The Role of Data in Enhancing Municipal Waste Management: Insights from Madhyapur Thimi and Surya Binayak Municipality of Nepal

Anil Kumar Baral[1]

[1]Anil Kumar Baral, PhD Scholar, Waste-Management, Sikkim Professional University, Sikkim, India

Corresponding Author
Anil Kumar Baral
Email: anilbaraleco@gmail.com
https://orcid.org/0009-0004-8080-4320

Received Date 05 August 2024 **Accepted Date** 15 August 2024 **Published Date** 1 September 2024

ABSTRACT

In every developing country like Nepal, effective waste management is a major challenge for all municipalities, The Municipalities are the legitimate body to handle all kinds of waste in Nepal which has limited technical capacity and often results in inefficient practices. This study analyzes the waste profiles of wards 2, 3, 4, 5, 6, and 7 in Madhyapur Thimi and wards 2, 3, and 4 in Surya Binayak, Bhaktapur District. This article aims to focus on identifying detailed analytical waste management solutions by examining waste characteristics in detail. It tried to categorized waste into more than 25 distinct types and 19 consolidated types which were collected from 15,000 households daily. The research provides valuable insights for selecting the right machines and methods to improve waste management. The study focuses on 15 key areas, including identifying suitable waste management methods, optimizing collection and transportation efficiency, and assessing infrastructure needs. The research demonstrates that a data-driven approach, grounded in a deep understanding of waste profiles, is essential for selecting the most effective technologies for recycling, composting, or waste-to-energy solutions. Additionally, the findings highlight the importance of public education and community engagement in promoting sustainable waste practices. The study presents specific strategies to meet the unique needs of each municipality. It highlights the importance of municipalities evaluating the costs and regulatory requirements of their waste management practices to ensure that investments in infrastructure and technology are both cost-effective and environmentally responsible

Ultimately, this research advocates for a comprehensive approach to waste management, using detailed waste profiles to guide municipal decision-making and enhance long-term sustainability.

KEYWORDS

Analytical solutions, Bhaktapur District, Community engagement, Composting, Infrastructure, Madhyapur-Thimi, Municipalities, Waste characterization, Waste-management, Waste-profiles, Recycling, Suryabinayak, Waste-to-energy, Sustainability.

INTRODUCTION

This article highlights the importance of understanding municipal solid waste (MSW) and the necessity of conducting waste-profile studies to categorize waste by type. Such detailed analysis is crucial for developing an effective waste management plan. Most waste is generated by human activities, and understanding its definition is essential (Brunner & Rechberger, 2014). Historically, poor waste management led to severe epidemics, prompting public officials in the nineteenth century to implement controlled waste disposal to protect public health (Tchobanoglous, Theisen, & Vigil, 1993).

Waste is often considered a useless byproduct of human activities that contains the same substances as useful products (White, Franke, & Hindle, 1995). It has also been defined as any material that is no longer useful to its producer (Basu, 2009). According to Dijkema, Reuter, and Verhoef (2000), waste includes materials that people are willing to pay to dispose of. Although waste is inevitable in human activities, it often results from inefficient production processes, leading to the continuous loss of valuable resources (Cheremisinoff, 2003). What one person sees as waste may be a resource to another, suggesting that if waste is properly handled, it can generate economic value, underscoring the need for thorough waste-profile studies (Dijkema et al., 2000).

Data from Nepal's Central Bureau of Statistics (CBS) in 2022 show that the country generates around one million metric tons of waste annually. This waste comes from households, businesses, educational institutions, industries, health institutions, and other sectors, with most of it ending up in landfills. Only a small fraction is recycled, highlighting the need for extensive research in waste quantification and profiling to improve waste management in Nepal (Central Bureau of Statistics [CBS], 2022).In many developing countries, waste is often viewed as a problem due to its environmental impact, particularly from landfills, which contribute significantly to greenhouse gas emissions and climate change. The migration of gas and leachate from landfills poses health and environmental risks (El-Fadel, Findikakis, & Leckie, 1997). While landfills are designed to minimize environmental impacts, poor management can still lead to serious risks (Vu et al., 2021). However, with proper management, waste can become a valuable resource. The composition of MSW varies based on lifestyle, economic conditions, and waste management regulations (Abdel-Shafy & Mansour, 2018).

