An Economic Evaluation of Solid Waste Management in Uttar Pradesh: Insights from Lucknow

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Abstract — This study attempts an economic evaluation of solid waste management (SWM) in Uttar Pradesh, specifically in the city of Lucknow. It analyzes waste generation, composition, collection systems, and disposal practices, offering valuable perspectives on the SWM challenges and capabilities within the city. Results show that about 47% of waste is organic waste, making the proper separation between different types of waste essential to reduce transport costs and reduce the impact on the environment. Despite positive step-changes in waste collection, such as the roll-out of a range of vehicles and smart bins, challenges like wet waste disposal or under-delivery on waste-to-energy solutions remain challenges. This way, analysis of the impact of MSW disposal highlights adverse effects on soil and water supply. The study calls for better practices, like the use of liners to reduce leachate contamination. As the study compares the systems of Lucknow against those of Delhi, it highlights a gap between the two cities, where Lucknow can benefit from a more economical, yet effective waste-to-energy systems based on this study, while in the longer run, it reiterates the necessity of integrated waste management system for sustainable economic and environmental development.

Keywords: Waste Segregation, Organic Waste, Municipal Solid Waste (MSW), Solid Waste Management (SWM), and Waste-to-Energy

I. INTRODUCTION

A major urban difficulty that many cities face is solid waste management (SWM), especially in developing countries like Uttar Pradesh, India [1]. The state capital, Lucknow, must find sustainable solutions to the massive problem of municipal solid waste (MSW) in both an economic and environmental sense. This study estimates the economic and environmental implications of SWM practices in Lucknow based on waste generation, composition, collection systems and disposal methods. The results show that organic waste constitutes almost 47% of the total waste produced in the city which points to the critical need for proper segregation at the source to help reduce transportation cost and environmental impact [2]. While there have been advancements in terms of waste collection methods (utilizing various kinds of vehicles for portability and smart bins for efficient disposal), some major challenges remain; including improper disposal methods and waste-to-energy systems not yet fully applied. Furthermore, geotechnical studies of soil and groundwater around MSW disposal locations report adverse environmental effects, including the decrease in soil strength and alteration in water sources [3]. The study reinforces the importance of using best practices with waste management including the use of liners to prevent leachate from contaminating the surrounding soil. This study makes a comparison between waste management practices of Lucknow with that of cities like Delhi to identify opportunities to adopt more efficient and sustainable waste-to-energy practices. The results emphasize how crucial integrated waste management strategies are to long-term environmental and economic sustainability [4].

II. LITERATURE REVIEW

Economic appraisal of solid waste management (SWM) of Uttar Pradesh specifically in Lucknow is essential to understand its operational effectiveness, expenditures, financial management and eventual impacts on environment from disposal and treatment of MSW. The present review discusses studies, which are carried out on waste generation, composition, collection system and disposal practice in urban areas. It emphasizes the critical role of efficient waste separation, advanced technology integration, and energy-from-waste systems in enhancing economic and environmental results. Importance of Lucknow Insights from Lucknow can guide the sustainable waste management strategies of other urban areas of India.

Summary of Literature Review

Author’s	Work Done	Findings
Tirkey, S. (2022)	study of solid waste management from a theoretical perspective.	Focuses on conceptual and theoretical frameworks for solid waste management, offering insights into best practices and challenges faced by municipalities.
Taweekun, J. (2021)	A review study on municipal solid waste management and waste-to-energy technologies.	Highlights advances in waste-to-energy technologies, such as incineration and gasification, and their role in reducing landfill waste.
Taweekun, J. (2021)	An overview of waste-to-energy technologies and municipal solid waste management.	Discusses various waste management strategies, evaluating the effectiveness of different technologies in waste minimization and energy recovery.
Singh, S. (2020)	An analysis of technology alternatives for decentralized solid waste management in India.	Focuses on the decentralization of waste management, presenting technological options suitable for Indian cities to manage solid waste locally.

