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ScienceDirect
Waste Management 28 (2008) 1276–1287
waste management
www.elsevier.com/locate/wasman

State of municipal solid waste management in Delhi, the capital of India

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Accepted 17 May 2007
Available online 9 August 2007

Abstract

Delhi is the most densely populated and urbanized city of India. The annual growth rate in population during the last decade (1991–2001) was 3.85%, almost double the national average. Delhi is also a commercial hub, providing employment opportunities and accelerating the pace of urbanization, resulting in a corresponding increase in municipal solid waste (MSW) generation. Presently the inhabitants of Delhi generate about 7000 tonnes/day of MSW, which is projected to rise to 17,000–25,000 tonnes/day by the year 2021. MSW management has remained one of the most neglected areas of the municipal system in Delhi. About 70–80% of generated MSW is collected and the rest remains unattended on streets or in small open dumps. Only 9% of the collected MSW is treated through composting, the only treatment option, and rest is disposed in uncontrolled open landfills at the outskirts of the city. The existing composting plants are unable to operate to their intended treatment capacity due to several operational problems. Therefore, along with residue from the composting process, the majority of MSW is disposed in landfills. In absence of leachate and landfill gas collection systems, these landfills are a major source of groundwater contamination and air pollution (including generation of greenhouse gases). This study describes and evaluates the present state of municipal solid waste management in Delhi. The paper also summarizes the proposed policies and initiatives of the Government of Delhi and the Municipal Corporation of Delhi to improve the existing MSW management system.

1. Introduction

India is the second fastest growing economy and the second most populated country in the world. The population of India is expected to increase from 1029 million to 1400 million during the period 2001–2026, an increase of 36% in 26 at the rate of 1.2% annually (Census of India, 2001). About 742 million people live in rural areas and 285 million live in urban areas. The level of urbanization of the country has increased from 17.6% to 28% in the last 50 years and is expected to rise to 38% by the year 2026. An important feature of India's urbanization is the phenomenal concentration of the population in Class I cities[1] (metropolitan cities), urban agglomerations/cities having a population of more than 1 million, as depicted by the increase in the number of metropolitans from 23 to 35 in the last decade. Among these metropolitans, Greater Mumbai is India's largest city with a population of 16.4 million, followed by Kolkata and Delhi.

Generally, the greater the economic prosperity and the higher the percentage of urban population, the greater is the amount of solid waste produced (Hoornweg and Laura, 1999). In India, urban solid waste management has remained one of the most neglected areas of the urban system. The urban population in India generated about 114,576 tonnes/day of municipal solid waste (MSW) in the year 1996, which is predicted to increase 4-fold to about 440,460 tonnes/day by the year 2026 (Hoornweg and Laura, 1999). This tremendous increase in the amount of MSW generated is due to changing lifestyles, food habits and living standards of the urban population. The collection efficiency ranges between 70% and 90% in the major metro cities in India, whereas in several smaller cities collection efficiency is below 50% (CPHEEO, 2000). When the disposal method for the waste is considered, it has been

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[1] In India, over two-thirds of the total urban population lives in the 393 cities that have populations over 100,000 (Class I cities).

0956-053X/$ - see front matter
doi:10.1016/j.wasman.2007.05.017

observed that Indian cities dispose of their waste in open dumps located in the outskirts of the city without concern for environmental degradation or impact on human health. Further, the financial and infrastructural constraints, including non-availability of land for safe disposal of generated waste, and the lack of awareness and apathy at all levels also inhibit progress leading to efficient, safe management of urban solid waste (GoI, 1995).

In the present article, the municipal solid waste management system of Delhi, the capital city of India, is evaluated. The quantity and composition of MSW generated over the last three decades, and the pattern of primary collection, storage, transportation, treatment, disposal and recycling are discussed in detail. The policies proposed by the Municipal Corporation of Delhi to establish a sustainable MSW management system are also summarized.

2. Policy and legislative framework for municipal solid waste management (MSWM) in India

Under the fourth 5-Year plan (1969–74), the Government of India (GoI) initiated efforts to establish better facilities for municipal solid waste management (MSWM) by providing grants and loans to state governments to set up MSW composting facilities. Later, in 1975, the GoI appointed a high-level committee to review the problem of urban solid waste in India. This committee made 76 recommendations covering 8 important areas of waste management.

During 1975–1980, under the National Scheme of Solid Waste Disposal, 10 mechanical composting plants with processing capacities ranging from 150 to 300 tonnes of MSW per day, were set up in several Indian cities with populations over 300,000 (GoI, 1995; Hoornweg et al., 2000). At present most of these are non-operational and the remaining ones do not operate at full capacity, mainly because of the poor quality of waste, wrong choice of equipment, poor maintenance, high production costs, financial losses, low priority at the top level, and poor marketing efforts (Selvam, 1996). A review committee, set up by GoI has concluded that the unnecessary and avoidable mechanization of the plants pushed up the cost of organic manure production, while the lack of sales promotional effort on the part of the municipality was responsible for failure of these plants. The committee further pointed out that this scheme, based on sound principles, failed mainly because of inadequate planning, use of inappropriate technology and poor management (GoI, 1995). Following the failure of these mechanical compost plants, most municipal corporations showed little interest in promoting composting. However, in recent years some centralized as well as decentralized composting projects in different cities have been revived by many individuals, voluntary groups, community groups, non-governmental organization (NGOs), government agencies and private companies. Zurbrügg et al. (2003, 2004) assessed the technical, operational, organisational, financial and social set up of several decentralized composting facilities in different cities of India. The authors suggested that considering the economic and environmental benefits, composting could be a viable waste management option in large and small towns in India.

