SEBUKU	10	12.071	48.284	12.739	48.284	13.485	53.942	14.254	57.014	15.065	60.262	15.924	63.695
7	KRAYAN SELATAN	13	1.452	5.808	1.462	5.808	1.472	5.886	1.481	5.926	1.491	5.966	1.501	6.006
8	SEBATIK BARAT	4	12.888	51.552	13.673	51.552	14.505	58.020	15.388	61.553	16.325	65.300	17.319	69.275
9	NUNUKAN SELATAN	4	25.547	102.188	28.734	102.188	32.295	129.181	36.311	145.344	24.019	96.076	45.903	183.610
10	SEBATIK TIMUR	4	15.030	60.120	16.104	60.120	17.254	69.016	18.487	73.947	19.807	79.229	21.222	84.889
11	SEBATIK UTARA	3	8.278	33.112	8.599	33.112	8.932	35.727	9.278	37.110	9.637	38.548	10.010	40.041
12	SEBATIK TENGAH	4	8.988	35.952	9.444	35.952	9.923	39.693	10.427	41.708	10.956	43.824	11.512	46.048
13	SEI MANGGARIS	4	10.795	43.180	11.343	43.180	11.918	47.674	12.523	50.093	13.159	52.635	13.826	55.306
14	TULIN ONSOI	12	11.262	45.048	11.860	45.048	12.489	49.955	13.151	52.606	13.849	55.397	14.584	58.337
15	LUMBIS OGONG	26	2.989	11.956	3.030	11.956	3.072	12.288	3.114	12.458	3.157	12.629	12.804	51.215
16	SEBAKUNG ATULAI	10	3.281	13.124	3.331	13.124	3.382	13.526	3.483	13.732	3.485	13.941	3.538	14.153
17	KRAYAN TIMUR	17	1.558	6.232	1.569	6.232	1.580	6.321	1.392	6.366	1.603	6.412	1.614	6.457
18	KRAYAN BARAT	25	3.028	12.112	3.070	12.112	3.113	12.453	3.157	12.628	3.201	12.805	3.246	12.984
19	KRAYAN TENGAH	11	1.063	4.252	1.068	4.252	1.073	4.294	1.079	4.315	1.084	4.336	1.089	4.357
20	LUMBIS PANSIANGAN	13	1.514	6.056	1.524	6.056	1.535	6.140	1.546	6.183	1.556	6.225	1.567	6.269
21	LUMBIS HULU	10	810	3.240	813	3.240	816	3.264	819	3.276	822	3.288	825	3.300
	Amount	340	217.923	871.692	255.458	871.692	187.057	748.227	371.754	1.487.014	444.816	1.779.262	593.413	2.373.652

Source: Analyze, 2025

Table 3 Table of Names and Area per Subdistrict and Number of Villages

NO	District Name	Area Size (Ha)	Built-up Area (Ha)	Population density in built-up areas (people/Ha)
1	Kecamatan SEBATIK	510.700	8.198	3,32
2	Kecamatan NUNUKAN	5.645.000	12.193	30,045
3	Kecamatan SEMBAKUNG	17.649.400	350	200,586
4	Kecamatan LUMBIS	2.902.300	1.707	110,394
5	Kecamatan KRAYAN	2.543.500	336	286,269
6	Kecamatan SEBUKU	16.084.800	350	151,956
7	Kecamatan KRAYAN SELATAN	7.602.400	112	240,362
8	Kecamatan SEBATIK BARAT	932.700	5.355	5,996
9	Kecamatan NUNUKAN SELATAN	1.817.700	13.521	7,427
10	Kecamatan SEBATIK TIMUR	391.700	12.718	4,815
11	Kecamatan SEBATIK UTARA	153.900	6.419	3,652
12	Kecamatan SEBATIK TENGAH	477.100	12.614	2,669
13	Kecamatan SEI MANGGARIS	8.504.800	1.191	35,976
14	Kecamatan TULIN ONSOI	15.133.600	578	235,732
15	Kecamatan LUBIS OGONG	16.286.600	72	1.161,10
16	Kecamatan SEBAKUNG ATULAI	2.777.200	951	32,819
17	Kecamatan KERAYAN TIMUR	12.731.700	93	301,104
18	Kecamatan KERAYAN BARAT	3.072.200	131	612,164
19	Kecamatan KERAYAN TENGAH	9.974.200	51	304,033
20	Kecamatan LUMBIS PANSIANGAN	7.639.300	50	397,967
21	Kecamatan LUMBIS HULU	9.644.200	37	231,600
	Amount	142.475.000,0		

Source: Analyze, 2025

Table 4 Achievements in Waste Reduction and Management Year 2024 - Nunukan Regency

Indicator	Jakstaranas	2024 targets (Reference)		Short-Term Goals
		North Kalimantan Province	Nunukan Regency	
Urban Waste Management	70 %	83 %	72 %	70 %
Urban Waste Reduction	30 %	17 %	30 %	28 %

Source: DLH, 2025

Table 5. Urban Waste Management Targets Nunukan Regency

| No.	Indikator	Targets		Achievement	
		Ton/ Year	(%)	Ton/ Year	(%)
1	Waste Generation	15.966,42	-	15.966,42	-
2	Reduction	4.310,93	27	4.308,44	26,98
3	Handling	11.655,49	73	8.126,18	50,90

Source: Analyze, 2024

Table 6. Gap Analysis Against the Target

No	Component	Targets RPJMN 2025-2029 (%)	Targets - 2029 (%)		Short-Term Goals	Achievement (%) Year 2024	GAP (%) Against Target 2029	GAP (%) Against Short-Term Targets
			North Kalimantan Province	Nunukan Regency	Nunukan Regency			
1	Urban Waste Management	70 %	83 %	72 %	70 %	22,24 %	49,8 %	47,8 %
2	Urban Waste Reduction	30 %	17 %	30 %	28 %	0,01 %	30 %	28 %