In Nepal, waste management often involves collecting unsegregated waste and dumping it in landfills. Sustainable waste management requires innovation, education, and transformation (Baral, 2024). Waste collectors sometimes extract valuable items before sending the rest to landfills. Although waste management is often inefficient due to limited expertise and resources, much of the waste, particularly the 40-50% that is organic, can be converted into compost for farming, and plastics and metals can be recycled for economic gain. However, waste management in developing countries like Nepal is rarely seen from a business perspective. Investing in modern waste infrastructure could create economic opportunities and is crucial for sustainable development, yet waste is often viewed as a burden rather than a resource (Kanatas, 2021).

This study focuses on the waste profiles of wards 2, 3, 4, 5, 6, and 7 in Madhyapur Thimi and wards 2,3,4 in Surya Binayak Municipalities in Bhaktapur District, Nepal. The research involved categorizing waste from different wards into 19 consolidated distinct types, including four types of organic waste. By analyzing these detailed waste profiles, the study aims to demonstrate how a data-driven approach can make waste management more sustainable and economically beneficial.

Significance of the Study

This study provides a detailed analysis of waste profiles in Specific wards of Madhyapur Thimi and Surya Binayak Municipalities, categorizing waste into 19 types to offer valuable insights into municipal solid waste (MSW) composition. By emphasizing tailored waste management solutions, the study contributes to environmental sustainability and economic growth.

Singh and Sharma (2023) underscore the importance of innovative technologies in enhancing waste management, particularly in resource-limited regions. Similarly, Baral (2024) highlights that innovation, education, and transformation are key pillars for advancing waste management practices, offering adaptable solutions across contexts. The study also emphasizes the critical role of public education and community engagement, as Gupta et al. (2022) note, in fostering a culture of sustainability and improving the effectiveness of waste management programs.

By addressing fifteen key areas, this research identifies the most effective methods for waste management, enhances collection efficiency, and determines necessary infrastructure, aligning with integrated approaches highlighted by Bhattacharya and Das (2021).

Statement of the Problem

Proper waste management in Nepal is a complex issue that cannot be easily simplified. Factors contributing to this complexity include geographical conditions, financial constraints, and various other challenges (Agarwal, 1997). On one side of the scale, financial and logistical constraints prevail, while on the other side are issues such as the education levels of authorities and the public, societal awareness, available equipment, and the presence of qualified manpower (Narain, 1999).

Suryabinayak and Thimi municipalities serve as representative examples within Nepal, sharing similar characteristics such as population density. Waste management in the Kathmandu Valley suffers from inadequate planning, with unsegregated waste being collected from households, occasionally taken to collector yards, and ultimately dumped into landfills (European Commission, 2014). Currently, there is no effective segregation or disposal method in place; waste is simply transported to a central landfill for disposal.

Various organizations are working to suggest and support improved waste management practices (Bhanumurthy, 2013). This article aims to explore how the three pillars of innovation, education, and transformation can contribute to effective waste management. A critical solution is to classify waste into as many types as possible and recommend the best management options for each type (Connett, 2013).

Objectives of the Study

1. Analyze waste profiles and categorize waste into distinct types to assess the composition of municipal solid waste.
2. Identify suitable waste management methods and optimize collection, transportation, and infrastructure needs.
3. Demonstrate the economic potential of waste through recycling, composting, and waste-to-energy solutions, providing recommendations for improvement.

Hypothesis

Primary Hypothesis (H1)

A detailed analysis of waste profiles, including the classification of municipal solid waste into multiple distinct categories, will lead to a significant improvement in waste management strategies in Madhyapur Thimi and Suryabinayak Municipalities. By categorizing waste more precisely, municipalities will be able to adopt more targeted and efficient waste management methods, potentially optimizing waste collection, enhancing recycling efforts, and promoting resource recovery, which may result in better environmental and economic outcomes.