In 1990, the National Waste Management Council (NWMC) was constituted by the Ministry of Environment and Forests (MoEF) and one of its objectives was municipal solid waste management (UNEP, 2001). The NWMC advised 22 municipalities in a survey to estimate the quantity of recyclable waste and its fate during waste collection, transportation and disposal. In 1993 NWMC constituted a national plastic waste management task force to suggest measures to minimize the adverse environmental and health impacts arising out of plastic recycling. Based on the recommendations of this task force, in 1998 the MoEF came out with draft Recycled Plastic Usage Rules 1998, which bans storing, carrying and packing of food items in recycled plastic bags and specifies quality standards for manufacturing recycled plastic bags.

The outbreak of an epidemic in Surat in 1994 served as an alarm for the GoI and residents of the country as it reflected the magnitude of impacts of improper urban solid waste management. Consequently, in 1995, a high powered committee (Bajaj committee) was constituted to review urban solid waste management. This committee gave a number of suggestions including the need for source segregation, community based door-to-door collection and transportation, charging user-fees, standardization of the design of municipal vehicles for transportation, the need for composting of waste and use of appropriate technologies for waste treatment and disposal. In January 1998, another expert committee (Asim Burman Committee) was formed under the Honourable Supreme Court of India to identify deficiencies and make recommendations to improve solid waste management in Class I cities. After reviewing all aspects of solid waste management, the committee submitted its detailed recommendations in 1999. To ensure compliance, the principal recommendations of these committees have been incorporated in the Municipal Solid Waste (Management and Handling) Rules 2000 notified by the MoEF in 2000.

According to MSW Rules 2000, local municipal bodies are responsible for the implementation of the provisions of these rules, and for any infrastructure development for collection, storage, segregation, transportation, processing and disposal of municipal solid wastes. The rules mandate that biodegradable waste be processed by adopting an appropriate combination of processing systems (composting, vermicomposting, anaerobic digestion, pellatisation, etc.) and landfilling be restricted to only nonbiodegradable, inert waste and other appropriately stabilized biological waste. These rules mandated all cities to set up appropriate waste treatment and processing facilities by 2003 (Asnani, 2006). In 2000, a comprehensive manual on Municipal Solid Waste Management was published by the CPHEEO (Central Public Health

Environmental Engineering Organisation) under the Ministry of Urban Development for the guidance of urban local bodies (ULBs) to implement the MSW Rules 2000. Besides these rules, the GoI and the state governments have drafted several other acts and rules to deal with solid waste management as listed in Table 1.

Despite consistent efforts of different regulatory bodies and directives from Honorable Supreme Court of India and from time to time regulatory bodies, the implementation of these rules is still a distant dream. Asnani (2004) carried out a study to ascertain the status of compliance with the MSW Rules 2000 by Class 1 cities as on 1.4.2004. The results of this study reveals that out of 393 Class I cities, 128 responded and the status of compliance shows that there has been insignificant progress in the matter of processing of waste and construction of sanitary landfills, and only about one-third compliance in the remaining five steps as shown in Fig. 1. Many cities have not even initiated the implementation of the rules even though the timeframe prescribed in the rules is over. Major constraints for noncompliance are: unavailability of financial resources, lack of technical skilled workforce, lack of public awareness and motivation, and non-cooperation of the households, trade and commerce (Asnani, 2004).

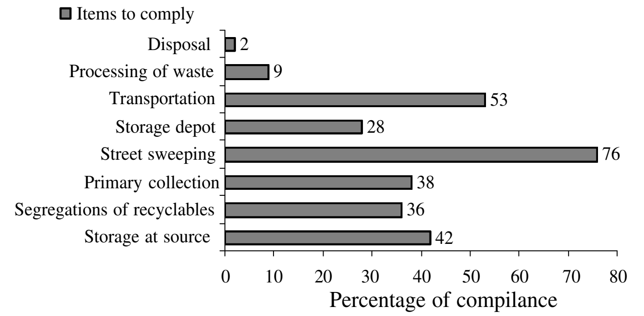

Fig. 1. Status of compliance of MSW Rules 2000 by Class-1 cities. Source: Asnani (2004)

3. Study area

Being the capital of India, Delhi is the center of power, trade and commercial activity and provides excellent employment opportunities, which account for its booming population and accelerated pace of urbanization. The population of Delhi has been growing at a steady rate of about 1000 persons per day (350,000 persons per annum) for a number of years. Approximately 125,000 persons per year of this increase in population is due to influx from neighboring states (DUEIIP, 2001). The annual growth rate of