Source: Analyze, 2024

Figure 1. Waste Management Service Chain
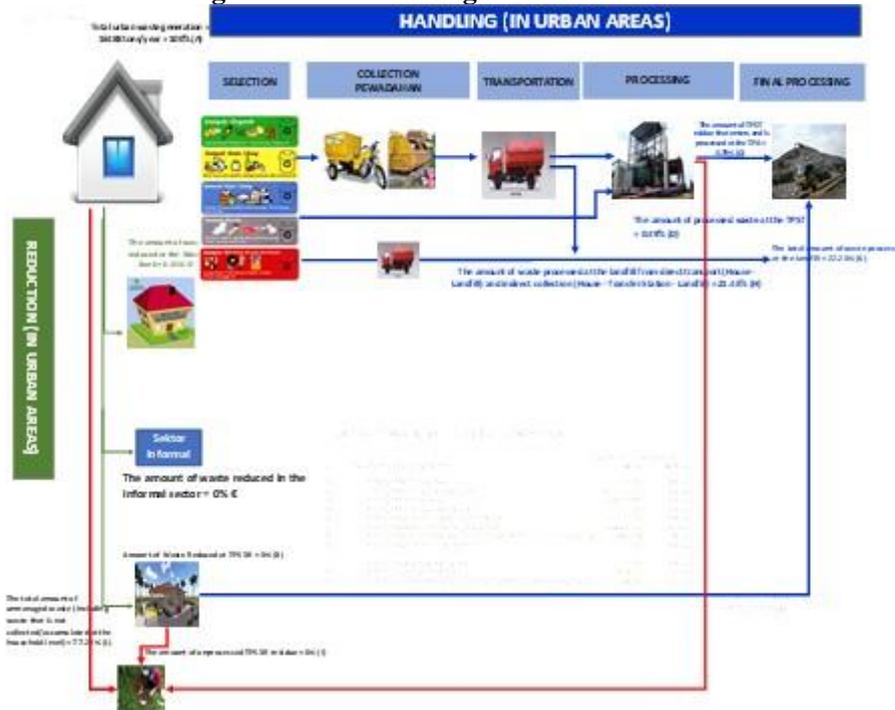
RESULTS AND DISCUSSION
Technical Aspects

In Nunukan Regency, technical aspects include various elements, from waste collection, transportation, processing, to final disposal. With unique geographical characteristics, including island and mainland areas, Nunukan Regency faces significant technical challenges in managing waste effectively. Therefore, a deep understanding of these technical aspects is crucial for designing an efficient, environmentally friendly, and sustainable waste management system.

Figure 2 Waste management and collection and recycling system
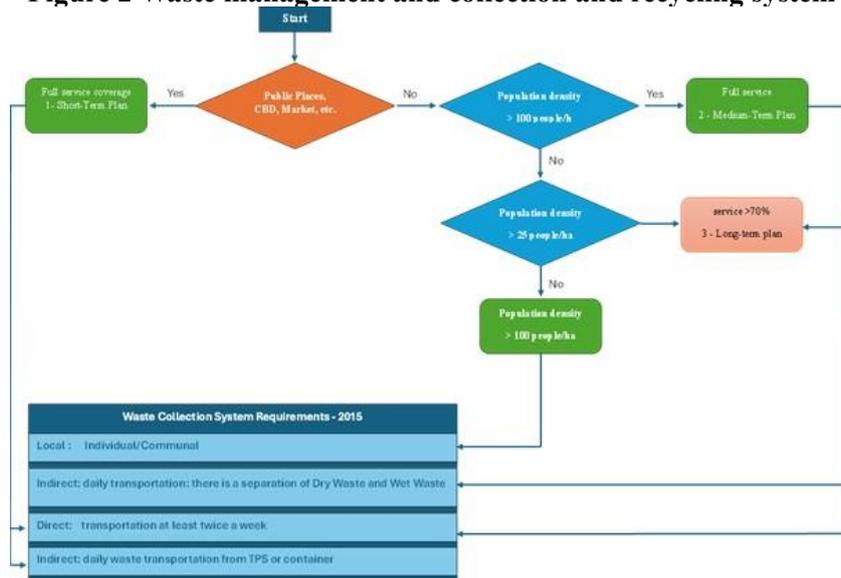
1) Waste Management Infrastructure:

Waste collection infrastructure is the first stage in the waste management system. In Nunukan Regency, waste collection is carried out through several methods, including the use of segregated waste bins, waste carts, and waste collection trucks. However, the availability of waste collection infrastructure is still limited, especially in remote areas and densely populated settlements. According to data from the Nunukan Regency Environmental Agency (2022), only about 60% of the regency has access to regular waste collection services. This results in a significant amount of waste not being collected and ending up in open environments, rivers, or the sea. To improve the effectiveness of waste collection, an increase in the number of segregated waste bins in strategic locations, such as markets, schools, and public areas, is needed. Additionally, community-based waste collection systems, such as waste banks, need to be expanded to encourage active community participation. According to research by the Ministry of Environment and Forestry (2020), the waste bank system has proven effective in reducing the volume of waste sent to TPAs while increasing community income.

Table 8. Condition of the Waste Collection Fleet

Type of vehicle	Amount (Unit)	Capacity (m3 /Unit)	Condition
Dump Truck Medium	15	7,5	3 severely damaged, 3 damaged
Truck Arm roll Large	7	6	3 severely damaged

Source: DLH & Analysis Results, 2025

Table 9. Condition of 3R TPS Nunukan Regency

No.	Name of TPS3R	Year built	Location
1	TPS 3R Tanjung Harapan	2014	Jl. Yos Sudarso Kelurahan Tanjung Harapan, Kec. Nunukan Selatan
2	TPS 3R Sei Bilal		Jl. Sei Bilal, Kel. Nunukan Barat, Kec. Nunukan
3	TPST 3R Sungai Batang		
4	TPS 3R Bina Mandiri	2016	JL. Pasar Baru RT.05 (Pasar Induk), Kec. Nunukan, Kel. Nunukan Timur, Kab. Nunukan
5	TPS 3R pancang Bersatu	2016	RT.10 Desa Sei Pancang Kec. Sebatik Utara, Kab. Nunukan
6	TPS 3R Desa Long Layu		di Desa Long Layu Kec. Krayan Selatan Provinsi Kalimantan Utara
7	TPST 3R	2018	Desa Long Layu Kec. Krayan Selatan Kab. Nunukan
8	TPS 3R	2021	Jl limau RT.02 dan 03, Kec. Nunukan, Kel. Nunukan Selatan, Kab. Nunukan

Source: DLH & Analysis Results, 2025

2) Waste Management Technology:

Waste management technology has become one of the critical aspects in global efforts to create a cleaner, healthier, and more sustainable environment. With rapid population growth, urbanization, and increased consumption, the volume of waste generated by humans has reached alarming levels. According to data from the World Bank (2018), in 2016, the world generated around 2.01 billion tons of solid waste, and this number is projected to increase to 3.40 billion tons by 2050 if no significant interventions are made. Waste that is not managed properly can cause various environmental problems, such as water, air, and soil pollution, and contribute to climate change through greenhouse gas emissions. Therefore, the development and application of innovative and sustainable waste management technologies are crucial to reducing the negative impacts of waste on the environment and human health.