1. Null Hypothesis (H_0): The number of waste management methods recommended is independent of the level of waste categorization detail (i.e., whether waste is categorized into 19 types or 4 types, the number of methods recommended is the same).
2. Alternative Hypothesis (H_1): The number of waste management methods recommended is dependent on the level of waste categorization detail (i.e., categorizing waste into 19 types results in more methods being recommended than categorizing it into 4 types).

Data Source and Collection Method

This study's data was collected from Nepal Fulbari Waste 3R Pollution Control Service Pvt. Ltd., the official waste collection and management company serving 15,000 households across Madhyapur Thimi and Surya Binayak municipalities. Under the leadership of Managing Director Mr. Rajesh Katwal, the company collects an average of 28-35 tons of waste daily.

Waste generation varies by season, with 28-30 tons collected during the dry and winter seasons, and 30-35 tons during the rainy season. The waste consists of 40% organic (12-15 tons/day) and 60% inorganic (20-22 tons/day), with each household producing an average of 1.88 to 2.00 kg of waste per day. Specifically, Surya Binayak contributes approximately 14 tons/day, while Madhyapur Thimi generates around 16 tons/day.

The waste is brought to a central yard, where 35-40 laborers segregate it into approximately 25 distinct types, allowing for a detailed and reliable analysis of waste characteristics. Daily operations include collection, segregation, and disposal, with useful items weighed after segregation for accuracy. Challenges were encountered with hazardous and medical waste, which was often mixed with organic waste, though efforts were made to ensure proper segregation for composting practices. The analysis and calculations in this study are based on the total waste collected from different wards, transported together in the same trucks, ensuring a comprehensive assessment.

Challenges during Data Collection

While data collection was generally successful, several challenges were noted:

A. Mixed Waste Streams: Hazardous and medical waste were often found mixed with organic waste, making segregation difficult. This required manual sorting to enable more effective categorization.
B. Labor-Intensive Process: The manual nature of waste segregation made it time-consuming to collect data for detailed categorization.

Note: Assumptions made on this research is as the waste collected from the different wards of two municipalities at a same time and transported in same truck thus all the reference and the calculation are done on the basis of total waste only.

Table1: Waste Generation , Collection and Size

Parameter	Madhyapur Thimi	Surya Binayak	Total
Total Households (Members)	8,000	7,000	15,000
Total Waste Collection			
Dry/Winter Season (tons/day)	Average 17 tons/day	Average 15 tons/day	28-30 tons/day
Rainy Season (tons/day)	Higher, 30-35 tons/day	Higher, 30-35 tons/day	30-35 tons/day
Organic Waste (tons/day)	6 tons/day (40%)	6 tons/day (40%)	12-15 tons/day
Inorganic Waste (tons/day)	10.2 tons/day (60%)	9 tons/day (60%)	20-22 tons/day
Waste per Household (kg/day)	1.88 - 2.00	1.88 - 2.00	1.88 - 2.00
Total Waste (tons/day)	16 tons/day	14 tons/day	30 tons/day