Table 1
Summary of acts and rules on MSW in India

Act and Rules	Brief description	Issuer
Municipal Solid Waste (Management and Handling) Rules, 2000	Set criteria and procedure for municipal authorities for collection, segregation, storage, transportation processing and disposal of MSW The criteria and procedure for management and handling of MSW are specified in schedule II, specifications for landfill sites in schedule III and setting up of waste processing facilities with the adoption of appropriate technology in schedule IV	MoEF[a], Government of India
The Delhi plastic bag (Manufacture, Sales and Usage) And Non-Biodegradable Garbage (Control) Act, 2000	Prevents manufacturing, sale, etc. of recycled plastic bags for food packaging and also prohibits throwing or depositing non-biodegradable garbage in public drains, roads and places open to public view Act also defines that the placement of receptacles and places for deposit of garbage is the responsibility of MCD, NDMC or CDB	Legislative Assembly of the National Capital Territory of Delhi
Hazardous Wastes (Management and Handling) Rules, 1989 and Amendment Rules, 2000 and 2003	Specify the processes, hazardous wastes, constituents, concentration limits and waste applicable for import and export. The occupier should take responsibility for proper management and handling of waste either himself or through the operator of a facility The different categories of hazardous waste are specified in schedule 1	MoEF, Government of India
The Bio-Medical Waste (Management and Handling) Rules, 1998 and Amendment Rules, 2003	Recommended treatment and disposal options according to the 10 different categories of biomedical waste generated are defined in schedule 1 of the rules. Standards for the treatment technologies are given in schedule V	MoEF, Government of India
Delhi Municipal Corporation Act, 1957	Early legislation, deals with the environment pollution caused by MSW The provisions related to MSW are defined under chapter 3 ‘Functions of the Corporations’ and chapter 7 ‘Sanitation and public health’	Act of Parliament, Government of India

[a] MoEF – Ministry of Environment and Forest.

population during the last decade (1991–2001) was recorded as 3.85%, almost double the national average (Census of India, 2001). The rapid urbanization of Delhi has resulted in a sharp increase in the density of population. The density was 274 persons/km^{2}in 1901, increased to 1176 persons/km^2 in 1951 and 9294 persons/km^2 in 2001 (Economy survey of Delhi, 2002–03). Delhi is also the most urbanized city of India with a 93.1% urban population. The urbanization results in expansion of the urban areas. The city witnessed a 16% reduction in rural area as the number of villages declined from 209 in 1991 to 165 in 2001. The ever increasing population and rapid pace of urbanization have created a number of problems, such as shortage of dwelling units, mushrooming growth of slums, encroachment of public land, and expansion of unauthorized colonies (GoI, 2002).

The Municipal Corporation of Delhi (MCD), New Delhi Municipal Corporation (NDMC) and Delhi Cantonment Board (DCB) are three municipal entities responsible for MSW management in Delhi. MCD is the largest local body, covering almost 95% of the area; the rest of the area is almost equally divided between NDMC and DCB. MCD covers approximately 1390 km^2, with about 43% of the area urban. The population density in the area under the jurisdiction of MCD is far greater than that of NDMC and DCB (Fig. 2). MCD and NDMC have divided the area of Delhi under its administration in 12 and 2 zones, respectively. Some other entities share the responsibilities of solid waste management with MCD. The prominent ones are Delhi Development Authority (DDA), for siting and allotment of land for landfilling; Delhi Energy Development Agency (DEDA), for solid waste utilization projects aiming at biogas or energy generation; and Department of Flood Control of Delhi (DFCD), for supplying soil to be used as cover for landfills by MCD (2004).

4. Generation and composition of MSW

In Delhi, 13.9 million residents living in 2.96 million households generate approximately 7000 tonnes/day of MSW at the rate of 0.500 kg/capita/day (DUEIIP, 2001). The planning department of Delhi projected that the present population is likely to increase to 22.4 million and the waste generation to 17,000–25,000 tonnes/day by the year 2021. Even if it is possible to accomplish maximum reduction of waste through composting and incineration, there would still be a minimum of 20% residue (i.e., 4000–5000 tonnes/day) that would have to be landfilled in 2021 (DUEIIP, 2001). Therefore, the local municipal bodies are going to face a tremendous pressure to manage this enormous amount of MSW in the near future.

In order to monitor and control existing waste management systems and to make regulatory, financial, and institutional decisions, it is necessary to characterize the solid waste by its source, type, generation rate and composition (Hoornweg and Laura, 1999). All over the world, different procedures are followed for characterization and the way municipal solid waste is defined. The MoEF, GoI has defined MSW as ‘‘commercial and residential wastes generated in a municipal area in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes’’ (CPHEEO, 2000).

The source wise quantity of MSW generated in Delhi is given in Table 2. The figures quoted in the tables only indicate the amount of MSW that is collected and disposed by MCD. Although measuring the waste quantity arriving for final disposal is the most practical approach for municipal purposes, this method does not represent the composition or quantity of the waste stream accurately (Hoornweg and Laura, 1999). This method does not take into account the significant amount of waste removed prior to disposal by the informal sector involved in recycling, or the absence of formal services in JJ (Jhuggie–Jhopari) clusters (slums) and all rural areas where the waste is dumped at open sites rather than landfilled.

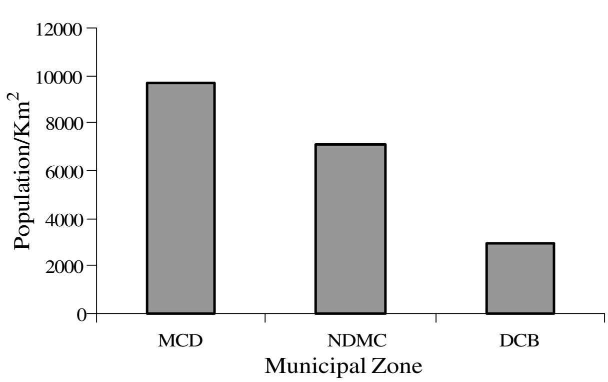

Fig. 2. Density of population in different municipal zones of Delhi.