According to Indrawanto, Denny (2025), integrating sustainable architecture principles can significantly reduce the carbon footprint of vertical buildings by up to 30% through optimized energy consumption and waste management. Waste management technology encompasses a range of methods and processes designed to collect, process, recycle, and dispose of waste in an environmentally friendly manner. The main goal of this technology is to reduce the volume of waste sent to final disposal sites (TPA), maximize recycling and reuse of materials, and minimize the negative impacts of waste on the environment. In recent decades, various waste management technologies have been developed and implemented worldwide, from traditional methods such as composting and recycling to advanced technologies like waste-to-energy (WTE) and bioreactors. However, the effectiveness of these technologies depends heavily on factors such as infrastructure, resources, and community participation.

One of the most commonly used waste management technologies is recycling. Recycling involves the process of converting waste into new raw materials that can be used to produce other goods. This process not only reduces the volume of waste sent to TPAs but also saves natural resources and energy required to produce new materials. For example, recycling paper can reduce tree cutting, while recycling plastic can reduce the use of fossil fuels as raw materials for new plastic. According to the Environmental Protection Agency (EPA, 2021), recycling one ton of paper can save around 17 trees and 7,000 gallons of water. However, despite its many benefits, recycling also faces various challenges, such as high costs, the need for advanced technology, and a lack of community awareness about the importance of waste segregation. In addition to recycling, composting is also a popular waste management technology, especially for organic waste. Composting is a natural process in which microorganisms decompose organic materials, such as food scraps and leaves, into nutrient-rich compost that can be used as natural

fertilizer. This technology not only reduces the volume of waste sent to TPAs but also produces a beneficial product for agriculture and gardening. According to the United Nations Environment Programme (UNEP, 2020), composting can reduce greenhouse gas emissions by up to 30% by preventing the anaerobic decomposition of organic waste in TPAs, which produces methane gas. However, composting also has limitations, such as the need for sufficient land and a long time for the decomposition process. In addition to traditional methods like recycling and composting, more advanced waste management technologies have been developed to address increasingly complex waste problems. One of these is waste-to-energy (WTE) technology, which converts waste into electrical or thermal energy through combustion, gasification, or pyrolysis. This technology not only reduces the volume of waste sent to TPAs but also generates renewable energy that can be used to meet community electricity needs. According to the International Solid Waste Association (ISWA, 2017), WTE technology has successfully reduced waste volume in TPAs by up to 90% in some European and Asian countries. However, this technology also faces challenges, such as high investment costs and the potential for pollutant emissions if not managed properly.

In addition to WTE, bioreactor technology has also been developed to improve the efficiency of waste management in TPAs. Bioreactors are waste management systems that use microorganisms to accelerate the decomposition of organic waste and produce methane gas, which can be captured and used as an energy source. This technology not only reduces the volume of waste sent to TPAs but also generates renewable energy and reduces greenhouse gas emissions. According to research by Reinhart et al. (2002), bioreactors can reduce the decomposition time of organic waste from 30-50 years to just 5-10 years, thereby increasing TPA capacity and reducing environmental impacts. However, this technology also requires significant investment and careful management to ensure its success.

In addition to waste processing technology, waste collection and segregation systems are also crucial components of effective waste management. Technologies such as automated waste collection systems and smartphone applications for reporting waste issues have been developed to improve efficiency and community participation in waste management. For example, in some European cities, underground waste collection systems have been implemented to reduce odors and improve environmental cleanliness. Additionally, applications like TrashOut and Litterati allow communities to report illegal waste and contribute to mapping waste issues in their areas. According to research by Guerrero et al. (2013), community participation in waste management can improve waste collection system efficiency by up to 40% and significantly reduce waste management costs.

Despite the development of various waste management technologies, challenges in their implementation remain significant, especially in developing countries. One of the main challenges is the lack of adequate infrastructure and resources to adopt advanced technologies. In many developing countries, waste management systems still rely on traditional methods such as open dumping and waste burning, which cause various environmental and health problems. Additionally, a lack of community awareness about the importance of responsible waste management also hinders the implementation of waste management technologies. According to research by Wilson et al. (2015), community participation in waste segregation can increase recycling rates by up to 50% and significantly reduce waste management costs.

In addition to technical and social challenges, the development of waste management technology also faces regulatory and policy challenges. In many countries, regulations on waste management are still weak or not well enforced, leading to environmentally unfriendly practices. For example, illegal waste dumping and TPA operations that do not meet standards are still common in various regions. Therefore, a strong regulatory framework and consistent law enforcement are needed to ensure that waste management technologies are applied responsibly. Additionally, policies that encourage waste reduction at the source, such as bans on single-use plastics and incentives for recycling, can help reduce pressure on waste management systems. According to the European Environment Agency (EEA, 2019), waste reduction policies can reduce the volume of waste sent to TPAs by up to 30% and improve overall waste management efficiency.