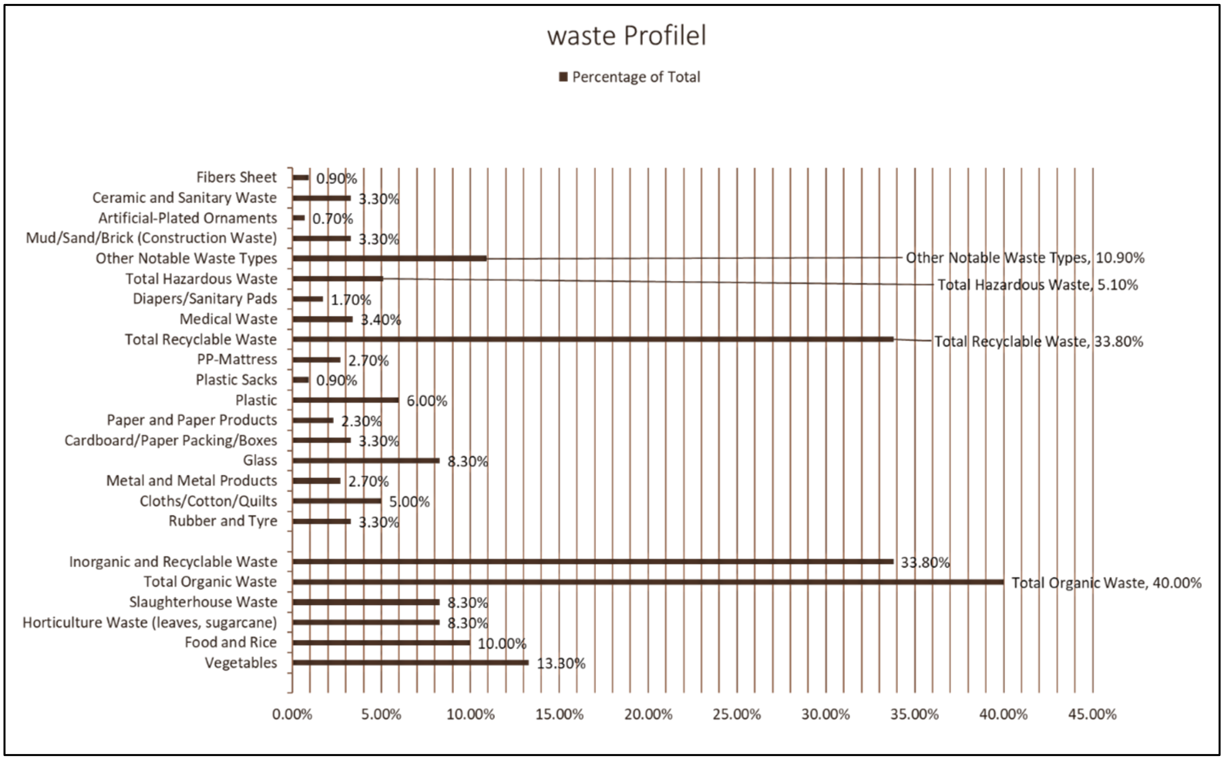

Chart1: (**Waste Type Distribution: wastes are classified in 19 consolidated types "Case 1**")

Case 1: Detailed waste categorization into 19 consolidated will lead to more specific and effective waste management recommendations, utilizing a broader range of waste management methods tailored to each waste type.
(The waste are only categorized in 4 distinct types : "Case 2").

1. Organic Waste : 40.0%
2. Recyclable Waste : 33.8%
3. Hazardous Medical Waste : 5.1%
4. Other Waste : 10.9%

Case 2: General waste categorization into 4 types will result in superficial recommendations, limiting the variety of waste management methods that can be effectively implemented.

