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Evaluation of cost benefit analysis of municipal solid waste management systems

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ABSTRACT

The rate of municipal solid waste (MSW) generation in developing countries is continuously growing in proportion to the gross national product. Landfilling, incineration, composting, and waste to energy (WtE) have a brief history as management strategies for MSW in India. Economic evaluation via cost benefit analysis (CBA) of MSW is establishing the most appropriate treatment/disposal strategy and it is often a major concern for solid waste management (SWM) policymakers. Thus, this study aims to analyze the municipal solid waste management (MSWM) activities in India's capital, Delhi, and the CBA of MSWM systems to identify the major problems and limitations involved. Sixty-six samples totaling 6,600 kg were collected and analyzed at random from various locations, including the sources of generation, composting plants, and disposal sites. Storage, collection, transportation, and recycling information were gathered from departments such as Municipal Corporation of Delhi (MCD), New Delhi Municipal Corporation (NDMC), Central Pollution Control Board (CPCB), and self-surveys. The total costs of each MSW option were calculated for cost analysis. The results revealed a high organic moisture content, indicating the possibility of composting and bio-methanation, except for waste from commercial, institutional area and restaurants that can be used to develop Refuse Derived Fuel (RDF). It was also revealed that only about 80% of the garbage generated in Delhi is collected. In terms of treatment and disposal, the MCD has proposed additional facilities such as disposal through sanitary landfills with linings, as well as a system for leachate collection and disposal. Furthermore, construction and demolition waste are used in the construction of various pavement components, such as base coarse, surface coarse, and so on. The total social value added by garbage trade operations in Delhi is expected to be INR 358.7 crores (approximately 46.60 million USD) between 2017 and 2020. Recycling saves the municipal budget about INR 17.6 crores (approximately 2.3 million USD per year).

1. Introduction

Better living standards, the movement of people from rural to urban areas for employment, and most importantly the rapid growth of population are some of the major reasons for the continuous increase in the MSW (Khan, 1994). In addition, poor collection and inadequate transport contribute to the accumulation of solid waste in every corner of Indian cities (Alam et al., 2021; Pervez et al., 2022). In most cities and towns in India, approximately 90% of MSW is directly disposed of in an unscientific manner. Unscientific disposal of solid waste is shown to directly affect human health and the environment (Wang and Nie 2001). Specif-

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ically, it creates environmental hazards in terms of health risks from flies and rats, pollution of water bodies through runoff and rainfall, pollution of groundwater from leachate, air pollution from burning of wastes, and aesthetics aspects as well (Mazhar et al., 2021). Furthermore, the growing waste is responsible for the increasing methane (CH_4) emissions (44%) (Mohammed et al., 2021). Therefore, MSW management (MSWM) is a serious concern for municipalities in developing countries due to its high cost and challenging implementation (Khan et al., 2022). In addition, MSWM has become a political, legal, socio-cultural, and environmental challenge that requires economic considerations as well as resource availability (Alam et al., 2020).

Usually, these issues have complex relationships in the MSWM system (Camobreco et al., 1999). For example, expensive management systems tend to have a less negative impact on the environment than inexpensive management systems, which may not provide adequate environmental protection. Therefore, the estimation of the MSW budget in order to establish the most appropriate treatment/disposal strategy is often a major concern for SWM policymakers (Gupta et al., 1998). Generally, MSW budget is divided into three cost service categories, a) MSW collection, b) disposal, and c) recycling. The total cost of each MSWM alternative is the planning cost, construction cost, and operation and maintenance costs (Idris et al., 2004; Guo et al., 2001). In most developing countries, MSWM is an expensive service, accounting for 20–50% of municipal service operating budgets (Chatterjee, 2010). However, the organization and planning of MSW collection services in these countries is very basic, as evident from the ineffective reuse and recycling initiatives that result in unknown types and quantities of MSW collected, recovered, and recycled, as well as the incorrect selection of final disposal sites (Ahring, and Johansen, 1992). Consequently, MSWM in India, and especially in urban cities like Delhi, is going through a critical phase where the disposal and treatment services available are fewer than the generated amount of MSW.

Therefore, this study aims to analyze the MSWM activities in India's capital, Delhi, and the CBA of MSWM systems to identify the major problems and limitations involved. The amount and composition of MSW generated in the last decade, and collection, storage, transfer, treatment, disposal, and recycling activities are also explored in detail. It is anticipated that doing so could potentially help in preparing some guidelines for improving the SWM system to meet future challenges.

