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Optimizing Household Solid Waste to Resource Management in Rajshahi Metropolitan City

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ABSTRACT: Urban solid waste management poses an urgent environmental and public health crisis in rapidly growing Asian cities like Rajshahi, Bangladesh. The city's explosive urbanization and limited resources have led to indiscriminate dumping and severe health hazards. This study seeks to develop sustainable strategies to transform household solid waste management, addressing critical deficiencies, exploring innovative solutions, and evaluating their environmental and health impacts. Employing a mixed-methods approach, data were collected from 349 residents between January and April 2024. A structured questionnaire assessed socio-demographic attributes (age, education, household income) and waste management practices (segregation habits, disposal methods, recycling awareness, environmental impact perceptions, and willingness to adopt sustainable practices). Analysis of the responses revealed a daily waste collection rate from households (61%), a high level of awareness regarding environmental health risks (86.53%), and significant barriers to financial willingness to contribute to enhanced waste management services (34.38%). This study highlights the critical need for immediate and effective waste management interventions in Rajshahi, providing actionable recommendations to mitigate environmental degradation and protect public health.

KEYWORDS: Household Solid Waste, Solid Waste Management, Waste to Resources, Renewable Energy, Hazardous Waste, Socio-economic factors, Urbanization, Public Health, Environment

1. Introduction

Bangladesh, a densely populated developing country, features Rajshahi as a significant urban center in its northern region, recognized for its educational and business contributions. With a population of approximately 984,000 (Haque 2010), Rajshahi ranks as the fourth-largest city in Bangladesh. Over recent years, the city has undergone remarkable development, transforming into one of South-East Asia's picturesque urban landscapes. However, this progress is shadowed by the critical challenge of managing household solid waste, which profoundly impacts the city's environmental sustainability and public health.

In most developing countries, including Bangladesh, the challenges associated with solid waste management are more acute compared to developed nations. A lack of financial resources and infrastructure creates a vicious cycle: insufficient resources lead to low-quality service provision, reducing public willingness to pay for these services (Afroz, Hanaki, and Hasegawa-Kurisu 2009), which further diminishes the resource base. Rapid population growth and urbanization exacerbate these issues, increasing the

volume of waste generated and overwhelming municipal waste retrieval and disposal services (Alamgir and Ahsan 2007). Effective municipal solid waste (MSW) management is crucial, yet cities face numerous obstacles at every stage of the MSW value chain.

The Rajshahi City Corporation (RCC) employs systematic waste management practices, including daily sweeping, waste collection, transportation, and processing using heavy machinery. Despite these efforts, significant challenges persist in managing household waste effectively, with only a portion of the waste being properly disposed of in landfills. RCC operates a single dumping station in 'Citir Hat,' spanning 10 acres, which has become a large waste mountain over time (Habib 2015). Additionally, the station's sole medical waste incineration plant is insufficient for the city's waste volume, indicating a critical capacity shortfall.

The improper disposal of solid waste, particularly through open-air dumping, poses significant health and environmental risks in Rajshahi, leading to unhygienic conditions, noxious odors, and the spread of disease (Ezema 2009). The mishandling of hospital waste exacerbates these hazards, while landfill decomposition produces harmful gases that contribute to environmental degradation.

Given this context, the primary aim of this study is to explore the perceptions and preferences surrounding household solid waste management practices in Rajshahi, Bangladesh. This study's overarching goal is to propose sustainable and efficient strategies for urban development that can mitigate these challenges.

Specifically, our study objectives are as follows:

1. Identify the shortcomings of the current household solid waste management practices in Rajshahi.
2. Evaluate the environmental and health risks associated with the ineffective management of solid waste in households.
3. Investigate technical solutions for converting household solid waste into valuable resources and assess their feasibility and effectiveness.

