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Municipal Solid Waste Management in an Urban Setting in India: A Case Study of Prayagraj City

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Abstract

The aim of this study was to evaluate the current state of the procedure for managing municipal solid waste (MSW) in Prayagraj City, India. The data for this study were obtained from various secondary sources, including government records, publications, research papers, and web sources. A detailed study was conducted on solid waste generation, collection, transportation, and disposal methods through personal interviews with the sanitary officers, staff, and people of Prayagraj Municipality. The study findings revealed that most of the city's waste collection frequency is irregular. MSW comprised compostable matter (41.57%), ash, fine earth, and others (40.52%), the rest is recyclable (17.91%). However, a considerable amount of waste continues to go uncollected or not disposed of properly, which presents substantial risks to the environment and public health. Ragpickers are essential in reintegrating discarded plastic into the value chain, preventing it from ending up in landfills and preventing long-term environmental hazard. This paper also explores the potential of waste processing methods like composting and bio-methanation, highlighting the importance of an integrated waste management system for promoting sustainable urban living. The research emphasises the importance of having a comprehensive waste management system incorporating improved waste segregation at its origin, adopting scientific processing techniques, and establishing sanitary landfills.

Keywords: Disposal, Municipal Solid Waste Management, Ragpickers, Segregation and Treatment.

Introduction

Solid waste is an unavoidable by-product of human activities. Economic development, urbanization, and improving city living standards have increased the quantity and complexity of generated waste. The World Health Organization (WHO) defines 'solid waste' as undesired and unwanted items generated from residential areas, street cleaning, and business and agricultural activities resulting from mass activities (1). The world's urban population is increasing faster than the total population. During 1950–2010, the urban population of the developed countries increased nearly two times from 427.27 million to 924.7 million, while during the same time interval, it increased approximately eight times from 309.52 million to 2569.9 million in developing countries (2). Over half of the world's population (52.1 percent) resides in urban areas. By 2050, 68 percent of the world's population is expected to be urban, with 81 percent concentrated on urban settlements in developing countries (3). Municipal waste includes solid waste such as paper, plastics, metal cans, glass bottles, plastic bottles and cans, aluminum foil, metal junk, polythene bags, garbage primarily generated from domestic households, etc. (4). Packing waste includes packaging materials such as polythene, plastics, paperboard, paper, jute, flax (gunny bags), etc. (5). These packaging are generally used several times in different forms in developing countries, but these are immediately discarded after their first use, which creates problems with their disposal.

Solid Waste Generation in India

In many Indian towns, the municipal authorities do not regularly quantify the refuse-carrying vehicles. Instead, they estimate the quantities based on the number of trips made by the collection vehicles. Solid waste generation and collection databases are rarely maintained. According to estimates, the per capita solid waste produced daily in India's small, medium, and major towns is roughly 0.1 kg, 0.3–0.4 kg, and 0.5 kg/person/day (6). The per capita generation rate varies between 0.3 and 0.6 kg/d and rises with city size, according to research by the National

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Environmental Engineering Research Institute (NEERI). This figure can be more than 0.5 kg per person per day in urban areas. The annual increase in per capita waste quantity is anticipated to be around 1.33 percent. As per the Central Pollution Control Board (CPCB), Delhi state records the highest amount of solid waste generated per capita per day (0.450 kg), while Assam records the lowest amount (0.035 kg) per day. Economically backward states like Meghalaya and Assam have a lower per capita/day generation of solid waste than economically developed states like Delhi, Gujarat, and Maharashtra. According to a recent survey (CPCB, 2021), the municipal solid waste generated in metro cities is based on the quantity transported per trip and the number of daily trips (7). India's population is gradually becoming urban. It generates an enormous quantity of solid waste daily, comprising even toxic materials. The generation of municipal solid waste (MSW) has increased multifold with improved lifestyles, changing dietary behaviour, including the use of packaging material, and the social status of populations in urban centres (8). India's daily municipal solid waste (MSW) generation rate has reached 160,038.9 tonnes, approximately 0.119 kg per person per day. Notably, 95.40 percent of the waste was collected and taken to places where it could be disposed away. Of that amount, 50 percent was processed and treated in different facilities before entering the landfill. In contrast, a significant % of the waste, 18.40% was disposed of in landfills, while 31.70% remained unaccounted for (9). The per capita waste generation varies from 0.2 kg to 0.6 kg per day in cities with populations ranging from 0.1 million and above. The Tata Energy Research Institute has estimated that waste generation will exceed nearly 260 million metric tonnes by 2047 (10). It reveals that urban areas will face in the coming decades in managing their daily waste (11). Thus, due to this rapid and uncontrolled urbanisation increasing the living standards of urban people, the problem of management of solid waste has become very acute (12). Insufficient infrastructure and rough practices make it very difficult for Allahabad City to properly manage solid waste. As municipal solid waste continues to grow, the management systems currently available, that include collection and removal of waste, become unclear, sloppy, and ineffective, and these lead to a disastrous environment and puts the health of the general populace at risk. The lack of organized collection of waste, along with irregular scheduled services, results in illegal dumping as well, which further pollutes the land, air, and water (13). The mismanagement of the disposal processes further makes things worse as most of the waste is left untreated with barely any sorting for composting or recycling. Surveys indicate that the citizens are aware of the issues mentioned above, in addition to being overly concerned about it, however, these sentiments are often ignored hence showing the necessity of better public engagement (14). Furthermore, there is barely any awareness around waste reduction and recycling that could have been caused by awareness campaigns directed toward the general populace. But, with proper integration of policies along with more participation from the community and empowering technologies, it is possible for Allahabad to create a functioning waste management system that will cater to all its inadequacies.