2. Methodology

2.1. Study area and site description

Delhi lies in northern India, between 28° 24′ 17″ and 28° 53′ 00″ North latitude and 76° 50′ 24″ and 77° 20′ 37″ East longitude. The weather in Delhi is intense in general and temperatures vary between 40 and 45 °C during summer and 4 °C during the winter with an average rainfall of 784.5 mm (Economic Survey of India, 2011). According to India's 2012 census, the population density in Delhi is roughly 9,294 people per square kilometer. The New Delhi Municipal Council (NDMC), the Municipal Corporation of Delhi (MCD), and the Delhi Cantonment Board (DCB) make up the National Capital Territory (NCT) of Delhi. Among them, MCD has the greatest jurisdiction in the entire state of Delhi, and it is organized into 12 Zones for administrative and operational purposes, with 134 municipal wards, 168 corporation members, and 70 assembly constituencies. Households are the largest source of MSW generation, but many other sources, such as agricultural markets, retail and commercial markets, hospitals and nursing homes, industries, slaughterhouses, construction and demolition activities, street sweeping, and institutional areas, also generate significant amounts of MSW in Delhi. Three municipalities were contracted to collect and dispose of municipal garbage. In most states, MCD's Conservancy and Sanitation Engineering (CSE) department manages MSW with primary duties ranging from road cleaning, MSW collection, transfer and disposal, repair and maintenance of urban waste storage facilities, trash cans, transportation vehicles, mobile devices, and other systems. The NDMC provides public facilities to VIP areas such as Rastrapati Bhawan (President's Office), Prime Minister's Office, Parliament Building, Supreme Court, Connaught Place, and adjacent areas.

2.2. Sampling of MSW

MSW samples were collected and analyzed in consultation with MCD to determine its characteristics and to ascertain the extent of recycling. As shown in Table 1 total of 66 samples (approximately 6,600 kg) were randomly collected both at the sources of generation, composting plant, and disposal sites: 36 samples from 12 zones in MCD area (3 samples/zone). The sampling and analysis of MSW have been carried out as per standard procedure (Peavy et al., 1985; Edjabou et al., 2015). In India, MSWM is directed by the Municipal Solid Wastes (Management and Handling) Rules, 2000) that provide directions to municipalities for the collection, segregation, storage, transportation, processing and disposal of MSW (MoEF, 2000).

2.3. MSW characteristics

The dry density and moisture content of solid waste samples has been determined as per the standard procedure. Furthermore, secondary data of organic carbon, nitrogen as N, phosphorus as P_2O_2, potassium as K_2O, C/N ratio, and calorific value information has been gathered from MCD department. All the characteristics of MSW have been carried out as recommended by (Solid Waste Management Rules, 2016).

2.3.1. Procedure for determination of density and moisture content

To determine the density of the samples, the raw waste was collected in a conventional type wheelbarrow of known weight (60 kg) and volume (70 × 50 × 50 cm = 0.175 m^3). The wheelbarrow was filled completely in refuse then it is weighed on a weighbridge to determine the weight of MSW and the MSW density can be determined using the Eqn. (1).

$$MSW\ Density\ (kg/m^3) = Weight\ of\ MSW\ (kg)\ /\ Volume\ of\ wheelbarrow\ (m^3) \quad (1)$$

To determine the moisture content of the MSW, a small sample (approximately 2 kg wet weight) have been taken to the laboratory and put in the oven for 24 h under the temperature of 77 °C then weighted again to get the dry weight. The moisture can be estimated by using the Eqn. (2).

Table 1
Details of sampling location and number of samples collected excluding MCD areas.

S. No	Sampling Zone	Number of MSW samples
1.	NDMC area	3
2.	DCB	3
3.	Dwaraka	3
4.	Vegetable markets	3
5.	Commercial areas	3
6.	Institutional areas	3
7.	Landfill sites (2 sample/each disposal site)	6
8.	Bhalswa composting plant (3 samples of waste entering Bhalswa compost plant and 3 samples of waste rejected from Bhalswa compost plant)	6

$$Moisture\ Content\ (\%) = 100 \times (Initial\ Wet\ Weight - -Final\ Dry\ Weight)/Initial\ Wet\ Weight \quad (2)$$

3. MSW treatment and disposal

Delhi has been disposing of its MSW in four landfills namely Okhla (OL), Ghazipur (GL), Bhalswa (BL), and Narela Bawana (NL). Narela Bawana landfill site is provided with proper lining and a leachate collection system. Rest three landfills are simple dumps with no adequate liners or leachate collection systems. Fig. 1 gives the details of the existing landfill sites. Around 250 employees work at the four landfill sites under the supervision of junior engineers, who oversee operations at the landfill sites. The MSW is weighed at the landfill site and then dumped at the specific working space. The deposited MSW is thereafter spread by a single pass of the bulldozer and then covered by soil and silt. Daily soil cover over the waste is not always applied at the landfill sites. A total of 36 bulldozers work at the different landfill sites. Rag pickers carry out the recycling operations at the landfill sites. Animals like vultures, pigs, cows, and dogs are common on the sites.

In addition, there are three WtE power plants, namely the Timarpur Okhla waste power plant. The Ghazipur Waste Power Plant and Narela Waste Power Plant in Delhi are also in operation. As shown in Table 2, the Timarpur Okhla WtE plant, the Ghazipur waste incinerator plant, and the Narela waste incinerator plant consume 1800, 1300, and 200 MTD of solid waste, respectively, and generating 16, 12, and 24 MW, respectively.

