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Characterising and Analysing the Composition and Characteristics of Municipal Solid Waste (MSW) in Delhi, India

Sumant Shekhar[1,2]*, Manoj Chandra Garg[1], Vinod Kumar Verma[3] and Tanu Jindal[1]

[1]Amity Institute of Environmental Science, Noida, Uttar Pradesh, India
[2]Lakshya - A Society for Social and Environmental Development, New Delhi, India
[3]Visiontek Consultancy Services Pvt. Ltd., Bhubaneswar, Odisha, India
✉ shekhar.sumant160879@gmail.com

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Abstract: This research presents a comprehensive analysis of municipal solid waste (MSW) composition and characteristics from four landfill sites in Delhi, India. The study reveals that the moisture content in the MSW from all sites was below 40%, impacting leachate formation and microbial activities. Varied compositions were observed among the sites, with the Okhla landfill having higher paper and plastic content, while the Ghazipur landfill exhibited elevated wood content. Recycling emerges as a crucial focus, with approximately 36.5% of the waste comprising reusable materials like plastic and paper. Composting, particularly vermicomposting, proves to be a promising waste disposal method due to the substantial organic content (approximately 75%) in the MSW. These findings hold significant implications for waste management policies in Delhi, encouraging sustainable practices and effective waste treatment strategies for a greener future.

Key words: Municipal solid waste, seasonal variation, characterisation, policy gap, Delhi.

Introduction

Indian municipalities have inferior alternatives for handling municipal solid waste (Rawat et al., 2013). India generates 1,35,198 tonnes of municipal solid waste (TPD) every day, according to CPCB (2010). Only 70% of trash in India is collected; 12.5% is treated waste, while the remaining 17.5% is not (Patel et al., 2023). The absence of sufficient waste delivery vehicles considerably impacts the average efficacy of municipal solid trash collection in Indian cities. Over 70% of Indian cities have these basic services, according to research (Sharma et al., 2019).

The majority of Indians have swiftly shifted from rural to urban areas due to rising industrialization in today's thriving economy. In response, the output of municipal solid waste has increased in metropolitan cities. The main element determining the variation in the waste proportion, according to Sarkar and Chourasia (2017), is the city's economic position. In India, the rate of MSW generation now ranges from 0.22 to 0.87 kg per inhabitant per day, and it is projected that this rate will rise even more in metropolitan areas. In most Indian cities, it is challenging to regulate the production of municipal solid garbage.

*Corresponding Author

India is a fast-growing country, with urbanization increasing by 31.8 percent in the previous decade. India produced over 52 million tonnes of residential waste in 2016. According to Sambhyal and Suchitra (2016), this statistic is fast rising with the country's population growth. Only 68 percent of this vast volume of rubbish gets collected, and only 19 percent of collected residential waste is managed (Kumar et al., 2017). Most of these cities burn their garbage or dump it in landfills due to a lack of such waste collection and treatment facilities (Singhal and Goel, 2021).

In cities, inadequate waste management contributes to various environmental and health hazards (Annepu, 2012; Biswas et al., 2010). An integrated solid waste management (ISWM) strategy is necessary for sustainable waste management (Saha et al., 2010). The United States Environmental Protection Agency defines ISWM as a complete recycling, collection, treatment, waste reduction, and disposal system. Waste characterisation is the first stage in a successful waste management programme since it allows you to estimate possible material recovery, identify waste sources, build waste treatment facilities, and dispose off garbage (Patel et al., 2023). The physical and chemical properties must be evaluated to select the optimum treatment and ensure its use. They ensure environmental standards compliance (Bansal et al., 2023; Patel et al., 2023).

The categorisation of MSW in Indian towns is a crucial factor to consider while selecting the optimal waste management techniques. Biodegradable organics make up a large amount of the garbage in Indian cities, with paper and inserts coming in second and third. According to research by Sharholy et al. (2008), the highest proportion of components by weight in Indian towns include organic waste (41%), leather (1%), metal (2%), glass (2%), plastic (4%), textile (4%), paper (6%), and inert (40%). DSM produced in India is made up of 45 to 60% organic material, 6 to 10% recyclable material, and the remaining material is inert (Bui et al., 2021). Municipal services such as street sweeping, dead animal trash, vegetable market garbage, home, business, and agency waste produce municipal solid waste (Kaushal et al., 2012). It contains many harmful and hazardous substances that come into contact with soil and water, causing environmental damage (Bui et al., 2021; Patel et al., 2023; Saha et al., 2010).