Amid these challenges, there are several innovations and solutions that can be applied to improve waste management. One of them is the implementation of a circular economy approach, which aims to minimize waste and maximize resource use by promoting recycling, reuse, and waste reduction at the source. In the context of waste management, this approach can be implemented by improving waste segregation at the source, developing recycling facilities, and utilizing organic waste for compost or biogas production. According to the Ellen MacArthur Foundation (2019), applying the circular economy to waste management can reduce the volume of waste sent to TPAs by up to 50% and create new economic opportunities. Additionally, partnerships between the government, private sector, and community also play a crucial role in improving waste management. The government can provide a regulatory framework and incentives to support waste management, while the private

sector can develop innovative technologies and invest in waste management infrastructure. The community, as consumers, can also contribute by adopting more environmentally friendly lifestyles, such as reducing the consumption of single-use items, segregating waste, and participating in recycling programs. According to the World Business Council for Sustainable Development (WBCSD, 2020), partnerships between the private sector and government can improve the efficiency and sustainability of waste management systems. Overall, waste management technology plays a crucial role in global efforts to reduce the negative impacts of waste on the environment and human health. By implementing innovative technologies, increasing community participation, and strengthening regulatory frameworks, we can create a more efficient, environmentally friendly, and sustainable waste management system. Additionally, a circular economy-based approach can help reduce reliance on TPAs and create a more sustainable waste management system for the future. Waste processing is a crucial stage in reducing the volume of waste sent to TPAs. In Nunukan Regency, waste processing is still limited to conventional methods, such as open burning and composting. However, these methods have negative environmental impacts, such as greenhouse gas emissions and air pollution. Therefore, the adoption of more environmentally friendly waste processing technologies, such as waste-to-energy (WTE) and recycling, is needed.

Waste-to-energy technology can convert waste into electrical or thermal energy through controlled combustion or gasification. According to research by the European Environment Agency (2019), WTE technology has proven effective in reducing waste volume by up to 90% while generating energy that can be utilized by the community. Additionally, recycling programs need to be expanded to process inorganic waste, such as plastic, paper, and metal, into new products with economic value. The use of technology in waste management in Nunukan Regency is still very limited. Simple technologies, such as manual composting, are used by some communities to process organic waste. However, modern technologies like biodigesters, environmentally friendly incinerators, or recycling facilities have not been widely implemented.

- **Composting:** Organic waste composting is carried out by a small portion of the community and local groups. Large-scale composting technology has not been implemented due to a lack of facilities and training.
- **Recycling:** Efforts to recycle plastic and paper waste are still sporadic, mainly carried out by scavengers and small businesses. An integrated recycling system is not yet available at the regency level.

3) Waste Transportation System

The waste transportation system is one of the key components of effective and sustainable waste management. Waste transportation involves a series of processes, from collecting waste from its source, transferring it to temporary storage sites, to transporting it to final disposal sites (TPA) or waste processing facilities. This system plays a crucial role in maintaining environmental cleanliness, preventing the spread of diseases, and reducing the negative impacts of waste on ecosystems. However, managing the waste transportation system often faces various challenges, such as a lack of infrastructure, high operational costs, and low community participation. Therefore, understanding the basic principles of the waste transportation system and identifying innovative solutions to address these challenges is essential. Rapid population growth and urbanization have led to a significant increase in waste volume in various regions, especially in large cities. According to data from the World Bank (2018), in 2016, the world generated around 2.01 billion tons of solid waste, and this number is projected to increase to 3.40 billion tons by 2050 if no significant interventions are made. This increase in waste volume puts significant pressure on existing waste transportation systems, especially in developing countries where infrastructure and resources are often limited. For example, in many cities in Asia and Africa, inadequate waste transportation systems have led to waste piling up in streets, rivers, and residential areas, ultimately causing serious health and environmental problems.

An effective waste transportation system begins with waste collection from its source, such as households, industries, and commercial areas. This process requires active community participation in segregating waste by type, such as organic, inorganic, and hazardous materials. Waste segregation at the source not only facilitates the transportation process but also improves the efficiency of recycling and waste processing. However, in many areas, community awareness about the importance of waste segregation is still low, leading to mixed waste that is difficult to process. According to research by Wilson et al. (2015), community participation in waste segregation can increase recycling rates by up to 50% and significantly reduce waste management costs. After waste is collected, the next step is to transfer it to temporary storage sites, such as temporary waste disposal sites (TPS) or waste containers. TPS serves as a transit point where waste from various sources is collected before being transported to TPAs or processing facilities. The design and location of TPS must be carefully planned to ensure accessibility and efficiency in waste transportation. However, in many cities, TPS is often inadequate or poorly managed,

leading to waste accumulation and unpleasant odors. According to the United Nations Environment Programme (UNEP, 2020), poor TPS management can become a source of air, water, and soil pollution, as well as increase the risk of disease spread. Transporting waste from TPS to TPAs or processing facilities is the most costly stage in the waste transportation system. This process involves the use of waste transportation vehicles, such as waste trucks, which require fuel, maintenance, and labor. In many developing countries, waste transportation fleets are often inadequate or outdated, leading to delays in waste transportation and increased operational costs. Additionally, long distances between TPS and TPAs can increase transportation costs and greenhouse gas emissions. According to research by Kaza et al. (2018), waste transportation accounts for about 5-10% of the total waste management costs in large cities, and emissions from waste transportation vehicles can contribute to global warming.

In addition to technical and financial challenges, the waste transportation system also faces social and cultural challenges. In many communities, especially in rural areas, there are still habits of littering or burning waste, which can pollute the environment and endanger health. Additionally, the social stigma against waste workers is also a problem that needs to be addressed. Waste workers are often considered to have low-status jobs, making it difficult to attract qualified labor. However, waste workers play a crucial role in maintaining environmental cleanliness and public health. According to the International Labour Organization (ILO, 2019), waste workers often work in unsafe and unhealthy conditions, so they need adequate protection and incentives. To address these challenges, a holistic and integrated approach to the waste transportation system is needed. One solution that can be considered is the application of technology in the waste transportation system. For example, the use of GPS systems to monitor waste transportation routes can improve efficiency and reduce operational costs. Additionally, the development of environmentally friendly waste transportation vehicles, such as electric or gas-powered trucks, can reduce greenhouse gas emissions and negative environmental impacts. According to the Environmental Protection Agency (EPA, 2021), the use of environmentally friendly vehicles in waste transportation can reduce carbon emissions by up to 30% and improve air quality in urban areas.

In addition to technology, community participation also plays a key role in the success of the waste transportation system. Education and awareness campaigns about the importance of responsible waste management can encourage communities to be more active in segregating and reducing waste. Additionally, economic incentives, such as lower waste transportation fees for households that segregate waste, can also increase community participation. According to research by Guerrero et al. (2013), community participation in waste management can improve waste transportation system efficiency by up to 40% and significantly reduce waste management costs. The government also plays a crucial role in supporting an effective waste transportation system. Clear policies and regulations on waste management, such as bans on littering and mandatory waste segregation, can help create a cleaner and healthier environment. Additionally, investment in waste transportation infrastructure, such as the construction of modern TPS and the procurement of adequate waste transportation fleets, is also needed to improve the capacity and efficiency of the waste transportation system. According to the United Nations Development Programme (UNDP, 2017), investment in waste management infrastructure can yield significant economic and environmental benefits, such as job creation and pollution reduction.