4. Procedure for CBA of MSWM

The details about the storage, collection, transportation, and recycling of MSW in Delhi were collected locally and by conducting surveys as well as from departments like MCD, NDMC, CPCB. The CBA of MSWM in Delhi was done by calculating the full costs of each MSW option. This includes the annual salaries of the employers, annual costs for collection and transportation of MSW, the annual costs for general operations and maintenance (costs incurred for the purchase of capital goods and payment made for the sitting and construction of MSW facilities). The annual cost of depreciation of the purchase price of collection vehicles and other equipment (the land price is not depreciated). The annual indirect costs are the costs of support services or oversight provided to the MSWM by other departments or agencies of the local government. Any other costs that are not accounted for should also be added and the revenues (that local municipalities obtain from MSWM) which include interest income and revenue generated from the sale of recyclable materials, energy and salvaging of equipment. The revenue should be identified to calculate the net costs incurred by the local government for providing MSW services. The revenue was computed in INR and then converted to USD (one crore INR is equal to 0.13 million USD at the time of writing this article).

$$Net\ costs = Total\ costs\ - - Revenue \quad (3)$$

5. Results and discussion

To plan the most appropriate type of MSWM system, set a piece of reliable information on quantity, type, amount of reusable or recyclable material, and effective goals such as regulatory compliance, environmental protection, and valid local goals is essential. A business that uses raw materials, provides employment opportunities, and saves resources. The analysis and results obtained are described in the next section.

5.1. Composition of MSW in Delhi

After carrying out the analysis, the composition of MSW generated from different zones and areas of Delhi was computed and reported in Table 3. The results revealed the high organic content and the moisture content thus indicating the possibility for composting and bio-methanation, except for waste from commercial, hotels, and institutional areas which, can be used for RDF because this waste has low moisture content and low organic waste. The physical and chemical characteristics of MSW generated in Delhi are given in Table 4 (MCD, 2020). The waste in Delhi has 38.6 %

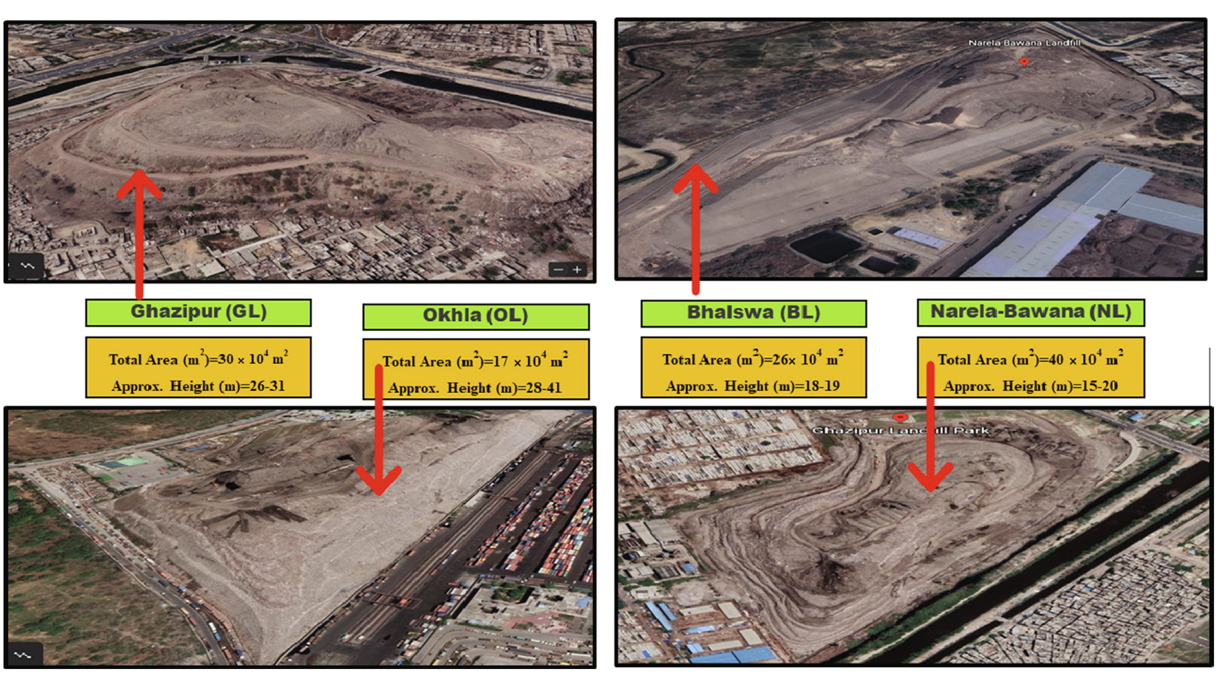

Fig. 1. Ghazipur, Bhalswa Okhla, and Narela Bawana landfill sites in Delhi.

Table 2
Details of waste to energy (WtE) plant.

S. No.	Name	Plant Capacity (MTD[a])	Electricity Generated (MW[b])	Status
1.	Timarpur Okhla WtE power Plant	1800.0	16.0	Working
2.	Ghazipur WtE power Plant	1300.0	12.0	Working
3.	Narela WtE power Plant	2000.0	24.0	Working

[a] MTD: Million Tonnes per Day
[b] MW: Megawatt

Table 3
Composition of MSW from different sources.