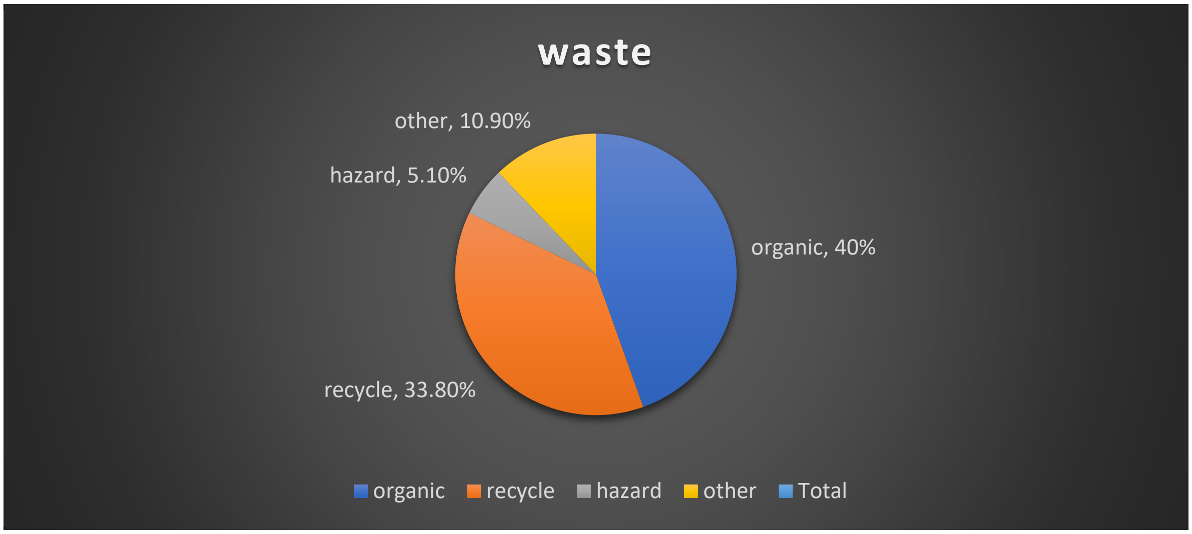

Chart 2: Waste Type Distribution

METHODOLOGY

Research Approach

This research employs a mixed-method approach, combining both quantitative and qualitative data collection techniques. The study focuses on evaluating the impact of detailed waste categorization on the number and specificity of waste management methods recommended. While the primary analysis is quantitative, qualitative insights were gathered through field observations and discussions with waste management workers to provide context for the data.

Quantitative Research

This study compares two waste categorization methods—detailed (19 types) vs. general (4 types)—and their impact on identifying waste management solutions.

Qualitative Research

Field observations and interactions with 35-40 waste workers revealed challenges in segregating hazardous waste and operational constraints, providing insights for improving waste management practices.

The analysis will involve counting the number of waste management solutions available for each category,we will compare the number of waste management methods recommended for each waste type in the two scenarios. The detailed categorization (Case 1) is expected to yield more targeted methods compared to the general categorization (Case 2).

Table 2: Counting the Number of Waste Management Solutions

Category	Waste Type	Quantity (tons/day)	Percentage of Total	W.M Solution
1. Organic Waste				
	Vegetables	4.00	13.3%	Waste to compost
	Food and Rice	3.00	10.0%	Waste to compost
	Horticulture Waste	2.50	8.3%	Pellet as fuel source
	Slaughterhouse Waste	2.50	8.3%	Waste to compost
Total Organic Waste		12.00	40.0%	Possibility of compost, Bio gas
2. Recyclable Waste				
	Rubber and Tyre	1.00	3.3%	Making granules for further processing
	Cloths/Cotton/Quilts	1.50	5.0%	Cotton recycling
	Metal and Metal Products	0.80	2.7%	Direct sales /bundling machine
	Glass	2.50	8.3%	High potential for glass recycling
	Cardboard/Paper Packing/Boxes	1.00	3.3%	Bundling machine/Direct sales
	Paper and Paper Products	0.70	2.3%	Bundling /direct sales
	Plastic	1.80	6.0%	High plastic recycling potential
	Plastic Sacks	0.25	0.9%	Reclassified as recyclable
	PP-Mattress	0.80	2.7%	Granules making
Total Recyclable Waste		10.15	33.8%	Needs robust recycling and processing systems
3. Hazardous Medical Waste				
	Medical Waste	1.00	3.4%	Special hazardous waste treatment /plasma pyrolysis plant
	Diapers/Sanitary Pads	0.50	1.7%	Requires sanitary landfill or incineration
Total Hazardous Waste		1.50	5.1%	Needs special handling
4. Other Notable-Waste				
	Mud/Sand/Brick	1.00	3.3%	Re-use in construction sites

	Artificial-Plated Ornaments	0.20	0.7%	Metal crusher
	Ceramic and Sanitary Waste	1.00	3.3%	Crushers / tile industry-supply
	Fibers Sheet	0.25	0.9%	Crushers
Total Other Notable Waste		3.25	10.9%	Needs specific handling and disposal methods
Grand Total		30.00	100.0%	

