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Municipal Solid Waste Management System: A Study of Aligarh City, Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Municipal solid waste management (MSWM) is a significant environmental challenge in Indian cities, including Aligarh. Inadequate handling of municipal solid waste (MSW) poses risks to public health and the environment. Studies indicate that approximately 90% of MSW in India is improperly disposed of in open dumps and landfills, leading to various ecological and health issues. A detailed examination of Aligarh's waste management system was conducted to assess the quantity, characteristics, and sustainable management options for its municipal waste. Findings from the study show that private collectors handle about 430 tons of waste per day in Aligarh, but neither residents nor collectors engage in waste segregation at the source. The combined collection efficiency of A2Z Private Limited and the Aligarh Municipal Corporation is estimated to be around 70%. Due to the high organic content in the waste, its energy potential remains untapped. Currently,

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about 80% of the collected waste is disposed of in open dumps, as Aligarh lacks a sanitary landfill. This study highlights the current state of municipal solid waste management in Aligarh focusing on the quantity, quality, and management strategies in Aligarh.

Methodology: For this study, Aligarh, a medium-sized city with a population of roughly 8.7 lakhs, which is located 130 kilometres from Delhi, India's capital, was chosen. A thorough assessment of the literature was done to create a theoretical framework. Visits to fields were carried out to gather basic data and comprehend the city's SWMS, including interaction During interviews with several municipality employees and executives in charge of SWM and citizens of the city. A procedure was created to examine the sources, calculate the amounts, and ascertain the waste streams' makeup.

Findings: Despite their best efforts, the local municipality's limited resources do not allow for the effectiveness of the solid waste management system in Aligarh. On the outskirts of the city, waste is frequently disposed of in open or low-lying regions without using the correct scientific or engineering techniques.

Keywords: Solid waste management; environmental challenge; landfill; recycling; waste management; waste disposal; commercial garbage.

1. INTRODUCTION

Residential and commercial garbage produced by communities is typically included in municipal solid waste (MSW) [1]. Municipal Solid Waste (MSW) is one of the global issues that has to be addressed. MSW is increasing quickly in emerging nations like India due to unchecked urbanization, rising living standards, population growth, and industrial expansion [2]. The volume and complexity of solid waste increase due to urbanization, economic expansion, and rising living standards in cities [3].

In India, rapid industrialization and population growth have spurred migration from rural areas to cities, resulting in thousands of tons of MSW daily. Poor waste collection and insufficient transportation lead to the accumulation of MSW in various places. The management of MSW is currently facing a critical phase due to the lack of adequate facilities for treating and disposing of the large quantities generated daily in metropolitan areas. This improper handling of MSW negatively impacts the environment and human health [4]. Modern solid-waste management in developed countries now focuses on recycling and waste reduction at the source rather than relying primarily on incineration and landfills [5]. India currently generates 0.34 kg of solid waste per capita per day, a figure projected to rise to 0.7 kg per capita per day by 2025 [6]. Despite this relatively low per capita waste generation rate compared to approximately 90% of other countries, India's enormous population results in a total waste production of over 168,403.24 tonnes per day [6]. Planning, and designing the operation of the MSW management system can be done based on composition and the quality of MSW generated shown in Table 1.

Table 1. Contents of municipal solid waste

S. No	Characteristics	Content
1.	Organic content	(51-53%)
2.	Inorganic content	(21-23%)
3.	Paper and clothes	(15-17%)
4.	Plastic	(21-23%)
5.	Food waste	(38-40%)
6.	Construction waste	(28-30%)

Source: [7]

The amount of waste produced in Indian towns and cities is rising daily due to the country's growing GDP and population. With an annual growth rate of 4.25 percent, the amount of solid trash produced in Indian cities climbed from six million tonnes in 1947 to 48 million tonnes in 1997. By 2,047, it is predicted to reach 300 million tonnes. India's GDP is growing at a pace of 9.3% annually and its population is growing at a rate of 2.15 percent annually [8]. This research report is restricted to the case of Aligarh City, where the investigation was carried out. Recommendations are made to enhance the current system further in light of the study's findings.