The study highlights the importance of proper waste disposal and treatment to mitigate potential environmental and health hazards (Mangizvo and Wiseman, 2012). Analyzing the composition and characteristics of municipal solid waste (MSW) over time and across seasons forms the basis for evaluating various waste treatment methods. The research conducted in Delhi, India, aids in developing waste management policies for urban areas and offers alternative garbage treatment options for other regions.

Material and Methods

Study area

For thirty years, unlined facilities in Delhi, Ghazipur, Okhla, Bhalswa, and Bawana dump sites have received MSW and construction and demolition trash. Tipping over is the favoured disposal method at these sites, leaving MSW loose. Rather steep hills encircle the dumps' perimeter. The repose angles of the slopes vary from 39 to 49 degrees. Vertical cuts between 3 and 6 m in height that are done to establish access roads, broaden them, or install benches have been seen to stay stable for lengthy periods. During field trips, they noticed extensive leachate ponding at the dump's side. The foundation of the landfill is buried 4 metres or more. As of August 2019, the mountain's total height, measured from the base to the summit, ranged between 55 and 65 metres.

Sample Collection and Composition Analysis

Samples for this research were meticulously collected from four distinct landfill sites, namely Bhalswa, Gahzipur, Okhla, and Bawana, in two separate phases spanning from August 2019 to January 2020. To ensure the integrity of the samples, they were carefully packaged in plastic bags, preserving their original state, and then promptly transported to a specialised examination facility.

The methodology employed for the MSW (Municipal Solid Waste) composition analysis was based on the approach described by Zekkos et al. (2010). The first step involved subjecting the air-dried municipal garbage samples to sieving, using a square-holed sieve with 20 mm dimensions. This process effectively divided the samples into distinct 20 mm fractions. Subsequently, sections larger than 20 mm were manually segregated into various components.

Maintaining utmost rigor and adhering to recognised standards, 120 and 150 kg of dry MSW samples were judiciously selected for the compositional analysis. This quantity surpasses the minimum recommended quantity of 91–136 kg as advised by ASTM D 5231 (2008) for conducting a thorough examination of unprocessed MSW composition.

Sample Analyses

By drying compost samples at 70°C and measuring weight loss, the gravimetric technique was used to assess the moisture content of the pieces. According to ASTM D2974 (2007), the total nitrogen and total organic carbon concentrations were measured. 100 g samples were obtained in triplicates and dried to constant weight for 24 hours at 105ºC in an oven; after cooling in a desiccator, the change in the mass was noted. The amount of sample mass lost during drying is known as moisture content. A bomb calorimeter is used in the laboratory to calculate the calorific value.

Result and Discussion

Composition of MSWs

Moisture content was found to be <40% by mass in municipal solid waste analysed for all four landfill sites of Delhi (Figure 1A). Moisture content could be the product of green manure, rainwater, domestic water and many more. At landfill sites, moisture content participates in leachate formation, microbial activities, foul smell, and increased waste weight (Qi et al., 2022). Apart from this, the moisture content is one of the operational parameters in deciding the effective