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Jain, S. (2019)	Overview of municipal solid waste generation, composition, and management in India.	Provides an overview of the types of waste generated in India, its composition, and current waste management practices in urban areas.
Pandey, B. W. (2019)	investigating Meerut, Uttar Pradesh's municipal solid waste management system.	Investigates the municipal waste management system in Meerut, identifying gaps in collection, segregation, and disposal processes.
Jain, A. (2018)	An analysis and plan for the management of municipal solid waste in Aligarh City, Uttar Pradesh, India.	analyzes Aligarh's waste management procedures and makes recommendations for enhancements to boost resource recovery and waste segregation.
Ahmed, S. (2016)	An overview of India's municipal solid waste management situation and issues.	outlines possible solutions and talks about the main issues facing municipal solid waste management, such as a lack of infrastructure and public awareness.
Singh, S. (2016)	India's policy strategy for sustainable municipal solid waste management.	suggests sustainability tactics and policy frameworks to enhance solid waste management while minimizing environmental effect.
Srinivasarao, M. (2014)	An overview of municipal solid waste management in India, along with some recent findings.	Reviews existing waste management methods and introduces new findings on the efficiency of different waste handling techniques in India.
Srivastava, R., et al. (2014)	A case study of Varanasi, India, focusing on the management and characterization of municipal solid waste.	Analyzes the waste management situation in Varanasi, identifying major challenges and proposing practical solutions for waste collection and recycling.
Shalini, C., et al. (2012)	research on solid waste management in Lucknow's various socioeconomic brackets.	examines how income affects garbage generation and management in Lucknow, emphasizing the differences in how waste is handled by various social classes.

A. *Research Gap*

Even though a lot of research has been done on the various facets of India's solid waste management (SWM) in relation to trash generation, segregation, and disposal, etc., very few studies have hitherto examined the economic and environmental effect of SWM measures in UP and, more particularly in Lucknow. Furthermore, although there is discussion around improved technologies for waste collection as well as waste-to-energy solutions available, there are gaps in understanding how effective these systems actually are in mitigating environmental degradation or supporting economic efficiency, especially in the case of fast-growing cities like Lucknow

III. PROBLEM STATEMENT

The problem addressed in this study is the inefficient and unsustainable management of municipal solid waste (MSW) in Lucknow, Uttar Pradesh. Despite improvements in waste collection systems, challenges like improper disposal, limited waste-to-energy initiatives, and environmental contamination persist, requiring integrated solutions.

IV. METHODOLOGY

Techniques The economic aspects of managing municipal solid waste (MSW) in Uttar Pradesh, with a particular emphasis on Lucknow, are primarily predicated on organized data regarding the generation, composition, collection, disposal, and environmental aspects of trash. Based on the amount of MSW generated in the city, this study evaluates the economics of waste management systems, and indicates that the MSW has a composition of 47, 17 and 16% organic waste, recyclables and construction debris, respectively, translated into a total generation rate of 1600-1700 metric tons per day. Data on collection and transportation were extracted from the city's waste management practices, incorporating a variety of vehicles rickshaw trolleys, handcarts and compactor trucks operating across 110 wards. The study also evaluates the financial benefits of waste segregation initiatives, which prompt residents to segregate wet and dry waste and, in turn, decrease transportation and processing costs. Moreover, the research also examines the environmental cost of indiscriminate waste disposal by geotechnical characterization of soil samples in the vicinity of the MSW dumping site and found adverse implications on soil strength, permeability, and compressibility. Analysis of groundwater quality adds an extra dimension with local aquifers being impacted, resulting in potential public health risks and increased costs in the long term. Comparing it with other Indian cities like Delhi can give a clearer picture of waste-to-energy practices that also appear to be efficient. Finally, we discuss the economic implications of using liners to sequester leachate contamination, as well as the necessity for improved management practices for both economic and environmental sensibility.

V. RESULT & DISCUSSION

A. *Municipal Solid Waste Generation, Composition, and Disposal System in Lucknow*

According to Google Earth, Lucknow is about 123 meters above sea level and occupies about 402 square meters (as of December 2019). [5] square kilometers and lies between 26°55' latitude north and 80°59' longitude east. Under a 2021 Master Plan, the city is divided into 8 zones to help organize the management of services to residents. This increased number of 8 versus the 6 zones included in the 2011 Master Plan was introduced to facilitate management issues within the city limits.

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1) Generation:

In Lucknow, organic waste makes up 47% of the Municipal Solid Waste (MSW), followed by recyclables at 17%, construction and demolition debris at 16%, mixed rubbish at 11%, and street sweepings and drain silt at 9%. The creation of new business districts and a boom in housing developments are contributing to the city's rapid urban growth, which is raising the amount of municipal solid garbage produced. Currently, between 1600 and 1700 metric tons of trash are created per day [6].