On the other hand, the private sector can also contribute to improving the waste transportation system through partnerships with the government and community. For example, private companies can develop innovative technologies for waste transportation, such as automated waste collection systems or smartphone applications for reporting waste issues. Additionally, companies can participate in corporate social responsibility (CSR) programs focused on waste management and environmental conservation. According to the World Business Council for Sustainable Development (WBCSD, 2020), partnerships between the private sector and government can improve the efficiency and sustainability of the waste transportation system.Overall, the waste transportation system is a crucial component of effective and sustainable waste management. By improving the efficiency and capacity of the waste transportation system, we can reduce the negative impacts of waste on the environment and public health. However, the success of the waste transportation system requires commitment and collaboration from all parties, including the government, private sector, and community. Only by working together can we create a more efficient, environmentally friendly, and sustainable waste transportation system for a cleaner and healthier future. Transporting waste from its source to processing or final disposal sites is a critical stage in the waste management system. In Nunukan Regency, waste transportation is carried out using waste trucks operated by the local government and private partners. However, the capacity of the waste truck fleet is still limited, leading to waste accumulation at collection points. Additionally, poor road conditions in some areas also hinder the waste transportation process.

To address this issue, an increase in the waste truck fleet and road infrastructure improvements are needed. Additionally, more efficient waste transportation technologies, such as compactor trucks, can be adopted to increase transportation capacity. According to a study by the World Bank (2018), the use of modern technology in waste transportation can reduce operational costs and improve the effectiveness of the waste management system. The process of transporting waste from TPS to TPAs in Nunukan still faces various obstacles, such as:

- Limited Fleet: The number of waste transportation vehicles owned by the local government is insufficient to serve the entire regency, especially in remote areas.
- Irregular Transportation Frequency: Waste transportation is often not carried out regularly, leading to waste accumulation at TPS.
- Operational Efficiency: The transportation system does not yet use optimal routes, resulting in high time and operational costs.

4) Final Disposal Sites (TPA)

Final Disposal Sites (TPA) are one of the crucial components of a responsible and sustainable waste management system. TPAs serve as the final location where waste that cannot be recycled or further processed is disposed of and managed in a way that is safe for the environment and human health. Although TPAs are often considered the last resort in the waste hierarchy, their role remains critical in handling the increasing volume of waste, especially in densely populated urban areas. However, improper TPA management can lead to various environmental problems, such as groundwater pollution, greenhouse gas emissions, and the spread of diseases. Therefore, understanding the principles of good TPA management and identifying challenges and solutions in its operation is essential.

Rapid population growth and urbanization have led to a significant increase in waste volume in various regions worldwide. According to data from the World Bank (2018), in 2016, the world generated around 2.01 billion tons of solid waste, and this number is projected to increase to 3.40 billion tons by 2050 if no significant interventions are made. Most of this waste ends up in TPAs, especially in developing countries where recycling and waste processing systems are still limited. In Indonesia, for example, about 69% of urban waste is disposed of in TPAs, while only 7% is recycled and 24% is processed into compost (Ministry of Environment and Forestry, 2020). This highlights the importance of TPAs in addressing waste problems, while also emphasizing the need for better TPA management to reduce its negative impacts.

Modern TPAs are designed to minimize environmental impacts by implementing various technologies and management methods. One commonly used method is sanitary landfill, where waste is buried in compacted layers and covered with soil or other covering materials daily to prevent the spread of odors, flies, and rodents. Additionally, modern TPAs are equipped with leachate (water contaminated by waste) collection and processing systems, as well as methane gas management systems. Methane gas, which is a greenhouse gas with a global warming potential 28-36 times higher than carbon dioxide (EPA, 2021), can be captured and used as a renewable energy source. According to research by Bogner et al. (2007), methane gas management in TPAs can significantly reduce greenhouse gas emissions and contribute to climate change mitigation.

However, not all TPAs worldwide are managed to high standards. In many developing countries, TPAs often do not meet sanitary landfill criteria and operate as open dumps, where waste is disposed of openly without adequate management. This practice causes various environmental and health problems, such as groundwater pollution from leachate, uncontrolled methane emissions, and the spread of diseases through vectors like flies and rats. According to the United Nations Environment Programme (UNEP, 2020), about 40% of the world's waste is still disposed of in uncontrolled TPAs, especially in rural areas and small towns in low-income countries. This highlights the need for improved capacity and standards in TPA management across various regions.

One of the main challenges in TPA management is the high operational cost. Building and operating a TPA that meets environmental standards requires significant investment, from constructing infrastructure such as leachate and methane gas collection systems to long-term maintenance and monitoring costs. In many developing countries, budget and resource limitations often hinder the adoption of better TPA management technologies and methods. Additionally, a lack of skilled personnel and adequate training also poses challenges in improving TPA management quality. According to research by Hoornweg and Bhada-Tata (2012), the cost of effective TPA management can reach 20-50% of the total waste management budget in large cities, requiring sustainable and innovative funding to address this challenge.

Another challenge often faced in TPA management is resistance from surrounding communities. Many people do not want TPAs built near their residences due to concerns about negative environmental and health impacts. This often leads to social conflicts and delays in the construction of new TPAs. To address this issue, a participatory approach involving the community in the planning and decision-making process is needed. Additionally, compensation and incentive programs, such as providing public facilities or economic opportunities for surrounding communities, can help reduce resistance. According to research by Schübeler et al. (1996), community participation in TPA management can increase social acceptance and reduce conflicts.

In addition to technical and social challenges, TPA management also faces regulatory and policy challenges. In many countries, regulations on TPA management are still weak or not well enforced, leading to environmentally unfriendly practices. For example, illegal waste dumping and TPA operations that do not meet standards are still common in various regions. Therefore, a strong regulatory framework and consistent law enforcement are needed to ensure that TPAs are managed responsibly. Additionally, policies that encourage waste reduction at the source, such as bans on single-use plastics and incentives for recycling, can help reduce pressure on TPAs. According to the European Environment Agency (EEA, 2019), waste reduction policies can reduce the volume of waste sent to TPAs by up to 30% and improve overall waste management efficiency.