Table 2
Source wise generation of the MSW (tonnes/day) in Delhi

Residential waste	Main shopping centres	Vegetable and fruit markets	Construction waste	Hospital waste	Industrial waste
3010	1017	538	382	107	502

Source: MCD (2004).

Table 3
Physical composition (as wt.%) of MSW in Delhi

Parameters	2002	1995	1982
Biodegradable	38.6	38.0	57.7
Paper	5.6	5.6	5.9
Plastic	6.0	6.0	1.5
Metal	0.2	0.3	0.6
Glass and Crockery	1.0	1.0	0.3
Non-biodegradable (leather, rubber, bones, and synthetic material)	13.9	14.0	5.1
Inert (stones, bricks, ashes, etc.)	34.7	34.8	28.9

Sources: TERI (2002), NEERI (1996), IHPH (1982).

Table 4
Chemical composition (as wt.%) of MSW in Delhi

Parameters	2002	1995	1982
Moisture	43.8	43.7	15–40
Organic carbon	20.5	20.5	22.8
Nitrogen as N	0.9	0.9	0.86
Phosphorus as P_2O_5	0.3	0.3	0.74
Potassium as K_2O	0.7	0.7	0.52
C/N ratio	24.1	24.0	28.0
Calorific value (kCal/kg)	713.0	712.5	661–1200

Sources: TERI (2002), NEERI (1996), IHPH (1982).

Several studies have been conducted in Delhi by different agencies (IHPH, 1982; NEERI, 1996; TERI, 2002) to determine the physical and chemical composition of MSW as given in Tables 3 and 4, respectively. The results reflect that in the last decade the composition of MSW is almost unchanged. The major component of the MSW is the biodegradable fraction, followed by inert waste, non-biodegradables (leather, rubber, bones and synthetic material), plastic, paper, glass and metal. The inert material (stones, bricks, ashes, etc.) in the MSW stream has increased, which indicates the high pace of construction and demolition activities in Delhi. As the economy grows and the population becomes more urbanized, the substantial increase in use of paper and paper packaging is probably the most obvious change. However, the percentage of paper in MSW has remained unchanged in the last two decades, but this may not be a true representation. The possible reason may be recycling of paper, which is a highly prevalent activity in Delhi. The proportion of plastic and non-biodegradables is increasing steadily. This may be the result of a shift towards plastic packaging, a reflection on the improved living standards and consumerist attitude of residents.

The composition of MSW varies according to the cultural habits and economic status of the residents, urban structure, density of population, extent of commercial activity and climate. Information and data on physical components of the waste stream are important in the selection and operation of equipment and facilities, in assessing the feasibility of energy and resource recovery and in the design of a final disposal facility (Tchobanoglous et al., 1993). Recently a survey has been conducted in Delhi to evaluate the composition and the properties of the individual waste streams to judge the suitability of specific waste treatment technologies (MCD, 2004). Samples have been collected from different socio-economic residential zones (high, medium and low income groups and JJ clusters), commercial areas, vegetable markets, institutional areas, streets and landfills. A summary of the results is provided in Table 5.

5. Current practices for MSW management in Delhi

5.1. Primary collection and storage of MSW

Presently two types of primary MSW collection systems are followed in Delhi. In the first, old system, following the Delhi Municipal Corporation Act 1957, the owners and occupants of residential houses and of commercial and industrial establishments were responsible for depositing MSW in the receptacles provided by the municipal authority. But the implementation of MSW Rules 2000 reassigned the responsibility to municipalities to provide door-to-door collection (DTDC) of segregated waste. It was planned that by December 2003, DTDC would be implemented in all municipalities. However, due to operational problems, such as lack of staffing and resources, MCD has not replaced the old primary collection system completely. Therefore, at present, both collection systems coexist. In the DTDC system, the segregated waste is collected from houses and transported to municipal bins through specially designed handcarts having two compartments, one for

Table 5
Composition (as wt.%) of MSW generating from various sources in Delhi

Parameters	Typical distribution of components in MSW (average)								
	Residential waste				Vegetable markets	Institutional areas	Streets	Commercial areas	Landfills
	Low income group	Middle income group	High income group	JJ Clusters (Slums)					
Food waste	58.4	76.6	71.9	69.4	97.2	59.7	28.4	15.6	73.7
Recyclables	15.7	21.2	23.1	14.1	2.3	33.8	12	68	9.2
Inert	22.8	0.5	0.3	15.8	0.5	4	56.1	–	10.8
Others	3.1	1.7	4.7	0.7	–	2.5	3.5	16.4	6.3
Moisture	54	65	59	63	76	50	19	18	47
Ash content	21.8	6.3	10.9	15.6	3.3	6.7	56.7	8.8	15.3
C/N ratio	39	30	31	46	16	35	51	158	38
Lower CV[a] (kcal/kg)	754–2226	732–1939	1300–1887	204–1548	0–1309	129–3778	1007–2041	1815–4593	191–4495
Higher CV[a] (kcal/kg)	2238–4844	3415–6307	4503–5359	1582–4912	3083–4442	2642–5459	1188–3289	3373–6185	2042–5315

Source: MCD (2004).
[a] Calorific value.

recyclables and the other for non-recyclables. Many residential welfare societies (RWAs), NGOs and private groups participate in the DTDC system. These agencies provide DTDC services to households on a specified monthly payment basis. For example, the DCB has recently entrusted an NGO (Manorama Social Services Centre) to provide DTDC services in its jurisdiction.