Municipal Solid Waste in Prayagraj

The physical composition of waste is obtained as a percentage of various constituents among daily refuse. The waste can be classified into wet and dry waste based on nature. Wet waste consists of more than half of the total proportion. The rest is a dry waste category, which constitutes paper that generally varies between 3.0 and 10.0 percent and varies with the increase in the population (15). The composition of plastics, rubber, and leather is much lower than the paper content and does not generally exceed 1 percent in most metropolitan cities. The metal content is much lower or less than 1 percent. The proportion of fly ash and acceptable earth content increases the density of the garbage, which varies between 330 and 560 kg/$m^{3.}$ Table 1 shows that MSW's nitrogen, phosphorus, and potassium content ranges between 0.5-0.7, 0.5-0.8, and 0.5-0.8 percent, respectively, while most metro cities' calorific value ranges from 200-3000 Btu/1b (16) see Table 1.

Table 1: Chemical Characteristics of Municipal Solid Waste in Indian Metropolitan Cities*

Name of City	Moisture	pH Range	C %	N %	P % as P2O5	K % as K2O	C/N Ratio	Volatile Organic Matter (VOC) %	Highest Calorific Value Kcal/ Kg
Agartala	60.06	5.21-7.65	28.82	9.96	0.53	0.77	30.02	49.52	2427
Agra	28.33	6.21–8.1	10.96	0.52	0.6	0.57	21.56	18.9	519.82
Ahmedabad	32	6.2–8.0	37.02	1.18	0.67	0.42	34.61	63.8	1180
Allahabad (Now Prayagraj)	18.4	7.13	17.12	0.88	0.73	0.7	19	29.51	1180.12
Asansol	54.48	6.44–8.22	10.07	0.79	0.76	0.54	14.08	17.73	1156.07
Bangalore	54.95	6.0–7.7	27.98	0.8	0.54	1	35.12	48.28	2385.96
Bhopal	42.66	6.99–9.03	23.53	0.94	0.66	0.51	21.58	35.78	1421.32
Bhubaneshwar	59.26	6.41–7.62	15.02	0.73	0.64	0.67	20.66	25.84	741.56
Daman	52.78	5.88–6.61	30.74	1.38	0.47	0.6	22.34	52.99	2588
Dehradun	79.36	6.12–7.24	23.08	1.24	0.91	3.64	25.9	39.81	2445.47
Dhanbad	50.28	7.11–8.01	9.08	0.54	0.55	0.44	18.22	16.52	590.56
Faridabad	34.02	6.33–8.25	14.92	0.8	0.62	0.66	18.58	25.72	1319.02
Gandhinagar	23.69	7.02	25.5	0.79	0.62	0.39	36.05	44	698.02
Guwahati	70.93	6.41–7.72	19.88	1.1	0.76	1.06	17.71	34.27	1519.49
Indore	30.87	6.37–9.73	21.99	0.82	0.61	0.71	29.3	38.02	1436.75
Jabalpur	34.56	5.84–10.94	25.17	0.96	0.6	1.04	27.28	46.6	2051
Jamshedpur	47.61	6.20–8.26	13.59	0.69	0.54	0.51	19.29	24.43	1008.84
Kohima	64.93	5.63-7.7	33.17	1.09	0.73	0.97	30.87	57.2	2844
Lucknow	59.87	4.8–9.18	20.32	0.93	0.65	0.79	21.41	34.04	1556.78
Ludhiana	64.59	5.21–7.40	25.32	0.91	0.56	3.08	52.17	43.66	2559.19
Meerut	32.48	6.16–7.95	15.47	0.79	0.8	1.02	19.24	26.67	1088.65
Nagpur	40.55	4.91–7.80	33.12	1.24	0.71	1.46	26.37	57.1	2632.23
Nashik	74.64	5.2–7.0	34.22	0.92	0.49	–	38.17	59	3086.51
Patna	35.95	7.42–8.62	14.32	0.77	0.77	0.64	18.39	24.72	818.82
Raipur	29.49	6.65–7.99	18.64	0.82	0.67	0.72	23.5	32.15	1273.17
Ranchi	48.69	6.96–8.02	17.2	0.85	0.61	0.79	20.37	29.7	1059.59
Vadodara	24.98	–	20.28	0.6	0.71	0.38	40.34	34.96	1780.51

***Source**: CPCB, 2005

Socio-economic Factor's Influencing MSW Management Scenario in City

Urbanization, changes in dietary patterns and economic disparities heavily influence the composition and the amount of municipal solid waste in Prayagraj. The rapid growth in urban populations has resulted in growing population density and increased consumption patterns leading to an increase in waste generation (Table 3). Dietary changes, such as increased dependency on packaged food items and single-use materials, have greatly proportionally enhanced the share of non-biodegradable and recyclable wastes made of plastics and paper. Economic inequalities in the city further burden the waste stream; richer zones tend to generate more packaging and e-waste, while the economically weaker sections generate more organic and compostable waste (Table 4). The ward-wise data on waste generation shows these disparities where densely populated and commercially active wards like Alenganj produce significantly higher volumes of waste than less

populated areas like Dariya Shah Ajmal (Table 2). This understanding calls for specific waste management approaches tailored to the socio-economic and cultural nuances that affect waste in Prayagraj.