1.1 Study Area

Located on the old grand trunk route and the Delhi-Kolkata Railway link, Aligarh is the first significant city in the western region of Uttar Pradesh. It is located between the plains of Delhi, the capital city of India, and the Delhi Province, 130 km southeast of Delhi [9,10]. The Yamuna

and Ganges rivers. The district of Aligarh is roughly 5,019 square kilometers, with the metropolis taking up approximately 34 square km. The terrain of the city is a saucer. Formed so that it is situated in a low-lying region with a mean sea level (MSL) of 184.73 meters. Surrounded by places that are rather high-lying. According to the 2011 Census, Aligarh has a population of 8,74,408 comprising 461,636 women and 461,772 men. The district's population density is 1,007 persons per square kilometer, surpassing the state average of 829 persons per square kilometer [11]. The city is located in a low-lying location between the plains of the Ganges and Yamuna rivers, 185 meters above sea level. Because of its saucer-like form, water logging poses a serious threat to municipal cleanliness. With a wet season in between, the weather is hot and dry in the summer and chilly and dry in the winter. Winter temperatures range from 10°C to 1°C, while summer temperatures range from 37°C to 46°C. The city receives roughly 590 mm of rain on average per year. The city is well-known for its Locks manufacturing facilities, a Central University called "Aligarh Muslim University," and a Maratha fort [12]. Fig. 1 shows the location of the study area.

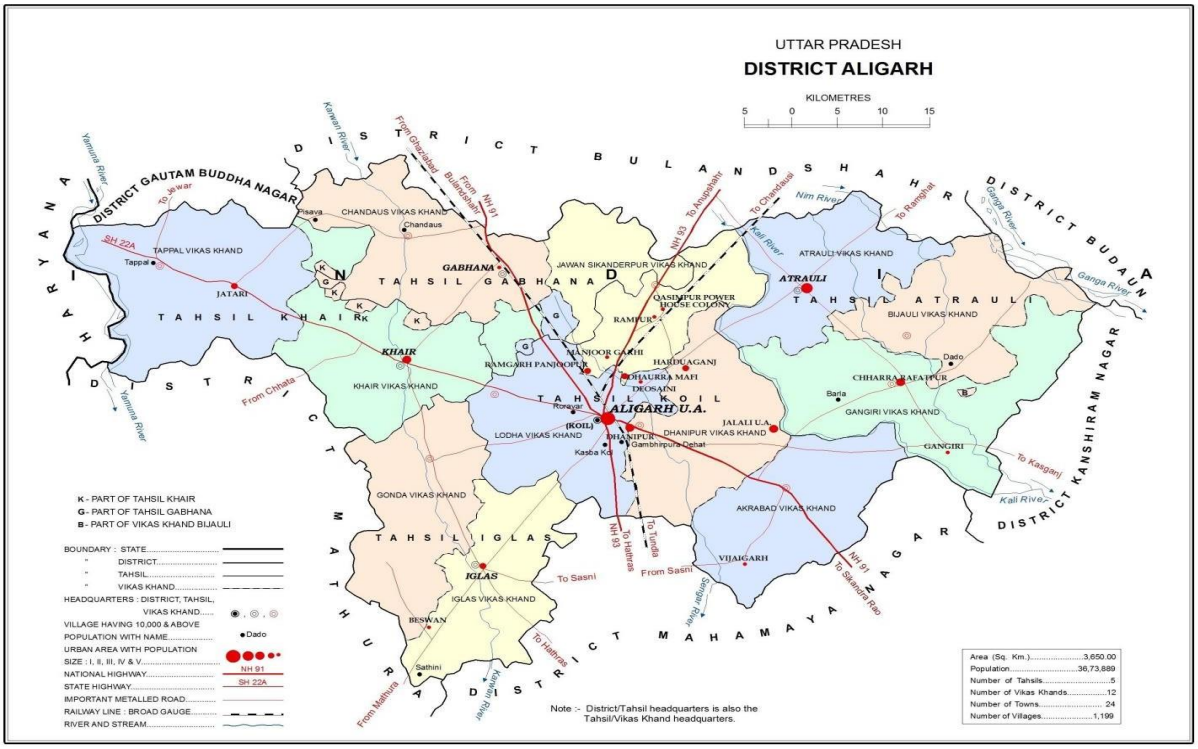

Fig. 1. District map Aligarh

Source: [13]