To ensure the segregation at the household level, the government has taken some initiatives such as: introduction of Garbage Handling Rules 2000 and institution of the 'Bhagidari: The citizen-government partnership'. Bhagidari literally means "collaborative partnership". The government of Delhi has initiated the concept to ensure the cooperation of the RWAs, civic agencies, NGOs and the government. The purpose of Bhagidari is building awareness, public participation and facilitation of segregation and primary collection of the waste. Such initiatives are going to play a major role in managing MSW in near future.

In Delhi, municipalities provide various types of primary storage facilities in the form of waste receptacles: 'Dhalaos', masonry enclosures, dustbins, metal containers and open collection points. Dhalaos are covered masonry structures of large capacity (50–72 m^3). These structures are used to serve about 10,000–15,000 residents with a capacity of 12–16 tonnes. Masonry enclosures and dustbins are of varying sizes and shapes, usually with a capacity of about 10 m^3 or more. These are generally open, but sometimes are covered with wire mesh. Metal containers and dumper bins are of 1 $m^3$and 4 m^3 capacity, respectively, and are emptied by modern hydraulic refuse collection trucks. Besides these receptacles (Dhalaos and containers), open unspecified space with no structure is also used for primary storage. Usually open dumpsites storage occurs in JJ clusters and other unorganised settlements, existing within the MCD periphery. The placement of MSW receptacles does not follow any standards, as on an average about 2–3 collection points are placed per km^2. TERI (2002) concluded that 16 collection points are provided per 100,000 residents (Dhalaos, containers or open dumpsites).

MCD, NDMC and DCB employ about 50,000, 2600 and 370 Safai Karamacharis (sweepers) (SKs) in their respective jurisdictions for primary and secondary collection of MSW from waste receptacles and for street sweeping. Depending upon the density of population, the SKs are assigned to sweep an area of 3000–12,500 m^2. Due to a lack of proper monitoring, the street sweeping and primary collection system is highly inefficient in Delhi. NEERI (1996) revealed that the labour productivity of this system is as low as 0.093 tonnes of waste/SK/day during summer and 0.125 tonnes of waste/SK/day during monsoon. Due to the significant increase in vehicular traffic on the main roads, commercial areas and other crowded areas, it is not possible to carry out street sweeping manually during the morning hours. Therefore, the State Government of Delhi proposes to adopt street sweeping during the night in 30% of the municipal areas, and to hire mechanical road sweepers in the tenth 5-Year plan (2002–2007) (GoI, 2002).

5.2. Transportation of MSW

MCD maintains a large fleet of vehicles for transportation and secondary collection of MSW from the various waste receptacles to the disposal sites. The vehicle fleet contains refuse removal trucks (RRTs), loaders, mini dumpers and tractor-trailers. In rural areas, buffalo carts are also used. Presently MCD uses 577 RRTs, 101 loaders, 1 mini dumper and 4 tractors. The NDMC and DCB operate fleets of 75 and 18 trucks, respectively, for collection and transportation of waste from dhalaos to the landfills. Although the available transport volume is adequate for the MCD areas at two trips per day per vehicle, due to operational inefficiency the available volume is not adequate even at four trips per day per vehicle. The situation has been worsened by poor maintenance and route planning. The situation is better in NDMC where operational efficiency is 75% as compared to 60% in MCD (Ansari, 1999). According to the NEERI, the requirement for RRTs will rise to 1200 by 2011. The report also reveals that about 50% of the collection vehicles in MCD are in need of overhauling or replacement.

5.3. Treatment of MSW

5.3.1. Composting

In the current MSW management system, 91% of the collected MSW is disposed in landfills and 9% is composted at three existing plants (Kumar et al., 2002). The first mechanical composting plant at Okhla in the periphery of MCD was set up in the year 1980, under the National Solid Waste Disposal scheme. The plant was designed for a treatment capacity of 150 tonnes/day. However, due to the absence of markets in the nearby areas and also due to the high production cost of compost, the plant was non-operational during 1991–1995. The plant was restarted in June 1996, as a result of the directives of the Honourable Supreme Court of India. In addition to this setup, two more composting plants were established in Okhla and Bhlaswa in 1985 and 1998, respectively. The details of all three composting plants are given in Table 6. However, these composting plants do not function at the intended capacity, and along with the process residue, a major

Table 6
Details of existing composting plants in Delhi

Composting plant	Starting year	Operating authority	Area (ha)	Capacity (tonnse/day)	
				Actual	Working
Okhla	1980	MCD	3.24	150	120
Okhla	1985	NDMC	3.44	200	120
Bhalswa	1998	MCD	4.9	500	200–250

fraction of MSW is diverted to the landfills. The main reasons are high operating and maintenance costs compared to open landfilling; higher compost cost compared to the commercial fertilizers; improper separation of the inert materials such as plastics and glass, which degrade the quality of final compost material for agricultural purposes; and poor operation and maintenance of these facilities. The unacceptability of final compost compared to the chemical fertilizer is also a major reason for its limited market demand.

5.3.2. Incineration

The state of Delhi has also tried treatment of waste using incineration technology. The Ministry of Non-conventional Energy Sources (MNES), GoI in collaboration with the Government of Denmark, set up an incinerator and power generation plant at Timarpur in the year 1989. The plant was designed to incinerate 300 tonnes/day of MSW to generate 3.7 MW of electric power. However, the plant was operational for exactly 21 days and then shut down because the waste being provided was unfit for burning due to its low calorific value (550–850 kcal/kg) (http://mnes.nic.in/tender_notice/information.pdf). For energy generation the minimum calorific value should fall between 1200 and 1400 kcal/kg. The low calorific value of the MSW provided to the incineration plant was due to the removal of most of the combustible materials through recycling, its high moisture content and the presence of inert material.