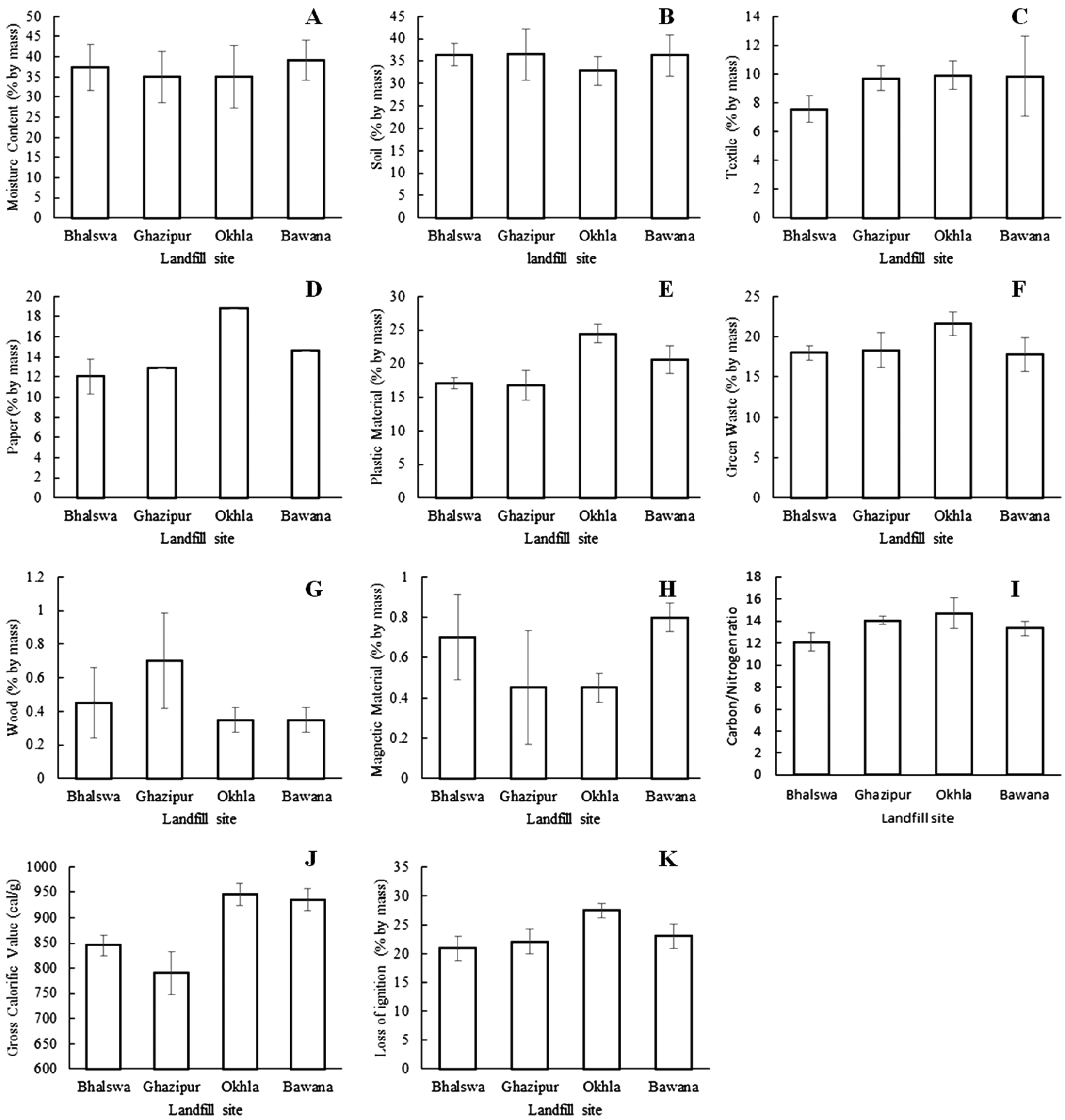

Figure 1: Municipal solid waste (MSW) composition of different landfill sites of Delhi. (A) Moisture content. (B) Soil. (C) Textile. (D) Paper. (E) Plastic material. (F) Green waste. (G) Wood. (H) Magnetic Material. (I) Gross Calorific Value. (J) Carbon/Nitrogen ratio and (K) Loss of ignition. The error bar represents the standard deviation of the respective component of MSW.

waste-to-energy techniques (Dong et al., 2016; Tom et al., 2016).