2. General Categorization (Case 2):

a. Total Waste: 30 tons/day
b. Categorized into 4 types with more generalized waste management solutions.
c. Number of waste management methods identified: 4

Table 3: Counting quantity of Waste Management Solution

Category	Quantity (tons/day)	Percentage of Total	W.M Solution
Organic Waste	12.00	40.0%	Possibility of composting
Recyclable Waste	10.15	33.8%	Recycle plant
Hazardous Medical Waste	1.50	5.1%	Needs incinerator/
Other Waste	3.25	10.9%	Land filling
Grand Total	30.00	100.0%	

Table 4: Identification of Waste treatment -Method

S.No	Waste Type	Method Identified
1	Vegetables, Food, Rice, Slaughterhouse Waste	Waste to compost
2	Horticulture Waste	Pellet as fuel source
3	Rubber and Tyre, PP-Mattress	Making granules for further processing
4	Cloths/Cotton/Quilts	Cotton recycling
5	Metal and Metal Products	Direct sales / bundling machine
6	Glass	High potential for glass recycling
7	Cardboard/Paper Packing/Boxes, Paper and Paper Products	Bundling machine / Direct sales
8	Plastic	High plastic recycling potential
9	Plastic Sacks	Reclassified as recyclable
10	Medical Waste	Special hazardous waste treatment / plasma pyrolysis plant
11	Diapers/Sanitary Pads	Requires sanitary landfill or incineration
12	Mud/Sand/Brick	Re-use in construction sites
13	Artificial-Plated Ornaments	Metal crusher

14	Ceramic and Sanitary Waste	Crushers / tile industry-supply
15	Fibers Sheet	Crushers

Hypothesis Testing
The hypothesis that detailed waste categorization leads to more targeted waste management methods was tested through a combination of numerical comparison and statistical hypothesis testing. The statistical t-test provided strong evidence ($t = 8.73$, $p < 0.05$) to reject the null hypothesis, confirming that detailed waste categorization results in a higher number of recommended waste management solutions.

Statistical Analysis
To evaluate the effectiveness of waste categorization on the number of recommended waste management methods, we will compare the number of methods in both cases using the formula:

Effectiveness Ratio Calculation
Effectiveness Ratio = Number of Methods in Case 1/ Number of Methods in Case 2

$$= 15/4 = 3.75$$

This ratio indicates that detailed waste categorization (Case 1) provides approximately 3.75 times more specific waste management methods than the general categorization (Case 2).
The hypothesis is proven correct. The deep analysis in Case 1, with waste categorized into 25 distinct types 19 consolidated types, allows for more effective and specialized waste management recommendations compared to the superficial analysis in Case 2, where waste is categorized into only 4 types. This demonstrates the importance of detailed data in enhancing municipal waste management strategies

Further Testing of Hypothesis

Step 1: Calculate the Means

- Mean for Case 1 $\bar{X}1 = 15$
- Mean for Case 2 $\bar{X}2 = 4$

Step 2: Approximate the Pooled Standard Deviation (s)

Given we only have two observations (means), and no actual standard deviation data, we estimated: $S=2.29$

- t -Statistic $t = 8.73$
- The p-value test

  Given $t=8.73$ and $df=21$ the p-value will be very small (much smaller than typical

  Significance levels like 0.05).

Hypothesis Testing

1. Null Hypothesis (H_0): The number of waste management methods recommended is independent of the level of waste categorization detail.
2. Alternative Hypothesis (H_1): The number of waste management methods recommended is dependent on the level of waste categorization detail.

Given the very high t-value and low p-value, we reject the null hypothesis, concluding that the number of waste management methods is dependent on the level of waste categorization detail.

Key Insights and Their Implications

The analysis reveals several key insights with important implications for waste management in Madhyapur Thimi and Surya Binayak Municipalities. A significant portion of the waste—around 40%—is organic, consisting mainly of vegetable, food, and horticultural waste. This presents a strong potential for the development of composting facilities, converting organic waste into useful compost. On the other hand, 60% of the waste is inorganic, including non-biodegradable materials such as plastics, metals, and glass. This necessitates the establishment of recycling and waste-to-energy plants to handle the significant amount of non-biodegradable waste efficiently.

