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Modeling and Simulation of Smart Technology for Sustainable Utilization of Municipal Solid Waste: A Case Study of Bishnupur Municipality

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ABSTRACT

Rapid urbanization in Bishnupur Municipality, Bankura District, has outpaced the capacity of conventional municipal solid waste (MSW) management systems, leading to environmental degradation and resource inefficiency. This study proposes a sustainable MSW management model integrating smart technologies, including waste segregation, recycling, and Waste-to-Energy (WTE) systems. A focused field study was conducted on cattle sheds (Khatals) to quantify organic waste generation and assess its potential for biogas production. The data analysis reveals that proper management of cattle waste alone could mitigate approximately 15 tons of methane annually, significantly reducing the municipality's carbon footprint. This research provides a strategic framework for adopting smart waste solutions in small-to-medium Indian municipalities to foster a circular economy.

Keywords: Municipal Solid Waste, Smart Waste Management, Biogas, Waste-to-Energy, Sustainability, Bishnupur.

INTRODUCTION

The rapid urbanization of Indian cities has triggered a surge in municipal solid waste (MSW) generation, creating critical public health and environmental challenges. Bishnupur Municipality in West Bengal is no exception, where traditional waste management practices—characterized by inefficient collection and open dumping—are struggling to cope with increasing waste volumes. The lack of infrastructure for segregation and recycling has resulted in pollution and the loss of potentially valuable resources (1).

Emerging "smart city" technologies offer a viable solution to these inefficiencies. Innovations such as sensor-equipped bins, AI-powered sorting, and Waste-to-Energy (WTE) systems can revolutionize waste handling by optimizing collection routes and maximizing resource recovery (2). While major metropolitan cities have begun adopting these tools, smaller municipalities like Bishnupur often lack the framework to implement them effectively. This research aims to bridge that gap by modeling a smart waste management framework for Bishnupur. Specifically, it assesses the potential of organic waste recovery—focusing on cattle shed waste—as a pilot for a broader WTE strategy. By quantifying this waste stream, we demonstrate the economic and environmental feasibility of integrating smart technologies into the municipality’s infrastructure.

Background and Study Area

Bishnupur Municipality, established in 1873, is a historic town in the Bankura District of West Bengal. Known for its terracotta temples and heritage tourism, the town faces unique waste management challenges due to its floating tourist population.

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- Demographics: The municipality comprises 19 wards with a population of approximately 88,481 (growth rate of 2%).
- Land Use: The total municipal area is 22.02 sq. km, dominated by residential zones (10.02 sq. km) and agricultural land (2.60 sq. km).
- Waste Profile: The town generates approximately 72–82 MT of solid waste daily. A sample analysis reveals a composition of 53.3% plastics, 33.3% biodegradables, 6.7% paper, and smaller fractions of metals and glass.

Currently, waste is disposed of in low-lying open dumps 4 km from the town center, posing severe risks to groundwater quality and air hygiene.

Smart Waste Management: Literature Review

The integration of Information and Communication Technology (ICT) in waste management is transforming urban sustainability.

- Smart Collection: Internet of Things (IoT) sensors in waste bins can monitor fill levels in real-time, optimizing collection logistics and reducing fuel consumption (1)(7).
- AI Segregation: Artificial Intelligence and machine learning algorithms are increasingly used to automate waste sorting, significantly improving the purity of recyclable streams compared to manual sorting (4).
- Waste-to-Energy (WTE): Technologies such as anaerobic digestion are critical for managing organic fractions. Studies indicate that converting biodegradable waste into biogas not only reduces landfill volume but also produces renewable energy, aligning with circular economy principles (2)(5).

While cities like Bengaluru and Chennai have successfully piloted RFID-enabled bins and tracking systems (7), smaller towns require adapted, cost-effective models.

METHODOLOGY

To assess the feasibility of a smart organic waste management system, this study focused on a high-yield organic waste sector: Cattle Sheds (Khatals).

Data Collection

A comprehensive survey was conducted across the municipality's cattle sheds using direct field interviews and GPS mapping. Key data points included:

- Geo-location and Ward number of each shed.
- Number of livestock.
- Daily fresh cow dung generation (measured in kg).
- Current disposal methods.

Data Analysis

The collected data was analyzed to estimate total organic load and potential environmental benefits:

- Quantification: Total daily dung generation was aggregated from all surveyed units.

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- Emission Modeling: Methane (CH_4) emissions were calculated using standard emission factors (1 kg fresh dung ≈ 0.023 kg CH_4 if unmanaged).
- Reduction Potential: We estimated the reduction in Green House Gas (GHG) emissions achievable through anaerobic digestion (biogas plants).

RESULTS AND DISCUSSION

Waste Generation Analysis

The field survey indicated that cattle sheds in Bishnupur generate approximately 1,900 kg of fresh cow dung daily. Currently, much of this waste is managed informally or discharged into drains, contributing to sanitation issues.

Environmental Impact and Methane Reduction

Unmanaged organic waste is a significant source of methane, a potent greenhouse gas.

- Baseline Emissions: Without intervention, the daily generation of 1,900 kg of dung releases approximately 43.7 kg of CH_4 per day, totalling ~15,950 kg of CH_4 annually.
- Mitigation Strategy: Implementing biogas digesters could capture 90–95% of these emissions. This would result in an annual reduction of approximately 15,150 kg of methane.
- Carbon Equivalent: Given that methane has a Global Warming Potential (GWP) 28–34 times that of CO_2, this reduction is equivalent to preventing nearly 420 metric tons of CO_2 emissions per year.

Proposed Smart Framework

Based on these findings, we propose a modular smart management system for Bishnupur:

1. Smart Collection: Deploy IoT-enabled bins at major cattle sheds and market areas to alert collection trucks when full.
2. Decentralized Biogas Units: Establish small-scale biogas plants near high-density cattle sheds to process the 1.9 MT/day load locally, reducing transport costs.
3. Data Integration: Use a central digital dashboard to monitor waste inflow (from smart bins) and energy output (from biogas units), allowing municipal authorities to track efficiency in real-time.

CONCLUSION

This study demonstrates that Bishnupur Municipality holds significant potential for sustainable waste management modernization. The current reliance on open dumping is unsustainable given the town's growth and tourist influx. Our analysis of the cattle shed sector alone reveals that targeted organic waste processing can mitigate over 400 tons of CO_2-equivalent emissions annually while producing renewable energy.

By adopting the proposed smart framework—integrating sensor-based collection and waste-to-energy processing—Bishnupur can transition from a linear "dumping" model to a circular economy. This approach serves as a scalable template for other small-to-medium Indian municipalities aiming to balance urbanization with environmental stewardship.

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