District Highlights

- *Aligarh district ranks 19th in population size within the state of Uttar Pradesh. The urban population constitutes 33.1% of the district's total population, higher than the state average of 22.3%.*
- *The district's population density is 1,007 persons per square kilometer, surpassing the state average of 829 persons per square kilometer.*
- *Aligarh district ranks 46th in terms of sex ratio with 882 females per thousand males, lower than the state average of 912.*
- *In literacy, the district ranks 41st with a rate of 67.5%, slightly below the state average of 67.7%.*
- *There are 5 Tehsil or sub-divisions and 1210 revenue villages in the district. Aligarh consist 122 panchayat samiti, 2 Nagar Palika and 853 Gram panchayat. It is under Mahanagar criteria [10].*

- *With a decadal growth rate of 22.8%, the district outperforms the state average of 20.2%. There are 361 inhabited villages in Koil Tahsil, more than in Gabhana Tahsil (157).*
- *The district encompasses 24 towns, of which 12 are statutory and census towns, and there have been no additions, mergers, or declassifications since the 2001 census.*
- *Aligarh district has 611,371 households, accounting for 1.8% of the state's total households, with an average household size of 6.0 persons [13].*

2. METHODS

A Haryana-based private company, A2Z, was awarded a contract by the Aligarh Municipal Corporation on a BOOT (Build, Own, Operate, Transfer) basis for 30 years. The company was tasked with managing 220 tonnes per day (TPD) of municipal solid waste (MSW). The total project cost of ₹34.17 crores was financed through a combination of debt, equity, and capital subsidy from the Municipal Corporation. A2Z secured a loan of ₹11.50 crores, and operations commenced in February 2011. The company's responsibilities included door-to-door (D2D) collection, transportation, resource recovery, and disposal of waste remnants in a landfill. A2Z began its presence in Aligarh in May 2010, with the D2D collection starting in June 2011 (Group, n.d.). Although landfilling is an essential part of a well-structured MSWM system, the company failed to meet its objectives, and in January 2014, due to financial difficulties, it reduced its operations from seven zones to just two. The remaining five zones have been managed by the Aligarh Municipal Corporation (AMC) since January 2014. Currently, both AMC and A2Z are working together on solid waste management in the city [14].

Aligarh does not currently have a suitable disposal system. The wastes are being disposed of openly in low-lying areas on the city's periphery. The distance between Aligarh City's disposal sites and the city limits was only five km. Goolar Road, Mathura Road, Quarsi Chilkora, and Quarsi are a few of the disposal locations. Burning the rubbish was caused by disposing of it in a landfill, and most nations still use this standard procedure. Landfills were frequently established in mining voids, borrow pits, and plentiful or underutilized quarries. Waste materials can be disposed of affordably and hygienically by using a landfill that has been carefully planned and maintained.

To accomplish the research goals, a suitable approach and methodology were used to gather data. To create a theoretical framework for the investigation, a thorough examination of the literature was done at the outset. To ascertain the waste stream's composition, a methodology was created. The Municipal solid waste composition and source analysis are based on the process inside the protocol, which moreover comprises questionnaires. The specific aim was to determine the waste generated by residential and commercial units in the study area and the efficiency of waste collection and segregation of waste at the source. In the current investigation,

Table 2. The average quantity of MSW generated per day in Aligarh city

Categories of waste	Quantity in tonnes/day	Items	Percent by weight	Parameters of the Solid Waste	In percent except for Ph and Calorific value
Domestic Waste	340	Organic Content	55.30	Ph	6.4-8.3
Commercial Waste	90	Inert/Stone /Ashes	19.70	Moisture content	15.0-25.0
Institutional Waste	80	Paper	12.80	Volatile Matter	28.0-30.0
Industrial waste	20	Plastic	4.6	Ash	40.0-45.0
Street Waste	30	Wood	0.7	Fixed Carbon	10.0-12.0
Total waste- 560 tonnes/day		Bones	2.4	Calorific Value	1500-1800(Kcal/Kg)
		Metal	1.9	Compostable Matter	13.0-15.0