Methodology

Study

The primary aims of this paper are to examine the city's solid waste generation, collection, transportation, processing, and disposal methods. We had evaluated the current state of the procedure for managing municipal solid waste in Prayagraj city as well as generated few recommendations for an efficient waste management system. The data for this study was obtained data from various primary and secondary sources, including the Prayagraj Municipal Corporation, government records, publications, research papers, and web sources. A detailed primary study was conducted on the collection, generation, transportation, and disposal method of solid waste. Primary data is collected through personal interviews with the sanitary officers, staff and people of Prayagraj Municipality. The authors also conducted personal observations of the city and recorded information. We conducted a field survey to determine the actual status of solid waste management practises in Prayagraj city. Whether the MSW management in city is under compliance of Municipal Solid Waste (Management and Handling) Rules, 2016, and the Central Public Health and Environmental Engineering Organization (CPHEEO) Manual on Municipal Solid Waste Management (17).

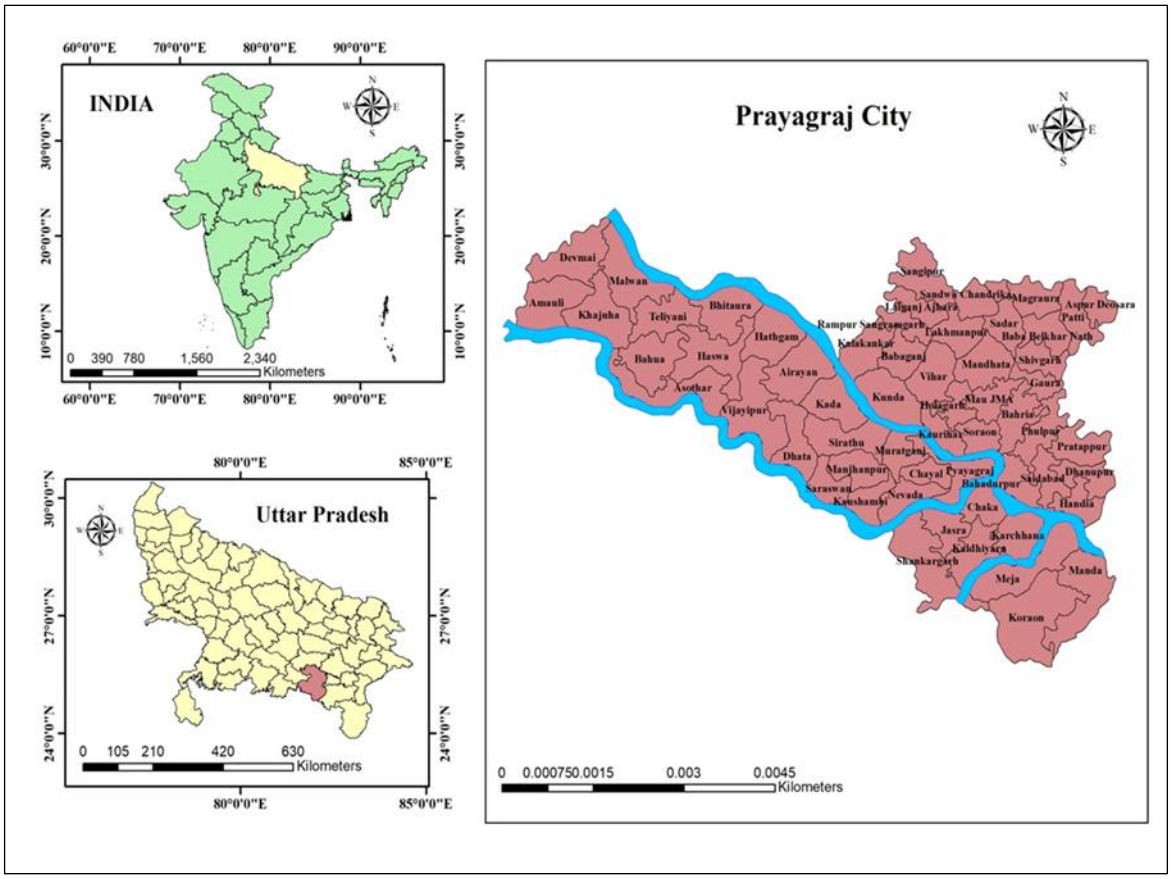

Figure 1: Map of the Study Area (Prayagraj city)

About the Study Area

The city's population has grown approximately three times from 3, 32,295 in 1951 to 11, 68,385 in 2011 and is estimated to have 13, 50,000 in 2024. With the increasing population, solid waste increased from 650 tonnes/day in 2010 to 925 tonnes/day in 2023 (Prayagraj Municipal Corporation, 2023). About 70 percent of the total generated solid waste is domestic, and the rest originates from other sources. The physical composition of generated solid waste has more than half of the waste comprised of biodegradables. The average amount of solid waste generated in the city is 700 grams/person/day. Household or residential garbage makes up 48% of the solid waste generated daily. Interestingly, the

share of industrial waste in the city's total waste generation is the lowest. More than half of the total generated solid waste is biodegradable. i.e., 490 tonnes/ day, followed by non-biodegradable .i.e.210 tonnes/day and recyclable types. By 2051, the city's population is expected to grow approximately twice that of the current time; solid waste generated will increase more than five times (Table 3).