5.3.3. Disposal of MSW

In India, MSW from the urban areas is commonly disposed in the nearest available low-lying areas and wastelands on the outskirts of the city. Selection of these disposal sites depend solely on availability and not on scientific and socio-environmental criteria for a landfill. MSW is disposed in an uncontrolled manner and the daily cover material is not applied regularly, although it is known that daily cover is necessary to abate odor, rodents and birds and to decrease site litter. These landfills are devoid of landfill gas (LFG) and leachate collection and treatment systems. Poor maintenance of these landfills renders them a threat to health and the environment rather than a solution to the problem of MSW management.

Since 1975, 20 such landfills have been created in Delhi, 15 of which have already been exhausted and 2 have been suspended. At present, three landfills sites are operational, namely Gazipur, Bhalswa and Okhla, spreading over a total area of 60 ha. The details of the existing landfills are given in Table 7. These landfills sites receive MSW from 12 zones of MCD, 2 zones of NDMC and DCB. All types of wastes, household, industrial, medical, hazardous and slaughterhouse, are disposed together. To save landfill space, the dumped waste is leveled and compressed with four to five passes of hydraulic bulldozers. The MSW is deposited in layers of 2–5 m and a covering is provided at the end of the day. Generally, construction and demolition waste and inert material are used for daily covering. A fraction of the deposited MSW is not provided daily cover because of an insufficient quantity of the covering material. The liquid that collects at the bottom of a landfill is called leachate, which contains various chemical constituents derived from the solublization of the deposited waste and from other chemical and biochemical reactions occurring in the landfill (Tchobanoglous et al., 1993). In Delhi, landfills are not provided with a base liner or with a leachate collection, treatment, and disposal system. Therefore, leachate generated from these landfills (active and closed) percolates to the groundwater or flows to nearby drains. The area covered by landfills is at least 1% (14.83 km^2) of Delhi's total area. It has been estimated that these active and closed landfills produce approximately 81.5 million liters of leachate annually, most of which is produced during the rainy seasons (Kumar et al., 2002). All of the landfill sites are located very close (0.5–6 km) to the river Yamuna, which accounts for more than 70% of Delhi's water supply. Zafar and Alappat (2001) concluded that the leachate and runoff from these landfills finally reaches Yamuna through groundwater or drains. Various other studies also concluded that the groundwater of residential areas near landfills is significantly contaminated by leachate percolation (Mor et al., 2006; Kumar and Alappat,

Table 7
Details of the current landfill sites in Delhi

Landfill site	Starting year	Area (ha)	Average depth (meter)	Trips of refusal removal trucks (RRTs)	Waste received (Tonnes/day)	Density (Tonnes/m^3)	Remaining lifetime (years)	Volume (Million m^3)		Zones supplying waste
								Occupied	Remaining	
Gazipur	1984	29.16	7	500–550	2000–2100	1.2	4.5	3.95	2.6	Civil Lines, Karol Bagh, Rohini, Narela, Najafgarh and West
Bhalswa	1993	21.06	7	550–600	3200	1.2	1.5	3.52	1.3	Shahdara South and North, City, Sadar, Paharganj, and NDMC
Okhla	1994	16.2	9	300–325	1200	1.2	2	2.36	0.61	Central, Najafgarh, South and DCB

Sources: MCD (2004), TERI (2002).

2003). Mor et al. (2006) analysed the leachate and groundwater quality at 12 sites located within 1.5 km of the Gazipur landfill and concluded that the groundwater quality of most of the wells has deteriorated due to the presence of various inorganic and organic constituents, which have made it unsuitable for drinking and other domestic purposes. Available information on leachate quality shows the presence of heavy metals like nickel, cooper and zinc and chemical oxygen demand (COD) exceeding the permissible limits.

Despite the negative impact on health and the environment LFG can be utilized as a potential source of energy due to its high average calorific value of 20 MJ/m^3. The GoI, under the MSW Rules 2000, notified that installation of a LFG control system, including gas collection, at landfills is mandatory. LFG should be utilized either for direct thermal use or power generation or should be flared to avoid direct escape to the atmosphere. However, due to delays in planning and other operational constraints, no such facility for LFG collection has yet been started at active or closed landfills. Therefore, the LFG generated is released directly to the atmosphere. Some studies estimate that these landfills contribute to about 80% of the total methane emission in Delhi (Table 8) (Sharma et al., 2002; Garg et al., 2002; Gurjar et al., 2004; Talyan et al., 2006a, 2007). NEERI (1996) reported that in the absence of a base liner and proper top covering of these landfills, only 25–30% of the available LFG can be recovered and the rest escapes through cracks and crevices in the landfills along their periphery. The report also concluded that the deposited MSW can yield an average of 95 m^3CH_4/tonne, having a calorific value of 19.43 MJ/m^3. Assuming a conversion efficiency of 25% and overall generator efficiency of 80%, electrical energy can be produced from LFG at a rate of 12.98×10^5 kWh/year (Kumar et al., 2002). Despite directives from the Honourable Supreme Court, MCD has so far failed to address the issue of LFG recovery, causing great harm to environment and loss of a potential source of energy.