Samples Area	Physical Composition of MSW from Different Areas in Delhi							
	Biodegradable[a]	Paper and cardboard	Plastics	Metals	Glass and Ceramic	Others[b]	Moisture %	Density kg/m^3
Central zone	72.32	1.21	0.65	0.5	0.29	25.03	62	318
West zone	74.62	2.26	0.74	0.65	0.35	21.38	43	324
South zone	78.1	0.95	1.12	0.48	0.24	19.11	51	342
Karol Bagh zone	67.54	2.75	2	0.95	0.6	26.16	49	285
City zone	68.21	1.94	0.54	0.74	0.51	28.06	57	294
Sadar Paharganj zone	72.93	3.52	0.96	0.75	0.34	21.5	55	322
Shahdara (South) zone	71.21	2.54	1.25	1.1	0.26	23.64	61	305
Narela zone	71.34	0.95	1.03	0.9	0.41	25.37	47	298
Najafgarh zone	71.51	3.32	0.84	0.94	0.39	23	39	286
Shahdara (North) zone	60.25	3.98	0.42	0.84	0.57	33.94	45	269
Civil Lines zone	68.36	2.25	1.36	0.52	0.52	26.99	46	320
Rohini zone	78.32	1.7	0.75	0.35	0.28	18.6	65	395
NDMC Area	68.85	2.7	1.67	1.36	0.36	25.06	52	345
DCB Area	72.24	3.12	1.52	0.95	0.35	21.82	46	320
Dwaraka	71.26	2.65	1.38	1.05	0.51	23.15	41	316
Commercial Areas	51.31	5.4	1.99	1.16	0.84	39.29	27.5	207.67
Vegetable Markets	88.83	0.85	0.67	0.44	0.21	9	74	369
Institutional Areas	54.16	6.46	1.96	1.54	1.42	34.47	31.22	253.67
Hotels	47.43	6.41	1.72	1.8	1.17	41.46	34.25	261
Landfill sites	58.86	0.98	0.62	0.46	0.52	38.57	47.67	369
MSW entering compost plant	75.7	1.35	0.97	0.63	0.46	20.89	51	362.33
MSW rejected from compost plant	37.57	0.94	1.14	0.89	0.65	58.82	21.67	235
AVERAGE	67.31	2.65	1.15	0.86	0.51	27.51	47.56	308.94
STDEV	11.56	1.69	0.49	0.37	0.3	10.33	12.44	46.17
% Error at 95% confidence	4.83	0.71	0.2	0.15	0.13	4.32	5.2	19.29

[a] Food waste, vegetable leaves and peels.
[b] Rags, ash, leather, rubber, wood, construction and demolition waste etc.

Table 4
Physical and chemical composition of MSW in Delhi.

Parameters	%
Physical composition	
Non-biodegradable (rubber, leather, stones, bricks, ashes, etc.)	48.60
Paper	5.60
Plastic	6.0
Metal	0.20
Glass and crockery	1.0
Chemical composition	
Moisture content	43.8
Organic carbon	20.5
Nitrogen as N	0.9
Phosphorus as P_2O_2	0.3
Potassium as K_2O	0.7
C/N ratio	24.1
Calorific value	713 kcal/kg

biodegradable 5.6% paper metal 5.6% and glass and crockery 1%. Non-biodegradable waste which includes leather, rubber, bones, stones, bricks, ashes, etc. was found to be 48.6%. As far as chemical composition is concerned, the moisture, organic carbon, nitrogen (as N), phosphorus (as P_2O_2), potassium (as K_2O), C/N ratio, and calorific value are 43.8, 20.5, 0.9, 0.3, 0.7, 24.1 and 713 kcal/kg respectively.

5.2. Variation of MSW

The daily generation quantities of MSW in Delhi city vary as determined from the quantities received at the landfill sites (Fig. 2). In addition, the monthly quantities of MSW and its changes are shown in Table 5. Information on the daily/monthly/yearly MSW quantities received at landfills based on weighbridge data collected from MCD, NDMC and CPCB. According to the weighbridge data and features from 2016 to 2019, Delhi City alone creates approximately 8,810 tonnes of garbage every day. Approximately 6,554 tonnes (or 74.39% of total garbage generated) were collected from 2,400 secondary collection stations, however, 2,256 tonnes (or 23.5%) did not make it to the city stream. Scavengers may recycle this unaccounted garbage at various sites, or it may be left unmanaged during various stages of waste generation, collection, and transportation where services are not given in a proper manner. In Delhi, the per capita generation of solid waste is roughly around 0.5 kg per capita/day.

The annual MSW quantities generated from different zones in Delhi are shown in Table. 6 and Fig. 3 respectively. The result revealed that the maximum solid waste has been generated in 2019 in North Municipal Corporation followed by Delhi Municipal Corporation. The maximum percentage increase has been found in year 2018 in comparison to 2017.