Results and Discussion

Generation and Physio-Chemical Characteristics of MSW in Prayagraj City

Table 2 and Figure 1 show the ward-wise generation of municipal solid waste of Prayagraj. It has been observed that the minimum quantity of solid waste generated is in Dariya Shah Ajmal ward with 6.94 MT per day, while it is maximum in Alenganj ward (9.31 MT). Sanitary ward-wise generation of municipal solid waste is shown in Table 2. However, the Dariya Shah Ajmal sanitary ward is comparatively more minor in area than other wards. Due to Cemetery's partial occupancy, the ward produces less solid waste. Besides this, Alenganj produces a considerable quantity of solid waste due to its dense population. This ward also occupies several government offices and institutions, contributing considerable garbage. i.e., 9.31 MT/day (Figure 2). The quantity of MSW generation also depends upon several factors, such as food habits, standard of living, and degree of commercial activities, which are highly related to population growth and density. Except in a few wards (Civil line Area—Ist, Neem Sarai, Sulem Sarai, Mumfordganj, Ashok Nagar, etc.), all other wards are influenced by the above mentioned factors in generating municipal solid waste.

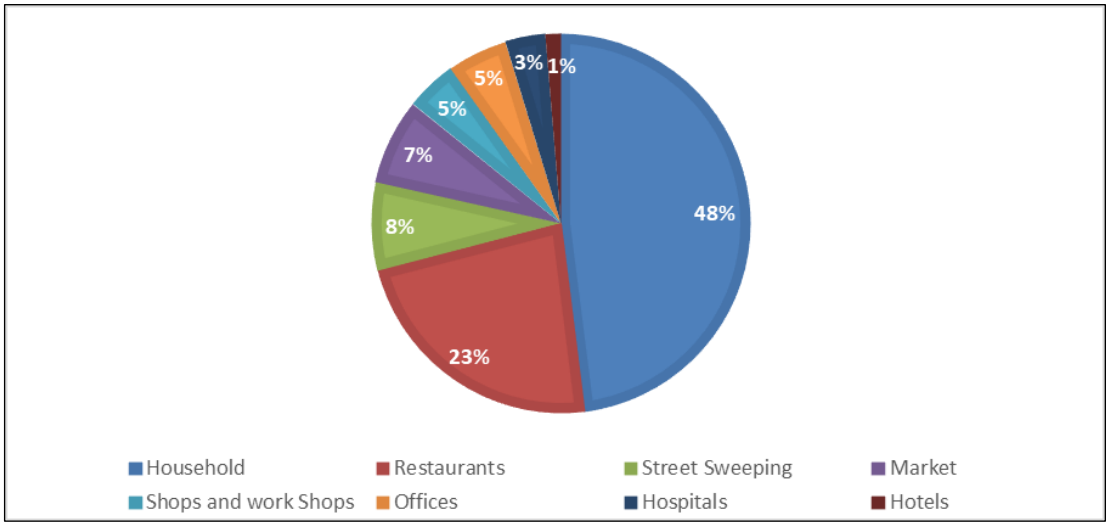

Figure 2: MSW Generation by Different Sources in Prayagraj city 2023

Table 2: Ward-wise Generation of Solid Waste in Prayagraj City

Sl. No.	Name of Wards	Solid Waste Generation (per day in MT)	Sl. No.	Name of Wards	Solid Waste Generation (per day in MT)
1	Sulem Sarai	9.15	41	Nai Basti	7.05
2	Saidabad	8.23	42	Chakdodi	7.65
3	Jaintipur	7.55	43	Katra	9.17
4	Rajapur	8.32	44	Pura Parani	8.84
5	Mumford Ganj	9.30	45	Civil Line Area – I	8.71
6	Ashok Nagar	7.03	46	Chak Bhatahi	6.97
7	Ishwar Saran	7.80	47	Azad Square	7.09
8	Neem Sarai	9.28	48	Chadpur Nagar	7.15
9	Sheqkuti	8.74	49	Pritam Nagar	8.90
10	Civil Area – I	9.27	50	Chak Raghunath	7.41
11	Qazipur	8.70	51	Katghar	7.84
12	Malak Raj	7.06	52	Karaila Bagh	8.91

13	Harwara	9.05	53	Alopi Bagh	7.09
14	Alen Ganj	9.31	54	Salori	8.26
15	Himmat Ganj	9.00	55	Chaukhandi	7.00
16	Chakniratul	7.50	56	Bakshi Khurd	9.06
17	Nyay Marg	8.03	57	Sarai Garhi	7.54
18	Engineering College	8.87	58	Dariyabad	7.32
19	Mundera	7.61	59	Dara Ganj	8.22
20	Jhulelal Nagar	7.34	60	Muthi Ganj	8.04
21	Phaphamau	7.52	61	Khalashi Line	7.81
22	New Katra	9.16	62	Meera Pur	7.29
23	Krishna Nagar	9.09	63	Shah Ganj	7.20
24	Madhawa Pur	7.09	64	Puramandhardas	8.51
25	Bhardwaj Puram	9.11	65	Dariyabad	9.09
26	Govind Pur	8.39	66	Mohtshim Ganj	7.07
27	Muirabad	7.98	67	Ram Bhag	7.16
28	University Area	7.40	68	Muthi Ganj –Ii	7.24
29	Transport Nagar	8.93	69	Sadia Pur	8.11
30	Teliyar Ganj	8.59	70	Tulshi Pur	7.02
31	Medical College	8.72	71	Narainsingh Nagar	7.06
32	Ganga Nagar	7.13	72	Sultanpur Bhawa	8.37
33	Chakia	8.27	73	Malviya Nagar	8.85
34	Minhaj Pur	7.33	74	Bhadur Ganj	7.29
35	Om Prakash Nagar	8.15	75	Meer Ganj	7.86
36	Jahagirabad	8.51	76	Kareli	9.14
37	Bagambari Gaddi	9.05	77	Bakhi Bazaar	9.08
38	Colonel Ganj	8.92	78	Atala	8.86
39	Mehdauri	9.02	79	Attar Suiya	8.65
40	Beni Ganj	7.57	80	Dariya Shah Ajmal	6.94