Source: [14]

material was gathered from both primary and secondary sources. Interviews with different Municipal Corporation SWM officials (from the departments of engineering, health, and city cleaning) are one source of primary data. Municipal employees (drivers, sanitary workers, inspectors of sanitation, etc.), citizens of the city, pertinent parties, and the unofficial recycling sector. Domain observations were made to confirm the respondents' claims relating services for collecting garbage. Among the secondary information sources are current reports published by the Municipal Corporation.

2.1 Operation and Practices Done by AMC

The four main functions of the solid waste management (SWM) system are collection, transportation, disposal, and street cleaning. The MSW is transported and disposed of by the AMC Transportation Department, while the Public Health Department handles the cleaning and collection activities.

The city is divided into the so-called City Area and Civil Lines Area by the Delhi-Kolkata railway line. Solid waste management in the municipal area is regulated by seven sanitary zones: Baradwari, Achal Taal Road, Jaigang Thana Sasni Gate, Turkmaan Gate, Uday Singh Jain Road, Ganta Ghar Kachahri Road, and Ramghat Road. Five of the seven sanitary wards are in the City Area, while two are in the Civil Lines Area. The goal of dividing these seven zones into a total of seventy sanitary wards is to facilitate the collection and transportation of solid waste. The given graph shows the ward-wise population of Aligarh.

2.2 Organization Structure for Public SWM Services

Among its other responsibilities, Aligarh Municipal Corporation is in charge of managing the MSW produced in the city. The assignments have been given to AMC's Public Health Department. The public health department is in charge of food adulteration, street cleaning, sanitation, and epidemic control. Within the AMC, there is a distinct and robust hierarchy of jobs. The Mayor, who is chosen for a five-year term in office, is the top authority within AMC. A City Commissioner reports to the Mayor. Under the city commissioner, there is an Executive Officer who oversees several departments, each headed by a department head, including public health, water and works, public works, house tax, lighting, projected tax, demand, and a workshop.

The following are the personnel in the Public Health Department and their responsibilities:

Health Officer: The chief of the public health department is called the health officer (H.O.). For an average of five years, he or she is a licensed professional physician on deputation from the medical health department. His/her primary responsibilities include supervising sewage line operations, street sweeping collection and disposal, and other public health initiatives including immunization and epidemic control.

Chief sanitary and food inspector: A city the size of Aligarh typically has two positions: head sanitary inspector and food inspector. They support the health officer as they carry out their responsibilities. They supervise every sanitary ward's operation. They are science graduates who ought to have finished a year-long program to become sanitary inspectors.

Sanitary and food inspector: The positions of food and sanitary inspectors total seven. They are in charge of the hygienic wards that have been given to them. They report to the chief food and sanitary inspector. A bachelor's degree is required for this position in education.

Sanitary Supervisor: In the designated sanitary ward, the sanitary supervisor reports to the food and sanitary inspectors. Each ward at AMC has a sanitary supervisor or roughly seventy in total. Sanitary supervisors are accountable for maintaining appropriate sanitation standards and hygiene in their assigned sanitary wards. To achieve this, they regularly conduct field surveys, monitor and oversee the daily cleaning of streets, and de-silt tiny roadside drains. They either finished a year-long certificate program following high school or are at the intermediate school level.

Sweepers: They are in charge of collecting the majority of the rubbish and cleaning the streets. They gather the drain cleanings and sweepings, then push them on handcarts to the bins/depots in their mohallas (localities). About 2,000 people work as sweepers. However, the number of them rises following the daily salary basis of

demand. Sweepers have relatively low levels of schooling. They only have a primary or junior school education, if they have any formal education at all.