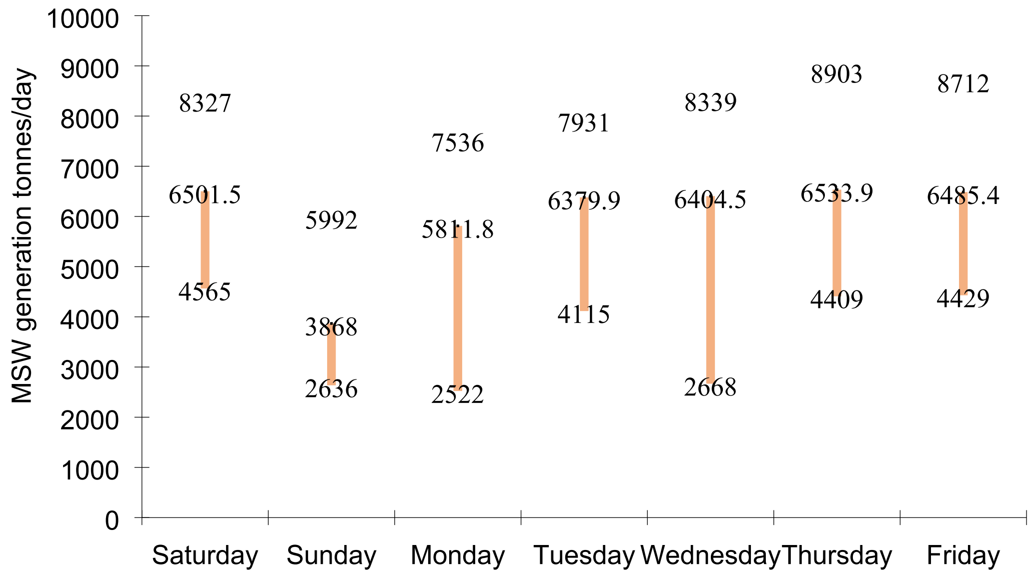

Fig. 2. Daily variation of MSW generation during 2019.

Table 5
Monthly quantities of MSW in Delhi.

Year	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
2016	184,321	216,543	223,875	221,940	231,986	229,812	237,823	270,813	216,042	229,013	219,042	272,190
2017	201,967	223,189	230,956	240,912	265,109	245,198	289,231	301,832	263,091	283,412	289,021	354,210
Increase/ decrease % (02–03)	8.7	2.9	3.06	3.70	2.6	6.2	17.7	10.2	**17.88**	**19.19**	**24.2**	**23.15**
2018	316,384	387,325	390,123	419,345	438,914	441,984	447,805	453,091	483,013	471,042	476,104	460,913
Increase/ decrease % (03–04)	**29.8**	**32**	**47.7**	**85.1**	**132.8**	**109.8**	**80.9**	7.8	−12.8	−7.5	−9.9	−2.5
2019	332,198	420,912	461,207	432,903	452,109	446,712	412,096	430,923	498,231	462,109	431,209	463,210
Increase/ decrease % (04–05)	11.4	4.2	−1.7	−23.2	−46.9	−50.3	−26.3	−3.3	0.4	−4.8	−9	−14.7

Table 6
MSW quantity generated from different Municipal Corporations of Delhi.

Municipal Corporations	**MSW quantity during 2016 (tonne/year)**	**MSW quantity during 2017 (tonne/year)**	**Increase/ decrease (%)**	**MSW quantity during 2018 (tonne/year)**	**MSW quantity during 2019 (tonne/ year)**	**Increase/ decrease (%)**
North Delhi (ND)	4,02,827	5,98,366	32.68	6,32,011	6,50,923	2.91
Delhi Municipal Corporation (DMC)	4,55,029	4,62,709	1.66	5,29,712	5,49,013	3.52
South Delhi Municipal Corporation (SDMC)	3,20,461	3,88,986	17.62	4,16,723	4,30,971	3.31
North Delhi Municipal Corporation (NDMC)	2,98,360	3,08,831	3.39	3,38,931	3,89,123	12.90
East Delhi Municipal Corporation (EDMC)	2,15,242	2,79,267	22.93	3,01,765	3,29,871	8.52
Delhi Cantonment Board (DCB)	99,354	77,517	8.80	1,18,952	1,32,675	10.34

Source: Municipal Corporation of Delhi (MCD).

5.3. Storage and collection

As per the Delhi Municipal Corporation Act, it is the responsibility of the owners and occupants of residential houses to deposit waste in the receptacles provided by the municipality. MCD is entrusted with the collection of MSW from the receptacles and transporting it to disposal sites. MCD uses MSW receptacles of two types: *Dhalaos* (covered structures) and street dustbins of different designs and sizes. In addition, there are open sites in some localities, which are used for the dumping of MSW. The street sweeping and the collection of MSW from the receptacles are carried out by municipal workers. The standards adopted by MCD for street sweeping are shown in Table 7.

NDMC workers collect the waste from the households and commercial areas and bring it to the nearest waste receptacles. The collection equipment available includes 275 masonry dustbins (of 1–1.5 tonnes capacity), 400 non-moveable iron trolleys (0.5 tonne), and 16 garbage stations. The DCB has garbage collection points spread out in civil and military areas. These include 400 numbers of 1100 L bins. Street sweeping in the military area is carried out by the military, while sweeping in the civil areas is undertaken by DCB. The DCB has recently entrusted an NGO (Manorama Social Services Center) to provide door-to-door collection. However,