Source: Municipal Corporation of Prayagraj, 2023

Estimation of Solid Waste Generation in Prayagraj City

The amount of solid waste generation, in general, increases with immigration (rural to urban), resulting in the annual exponential growth of population, leading to an increase in the quantity of solid waste generation in Prayagraj City [Table 3, (18)]. The present population projection is based on the trends of population growth observed during 1991–2011. The projected populations and estimated quantity of solid waste generation have been calculated using the compound interest formula from business arithmetic (19).

$$P_t = P_0 \left\{1 + \frac{r}{100}\right\}^t$$

$$Where, P_t = the\ census\ count\ of\ the\ later\ period$$

$$P_0 = the\ census\ count\ of\ the\ earlier\ period$$

$$r = the\ average\ annual\ exponential\ growth\ rate\ in\ percent$$

$$t = the\ interval\ of\ years$$

Table 3: Estimated Generation of Solid Waste in Prayagraj City

Year	Population	Estimated Waste Generation (MT /day)	Per capita/kg/day Waste Generation
2001	9,753,93	506.00	0.51
2011	10,77,300	699.00	0.70
2021	11,89,900	831.74	0.83
2031	13,14,300	1093.16	1.09

2041	14,51,400	1586.61	1.59
2051	16,03,600	2544.29	2.54

Source: Census of India, 2011, Prayagraj Municipal Corporation, and the rest of the figures calculated by the authors based on the yearly exponential growth rate

The population and solid waste generation exhibit an annual exponential growth rate of 1.437 percent. The population is projected to rise from 9, 75,393 persons in 2001 to 16,03,600 in 2051 (Census of India, 2011). According to the population growth, estimated solid waste generation will also increase from 506 metric tonnes per day in 2001 to 2544.29 metric tonnes per day in 2051. Based on the above analysis, per capita generation of solid waste in the city will also increase approximately five times from 510 gm/person/day in 2001 to 2,540 gm/person/day in 2051 (Table 3). Thus, massive waste requires proper disposal and an integrated solid waste management system to make the city cleaner and habitable. The generation of solid waste in different areas also fluctuates seasonally. It has been observed that during festival season, the quantum of solid waste in general increases. Solid waste generation was very high (26,798 MT) in January and February (21,146 MT) because the city witnessed the maximum influx of people because of the Kumbh mela [Kumbh Mela, is a significant pilgrimage and festival in Hinduism. Kumbh Mela experiences the largest public gathering.It is observed in a cycle of roughly 12 years, coinciding with each revolution of Brihaspati (Jupiter), at four pilgrimage sites along riverbanks: Prayagraj (confluence of the Ganges, Yamuna, and Sarasvati rivers), Haridwar (Ganges), Nashik (Godavari), and Ujjain (Shipra)], marriage, and other cultural activities. Further, it is also slightly high in September (24,489 MT) and October (20871 MT) (Table 4).

Physical Characteristics of MSW in Different Sanitary Wards of Prayagraj city

Knowing solid waste's physio-chemical characteristics helps to make informed decisions for proper management. High levels of compostable material can be used for composting, while other waste should be managed through MSW Guidelines (20). The content of compostable materials increases with a higher composition of carbon and nitrogen and thus provides nutrients to the soil for the healthy growth of plants. This organic manure can be produced through composting and used as a soil supplement. The physical composition of waste, expressed as a percentage of different materials by dry weight equivalent to 1 kg of solid waste, is detailed in Table 4. The waste of paper content generally varies from 2.8 percent to 9.8 percent. The quantity of paper present in Prayagraj's MSW is much less. A major portion of paper disposed of in MSW is picked up by waste pickers for recycling. As a result, a lower percentage of paper is found in solid waste in different city localities. In some parts of the city (Muthiganj, Bai Ka Bagh, Ashok Nagar, Mauir Hall, Hasimpur Road), the content of plastics, textiles, and leather is lower in percentage than paper content, and in some parts (Leader Road Ist, Attarsuiya, Rasoolpur, Atala, Leader Road IInd, Khuldabad Ist, Khuldabad IInd), plastics, textiles, and leather is very high. However, on average, it is found as 4.70, 3.73, and 1.43 percent, respectively. The metal content is as low as less than 1 percent. These low values of recyclables, as reported in Table 4, are essentially due to rack pickers' large-scale collection of these recyclable materials for further use. Paper is recycled on a priority basis, while plastics and glass are recycled less (21). Most solid waste comprised compostable matter (41.57%) and ash, fine earth, and others (40.52%).