Soil content was found to be <36.5% by weight (Figure 1B). Paper materials were the highest in the case of the Okhla landfill (Figure 1D). Soil content and paper materials are the critical component that influences the shear strength of municipal solid waste (Bareither et al., 2012). So, Soil content, along with textile and paper materials, is essential to get insight into the engineering properties of municipal solid waste (Dixon and Jones, 2005). Comparatively, the Okhla landfill site's MSW had the least shear properties due to higher paper content and textile materials (Figure 1C-D). Plastic materials and green wastes were found the highest in the case of the Okhla landfill (Figure 1E-F). The source for plastic materials in landfill MSP was majorly domestic and industrial non-biodegradable refuse, including polybags, packaging materials, plastic containers, and others (Ghosh and Agamuthu, 2019). Plastic materials in MSW might result from plastics not going through segregation and recycling systems (Agarwal et al., 2005). The low concentration of plastic material in landfill MSW in current studies was a relief. It might be because of awareness of the on-site segregation of plastic materials and different treatment strategies applied at landfill sites. Wood material was found the highest in the case of the Ghazipur landfill (Figure 1G). Wood materials, along with green wastes, paper contents and moisture content, might be the reason for the occurrence of methane emissions at the Ghazipur landfill site (Mor et al., 2006). Magnetic material, including iron, used in different construction and domestic needs, was found to have a high solid waste in the Bhalswa and Bawana landfill (Figure 1H). It was observed that the non-systematic and informal collection of magnetic materials from MSW of landfill sites was linked with social and cultural exploitation and had mild to severe health risks for the workers (Sarkar, 2003). The higher calorific value of solid waste was found in the case of Okhla landfill and Bawana (Figure 1I). The calorific value of MSW is related to the composition percentage of green wastes, plastic materials, papers, and textile materials. MSW's calorific value is essential when deciding the effective and feasible treatment techniques at landfill sites (Komilis et al., 2012). The carbon-nitrogen ratio (C-N ratio) is a vital parameter to get insight into the composting kinetics of MSW (Hamoda et al., 1998). The carbon-nitrogen ratio and biological oxygen demands (BODs) of leachates also help to understand the biodegradation stage of landfill sites (Trabelsi et al., 2000). Loss of ignition (LOI) analysis is linked with the concentration of volatile species and unburned carbon content in the MSW (Mu et al., 2017). In the present study, the C-N ratio and LOI followed a similar trend of green waste and plastic materials in all landfills (Figure 1 J-K).

Principal Component Analysis of Municipal Solid Waste

Green waste and carbon-nitrogen ratio mainly influence Okhla landfill site waste composition. The correlation between the C-N ratio and biodegradable materials of MSW was supported by the work of Trabelsiet al. (2000). More influence on wood content was found in the case of the Ghazipur landfill site waste composition. The position of the Ghazipur landfill site near the Uttar Pradesh border might be the reason for more influence on the wood composition and the negligible effect of plastic components. Bhalswa and Bawana landfill site waste composition was found the influence moisture content, stone, and soil. Both landfill sites are near the Haryana border, which might be why both show similar influence by compositional parameters (Figure 2). The more substantial impact of soil components along with moisture content might be the reason for the better shear quality of municipal waste, and it could be utilised as waste to engineering materials, as explained in the work of Bareither et al. (2012).

Correlation Plot Using Linear Model Among Different Components of MSW

The correlation plot using the Linear r (Pearson) model demonstrated a positive correlation between paper, plastic material, and Loss of ignition. It might indicate the influence of plastic material and paper for volatile species in MSW composition on the Okhla landfill site, which is demonstrated by the LOI component as supported by Mu et al. (2017). Soil and loss of ignition were found to be significantly negatively correlated. Green waste was negatively correlated with soil and stone (Figure 3), which is indicative of influencing the MSW composition of Bawana and Bhalswa.

Potential for Recycling

The high amount of reusable materials in the Delhi MSW (36.5%) says recycling should be a focus. Plastic and paper trash made for more than 28.6% of total MSW (CPCB, 2021; Bhada-Tada and Hoornweg, 2012; Gour and Singh, 2022; Mathur, 2012; Sridhar, 2016; Suresh et al., 2003). Proper classification increases the chance of a scientific removal and improves the quality of reusable materials, producing more income for local