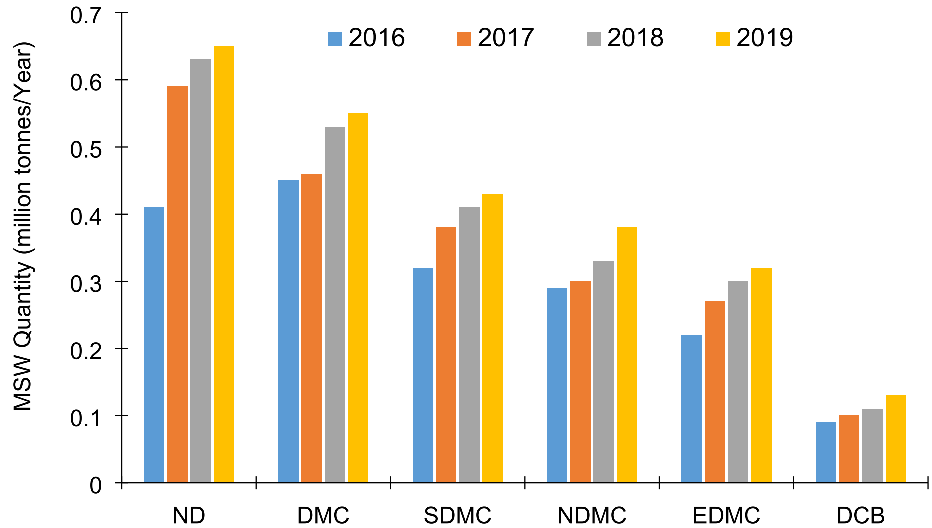

Fig. 3. Estimated zone wise MSW generated in Delhi.

Table 7
Standards for areas to be swept by each municipal worker per day.

Categories of Areas	Standard for Sweeping (area in m^2)
Congested areas	3,000
Roads more than 20 m wide	6,000
Rural areas	7,500
Roads less than 20 m wide	12,500

municipalities do not collect and dispose of the total amount of MSW, and consequently, garbage collection efficiency in Delhi is often below 80%.

5.4. Transportation of MSW

MCD maintains a large fleet of vehicles for transporting MSW from various trash receptacles to disposal facilities as well as secondary collection. Refuse removal trucks (RRTs), loaders, mini dumpers, tractor-trailers, and buffalo carts are the most common vehicles utilized in rural areas. MSW is transported in a variety of ways, which are determined by the type of collecting points. MCD's MSW transportation system is in disarray; probably the lack of a sufficient number of loaders and collecting trucks is the primary reason for the poor status of MSWM in MCD. The waste is covered by jute fabric in the collection trucks, but most of the time the jute cloth is ripped and insufficiently long to entirely cover the garbage in the truck. As a result, waste is sometimes lost during transportation to the dump site. The respective bodies carry out the MSW collection and transportation, whereas MCD receives waste from NDMC and DCB at its disposal and treatment facilities (landfills and composting plants). MCD alone manages almost 95% of the total area of the city; it spends over Rs. 1000/tonnes of MSW and about 80–85 % of its budget is spent in the collection and transportation of waste.

5.5. MSW treatment and disposal

As discussed, Delhi has been dumping MSW at four landfills: Ghazipur, Okhla, Bhalswa, and Narela Bawana; these landfills are simple dumps with no liners or leachate collection systems (Table 8). The transport vehicles carrying the MSW are weighed at the landfill site and then dumped at the specific working space. The deposited MSW is thereafter spread by a single pass of the bulldozer and then covered by soil and silt. Daily soil covered over the waste is not applied always at the landfill sites (Ayub and Khan, 2014). At several dump sites, bulldozers are in use. At landfill sites, rag pickers do recycling activities. Vultures, cows, and dogs are frequent on the grounds. (MCD, 2020; NDMC, 2020, CPCB, 2020).

There are three compost facilities for MSW treatment and processing: two in Okhla run by MCD and NDMC, and a privately-owned one in Bhalswa. MCD built a mechanical composting plant with a capacity of 150 tonnes per day in Okhla in 1980. However, due to the lack of markets in neighboring areas and the high operating costs of the plants, operations had to be shut down. In addition, as a joint venture with a private developer, MCD has built another composting plant at the Bhalswa landfill with a capacity of 500 tonnes per day. This plant is also not in full operation and currently produces 300 tonnes of compost per day. NDMC has also set up 200 tonnes composting plant per day in Okhla. The facility is not fully operational, and the compost produced is used for horticultural purposes in the NDMC operating area. Delhi also has the technology to incinerate municipal waste by constructing an incinerator with a capacity of 3.7 MW and a capacity of 300 tonnes per day in Timarpur in 1989 through the Ministry of Non-Conventional Energy Sources with Danish funding. However, due to the low calorific value of MSW, operations had to be stopped in a short period of time. There are also three waste incinerators in operation: the Timalpur Okhla waste incinerator, the Ghazipur waste incinerator, and the Narella waste incinerator in Delhi. It uses 1800, 1300, and 2000 MTD solid waste and produces 16, 12, and 24 MW of electricity, respectively.

The MCD has proposed additional facilities for the treatment and disposal of MSW (Fig. 4). These include disposal through sanitary landfills having liners, leachate collection, and treatment disposal systems. Currently, it is expected that these landfills will be developed (constructed, operated, maintained, and closed) by private agencies, with long-term post-closure care being possibly undertaken by the MCD. Further, treatment facilities are also being planned at Okhla in southern Delhi (RDF and Bio-Methanation), Ghazipur in eastern Delhi (RDF), Bakarwala in western Delhi (Bio-Methanation), and Narela Bawana in northern Delhi (RDF and Bio-Methanation).