According to the survey, there is a thriving informal industry that actively gathers recyclables at different points in time, from individual homes to disposal facilities. Itinerant purchasers recover the majority of recyclable or reusable items from individual residences. Waste pickers gather waste that ends up in open dumps or bins by the side of the road. The majority of those who participate in rubbish picking are women and children. The intermediaries purchase the recyclables from the purchasers and rubbish pickers and resell them to the various recycling facilities. A SWM material flow diagram for Aligarh is shown in Fig. 3.

2.3 Primary Collection

2.3.1 Door to door collection

The garbage that is gathered from door to door is taken to open dumps and dustbins. Even though a huge number of private garbage collectors are collecting rubbish from door to door for a modest cost, the collection is not very efficient at this point. Most people dispose of their waste outside of their homes due to ignorance, which usually results in little dump sites that are challenging to collect. Some of this trash gets blown into drains, suffocating them. Such waste is removed from the roadway by street sweeping and transported to adjacent secondary disposal sites by Nagar Nigam employees.

Household solid waste is usually thrown into the streets in plastic bags or without a bag, where road sweepers collect it into mounds. After that, they are either transported by tractor trolley straight to the city's perimeter or, if necessary, via hand cart trolley to nearby open dumps or bins. Road sweepers' instruments include a broom, pan, favda (spade/showel), hand carts, panji (little pointed hand rake), gayti (pointed small spade to clean roadside open drains), and buckets.

The trash from street cleaning is gathered in wheelbarrows and then disposed of with regular home rubbish in roadside containers or open dumping areas. Figs. 4 & 5 depict the roadside disposal of waste.

2.3.2 Secondary collection

Waste is gathered by municipal employees from collection stations (open dumping areas or bins), loaded onto tractors and mini tippers, and transported to disposal locations. In certain instances, the laborers hand load the MSW into the vehicles after gathering it from the collecting sites in chabras, or wooden baskets. Refuse collection trucks utilise a variety of loading mechanisms (loaders) on main routes.

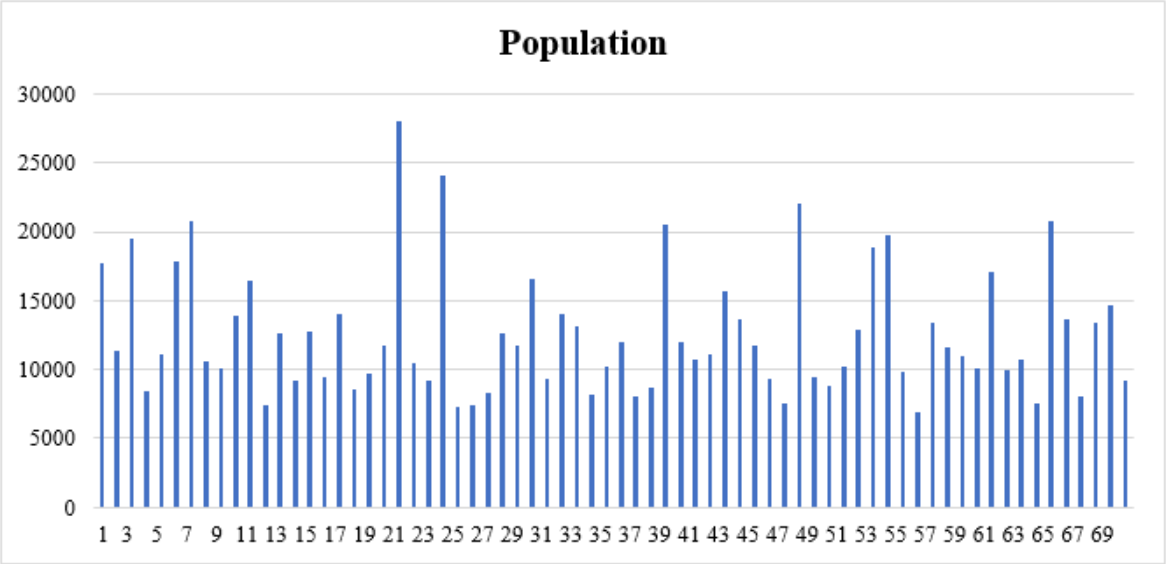

Fig. 2. Ward-wise population of Aligarh
[15]