Amid these challenges, there are several innovations and solutions that can be applied to improve TPA management. One of them is the implementation of waste-to-energy (WTE) technology, where waste in TPAs is processed into electrical or thermal energy through combustion, gasification, or pyrolysis. This technology not only reduces the volume of waste sent to TPAs but also generates renewable energy that can be used to meet community electricity needs. According to the International Solid Waste Association (ISWA, 2017), WTE technology has successfully reduced waste volume in TPAs by up to 90% in some European and Asian countries. Additionally, the development of regional TPAs serving multiple cities or areas can improve efficiency and reduce operational costs. By combining resources and infrastructure, regional TPAs can manage waste on a larger scale and meet higher environmental standards.

In addition to technology, a circular economy-based approach can also be applied in TPA management. The circular economy concept aims to minimize waste and maximize resource use by promoting recycling, reuse, and waste reduction at the source. In the context of TPAs, this approach can be implemented by improving waste segregation at the source, developing recycling facilities, and utilizing organic waste for compost or biogas production. According to the Ellen MacArthur Foundation (2019), applying the circular economy to waste management can reduce the volume of waste sent to TPAs by up to 50% and create new economic opportunities.

Overall, TPAs play a crucial role in the waste management system, especially in handling waste that cannot be recycled or further processed. However, improper TPA management can lead to various environmental and health problems, requiring a holistic and sustainable approach. By implementing innovative technologies, increasing community participation, and strengthening regulatory frameworks, we can create more efficient, environmentally friendly, and sustainable TPAs. Additionally, a circular economy-based approach can help reduce reliance on TPAs and create a more sustainable waste management system for the future.

TPAs are the final stage in the waste management system. In Nunukan Regency, the existing TPAs still use the open dumping method, where waste is disposed of openly without further processing. This method causes various environmental problems, such as soil, water, and air pollution, as well as methane emissions that contribute to global warming. Therefore, the construction of TPAs that meet environmental standards, such as sanitary landfills, is needed.

Sanitary landfill TPAs are designed with impermeable layers to prevent leachate (waste liquid) from leaking into the soil and groundwater. Additionally, these TPAs are equipped with leachate treatment and methane gas collection systems to reduce environmental impacts. According to Law No. 18 of 2008 on Waste Management, every region is required to have a TPA that meets environmental standards. However, building a sanitary landfill TPA requires significant investment and adequate technical support.

5) 3R System (Reduce, Reuse, Recycle)

The implementation of the 3R principles in Nunukan Regency is still minimal. Although there are some waste bank programs at the community level, their scale is still limited and not integrated with a broader waste management system. According to Susilawati and Rahayu (2019), the implementation of the 3R principles requires infrastructure support, community education, and economic incentives to encourage active participation.

The 3R system, which consists of Reduce (reducing), Reuse (reusing), and Recycle (recycling), is an increasingly popular approach to addressing environmental issues, particularly in waste management. This concept

not only provides a practical solution to reduce the volume of waste generated but also serves as a strategic step in environmental conservation and natural resource conservation. In the modern era, where population growth and industrialization are rapidly increasing, waste production has reached alarming levels. According to data from the World Bank (2018), in 2016 alone, the world generated around 2.01 billion tons of solid waste, and this number is predicted to increase to 3.40 billion tons by 2050 if no serious action is taken. Therefore, the implementation of the 3R system is highly relevant and urgent to reduce the negative impacts of waste on the environment and human health.

The concept of Reduce (reducing) is the first step in the 3R system. Its goal is to minimize the amount of waste generated from the outset. This can be achieved by reducing the consumption of unnecessary items, choosing products with minimal packaging, or using environmentally friendly materials. For example, by reducing the use of single-use plastic bags and switching to reusable shopping bags, we can significantly reduce the amount of plastic waste that pollutes the environment. According to research by Jambeck et al. (2015), around 8 million tons of plastic enter the oceans each year, most of which comes from poorly managed plastic waste. Therefore, reducing waste not only helps decrease waste volume but also reduces plastic pollution, which has detrimental effects on marine ecosystems.

The second step in the 3R system is Reuse (reusing). This concept encourages communities to reuse items that are still functional, rather than discarding them immediately. For example, used glass bottles can be reused as storage containers or plant pots. By reusing items, we not only reduce the amount of waste generated but also save resources and energy required to produce new items. According to the United Nations Environment Programme (UNEP, 2020), reusing items can reduce greenhouse gas emissions by 20-30% by reducing the need for new production. Additionally, reuse can provide additional economic value, as seen in the creative industries that utilize used items to create high-value products.

The final step in the 3R system is Recycle (recycling). This process involves processing waste into raw materials that can be used to produce new items. Recycling is crucial because it reduces the amount of waste that ends up in final disposal sites (TPAs) and reduces the exploitation of natural resources. For example, recycling paper can reduce tree cutting, while recycling plastic can reduce the use of fossil fuels as raw materials for new plastic. According to the Environmental Protection Agency (EPA, 2021), recycling one ton of paper can save around 17 trees and 7,000 gallons of water. However, despite its many benefits, recycling also faces its own challenges, such as high costs and the need for advanced technology. Additionally, not all types of waste can be recycled, so it is important to segregate waste properly before the recycling process.

The implementation of the 3R system not only provides environmental benefits but also has significant economic and social impacts. Economically, this system can create new jobs, especially in the recycling and creative industries. According to the International Labour Organization (ILO, 2019), the recycling industry can create up to 1.5 million jobs worldwide if managed properly. Additionally, the 3R system can reduce the waste management costs borne by the government and community. Socially, this system can increase community awareness about the importance of environmental conservation and encourage active participation in nature conservation efforts.