Table 8
Details of the existing landfill sites.

Name	Location	Area (hectares)	Starting year	Initial amount of MSW T/day	MSW received T/day
Bhalswa	Delhi (North)	26.0	1993	1200.0	3200.0
Ghazipur	Delhi (East)	30.0	1984	800.0	2100.0
Okhla	Delhi (South)	23.0	1994	400.0	1200.0
Narela-Bawana	North	40.0	2012	1687.0	1856.0

Source: (MCD, 2020).

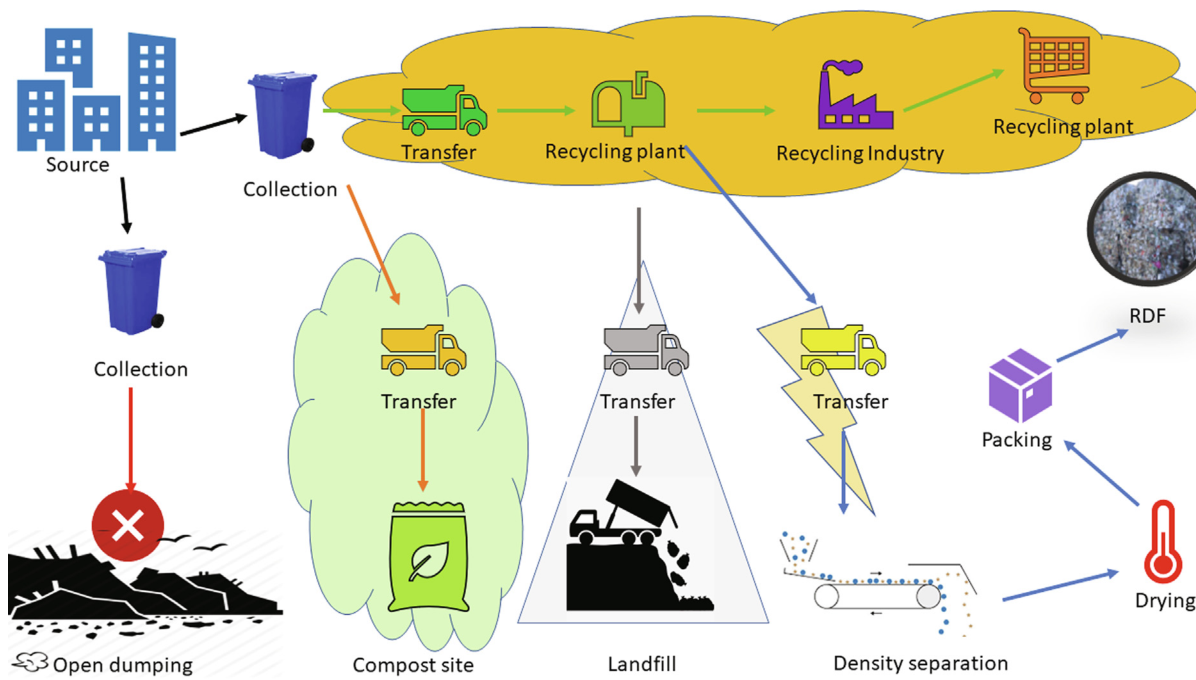

Fig. 4. MCD proposed scheme with additional facilities for treatment and disposal of MSW.

5.6. Recycling and reuse of MSW

Recycling municipal waste is a widespread activity in Delhi, and an extensive network of informal and official stakeholders is involved in this process. Recycled waste includes materials of market resale value such as paper/cardboard, plastic, metal, glass, rubber, leather, and textiles (Pervez et al., 2021). Rag pickers collect recyclables from disposed waste also households sell recyclables to itinerant buyers who make instant payments for the items. The recyclable materials pass from the rag pickers or small waste dealers to wholesale buyers and from there it goes to market level dealers as shown in Fig. 5. End users of cleaned and sorted recyclables are recycling units or factories, which use these recyclables as raw materials for manufacturing a new product.

The number of rag pickers in Delhi ranges from 80,000 to 100,000, each collecting approximately 15 kg of waste daily, reducing the processing and disposal burden by 1,200 to 1,500 tonnes per day. The estimated total number of shoppers traveling in Delhi is 17,587. Delhi's recycling units operate in both formal and informal departments and are spread throughout Delhi. Recycling is usually dirty and unsanitary. Solid waste often remains outside the recycling facility and causes air, soil, and groundwater pollution. Technologies are often old, and machines are rudimentary. Improper maintenance of the machine can lead to high power consumption. Manual sorting based on experience and know-how is a common method. Most areas with recycling facilities do not have sewage treatment or sanitation facilities. Table 9 shows that the total social value created through garbage trading operations in Delhi between 2017 and 2020 is anticipated to be Rs. 358.7 crores or approximately USD 46.60 million (MCD, 2012). The municipal budget saves roughly Rs. 17.6 crores or approximately USD 2.3 million per year due to recycling. However, the recycling sector's contribution to environmental conservation in terms of preserving virgin materials may be greater, albeit this is difficult to quantify.