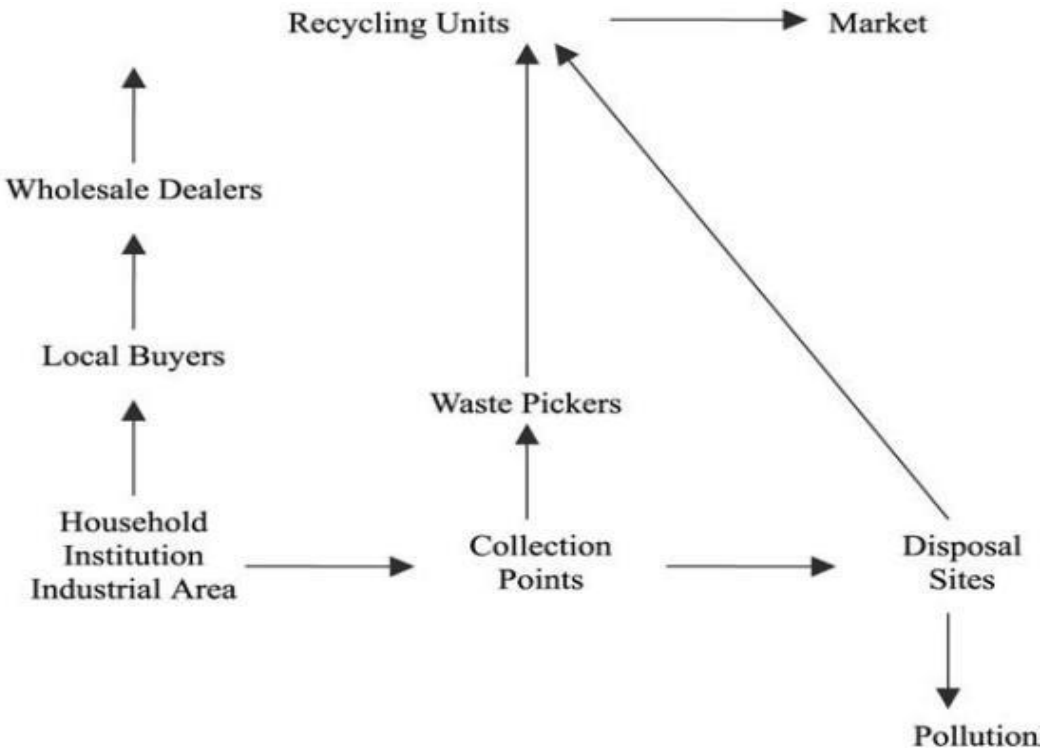

Fig. 3. SWM material flow diagram for Aligarh
Source: [8]

Fig. 4. The visual shows roadside dumping at Jamalpur near the Municipal garbage house

Fig. 5. The visual shows roadside dumping at Purani Chungi near Centenary Gate, AMU

Officially, the municipality operates on a six-day workweek, with Sundays off. However, due to political pressure and popular demand, it is not unusual for employees to work on Sundays and other holidays.

The AMC covers the task of secondary collection and disposal. In Aligarh, three different transportation systems are used

1. Open and closed tipper trucks
2. Dumper placers, and
3. Tractor Trolley

2.4 Staffing for Solid Waste Management

"In the city, there are 1350 sweepers assigned to 70 wards for daily sweeping duties from 7:00 am to 11:00 am. Each sweeper is equipped with a wheelbarrow, a long broom, and a panzer for efficient cleaning. They are allocated specific areas called beats where they collect garbage using wheelbarrows to transport it to designated waste storage sites, also known as collection points."

2.5 Transportation of Waste

"AMC and A2Z jointly operate a fleet of 379 vehicles for waste collection and transportation from collection points to the disposal site. Each vehicle is assigned a designated area for daily collection and transportation to processing sites. These vehicles visit collection points daily except Sunday and other locations as scheduled or directed by health officers."