2) Collection:

In Lucknow, waste collection is done in two phases. Around areas like Gomti Nagar and Indira Nagar, the sweepings and small heaps of waste are collected and taken to secondary collection points in front of Nagar Nigam. The city introduced a fresh waste management model in 2022 a streamlined system where multiple types of vehicles collect waste from the city's of 110 wards. Collection of household waste is done through rickshaw trolleys and hand carts from 57 wards in the city and the remaining 53 wards, the residents dump waste in adjacent Dhalaos (waste storage points) or road bins [7]. For solid waste, dirt is swept from the streets and collected with barrows and disposed of directly at 52 depots. The waste is loaded onto trucks from these depots and taken to disposal sites.

3) Segregation:

The waste collection in Lucknow is done by the segregated waste, separating the waste from households as well as from the markets and shopping malls. The waste is compacted to reduce volume before it is shipped to disposal sites to reduce cost of transportation and environmental impacts during transportation [8]. These are being used in an integrated waste management system that the city is actively working to enhance with improved sustainability and public health results. Residents are advised to separate waste as wet (organic) and dry (inorganic) materials before handing it over to collectors. Collection is conducted daily in all but low-density or outlying regions, where the frequency is reduced to alternate days in most areas.

Sources	Restaurants	Street sweeping	Market	Shops	Workshop	Offices	Hospitals	Hotels
Contribution (%)	44	26	6.8	8.3	7.5	4.2	1.7	1.5

Table 1: Sources of municipal solid waste.

Category of vehicle	Total number of vehicles	Capacity
Ricks haw trolleys	500-600	200-250kgpertrip
Handcarts	300-400	100-150kgpertrip
Compactor trucks	60-80	5-10metrictonspertruck
Minitippers	100-150	1-1.5metrictonspertrip
Dump trucks	50-60	5-12metrictonspertrip
JCB and loaders	20-30	Dependent one equipment, generally used for bulk waste collection

Table 2: Vehicles used in waste collection (LNN) in Lucknow city.

4) Transportation:

At present, municipal solid waste in Lucknow is carried from its source (houses) to feeding point (vehicle aggregation point) by the vehicles of Lucknow Nagar Nigam (LNN) and no private tractors. There are 48-54 trucks and approximately 100 Chhota Haathi vehicles, which transport waste from primary and secondary locations. They are fitted with GPS systems to track routes and facilities for on-time collection [9]. Lucknow is also getting smart bins that have sensors to report when they are full, enabling optimal frequency of collection. The city has also been enhancing its waste collection strategy with well-designed campaigns and partnerships with private sector operators to make collection seamless. It was observed that waste processing in Lucknow is done LMC Lucknow Municipal Corporation and not by private contractors during our on-site visit. Dumpsites were traditional in nature and poorly managed historically. Such sites in congested areas like the vicinity of Gomti Nagar Fun Shopping Mall area, Telibagh, Bhattha Maidani and Ghaila (Dubbga) are now shut. In 2017, a waste processing plant called Shivri Plant was also proposed at Phalenda Village, Mohan Road, Lucknow. Its operation is irregular [10]. The plant is spread over 21 hectares of land and has a small concrete sump beside the dump to collect leachate.

5) Waste-to-Energy:

An electricity generation plant has been established in Ghaila on Hardoi-Sitapur Road which is yet to become operational. At present, LNN employs ballistic separators for waste material segregation. Rag pickers and scrap dealers are key players in waste management involving the sorting of non-biodegradable waste such as plastics and paper. These are forwarded to a cement factory as Refuse-Derived Fuel (RDF) after segregation [11]].