Generally the workers employed at landfills do not use protective masks and gloves, thereby exposing themselves to a wide range of pathogens, helminth eggs and sharp materials such as broken glass or used needles. In a recent study, the respiratory and general health of workers employed at the Okhla landfill site was examined (Ray et al., 2005). The workers suffered more often from diarrhea, fungal infection and ulceration of the skin, burning sensation in the extremities, tingling or numbness, transient loss of memory, and depression. The results demonstrated higher prevalence of respiratory symptoms, inflammation of the airways, lung function decline and a wide range of general health problems in MSW disposal workers.

Table 8
Potential of methane emission from MSW landfills in Delhi

References	Methane emission (Gg/year)			
	1991	1995	2000	2005
Sharma et al. (2002)	86	–	–	–
Garg et al. (2002)	–	106	–	–
Gurjar et al. (2004)	113	132	–	–
Talyan et al. (2007)	83	100	115	138

5.3.4. Recycling

In Delhi, like other urban areas of India, recycling of MSW is a widely prevalent activity involving both the formal and informal sectors. The informal recycling sector refers to the waste recycling activities of waste pickers and waste collectors, paid mainly by the sale of collected materials. The informal sector of Delhi has a hierarchical structure constituting recyclers (waste pickers and collectors) at the bottom, dealers (small, medium and large) and finally the recycling units (RUs) at subsequent levels (Agarwal et al., 2005; Hayami et al., 2006).

Informal waste collection by the waste pickers and waste collectors is carried out at several levels such as: the households, commercial establishments, streets, dhaloas, and landfills. Waste pickers and the collectors operate through different modes of transport. The majority of waste collectors regularly use vehicles such as bicycles and tricycles (i.e., rickshaw carts), whereas a major fraction of waste pickers carry a sack and rely on their back and a smaller fraction rents the vehicles according to the requirements of the area (Agarwal et al., 2005; Hayami et al., 2006). According to their transportation facility, the modes of operation, working area and the quantity collected vary. The collectors go from door to door at shops and restaurants for collecting sorted dry recyclable materials on an instant payment basis and collect a relatively large amount of waste, while waste pickers are more active in collecting waste thrown away in public places such as streets, parks and landfills within a 4–5 km vicinity of their residence (MCD, 2004; Agarwal et al., 2005; Hayami et al., 2006).

Commonly, waste pickers and collectors collect recyclables such as paper/cardboard, plastics, metals, glass, rubber, leather and textiles. The degree to which a particular material is recycled depends on the income levels of the residents, the existence of local and national markets, the need for secondary raw materials, the level of financial and regulatory governmental intervention, and the prices of virgin materials (Wilson et al., 2006). In Delhi, the typical composition of the materials collected by waste

Table 9
A typical composition of the wastebasket of waste collectors or pickers

Materials	Quantity (kg/day)	
	Hayami et al. (2006)	Chowdhary et al. (2002)
Plastics	1.2	1.5–2
Polythene	7.8	4–6
Carton	–	6–7
Paper	6.4	5–7
Metals	4.7	2–3.5
Bottles (unbroken)	1.9	10–12 pieces
Broken glass	1.7	<1
Rubber	0.9	–

pickers and collectors is given in Table 9. The average income varies according to the collected waste. Generally, a waste picker earns US$1.35 per day (i.e., about half the minimum labor charges payable to an employee as per the Indian labor Law), whereas a waste collector earns about US$2.50 per day (Agarwal et al., 2005; Hayami et al., 2006).

Mostly waste pickers and collectors are the migrants from the poor states of India, mainly from West Bengal, Uttar Pardesh and Bihar. About 10% of the waste pickers are from the neighbouring country of Bangladesh. Waste pickers and collectors have an average family size of larger than five. About 45% are above the age of 25 years, and 31% are in the age group of 16–25 years. The rest (24%) are children below the age of 16 years (MCD, 2004). Educational level also varies significantly: more than 90% of pickers are illiterate, whereas 80% of collectors have received education up to the 8th grade (Hayami et al., 2006). Despite being in the same profession, there is a significant difference in the living standards of waste pickers and collectors. Most of the pickers live in temporary shelters (i.e., JJ clusters) on a share basis, while most of the collectors own permanent houses. The working conditions are unhygienic; safety equipment such as gloves and boots are unaffordable for waste pickers. A study conducted on 198 waste collectors in Delhi found that 68% injured themselves regularly, 21% often and 11% never during waste collection (Srishti, 2002).

The recyclables collected are segregated by pickers and collectors on a daily basis and transferred to small, medium and large dealers. Generally the pickers and collectors sell to small recyclables dealers in the slums, near their residence. The small dealers help the waste collectors by providing them with rickshaws and other support for collection. These small dealers, after primary segregation, sell different fractions of waste to medium or large dealers of the specific waste component and finally to the recycling units (RUs). According to Hayami et al. (2006), the income distribution of materials sold to the recycling units differs widely across waste items but, on average, the waste producer's share is about one-third and the rest (two-thirds) is evenly distributed among the pickers, collectors and dealers.

Estimates vary, but there are around 80,000–100,000 waste pickers and 17,857 waste collectors involved in the recycling industry in Delhi (MCD, 2004; Agarwal et al., 2005; Hayami et al., 2006). The huge informal sector is responsible for 17% of MSW recycling in Delhi. Therefore, it contributes significantly in reducing monetary expenditures on the collection, transportation and disposal of MSW (Agarwal et al., 2005). Generally, MCD spends about US$6.15/tonne for disposal of MSW. Thus, the presence of informal recycling results in large savings (about US$4 million) for MCD (Hayami et al., 2006). Nevertheless, the contribution to the environment could be greater. This informal sector greatly benefits society and the environment, but their valuable contribution goes unacknowledged.