2. Methods

2.1. Study Design and Recruitment

This mixed methods study assessed household solid waste management practices in Rajshahi Metropolitan City. A cross-sectional design was employed, utilizing a multi-stage random sampling technique to select a representative sample of 349 respondents from diverse demographic segments within the city (Kotary 2015, 179.). Household recruitment involved selecting two roads from each ward and five houses from each chosen road. Additionally, the sample included 49 employees from various positions within the RCC, ranging from the mayor to cleaning and waste management personnel. The study focused on residents aged 18 and above who had resided in the area for more than two years.

2.2. Data Collection

A structured questionnaire, validated by experts and translated into Bengali, was administered from January 2024 to April 2024 to assess: (1) socio-demographic attributes such as household income, and education, (2) evaluate waste management practices including segregation habits, disposal methods, recycling awareness, perceptions of environmental impact, and (3) willingness to adopt sustainable practices. The survey underwent validation and refinement with healthy adult volunteers to ensure readability, clarity, and appropriate literacy level before administration.

2.3. Data Analysis

Data analysis utilized IBM Statistical Package for Social Sciences (SPSS) (IBM Version 25.0). Descriptive analyses presented frequency distributions and percentages for socio-demographic patterns, waste disposal methods, and perceptions towards waste management. The Chi-square goodness of fit test was employed to assess relationships between categorical variables, while chi-square bivariate correlation tests examined correlations between waste segregation perceptions and socio-demographic factors. Principal component analysis (PCA) was conducted to identify variable groupings and interrelations, with the Kaiser-Meyer-Olkim (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity used to evaluate data suitability for exploratory factor analysis.

3. Results

This study aims to present the findings from the survey conducted among 349 respondents in RCC. The results are organized to address the three primary objectives of this research: (1) identifying shortcomings in current waste management practices, (2) evaluating environmental and health risks, and (3) investigating technical solutions for waste conversion.

Objective 1: Identify the shortcomings of the current household solid waste management practices in Rajshahi

Current Waste Management Practices: The survey indicated that 97.13% of households have waste collection services (Figure 1), predominantly provided by the local city authority (95.1%, Table 1). However, the frequency of collection varies, with 61% of households having daily waste collection, while others experience less frequent collections (Table 2).

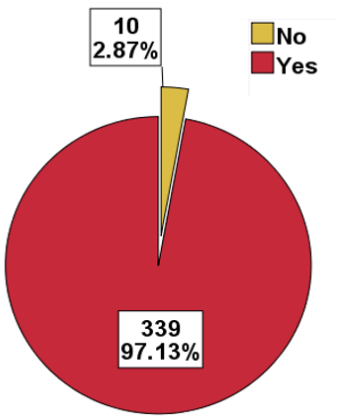

Figure 1. Distribution of Household Waste Collection Services Among 30 Wards (n=349)

Table 1. Methods and Frequency of Household Waste Collection (n=349)

Method	Frequency	Percent Frequency (%)
Local City Authority	332	95.1
Private Waste Collector (Constructor)	1	0.3
Do Not Know	10	2.9
Others	6	1.7
Total	349	100

Table 2. Frequency of Household Waste Collection from 30 Wards (n=349)

Pattern	Frequency	Percent Frequency (%)
Everyday	213	61
Every Other Day	94	26.9
Bi-Weekly	8	2.3
Once a Week	3	0.9
Do Not Know	13	3.7
No Schedule	16	4.6
Other	2	0.6
Total	349	100

Satisfaction with Waste Collection: The satisfaction level with the current waste collection system is relatively high, with 65.04% of respondents satisfied and 14.04% very satisfied. However, a notable 18.62% are dissatisfied, highlighting areas for improvement (Figure 2).