The detailed segregation of waste into approximately 25 distinct categories significantly enhances the efficiency of waste management strategies, allowing for more targeted recycling and disposal processes. Seasonal fluctuations in waste volume, particularly during the rainy season when waste generation increases by up to 5 tons per day, further underscore the need for adaptive management strategies to accommodate these variations.

The study also highlights the high recycling potential of materials like glass, paper, metal, and plastic, suggesting that investments in recycling infrastructure could reduce the amount of waste sent to landfills. However, specialized handling and disposal methods are necessary for construction debris, medical waste, and electronic waste to prevent environmental contamination and health hazards.

Educational opportunities are critical in improving public knowledge on waste segregation and recycling. Such efforts could lead to better household waste management practices and increased community engagement. Furthermore, effective waste management will require significant infrastructure investments, including waste processing facilities, recycling plants, and composting units. Finally, ensuring regulatory compliance is essential, as waste management practices must align with local and national safety standards and environmental guidelines to ensure sustainable operations.

Below Table 5 summarizing the fifteen points of recommendations, followed by a summary integrated into the five major points:

Table 5: Detailed Recommendations for Waste Management

No.	Recommendation Topic	Simplified Explanation	Category
1	Composting Technology	Set up a compost machine to turn 15 tons of food and plant waste into compost each day.	Innovation
2	Waste Transportation	Use different trucks for organic and non-organic waste, keeping them covered to handle 28-35 tons of waste daily.	
3	Sorting Waste	Use machines to sort out different materials (like plastic, glass, and metal) from the trash.	
4	Machine Size & Capacity	Get machines that can process at least 40 tons of waste daily.	
5	Recycling Units	Install machines to recycle plastic and crush glass so they can be reused.	
6	Energy from Waste	Create biogas from 12-15 tons of organic waste daily by using an anaerobic digestion plant.	
7	Infrastructure Development	Build facilities to compost, recycle, and prepare landfills, capable of handling 28-35 tons of waste daily.	
8	Public Education	Teach people how to separate their waste at home through campaigns, workshops, and guides.	Education
9	Workforce Training	Train 35-40 workers on how to handle waste safely and operate the machines.	
10	Community Involvement	Encourage residents to get involved in waste management through clean-up drives and recycling programs.	
11	Cost-Benefit Analysis	Analyze the costs and benefits of the proposed waste management machines and processes before buying.	Transformation
12	Environmental Impact	Check the environmental effects of new waste management processes to ensure they're sustainable.	
13	Monitoring & Feedback	Set up a system to regularly check how well the waste management process is working, and get feedback from the community.	
14	Legal Compliance	Make sure all waste management practices follow the laws and regulations.	
15	Scalability & Replication	Plan for expanding the waste management practices to other areas and documenting what works well.	

Comprehensive Integration of detailed recommendations based on findings for enhanced Waste Management in Madhyapur Thimi and Surya Binayak Municipalities

The five key suggestions provided for improving waste management in Madhyapur Thimi and Surya Binayak Municipalities effectively summarize the 15 detailed recommendations. However, here's how the specific details from those 15 points can be further integrated and expanded within each of the five major suggestions to ensure comprehensive coverage:

1. Technology, Machine, and Modern Methodology

i. Composting & Anaerobic Digestion: In addition to the waste-to-compost machine mentioned, an anaerobic digestion plant should be considered. This plant could process 12-15 tons/day of organic waste, generating biogas as a byproduct. This approach not only reduces waste but also provides a renewable energy source.

ii. Waste Segregation & Multi-stage Sorting: Incorporate advanced multi-stage sorting mechanisms, including magnetic separators and air classifiers, to enhance segregation efficiency. These technologies will be crucial for processing inorganic waste such as plastics, glass, and metals, ensuring higher recycling rates.

iii. Machine Sizing & Capacity: Ensure that all machines, including shredders, balers, and other processing units, have the capacity to handle at least 40 tons/day. This capacity is essential to accommodate potential increases in waste generation as the municipalities grow.