2.6 Role of Nagar Nigam in the Transportation of Waste

- Solid waste in the primary collection is transported by hand-cart trolley to the nearby open dumps or bins, or directly by tractor trolley to the out-skirt of the city
- The Aligarh Nagar Nigam has 264 waste collection vehicles, used for the day-to-day collection/transportation of waste.
- These vehicles make three to four trips per day to collect and transport municipal solid waste from secondary collection points to the waste disposal sites.
- These vehicles transport about 430 t/day of municipal solid waste.
- No. of dump points all over Aligarh is 198
- No. of GVP (Garbage vulnerable points) is 266

2.7 Role of A2Z Pvt Ltd. In the Transportation of Waste

A2Z waste management system (Aligarh) Pvt Ltd. Is successfully providing integrated MSW services in Aligarh city from 1st May 2010. This project is for 30 years.

- Door to door collection of MSW is done by both A2Z and AMC.

- Secondary collection and transportation of waste, from 80 municipal wards.
- Collection of user charges on behalf of ULB.
- Processing and disposal of solid waste is done at the A2Z office on Mathura Road.
- Manufacturing city compost from the mixed waste.
- Manufacturing coal and ash from the non-biodegradable part of the waste.
- Daily processing of MSW is 220 MT/ day.
- The A2Z Pvt Ltd. has 115 waste collection vehicles, used for the day-to-day collection/transportation of waste from 80 municipal wards.
- A2Z Pvt Ltd. has 25 supervisors and 275 laborers.

2.8 Waste Disposal

The Aligarh Municipal Corporation (AMC) utilizes a 7.5-acre landfill site for waste disposal, located in Pala Sahibabad, approximately 7.5 km from the city centre. Currently, there is no scientific method employed for waste disposal at this site, and all waste is crudely dumped. Approximately 28 tonnes of waste are disposed of here daily [17].

Additionally, A2Z has established a disposal site on Mathura Road, situated 7.5 km from the city centre. A waste processing plant operated by a private organization has been commissioned there, capable of processing up to 220 metric tonnes of municipal solid waste (MSW) per day through composting.

Fig. 6. The visual shows the trash mountain at A2Z disposal site Mathura Road, Aligarh

Table 3. Number and type of vehicles used by Aligarh Nagar Nigam for solid waste transportation

Vehicle type	Numbers	Capacity (Tonnes)
Hydraulic Tipper	16	7-8
Dumper Placer	05	7
Tractor	51	3.5
Mini Tipper	154	4.5
Refuse collector	15	6
JCB	13	-
Mechanical loader	4	-
Compactor	06	8

Source: [16]

3. RESULTS AND DISCUSSION

1. Storage of waste at its source is not fully practiced, as people tend to dispose of waste immediately where it is generated.
2. Segregation of recyclable waste has not been widely adopted, often resulting in recyclables being mixed with general waste at disposal sites.
3. Street sweeping is used in addition to door-to-door rubbish collection systems as the mainmeans of waste collection.
4. The street sweeping is done by a team of 3 members, out of them one sweeps the street, another cleans open drains and picks up the waste in the cart, and the third one is the supervisor who takes pictures during cleaning and shows in Nagar Nigam for theirattendance.
5. Waste is transported using a variety of vehicles, including dumpers, trucks, trolleys, and garbage compactors. On Sundays and public holidays, there is no transport.
6. The city generates about 560 MT of SW every day. A door-to-door collection system, street sweeping, and communal waste storage sites are used to gather about 430 MT of SWper day.
7. About 560 MT of SW is generated in the city per day. About 430 MT of SW per day is collected through a door-to-door collection system, street sweeping, and from the communal waste storage sites.
8. The AMC has 7.5 Acres of land located about 7.5 km from the city center, at Agra Road (inthe Pala Sahibabad).
9. Only 70% of the generated solid waste is collected and disposed of, indicating a low level of efficiency in the solid waste collection process.
10. The methods for solid waste management's collection, storage, and transportation are not coordinated.
11. The municipal corporation lacks a system for the disposal of biomedical waste.
12. Currently, AMC does not segregate waste into organic and other categories, and only 30- 40% of waste undergoes processing (composting).
13. The disposal techniques employed are unscientific and do not comply with the MSW Rules 2000 for the next 30 years.
14. Only 28 tons of SW per day is transported to the disposal site (Pala Sahibabad).