5.7. Recycling of construction and demolition waste (CDW)

Construction and demolition waste accounts for about 10% of total waste dumped in landfills. Thus, it is necessary to reuse in different construction activities. CDW is large and bulky, making them unsuitable for composting or incineration. A waste management plan should be made to handle the CDW residues before the commencement of a construction project and control the quantity of material used in such projects, so when the building is demolished, no major consequences of the waste would appear.

Thus, by utilizing this waste, the amount of raw material utilized in the building is reduced, resulting in conservation. In general, 70% of CDW is used in the construction of different components of pavement. Such as base coarse, surface coarse, etc. In addition, energy costs associated with mining (quarrying), extraction, and transportation of aggregates would be reduced, in line with natural resource conservation and the creation of cost-effective pavements.

5.8. Cost analysis of MSWM in Delhi

The process involved in the cost analysis of MSWM in Delhi has been discussed in the methodology section. In order to know the

Fig. 5. Flow diagram of MSW management and trade chain in Delhi.

Table 9
Social value per year - marketing of recyclable waste in Delhi.

Category		**Rs. (Crores)**	**USD (Million)**	**%**
A	Waste trader	178.9	23.2	49.9
	Rag pickers	13.7	1.8	3.8
	Itinerant buyers	61.5	8.0	17.1
	Dealers	49.4	6.4	13.8
	Wholesalers	54.3	7.1	15.2
B	Waste producers	162.2	21.1	45.2
	Households	81.4	10.6	22.5
	Business establishments	80.8	10.5	22.5
C	City administration (public cost saving)	17.6	2.3	4.9
Total (A + B + C)		358.7	104.6	100

Table 10
Expenditure budgets 2018–2019 and 2020–2021 for MCD on MSWM.

Account		**Revised budget estimate 2018–2019 (Lacs)**	**Revised budget estimate 2018–2019 Rs. per capita**	**Budget estimate 2020–2021 (Lacs)**
A	Conservancy and street cleansing	36502.7	253.5	38123.7
	a) Street cleansing	35135.1	244	36431.2
	b) Removal of refuse	505.5	3.5	675.6
	c) Transportation	752.8	5.2	830.7
	d) Disposal of refuse	25.1	0.2	42
	e) Compost plant	84.3	0.6	144.4
B	Repairs and maintenance to buildings	0.5	0	0.5
C	Purchase of trucks, tempos and machinery	10	0.1	10
D	Improvement of conservancy services and sanitary landfills	200	1.4	1200
E	Purchase of wheelbarrows	2	0	2
F	Supervision and control	1886.1	13.1	1764.1
Total expenditure (A + B + C + D + E + F)		38601.2	268.1	41100.3

Source: (MCD, 2020).

Table 11
Revenue budgets 2019–2004 and 2020–2021 for MCD from MSWM.

Account	Revised budget estimate 2018–2019 (Rs. Lacs)	Budget estimate 2020–2021 (Rs. Lacs)
Private removal charges	120	120
Other receipts (recycling etc.)	100	120
Sale of compost	–	–
Government contributions	–	–
Total revenue	220	240

(-): Data not available.
Source: (MCD, 2020)

best and optimal MSWM options, it is important to estimate both the total costs for each option (collection, transportation, operation, environmental, and construction costs) and the total benefits (incomes or revenues from different facilities) then by minimizing the net costs (total costs – benefits) the optimal SWM options can be determined (Abounajm and Elfadel, 2004). MSWM falls under Head no. 7 Conservancy, Street Cleansing (CSC) of MCD. During 2005–06 the total annual budget for CSE Department was Rs. 175 crores (22.7 USD million) and the expenditure on MSWM was Rs. 107/capita. Table 10 shows the current expenditure of MCD for MSWM, and the per capita expenditure on MSWM on the basis of a total population of 15 million in MCD's area. Table 11 shows MCD revenues from MSWM.

6. Conclusion

After analyzing the composition of MSW generated in various zones and areas of Delhi, it was discovered that solid waste with high organic content and moisture content has the potential for composting and bio-methanation, except for waste from commercial, hotel, and institutional areas, which can be used for RDF due to its low moisture content and low organic waste. The study also concluded that Delhi has 38.6% biodegradable waste, 5.6% paper and metal waste, and 1% glass and crockery waste. As far as concerned with CBA aspects, that governs the appeal of a given SWM project in a profitable as well as sustainable manner. In this study, a CBA for setting up a recycling facility was successfully carried out. The analysis showed the viability of the project based on the five different scenarios tested in the sensitivity analysis.

Based on the results of the analysis, this study establishes that the strategy is profitable but could be efficiently improved by minimizing the load on dumpsites or landfill sites. In addition, the execution of waste segregation could further improve the socio-economic benefits of MSW management and contribute directly towards the sustainable development goal. Overall, such strategies not only directly benefit municipalities but also create more potential jobs from the facility. However, it should be noted that the participation of citizens, policymakers, strategic planners, researchers, and private and municipal agencies being crucial in handling MSWM challenges such as social, economic, and environmental impacts.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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