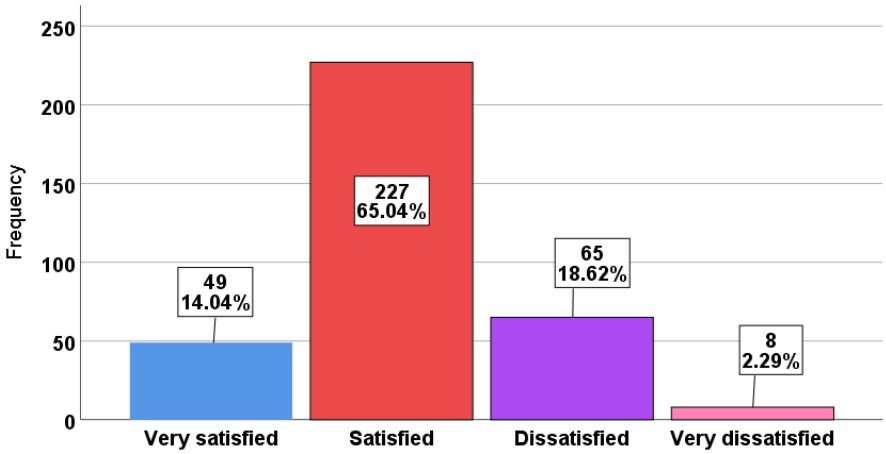

Figure 2. Satisfaction Levels with Waste Collection Services (n=349)

Summary Statistics of Household Waste Generation: Household waste generation statistics show an average daily waste production of 1.668 kg per household, with significant variability (Table 3). This variability indicates inefficiencies in waste generation and collection practices that need to be addressed.

Table 3. Summary Statistics for Household Income and Waste Generation (n=349)

Statistics	Total household monthly income (Taka)	Kilograms (kg) of waste in three days	Kilograms (kg) of waste in one day
Mean	26392.550	5.017	1.668
Median	20000	6	2
Mode	20000	3	1
Minimum	0.000	1	0.300
Maximum	110000	20	6.700
Range	110000	19	6.400
Standard deviation	16419.537	2.401	0.801
CV	62.213	47.857	48.022
Skewness	1.637	1.585	1.595
Kurtosis	3.780	5.239	5.289
Total respondents	349	349	349

Objective 2: Evaluate the environmental and health risks associated with the ineffective management of solid waste in households

Health and Environmental Awareness: A significant majority of respondents (86.53%) perceive the current waste management situation as harmful to human health (Figure 3). Additionally, nearly half (49.86%) of the respondents are worried about the impact of improper waste management on environmental quality (Figure 4). These perceptions underline the urgent need for improved waste management practices to mitigate health and environmental risks.

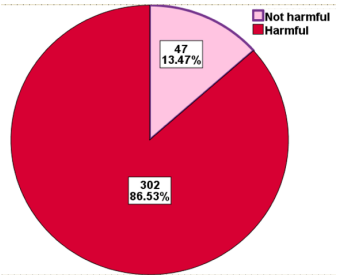

Figure 3. Perceived Environmental Health Risks from Ineffective Waste Management (n=349)

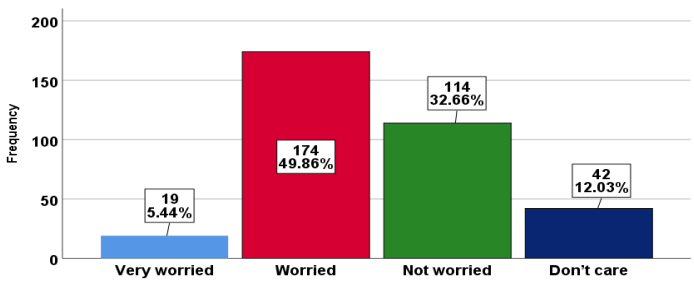

Figure 4. Awareness Levels of Environmental Quality Among Residents (n=349)

Objective 3: Investigate technical solutions for converting household solid waste into valuable resources and assess their feasibility and effectiveness

Household Willingness to Pay for Better Waste Management: The willingness to pay for better waste management systems is limited, with only 34.38% of respondents expressing willingness to contribute financially (Figure 5). This suggests that while there is recognition of the problem, financial constraints may hinder the implementation of advanced waste management solutions.