4. CONCLUSION

Solid Waste Management (SWM) is an essential public service system that must be effectively managed to maintain community aesthetics and public health standards. Municipal agencies must plan and implement SWM systems to accommodate the growing urban areas and populations.

The Aligarh Municipal Corporation (AMC) oversees a population of 921,000 [15] across 70 wards, covering an area of 3650 km². The management of solid waste does not have a dedicated department within AMC; instead, each division handles this task under the supervision of a sanitary inspector.

Aligarh is experiencing rapid growth, with a decadal growth rate of 22.78% or possibly higher, as unauthorized construction and population figures are not recorded. Despite the increasing population, the number of staff has remained unchanged.

The solid waste management situation in Aligarh remains inadequate despite the best efforts and limited resources of the Aligarh Municipal Corporation. The largest financial limitation facing the municipality is present. The role of the state government is to provide sufficient funding for SWM, but state governments are also confronted with financial strain on infrastructure management and facilities. A component of certain user fees would be added to federal, state, and local taxes. A method for making microcredit accessible to the unorganized sector would promote its growth as part of a sustainable and integrated waste management system.

5. RECOMMENDATIONS

1. **Acquisition of New Disposal Sites:** Given the inadequacy of the current disposal site to handle the city's waste, it is essential to acquire a new, larger site for waste disposal and treatment.
2. **Source Reduction:** Implement source reduction by encouraging households to use two separate plastic bins: one for biodegradable waste and another for non-biodegradable waste. Rag pickers can collect the non-biodegradable waste directly from houses for recycling, with the AMC charging a nominal fee. This method could reduce solid waste at the source by

30 to 50%, alleviating some of the disposal issues.

3. **Enhanced Collection Efficiency:** By offering suitable containers (1 m^3 and 4.5 m^3) based on accessibility and population density, you may improve waste collection. Reduce the amount of manual handling by transporting household rubbish to these containers using company sweepers and neighbourhood initiatives.
4. **Efficient Transportation:** Utilize appropriate vehicles to transport waste, minimizing manual handling. Compactor vehicles can mechanically transfer waste from 1m^3 containers into compactors, while dumper placer trucks can transport larger 4.5m^3 containers directly to the landfill site.
5. **Provision of Garbage Bins:** Install two types of garbage bins at regular intervals:
   a) Local garbage bins with a 1-ton capacity placed every 100 meters for residents to dispose of household waste.
   b) Community garbage bins with a 4.5-ton capacity placed every 500 meters, where sanitary workers can deposit waste collected from local bins. Tractors and tippers will then transport the waste from these bins to disposal sites. These should be placed on wide main roads to allowfor vehicle movement.
6. **Smart Solutions for Waste Management:**
   a). Equip door-to-door waste collection vehicles with RFID and GPS systems for tracking, preventing malpractices, and ensuring efficient monitoring.
   b). Designate specific routes for door-to-door collection vehicles. Modernize the garbage collection system by installing underground bins along footpaths, featuring two compartments: one for public use and another for AMC waste collection. Sensors will alert the control room when bins reach 70% capacity.
   c). This system will prevent spillage and foul odors, enhancing the city's aesthetic appeal.
7. **Improved Waste Treatment and Disposal:** Construct and utilize sanitary landfills for the final treatment and disposal of domestic solid waste, as this is the most cost-effective disposaloption.
8. **Responsibility for Cleanliness:** Designate industrial facilities, large retail stores, commercial institutions, private organizations, and market complexes with the responsibility of maintaining cleanliness in their surrounding areas.
9. **Increase Staff and Vehicles:** Expand the workforce and the number of vehicles to meet the city's waste management requirements.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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