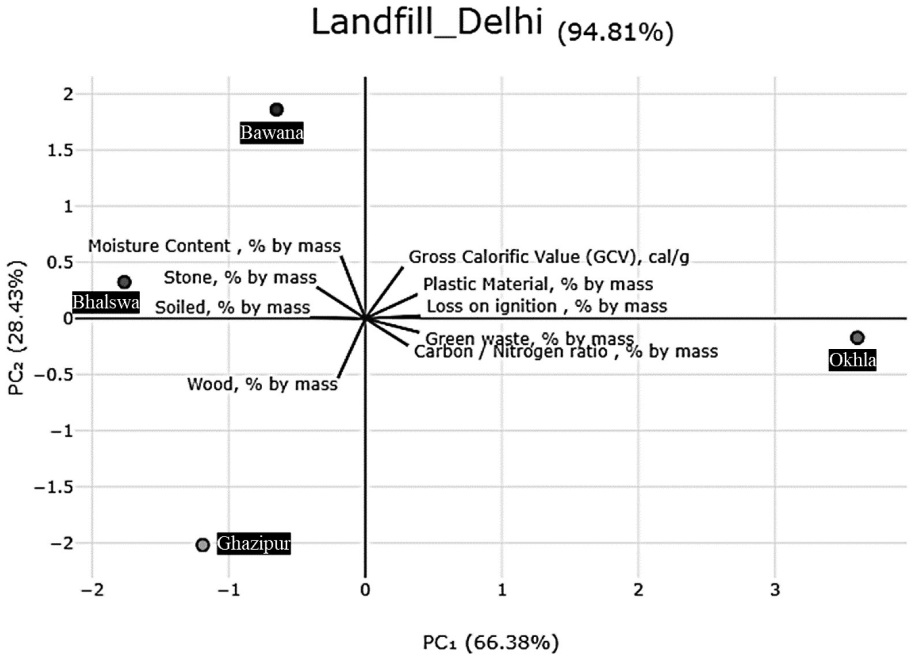

Figure 2: Principal component analysis of MSW composition of different landfill sites of Delhi with respect to different parameters.

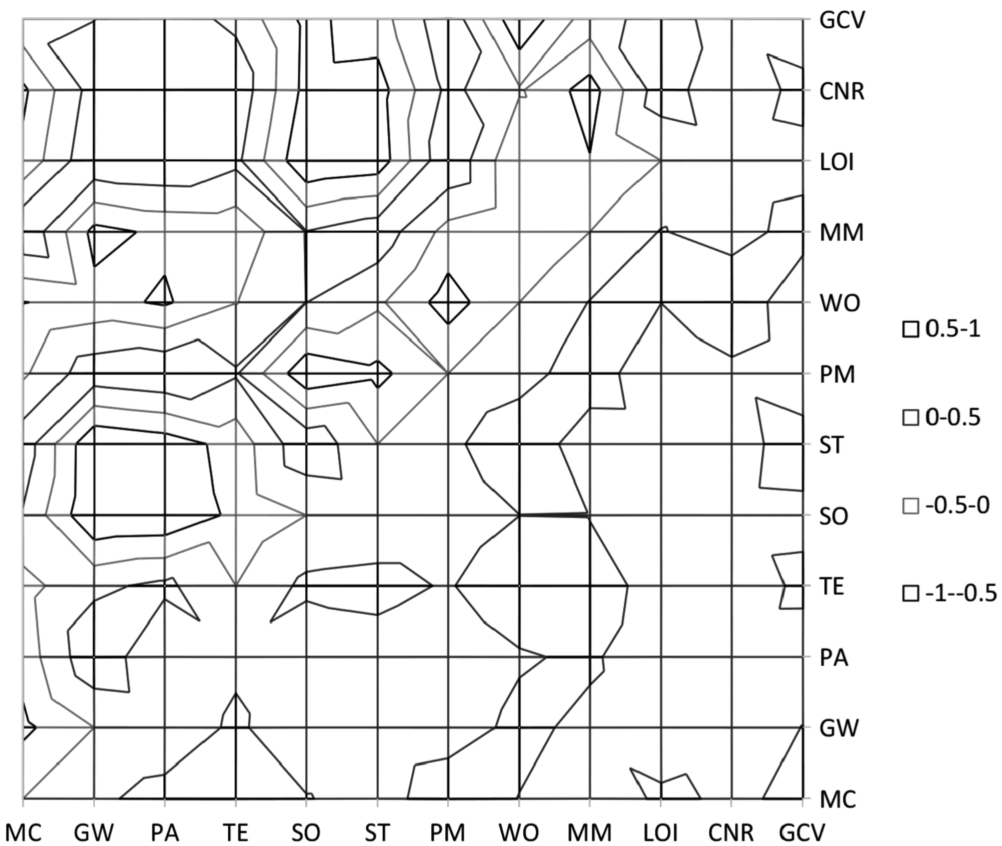

Figure 3: Correlation plot using linear r (Pearson) Model among different components of MSW. MC Moisture content, GW Green waste; PA Paper; TE Textiles; SO Soil; ST Stone, PM Plastic material, WO Wood; MM Magnetic Materials; LOI Loss of ignition; CNR Carbon-Nitrogen Ratio and GCV Gross calorific value.