However, despite its many benefits, the implementation of the 3R system still faces various challenges. One of the main challenges is the lack of community awareness and participation. Many people still do not understand the importance of reducing, reusing, and recycling waste. Additionally, inadequate infrastructure, such as a lack of recycling facilities and inefficient waste collection systems, also hinders the implementation of the 3R system. Therefore, collaborative efforts between the government, private sector, and community are needed to address these challenges and ensure the success of the 3R system. The government plays a crucial role in promoting the implementation of the 3R system through supportive policies and regulations. For example, the government can implement policies banning single-use plastics, provide incentives for companies that adopt recycling practices, or conduct educational campaigns to increase community awareness. Additionally, the government needs to invest in the development of waste management infrastructure, such as recycling facilities and integrated waste collection systems.

On the other hand, the private sector also has a responsibility to support the 3R system. Companies can reduce the use of environmentally unfriendly materials in their production processes, develop recyclable products, or collaborate with recycling institutions to manage their waste. Additionally, companies can play a role in community education through corporate social responsibility (CSR) programs focused on the environment. The community, as consumers, also plays an important role in supporting the 3R system. By adopting a more environmentally friendly lifestyle, such as reducing the consumption of single-use items, reusing items that are

still functional, and segregating waste for recycling, the community can significantly contribute to reducing the negative impacts of waste on the environment. Additionally, the community can encourage the government and private sector to take more serious action in addressing waste issues through active participation in environmental activities and advocacy.

6) Organic and Inorganic Waste Management

Organic and inorganic waste management requires different approaches. Organic waste, such as food scraps and leaves, can be processed into compost or biogas through composting and anaerobic digestion. In Nunukan Regency, composting programs have been implemented in several locations, but their scale is still limited. To improve the effectiveness of organic waste management, socialization and training for the community on proper composting techniques are needed. Meanwhile, inorganic waste, such as plastic, paper, and metal, can be recycled into new products. Waste bank programs have been introduced in Nunukan Regency to encourage community participation in segregating and collecting inorganic waste. According to data from the Nunukan Regency Environmental Agency (2022), the waste bank program has successfully reduced the volume of inorganic waste sent to TPAs by 15%. However, this program still needs to be expanded and supported by adequate recycling infrastructure.

7) Partnerships with the Private Sector

Partnerships with the private sector can be a solution to overcome budget and resource limitations in waste management. In Nunukan Regency, several private companies have participated in waste management programs, such as providing waste bins and sponsoring cleanliness activities. However, these partnerships still need to be enhanced, especially in terms of technology and infrastructure investment. According to research by Bappenas (2019), public-private partnerships can improve the effectiveness of waste management through risk and resource sharing. According to the government, there is a mandate to realize public services, including the provision of infrastructure, with private legal entities as project investors. Cooperation between the government and the private sector is called Public-Private Partnership (Shintarini Kristine Seyobudi, 2013). Collaborative governance is still dominated by the government's role (Syafi'i, Muhammad., 2020).

8) Community-Based Waste Management

Community participation is key to the success of waste management. In Nunukan Regency, community-based waste management programs, such as waste banks and cleanliness movements, have shown positive results. However, community participation still needs to be increased through education and incentive programs. According to Law No. 18 of 2008 on Waste Management, the community has a responsibility to segregate and manage waste independently. Waste management is one of the major challenges faced by modern society, especially in urban and rural areas. Population growth, urbanization, and changing consumption patterns have led to a significant increase in waste volume. If not managed properly, waste can cause various environmental, health, and social problems. Therefore, effective and sustainable waste management is crucial to maintaining environmental quality and community well-being.

Community-based waste management (CBWM) is an approach that involves active community participation in managing their own waste. This approach aims to reduce the volume of waste sent to final disposal sites (TPAs) by recycling, composting, and reducing waste production at the source. CBWM not only helps reduce the negative impacts of waste on the environment but also creates economic opportunities for the community through creative and innovative waste management. Waste is a global issue that requires serious attention from all parties. According to World Bank data (2018), the world generates around 2.01 billion tons of solid waste each year, and this number is expected to increase to 3.40 billion tons by 2050 if no significant action is taken. In Indonesia, waste issues are also becoming increasingly concerning. Data from the Ministry of Environment and Forestry (KLHK) in 2021 shows that Indonesia generates around 67.8 million tons of waste per year, with organic waste accounting for 60%, plastic waste 14%, and the rest consisting of paper, metal, and other materials.

Waste that is not managed properly can cause various problems, such as water, soil, and air pollution, as well as the spread of diseases. Additionally, waste that accumulates in TPAs can produce methane gas, a greenhouse gas that contributes to climate change. Therefore, a holistic and participatory approach to waste management is needed, one of which is through community-based waste management. Community-based waste management (CBWM) is an approach that involves active community participation in managing their own waste. This concept is based on the 3R principles (Reduce, Reuse, Recycle), which aim to reduce the volume of waste

sent to TPAs by reducing waste production, reusing items that are still functional, and recycling waste into economically valuable products. CBWM emphasizes the importance of community participation in every stage of waste management, from waste segregation at the household level, collecting segregated waste, to processing waste into compost or recycled products. This approach not only helps reduce waste volume but also increases community awareness about the importance of environmental conservation and responsible waste management. Community-based waste management offers various benefits, both environmentally, socially, and economically. Environmentally, CBWM can help reduce the volume of waste sent to TPAs, thereby reducing the negative impacts of waste on the environment. Additionally, CBWM can reduce greenhouse gas emissions generated from the decomposition of organic waste in TPAs.

Socially, CBWM can increase community awareness about the importance of environmental conservation and responsible waste management. Active community participation in waste management can also strengthen a sense of togetherness and social responsibility. Additionally, CBWM can serve as an educational tool for the community, especially children, about the importance of environmental conservation and responsible waste management. Economically, CBWM can create economic opportunities for the community through creative and innovative waste management. For example, organic waste can be processed into compost that can be sold or used for agriculture, while inorganic waste such as plastic and paper can be recycled into economically valuable products. Additionally, CBWM can create new jobs for the community, such as waste collectors, compost processors, and recycling artisans.

Despite its various benefits, community-based waste management also faces several challenges. One of the main challenges is the lack of community awareness and participation in waste management. Many communities still do not understand the importance of waste segregation and responsible waste management. Additionally, the lack of adequate facilities and infrastructure also hinders the implementation of CBWM. Another challenge is the lack of support from the government and related parties. Although the government has issued various policies and programs to support waste management, their implementation in the field is often suboptimal. Additionally, the lack of coordination between the government, community, and private sector also poses challenges in implementing CBWM.