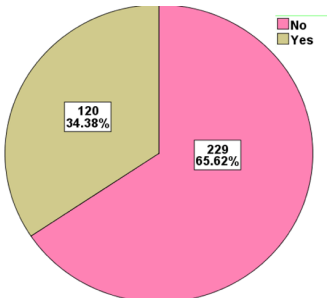

Figure 5. Willingness to Pay for Enhanced Waste Management Services (n=349)

Current Awareness and Education on Waste Management: Awareness about waste reduction is relatively high, with 60.17% of respondents familiar with the concept (Figure 6). The analysis also shows significant associations between education level and income (Table 4), suggesting that educational initiatives could play a crucial role in promoting effective waste management practices.

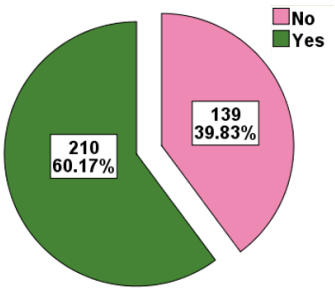

Figure 6. Respondents' Awareness of the term "Waste Reduction" (n=349)

Table 4. Correlation of Educational Qualification and Monthly Family Income.

Educational Qualification	Monthly Family Income (Taka)
No Formal Education	<5000
Primary Education	5000-10000
Secondary Education	10001-20000
Higher Education	20001-30000
Graduate Studies	30001-40000
Post-Graduation	40001-50000

4. Discussion

4.1. Limitations of current household waste management in Rajshahi

Efficient management of MSW is crucial for sustainable urban development in Rajshahi, Bangladesh. This study reveals several significant limitations in the city's current waste management practices, with dire implications for its residents. Firstly, the prevalent practice of open dumping persists due to inadequate infrastructure and resource constraints. This practice not only contributes to environmental degradation by leaching harmful chemicals into soil and water sources but also poses serious health risks to nearby communities. Open dumpsites attract disease vectors such as rats and mosquitoes, which spread illnesses like dengue and malaria, while the foul odors create an unbearable living environment. For residents living near these dumpsites, daily life is marred by a constant threat to their health and well-being, exacerbating respiratory issues and other health problems.

Secondly, there is a notable lack of awareness and adherence to waste segregation practices among households. Mixed waste streams containing organic, recyclable, and hazardous materials complicate waste management processes and reduce the efficiency of recycling efforts (Hondo and Arthur 2020). Without proper segregation, recyclable materials like paper and plastics become contaminated, rendering them less valuable and harder to process, which further increases operational costs (Zhuang et al. 2008). This results in missed opportunities for improved sanitation and reduced waste-related expenses for residents, as well as increased pollution and health risks from improperly managed hazardous waste.

Thirdly, the high-water content and organic composition of household waste, particularly food waste, hinder the recovery of recyclable materials and escalate operational costs. The organic fraction decomposes rapidly, producing methane—a potent greenhouse gas—if not managed properly (Enayetullah et al. 2005). Moreover, Rajshahi's waste management infrastructure struggles to keep pace with the city's growing waste generation, leading to inefficiencies in collection and disposal services. Limited collection frequency and inadequate processing facilities exacerbate these challenges, resulting in overflowing bins and illegal dumping. For residents, this means frequent exposure to uncollected waste, increased health risks, and a degraded urban environment. The constant presence of waste contributes to a pervasive sense of neglect and despair in the community, undermining efforts to improve public health and environmental sustainability.

4.2. What are the environmental and health hazards of ineffective waste management, and how can they be minimized?

In Rajshahi City, inadequate waste management practices pose significant public health risks. The reliance on open dumping and insufficient waste segregation leads to severe water contamination, introducing hazardous chemicals and pathogens that increase the risk of waterborne diseases like cholera and dysentery, particularly affecting children and the elderly (Rahman 2005). This contamination also strains healthcare facilities and escalates medical expenses. Moreover, hazardous substances leaching from waste, such as heavy metals and toxic chemicals, compromise soil quality and contaminate local food supplies. These contaminants enter the food chain, contributing to chronic health issues such as neurological disorders, developmental problems, and various cancers, disproportionately affecting vulnerable populations near waste disposal sites and perpetuating health disparities.