Table 1: Sources and production of various solid wastes (Kumar and Agrawal, 2020)

S. No	*Source*	*Typical waste generators*	*Types of solid waste*
1	Residential	Single and multifamily dwellings	Household hazardous waste includes oils, aerosols, paints, cleaning agents, gas tanks, waste containing mercury, food waste, textiles, plastics, ashes, wood, yard waste, glass, cardboard, leather, e-waste, special waste (batteries, tires, bulky items, oils, white goods)
2	Industrial	Fabrication, manufacturing, power and chemical plants, construction sites	Hazardous waste, food waste, housekeeping waste, ashes, construction and demolition materials, packaging, special waste
3	Commercial	Office buildings, stores, resorts, restaurants, markets	Wood, hazardous waste, e-wastes, plastics, paper, food waste, metals, cardboard, glass, special wastes
4	Institutional	Government buildings, colleges, schools, prisons, airports, hospitals (non-medical waste)	Wood, e-wastes, paper, metals, glass, plastics, etc.
5	Construction and demolition waste	Renovation sites, road repairing, construction sites, demolition of building	Dust and dirt, steel, bricks, wood, tiles, concrete
6	Municipal services	Wastewater treatment plants, street waste, landscaping, waste from public places, beaches	Sludge, tree trimmings, landscape, sweepings, waste from recreational areas, parks, beaches, and other recreational areas
7	Process	Power plant, refineries, mineral extraction and processing, chemical plants, Light and heavy manufacturing	Slag, scrap, of- specification products, tailings, industrial process wastes
8	Medical waste	Hospitals, pathology, clinics, nursing homes	Pharmaceutical waste, hazardous waste like chemicals, used surgical instruments, chemicals, etc., radioactive waste due to cancer therapies, infectious wastes include blood, gloves, bandages, swabs, cultures and body fluids
9	Agricultural	Farms, crops, dairies, vineyards, feedlots, orchards	Hazardous waste includes pesticides, insecticides, fertilizers, chemicals, etc., agricultural wastes (rice husks, coffee waste, coconut shells, cotton stalks), spoiled food

Table 2: Forecasts for the rate of waste generation in 2025 from Kumar and Agrawal (2020)

Income level	*Projection for 2025*			
	Projected population		*Projected urban waste*	
	Total population (millions)	*Urban population (millions)*	*Per Capita (Kg/capita/day)*	*Total (tons/day)*
Lower income	1637	676	0.86	584,272
Lower middle income	4010	2080	1.3	2,618,804
Upper middle income	888	619	1.6	987,039
High income	1112	912	2.1	1,879,590
Total	7647	4287	1.4	6,069,705

governments. Understanding the source of waste, type of waste generator and the rate of waste generation become the key indicators to optimize effective waste handling and management (Tables 1 and 2). In contrast to other Indian cities, Delhi has a very good source separation system; yet, during secondary collection, all separated municipal garbage is combined into one container. In the secondary collection, waste containers are divided into recyclable materials and organic matter, and a material recycling centre is constructed in order to collect recyclable items and enhance their quality.

The Potential Composting of Vermicomposting

Composting is the bio-degradation of organic particles while exposed to oxygen, producing nutrient-rich byproducts that may be utilised in horticulture and agriculture. In the research region, about 75% of MSW is organic and has a moisture content of 33–46% (Bhada-Tada and Hoonberg, 2012; Gour and Singh, 2022; Sridhar, 2016). Composting is a waste disposal method that is both ecologically and financially sustainable since it needs very little initial investment, and operating and maintenance expenses. In a decentralised system, as opposed to a centralised one, vermicomposting is a superior alternative to conventional window composting.

Conclusion

The study revealed that the moisture content in the MSW from all four sites was below 40%, influencing leachate formation, microbial activities, and waste weight. Understanding the moisture content is essential for landfill operations and determining suitable waste-to-energy methods. Okhla landfill had the highest paper and plastic content, while the Ghazipur landfill showed a higher wood content. Such variations impact the landfill's shear strength and potential for methane emissions, emphasising the significance of site-specific waste management approaches. The results underscore the importance of recycling in Delhi, as a substantial portion (36.5%) of the waste comprises reusable materials, particularly plastic and paper. Composting, particularly vermicomposting, emerges as a promising waste disposal method due to the significant organic content (approximately 75%) in the MSW.

The implications of these findings for waste management policies in Delhi are significant. By incorporating this data into policy formulation, the city can move towards more sustainable waste management practices, reducing environmental impacts and promoting a greener future. The study's comprehensive insights provide a stepping stone for developing effective waste treatment strategies, optimizing resource recovery, and mitigating potential environmental and health hazards associated with inadequate waste management practices.

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