The government's strategy to address waste pollution is to create cities free from waste pollution (Prasetyo, Dimas Achmad., 2020). The government plays a crucial role in supporting community-based waste management. One of the government's roles is to provide adequate facilities and infrastructure for waste management, such as temporary waste disposal sites (TPS), integrated waste processing sites (TPST), and recycling facilities. Additionally, the government needs to provide training and education to the community on how to manage waste responsibly. The government also needs to issue policies and regulations that support community-based waste management. For example, the government can provide incentives to communities that actively participate in waste management, such as tax reductions or financial assistance. Additionally, the government needs to promote campaigns and socialization about the importance of responsible waste management.

9) Waste Management in Island Areas

Digital technology can be utilized to improve efficiency and transparency in waste management systems. In Nunukan Regency, the implementation of digital technology is still in its early stages but has great potential for development. For example, smart waste management systems can be used to monitor waste bin fill levels, optimize transportation routes, and track waste management performance in real-time. According to a study by the World Bank (2018), the use of digital technology in waste management can improve data accuracy and reduce operational costs. Island areas, with their unique geographical characteristics, face complex challenges in waste management. Limited land, expensive transportation infrastructure, and dependence on marine and coastal ecosystems make waste management not only an environmental issue but also an economic and social one. According to UNEP (2019), about 80% of waste in island areas comes from domestic and tourism activities, with plastic (40%) and organic waste (30%) dominating the composition. This situation is exacerbated by inadequate waste collection and processing systems, especially in remote small islands (World Bank, 2021). For example, in the Maldives, 58% of waste is not properly managed, polluting coral reefs and threatening the tourism industry, which is the backbone of the economy (Azmi et al., 2020). The main challenge in waste management in island areas is limited infrastructure. Transporting waste between islands requires high costs, while TPAs (Final Disposal Sites) on small islands often do not meet environmental standards. Research by Kurniawan et al. (2021) in the Thousand Islands, Indonesia, shows that 70% of plastic waste ends up in the sea due to the lack of recycling facilities. Additionally, consumption patterns that rely on single-use products worsen waste accumulation. This is in line with the findings

of Jambeck et al. (2015), which state that small island nations contribute 14% of the total global marine plastic waste. On the other hand, community participation is key to the success of waste management. The "Clean Island" program in the Philippines, for example, successfully reduced 30% of waste through education and economic incentives for residents who segregate waste (ADB, 2020). This community-based approach is supported by government policies that integrate circular economy principles. However, according to Hoornweg et al. (2018), the lack of strict regulations and law enforcement in many island areas hinders the implementation of sustainable solutions. Technological innovations are also being implemented, such as the use of biodigesters to convert organic waste into energy on Jeju Island, South Korea (Kim & Lee, 2022), and decentralized waste processing systems based on IoT in the Hawaiian Islands (Smith et al., 2023). However, the adoption of these technologies is still limited due to high costs and a lack of local technical capacity. Therefore, collaboration between the government, private sector, and international institutions is needed to create adaptive and sustainable waste management models.

10) Technical Challenges.

Some of the technical challenges faced in waste management in Nunukan include:

- Limited Budget: Budget allocation for the procurement and maintenance of waste management infrastructure is still low, leading to limited facilities.
- Lack of Trained Human Resources: Waste management personnel often lack the skills and knowledge related to modern technology or environmentally friendly waste management methods.
- Access to Modern Technology: Nunukan Regency still faces difficulties in accessing modern technology due to geographical factors and limited cooperation with the private sector.

11) Technical Opportunities

On the other hand, there are several technical opportunities that can be utilized to improve waste management, including:

- Development of Modern Infrastructure: The government can invest in the construction of TPAs that use sanitary landfill technology or large-scale composting systems.
- Implementation of Waste-to-Energy (WTE) Technology: This technology can convert waste into alternative energy sources, such as electricity or biogas, providing economic benefits while reducing the burden on TPAs.
- Collaboration with the Private Sector: Cooperation with the private sector can help provide recycling facilities and more efficient waste processing technology.

12) Technical Opportunities

Based on the analysis of technical aspects, several recommendations to improve the waste management system in Nunukan Regency include:

- Construction of Sanitary Landfill TPAs: The government needs to allocate a budget to build TPAs that meet environmental standards.
- Adoption of Modern Technology: Waste-to-energy technology and smart waste management systems need to be adopted to improve waste management efficiency.
- Improvement of Collection and Transportation Infrastructure: An increase in segregated waste bins and waste truck fleets is needed to expand waste management service coverage.
- Strengthening Waste Bank Programs: Waste bank programs need to be expanded and supported by adequate recycling infrastructure.
- Education and Socialization: Education and socialization programs need to be enhanced to increase community awareness about the importance of waste management

CONCLUSION

Effective and sustainable management is urgently needed to address the increasing waste problem. Nunukan Regency faces significant challenges in waste management, including inadequate infrastructure, low community awareness, and high waste volume, especially plastic. Efforts to improve the waste management system must involve various parties, including the government, community, and private sector. Environmental education and awareness must be increased to change community behavior in managing waste. Additionally, community empowerment through participatory programs such as waste banks can help reduce the volume of waste sent to final disposal sites (TPAs). Utilizing the economic potential of waste, such as recycling and processing organic waste into compost or

biogas, is also important, as it can create jobs and additional income for the community. To achieve a better waste management system, support and collaboration from all parties are needed, including infrastructure improvement and the use of environmentally friendly technology. With a holistic approach and active community participation, it is hoped that the waste management challenges in Nunukan Regency can be effectively and sustainably addressed.

Strategies for reducing, reusing, and recycling (the 3R concept) must be integrated into the existing management system to minimize the negative impacts of waste, especially from non-biodegradable plastic waste. Collaboration between the government, private sector, and community is crucial in creating environmental awareness and increasing community participation. Educational campaigns and participatory programs need to be developed so that the community better understands and actively participates in waste management. By leveraging the economic potential of waste management, such as recycling and processing organic waste, Nunukan Regency can not only address environmental issues but also create jobs and improve community welfare. Therefore, synergy is needed to strengthen waste management infrastructure and adopt environmentally friendly technology to achieve an effective and sustainable waste management system.

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