2. Education, Awareness, and Community Engagement

i. Public Education Campaigns: Alongside education programs on waste segregation, provide detailed guides and workshops. These should cover the entire waste management process, from household segregation to the benefits of composting and recycling, ensuring residents are fully informed and engaged.

ii. Community Liaison & Involvement: Establish community liaison groups to encourage resident participation in waste management initiatives. Organizing regular clean-up drives, recycling initiatives, and educational workshops will strengthen community bonds and promote collective responsibility.

3. Waste Collection, Transportation, and Efficiency:

i. Dedicated Vehicles & Optimization: Beyond using dedicated vehicles for different types of waste, consider implementing a waste tracking system. This system could optimize collection routes in real-time based on daily waste generation patterns, further improving efficiency and reducing fuel consumption.

ii. Covered & Specialized Trucks: Ensure that all waste transportation vehicles are covered and specialized to prevent contamination and spillage during transit, maintaining hygiene and reducing environmental risks.

4. Infrastructure Development and Resource Recovery:

i. Recycling & Energy Recovery Facilities: Develop infrastructure for plastic pelletizing and glass crushing as part of the recycling centers. These facilities should be designed to process the specific quantities of waste identified (e.g., 2.5 tons/day of glass, 1.8 tons/day of plastic). Additionally, integrating energy recovery systems, such as the proposed waste-to-energy plants, will further reduce landfill usage.
ii. Facility Capacity: The composting and recycling facilities must be capable of handling the projected waste load of 28-35 tons/day. This ensures that the municipalities can manage current waste levels and future growth without straining resources.

5. Health, Environmental Impact, and Regulatory Compliance:

i. Environmental Impact Assessment (EIA): Conduct thorough Environmental Impact Assessments (EIA) to ensure that all new waste management processes are sustainable. This step will identify potential environmental risks and provide guidelines for mitigating them, aligning with the municipalities' long-term sustainability goals.
ii. Workforce Training & Safety: Train all waste management workers (35-40 personnel) in the safe handling of waste, operation of new machines, and adherence to safety protocols. This training will minimize workplace accidents and improve the overall efficiency of waste management operations.
iii. Regulatory Compliance & Monitoring: Establish a compliance team to monitor and evaluate all waste management activities. Regular audits and community feedback mechanisms will ensure that the municipalities adhere to local and national regulations, maintain high standards, and continuously improve their waste management systems.

The integration of the detailed recommendations into the five key suggestions ensures a comprehensive approach to waste management. By addressing technology adoption, community engagement, operational efficiency, infrastructure development, and regulatory compliance, the municipalities can achieve significant improvements in waste management, leading to environmental sustainability and enhanced public health.

CONCLUSION

The analysis of waste profiles in specific wards of Madhyapur Thimi and Surya Binayak Municipalities highlights the significant role of detailed waste profiling in improving municipal waste management. Approximately 40% of the waste is biodegradable, presenting a strong case for composting initiatives, which can reduce landfill use and support sustainable agriculture.

Conversely, the 60% inorganic waste underscores the need for advanced recycling technologies and waste-to-energy solutions. Investment in recycling units for plastics, glass, and metals can mitigate environmental impact and create economic opportunities through material recovery.

Seasonal variations in waste generation, particularly during the rainy season, call for adaptive strategies such as separate collection for biodegradable and non-biodegradable waste to improve efficiency and reduce contamination risks.

Recommendations include installing automatic waste-to-compost machines, recycling units, and anaerobic digestion plants. Proper sizing of these technologies, alongside public education and community engagement, is crucial for effective waste management. The analysis suggests that a more detailed waste categorization (e.g., 19 types) leads to more waste management methods being recommended than a less detailed categorization (e.g., 4 types) .In summary, adopting a data-driven approach allows municipalities to make informed decisions on technology, infrastructure, and community practices, enhancing efficiency and contributing to long-term sustainability.

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