Table 4: Physical Characteristics of Municipal Waste Solid (% of Wet Weight of Sample)

Sl.No	Name of Sanitary Wards	Paper	Textile	Leather	Plastic	Metal	Glass	Ash, Fine Earth and Others	Compostable Matter
1	Meera Patti	5.2	0.9	0.2	3.7	0.6	--	48.3	41.1
2	Khuldabad I	7.5	3.7	–	6.9	2.6	6.1	33.2	40
3	Khuldabad II	9.8	4.5	2	4.2	0.3	1.6	34	43.6

4	Leader Road	8.6	3.6	0.2	1.5	0.5	0.2	42	43.4
5	Atala	9.8	2.6	0.9	6.5	0.8	3.6	34.9	40.9
6	Rasoolpur	4.3	8.7	0.4	6.3	--	0.2	46	34.1
7	Attarsuiya	5.4	3.4	0.6	2.5	1.4	1.2	49.3	36.2
8	Leader Road	8.5	2.1	0.5	2.3	0.7	--	46.3	39.6
9	Muthiganj	6	3.2	0.4	2.5	--	--	45	42.9
10	Bai Ka Bagh	5.8	2.5	0.8	2.4	0.2	1.9	45.1	41.3
11	Ashok Nagar	3.2	0.8	1.9	4.9	--	0.4	47.2	41.6
12	Mauir Hall	4.7	1.1	1.6	5.3	0.72	0.32	38.3	47.96
13	Hasimpur Road	2.8	3.9	1.4	2.8	1	--	46.1	42
14	Katra Pani ki Tanki	8.8	5	2.7	6.9	2.2	2.4	32	40
15	Teliyarganj Chungi	7.4	4.9	4.7	5.8	0.8	0.6	31.2	44.6
16	Daraganj	5.8	0.8	0.1	7.1	--	0.7	44	41.5
17	Haiza Hospital	4.5	8.6	2.9	6.7	0.35	1.2	43.4	32.35
18	Kidganj	3.7	4.3	2.8	6.4	0.3	2	37.6	42.9
19	Attarsuiya	4.8	5.4	3.8	7.3	--	1.8	28.3	48.6
20	Naini	3.8	4.6	0.8	2.1	0.3	3.6	38.1	46.7
	Total (in %)	6.02	3.73	1.43	4.70	0.63	1.39	40.52	41.57

Collection

The daily collection of solid waste depends on the efficiency of the municipal corporation. It also varies from one ward to another. Despite all local authorities' efforts, 20 –25 percent of daily generated solid waste is not collected for various reasons. As per the survey conducted in the city, more than 1500 street waste pickers collect recyclable materials varying from 10 to 15 kg every day by each waste picker. A reasonable chunk of waste is managed by waste pickers in urban cities like Prayagraj, which indicates the need to consider integrating the informal sector in solid waste management to collect solid waste effectively (22).

In Prayagraj City, Solid Waste is being collected in Three Ways

Door-to-Door Collection: Waste collection methods vary from city to city and even within the city's wards. The door-to-door collection is often practised. This method operates where cooperative residential localities exist, and they hire private vendors for the day-to-day collection of MSW (23). In some neighbourhoods (such as the Civil Lines area, High Court area, Mumfordganj, Daraganj, Katra, Rajapur, Circuit House area, Rambagh, Mauir Hall, etc.), the Prayagraj Lion Waste Management Pvt. Ltd. Company and Neelkanth waste Solutions Pvt Ltd. performs door-to-door garbage collection. The company provides services of house-to-house collection and processing of wastes for the next thirty years till 2040 as per an agreement made between Prayagraj Municipal Corporation (PMC) and the company. The programme is based on the public-private partnership (PPP) model. Sanitary workers of the company, wearing special dresses, by whistling manually collect waste every day from house to house during morning hours (8 a.m. to 11 a.m.) in sacks, preferably jute sacks, in compliance with MSW Rules 2016. After collecting garbage, they collect it on hand-driven containerised carts provided by PMC. Further, it is transferred to secondary storage depots (commonly known as Kuda-ghars) by sanitary workers of PMC through small vehicles (Trippers), from where they are transported via large trucks known as dumpers to a centralised processing station Baswar, where it is partially treated (Table 6). The complete treatment of collected MSW is not possible due to its mixed nature. Hence, some segregated waste is sent to the compost plant, and the rest is sent to six designated spots on the city's outskirts for final disposal. Currently, house-to-house collection of solid waste is being practised in many wards of the city. For this service, sanitary workers of Prayagraj Lion Waste Management Pvt. Ltd. take a nominal collection—fee of 30/household/month. However,

the situation is not so good inwards like Haiza Hospital, Kidganj, and Daraganj, where wastes remain littered here and there. It was also observed during the field survey that lack of public interest towards the new initiative (house-to-house collection) is an important reason for not achieving the target (24). In the new system, an individual has to wait for the sanitary workers to collect daily garbage, and most people are not ready to do so. This shows a lack of public awareness regarding effective handling of MSW. On the contrary, few people have their dustbins when sanitary workers of Prayagraj Lion Waste Management Pvt. Ltd. come to their doorstep.