B. Influence of Municipal Solid Waste on Soil and Water

1) Soil: Before this, municipal solid waste was being dumped at seven places in Lucknow, mostly low-lying areas and open spaces. To measure the effect of MSW on soil, soil samples were collected from the sites of disposal, at a depth of 1m, 1.5m, and 2m, with control samples being taken from surrounding areas. The samples were tested on geotechnical properties including distribution, consistency limits, packing, permeability, and direct shear strength. These properties were dependent on where the dumpsites were [12]. Moreover, the organic content of dump sites was higher than the control soil sample; therefore, the strength indicators´ values were lower. The specific shear strength parameters, including those of cohesion and angle of shearing resistance, were lower than those of the soil in the dump site, suggesting reduced bearing capacity. The permeability values around the MSW dumpsites varied from 2.11x10-5 cm/sec to 3.15x10-5 cm/sec while it was 4.44x10-4 cm/sec in the control sample. Results showed that the maximum dry density (MDD) of the MSW dump sites, varied between 17.5 kN/m³ and 19.5 kN/m³, whereas the control sample had an MDD of 19.8 kN/m³. As can be observed from the values of the liquid

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limit of the dump site samples (20%–30%), the magnitude of compressibility was greater than that of the control soil (15%).

2) Water: A study performed near the waste dumpsite of Lucknow showed very high concentrations of nitrates, sulfates, phosphates in ground water, suggesting contamination from disposal of MSW. Subsequent studies found that groundwater and surface water in the vicinity of these dumpsites exhibited higher levels of different parameters including calcium (Ca), magnesium (Mg), total alkalinity and total hardness over the WHO and BIS limits. MSW plays a considerable role in overall water quality and local water resources degradation. At waste disposal sites in Lucknow, it has been noted that sulfate, bicarbonate alkalinity, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are higher than the levels established by applicable regulations.
3) Waste Management in Lucknow Compared to Other Cities in India: It has been noticed that out of all the cities in India, Delhi produces the most waste and also has a robust process for converting waste to energy. Conversely, 'The Times of India' notices that in Lucknow, people's waste disposal methods most of the time inappropriately lead to dishes is clogged, and other environmental pressures are added, due to the little waste that is used in energy generation out of the little available waste.
4) Application of Liners in Municipal Solid Waste Management: Liners were not used in Lucknow to optimize groundwater contamination due to leachate in MSW dumping sites. The use of liners to prevent contamination of this type has been investigated in several studies. The self-healing rate was found to be strongest (in the first 48 hours) for puncture holes up to 8 mm wide, while larger holes took up to 72 hours to heal. Furthermore, the 0% BCS and 30% BCS specimens produced close permeability values after 72 hours. Additional studies for longer durations are required to benchmark performance with the larger puncture holes.

In addition, GCL must not have defects to ensure that the anti-seepage performance is always maintained. Under optimized conditions for liner materials, the mix having 24-28 percent bentonite gives desired results, i.e. higher dry density, optimum moisture content, higher cohesion and lower internal friction angle. As its name suggests, sodium bentonite expands, an important characteristic for reaching the required permeability. If clay is used for liners, the clay must have less than 30% gravel, a plasticity index (PI) greater than 10 and an activity (A) of greater than 0.3, where the thickness should be at least 0.9 to 1.0 m for compacted clay liners in municipal domestic waste landfills.

VI. Conclusion

In conclusion Important details about trash generation, composition, collection, and disposal in the city are provided by the technique used to evaluate the economic and environmental effects of MSW management in Lucknow. Since approximately 47% of waste produced is organic, the study suggests that the best way to lower costs and prevent environmental harm from long-distance transportation is to separate it at the source. But that's a far cry from proper waste disposal, as presented in improved waste collection systems, such as the use of various vehicles and the press of smart bins, all of which have proved an insufficient match against one of the greatest challenges in waste management: improper disposal and a lack of waste-to-energy initiatives. When performing geotechnical analysis of soil samples and groundwater near municipal solid waste (MSW) sites, it has been found that the sites negatively affect the surrounding environment, with soils in the area showing less strength, and the water quality being adversely impacted in both groundwater and surface waters. The study demands measure like application of liners used to prevent leachate contamination for proper waste management which is yet not in practice in Lucknow. With appropriately designed waste-to-energy systems, lucknow can avoid such situations, which are currently faced by cities like Delhi. The results as a whole highlight the role of integrated waste management approaches with emphasis on waste minimization, segregation and improved methods of disposal interms of providing economic efficiency and environmental security in the long run.

VII. Future Scope

- Make waste segregation systems more efficient and longitudinal in all wards.
- Study the technical feasibility & economic viability of waste to energy system in Lucknow
- Enquire on how liner systems are actually put in place to prevent groundwater contamination
- Investigate other disposal methods, like composting and biogas production.
- Utilise smart bins and GPS tracking to improve the collection of waste.

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