Air quality is also severely impacted by uncontrolled waste burning, releasing harmful pollutants like dioxins and furans (Bartone 2000). These toxic substances contribute to a rise in respiratory illnesses such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). The presence of fine particulate matter exacerbates these conditions, particularly affecting young children, pregnant women, and the elderly. Long-term exposure to these pollutants can lead to severe cardiovascular diseases and cancer, posing a lasting threat to public health.

To mitigate these urgent public health challenges, Rajshahi City requires comprehensive interventions. Enhancing community education on proper waste segregation and incentivizing participation can significantly improve recycling rates and reduce contamination levels. Public awareness campaigns should emphasize the severe health impacts of improper waste disposal, fostering a collective commitment to responsible waste management practices (Goel 2008). Furthermore, strengthening policy frameworks and regulatory oversight will ensure compliance with sustainable waste management practices, safeguarding public health and preserving environmental quality. Enforcing regulations against open burning and illegal dumping is essential for protecting public health.

4.3. Are technical methods for converting household waste into resources practical and economically advantageous?

Technical methods for converting household waste into resources offer significant promise for enhancing waste management systems and promoting sustainability in Rajshahi. Recycling processes can reduce the volume of waste sent to landfills and conserve natural resources. However, high moisture content and contamination from food waste often hamper the efficiency of these processes (Schübeler, Christen, and Wehrle 1996). Implementing source separation systems can significantly improve recycling efficiency.

Rajshahi should consider advanced treatment technologies, such as pyrolysis and gasification, which decompose organic waste at high temperatures in low-oxygen environments to produce syngas, biochar, and other valuable by-products (Parajuli 2016). These technologies offer high conversion efficiency and lower environmental impacts compared to traditional incineration. Such methods can convert waste into useful resources, provided there is proper implementation, public participation, and investment in the necessary infrastructure.

Waste-to-Energy (WTE) technologies, including incineration and anaerobic digestion, offer additional solutions (Tchobanoglous, Theisen, and Vigil 1993, 7). Incineration reduces the volume of waste significantly and generates energy, though it must be carefully managed to minimize air pollution. Anaerobic digestion processes organic waste in the absence of oxygen, producing biogas that can be used as a renewable energy source (Tchobanoglous, Theisen, and Vigil 1993, 7). These methods not only reduce waste volume but also provide alternative energy sources, contributing to energy sustainability.

Municipal authorities could also initiate programs like supplying every household with plastic buckets for waste segregation, supporting efficient source separation and management (Zhuang et al. 2023). This approach, coupled with public education and incentives, can enhance waste segregation practices, reduce contamination, and facilitate the recovery of valuable recyclables. By investing in these technologies and engaging the community, Rajshahi can achieve more sustainable and economically beneficial waste management outcomes.

4.4. Limitations

Time constraints posed challenges in conducting key informant interviews and discussions with city officials, including the City Mayor, potentially limiting the depth of insights into municipal waste management policies and strategies. Additionally, the qualitative assessment relied on self-reported attitudes and perceptions, which could introduce recall and social desirability biases. Future research could broaden its scope to include diverse populations in various cities across Bangladesh and other developing countries, thereby enhancing the generalizability of findings and providing a comprehensive understanding of waste management practices. This expansion could offer valuable insights into environmental sustainability and public health on a broader scale.

5. Conclusion

Effective household solid waste management is crucial for sustainable and livable cities, particularly in developing countries like Bangladesh. Despite its critical importance, waste management remains hindered by financial constraints. Integrated, efficient, and socially supported systems are essential to tackle these challenges. Moving forward, collaborative efforts are imperative to document and disseminate local innovations, ultimately enhancing the quality of life and environmental sustainability in Rajshahi. Continued research is essential, particularly in addressing persisting issues such as lack of education and misinformation in this evolving field. Engaging with stakeholders, including residents and practitioners, is vital to develop more effective approaches and ensure sustainable urban development.

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