Community Bin Collection: Besides the house-to-house or door-to-door collection of solid waste, community bin collection is also practised in Prayagraj City. Domestic waste is collected through house-to-house collection, and other types of waste, i.e., institutional, commercial, etc., are collected through community bins. At the primary stage, waste is dumped by the public in containers provided by PMC. Waste is collected and transported by small vehicles (Trippers) and later on transferred to secondary storage depots via dumper/compactor truck, from where, without segregation of recyclable materials, they are sent to dumping grounds with big vehicles (Dumpers) to dumping grounds for final disposal [Table 6, (25)]. The survey findings revealed that most of the city's waste collection frequency is irregular. It has also been noticed that waste collection practices are very inappropriate in Khuldabad IInd, Leader Road Ist, Haiza Hospital, Kidganj, Daraganj, Muthiganj, etc. wards (Table 5). Despite sufficient storage capacity, waste remains littered here and there on the road and lanes and has hardly been removed once or twice a week by PMC. People of respective localities are bound to live in unhygienic conditions and observe foul smells from heaps of waste (26). Officers of PMC often warned sanitary workers to use containers and storage depots for dumping waste, but its impact is invisible.

Table 5: Frequency of Clearance of Community Bins Filled with Solid Waste

Sl. No.	Wards Selected for Field Survey	According to PMC	Field Observation
1.	Meera Patti	2nd day	3rd day
2.	Khuldabad (II)	5th day	3rd-5th day
3.	Khuldabad (I)	3rd day	3rd-5th day
4.	Leader Road	2nd day	5th day
5.	Atala	Daily	Daily
6.	Rasoolpur	Daily	Alternate day
7.	Attarsuiya	Daily	3rd day
8.	Leader Road	3rd day	Weekly
9.	Muthiganj	Alternate day	3rd day
10.	Bai Ka Bagh	Daily	Daily
11.	Ashok Nagar	Daily	Daily
12.	Mauir Hall	Daily	Daily
13.	Hasimpur Road	Alternate day	2nd day
14.	Katra Pani ki Tanki	Daily	2nd day
15.	Teliyarganj Chungi	Alternate day	Alternate day
16.	Daraganj	Daily	3rd day
17.	Haiza Hospital	Alternate day	3rd day
18.	Kidganj	Daily	2nd day
19.	Attarsuiya	Alternate day	Alternate day
20.	Naini	3rd day	*CNA

*CNA = Containers Not Available

Collection by Waste Picker / Rag Picker (Informal Worker): After picking up recyclable materials from wastes at landfill sites and other residential areas, the remaining waste is either burnt or littered by ragpickers, which emits an odour and causes air pollution problems for people living in surrounding areas. There are more than 1500 rag pickers in the form of informal workers, and they contributed to the collection of MSW in the City. However, their collection criteria are selective; they only collect recyclables from refuse or waste dumped in bins/roadside or dump yards.

A reasonable amount of plastic is collected, i.e. 26 tonnes/day (27). Thus, Integration of the informal sector into urban local bodies (ULBs) will be an added advantage. Stray animals / Vermins (pigs, bulls, cows, dogs, etc.) may easily be assessed at secondary storage depots and disposal sites due to the dilapidated condition of walls and the absence of fences. They litter waste around these sites more freely in the middle of roads and create traffic congestion problems even during peak hours. However, cattle-catching vehicles regularly work 16 hours (2 shifts × 8 hrs.) to catch these cattle, and occasionally during festivals, fares, etc., 24 hours (3 shifts × 8 hrs.). However, the number of cattle caught is few because daytime traffic is high-speed and it is not easy to catch them from the road.

Segregation

It is observed during the field survey that in most parts of the city, segregation of recyclable waste is partially practised by households and ragpickers to sell to waste purchasers. The rest of the material is generally left behind on the streets, causing public nuisance. It also sometimes causes clogging of drains. PMC is considering charging fines of Rs 50 onwards (per economic standard) those caught disposing of waste in public places.

Storage

Each household, retail outlet, and workplace produces solid waste daily. Bins are generally not provided for separate waste storage according to the type of waste, i.e., recyclable, biodegradable, and non-degradable at source. Very few people keep personal bins for the storage of waste. There are 200 containers in the city where primary waste collection is undertaken unscientific, which also causes unhygienic conditions. Containers are unevenly distributed in the city without considering the amount of generated waste and population density in that area. Consequently, waste is commonly littered around containers. The conditions of containers are also deplorable; most are rusted, broken, and open-headed.

Transportation

Transportation is the most crucial segment of solid waste management. Transportation of waste involves two steps:

- Transfer of collected waste from bins to a secondary storage depot.
- Transfer of waste from depot to processing plant and disposal sites.

Table 6: Availability of Equipment with MCV for Solid Waste Management

Sl.No.	Vehicle/Equipment Type	Numbers
1	Dead Body (Caracas) Collector Vehicles	4
2	Dumper Placers	22
3	Excavator Cum Loaders	5
4	Loaders	4
5	Nalla Cleaner Bucket Machine	1
6	RC bins	200
7	Refuse Collector Bins	3
8	Richsaw Trolley	20
9	Three Wheelers	24
10	Tractors/ Tippers	6
11	Waste Hand Crat	1000
	Total	1289

Source: Municipal Corporation of Prayagraj

Processing

Processing methods are different for different types of solid waste according to the nature of the waste. A treatment facility is situated at Banswar, Prayagraj. It has the following facilities:

Composting

Composting is suitable for wet/biodegradable materials; three types of composting techniques are generally used:

- Vermicomposting: Not available.
- Windrow Composting: A Windrow facility for segregated wet waste is available at the processing plant, Baswar.
- Aerobic Composting: Not available.

Biomethanation or Anaerobic Method: Wet waste with moisture content over 90% or putrescible biomass is suitable for anaerobic digestion. They city has enormous potential because half of total proportion of MSW generated

in city is biodegradable. Currently, no anaerobic digestion facility is available.

Refuse Derived Fuel (RDF) through Pelletisation: The city produces 210 tonnes of dry waste and 7- 10 % is a recyclable portion. The suitable materials for RDF are combustible components of MSW with high calorific value. It comprises paper, plastic (low-valued / single-use plastic), textile, wood and Thermacol (28). These materials are compressed, pelletised, or baled per industry requirements to substitute conventional fuel. An RDF facility is available at the processing plant, Baswar Prayagraj. According to the new MSW rule, the government mandated that industries need to substitute their fuel with RDF for up to 5% of total conventional fuel usage.

Waste to Energy Plant/Incineration: No facility Available. Currently, PMC does not have facilities for the complete processing of MSW. All untreated solid waste is disposed of on the outskirts of the city. It has been calculated that 490 tonnes (out of 925 tonnes) of generated MSW in the city is of biodegradable type. Therefore, the city has good potential for producing MSW-based compost. If this technique is applied, a considerable quantity of organic manure may be produced economically, generating financial benefits for PMC.

Methods of Disposal

In many cities, almost more than half of the solid waste generated remains unattended. The non-biodegradable waste transported from the transfer stations, mainly rejected from the processing and recycling plants, shall be collected separately and disposed of using scientifically sanitary landfill sites (29).

Sanitary Landfill: A sanitary landfill refers to the engineered disposal of solid waste in a designated area. Sanitary landfilling requires careful planning and the execution of engineering principles and construction techniques. Prayagraj city is not an exception either. Unfortunately, the city has no scientific sanitary landfill site as prescribed in MSW Rules 2016 and the CPHEEO manual. About 925 MT of collected solid waste is disposed of haphazardly and unscientifically without being treated on six open dump sites. All use sites are located on the outskirts of the city. These sites are as follows: Kareli near the Sasur Khaderi River (area 50 ha.), Chandpur Salori (area 2 ha.), Phaphamau (area 25 ha.), Sulem Sarai (area 1.5 ha.), Alopi Bagh (area 1.5 ha.), and Naini (area 2 ha.).

Observations and Recommendations

During the survey, the following drawbacks were found:

- Uncontrolled waste in some parts of the city remains scattered and indisposed, which needs to be considered for proper waste management. It was also observed during the field survey that waste is being dumped on the banks of Sasur Khaderi Nadi. this may be due to non-monitoring and penalties imposition for non-compliance could face pushback due to limited local awareness or political pressure.
- PMC has not established a parameter to identify landfill sites. The option of disposal sites should be accounting for suitability rather than availability. In most cases, the PMC takes the opportunity to make mutual adjustments for both the person and the PMC itself.
- After dumping, a JCB machine levels the waste and occasionally covers it with soil. Such unscientific disposal practices attract birds and rodents to waste dumping sites, creating unhygienic conditions (30). Therefore, covering the soil should be mandatory as per MSW Rule 2016.
- Due to the lack of proper inspection by the authorities and the absence of fences around Dumping sites, ragpickers and stray dogs litter waste here and there. Strong fencing & CCTV's surveillance is required to avoid the following reasons.
- The unscientific disposal method is not feasible to continue with an increasing amount of solid waste generation. There is a need for an integrated solid waste management policy for the city of Prayagraj.
- Continuous public awareness through the Information, Education and communication (IEC) program for Behaviour change and enforcement regulations is strictly needed.
- Re-thinking for integration of informal sector as successful of Swachh Pune (31). The role of ragpickers in municipal solid waste management is crucial, Policies must encompass worker rights, equitable compensation, and workplace safety for the informal sector Their contribution promotes a more holistic and sustainable approach to waste management.

Conclusion

The study on municipal solid waste management in Prayagraj City highlights significant difficulties caused by insufficient infrastructure and ineffective waste collection and disposal methods. The problem is worsened by the growing population and urbanization, resulting in unsustainable waste generation levels. Despite the existing guidelines and ongoing efforts, a considerable amount of waste continues to go uncollected or not disposed of properly, which presents substantial risks to the environment and public health. The research emphasizes the importance of having a comprehensive waste management system incorporating improved waste segregation at its origin, adopting scientific processing techniques, and establishing sanitary landfills. The scope of the study was confined to the urban area of a single city – Prayagraj and ignored the peri-urban and rural regions. Future researchers would benefit from this comprehensive approach to waste quantitative techniques, incorporating measures such as GIS mapping and real time data to improve precision. More robust longitudinal studies like impact of public education campaigns and policy implementations on waste management efficiency would also provide deeper insights. This approach will not only enhance the city's quality of life but also make a significant contribution to broader environmental sustainability goals.

Abbreviations

CPHEEO: Central Public Health and Environmental Engineering Organization, CPCB: Central Pollution Control Board, Kcal: Kilo Calorie, MSW: Municipal Solid waste, MT: Metric Tonnes, NEERI: National Environmental Engineering Research Institute, PMC: Prayagraj Municipal Corporation, PPP: Public-Private Partnership, RDF: Refuse Derived Fuel, ULBs: Urban local bodies, WHO: World Health Organization.

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Author Contributions

The authors take complete responsibility for the following: Ravikant Dubey: contributed to the study by overseeing the conception and design, collecting data, analysing and interpreting the results, and preparing the manuscript. Deepak Rathore: Responsible for the conception, analysis, and interpretation of results. Dr. Amrita Dwivedi has contributed in editing and final proof Reading.

Conflict of Interest

The authors declared no potential conflicts of interest.

Ethics Approval

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