6. Initiatives towards improvement of MSWM

The government of Delhi has taken initiatives to establish a better MSW management system. A variety of MSW management strategies and awareness programs have been introduced involving the local community and the NGOs. The other step towards establishing better MSW management is enforcement of the MSW management plan (2005–2021).

6.1. Master plan for treatment and disposal of MSW for Delhi

To determine the options for economically and environmentally sustainable MSW management for Delhi, MCD carried out a feasibility study and proposed a Master Plan (MP) for the treatment and disposal of MSW for the period 2005–2021. The proposed MP addresses all aspects of MSW management and recommends measures for improvement in the treatment and final disposal of MSW. The broader objective of the MP is to implement these recommendations for the state of Delhi through public-private partnerships. The plan of action is divided in three time segments: a short-term period (2005–2009), a medium-term period (2010–2014) and a long-term period (2015–2021). The proposed MP comprises the key issues discussed in the subsequent section.

6.1.1. Privatization of MSW collection and transportation

MCD has approved the involvement of the private sector to improve the state of MSW management in Delhi. In the proposed partnership, MCD and the private groups have shared responsibilities. The private partner (PP) has to provide paid DTDC service; primary collection of MSW from Street Corner Bins (SCBs); maintenance and redesign of the existing dhaloas; operation and maintenance of the transportation system including equipment, vehicles and manpower to transfer segregated MSW from dhaloas and SCBs to the landfill. The private partners are subject to penalties if they are unable to provide satisfactory services. MCD will pay a fixed monthly tipping fee per tonne of segregated MSW brought to the landfills. However, the incoming MSW has to meet the segregation benchmark set by MCD; in case of failure, a penalty of 15% of the tipping fee will be deducted. The public-private partnership has been started in six zones of MCD. This project is to be executed for a period of 9 years. The private partners will hand over the entire project facility to MCD at no cost at the end of the 9 year term.

6.1.2. Identification of applicable MSW treatment technology

The shutdown of the Timarpur incineration plant in the 1980s, which was operational for exactly 21 days, was a result of unrealistic assumptions regarding the selection of the best suited waste streams. Therefore, MCD identified and selected applicable MSW treatment technologies, taking into account the suitability to treat the waste of Delhi, regulatory requirements (i.e., standards defined in MSW Rules, 2000), cost effectiveness, national and international experience, and social acceptance with minimum environmental impacts.

Composting, biomethanation and pelletisation (RDF) are the proposed treatment technologies for MP (2005–2021). The targets set for treatment of MSW for the period 2005–2021 are given in Table 10. To meet the targets, the treatment capacity of selected technologies will be enhanced in phases. Although the high organic fraction and moisture content of MSW in Delhi suits biological treatment, due to the mixed waste stream, success has not been achieved thus far. However, recent efforts by MCD and NGOs to promote source segregation followed by inspections and enforcement are likely to improve the quality of MSW for biological treatment in the near future.

The existing landfills are approaching the end of their operative life. The MSW Rules, 2000 prohibited the continuation of old unlined, landfill sites after 5 years. Therefore, MCD has proposed three additional sanitary landfills having liners and leachate collection, treatment and disposal systems, along with landfill gas collection systems. These will be the first engineered MSW landfills to be built in India.

6.1.2.1. India's experiences with identified treatment technologies. In India, composting has a long history of success in different parts of the country. The Karnataka Compost Development Corporation (KCDC), Bangalore Decentralized Waste Management and Composting Scheme, and Excel Industries in Mumbai are examples of successful implementation of composting in India. Biomethanation is also commonly used for agriculture and livestock products, but has not achieved the same level of reliability for the treatment of MSW. Lucknow municipal corporation (LMC) and Nagpur municipal corporation (NMC) have set up biomethanation facilities, a pioneering effort, which the MNES identified as full-scale national demonstration plants. Power generation has been started but, due to the poor quality of MSW, the intended capacity could not be achieved. A waste-to-energy plant for the production of RDF pellets was started in 1999 in Hyderabad, India. The installed capacity of the plant is 1000 tonnes/day and it can manufacture 200–250 tonnes/day of fuel pellets. The calorific value of the fuel pellets currently being produced is 400 kcal/kg (the project promoter, however, claims that this can be increased to 3000 kcal/kg) and the fuel pellets have an ash content less than 10%. At present the plant is processing only 100–150 tonnes/day of garbage since there is no demand from the industries and because, since the pellets are made up of mixed waste, they contain plastics and several heavy metals.

Table 10
Recommended targets for MSW treatment and disposal for Master Plan (2005–2021)

MSW diversion	2004	2009	2014	2019	2024
MSW for treatment (%)	9	22	33	39	42
MSW for sanitary landfilling (%)	91	78	67	61	58

Source: MCD (2004).

The public-private partnership makes provisions for segregation benchmarking and independent performance monitoring. These measures, with incentives and penalties, ensure the best from the government and the private sector. Some of the treatment technologies proposed in the plan have not met the desired success in various parts of the country due to improper segregation and collection, resulting in poor quality of waste. However, in the proposed plan, the improvement in the collection stage improves the quality of the waste collected and the implementation of integrated technologies avoid dependence on any particular technology for desired results. The proposed Master Plan's cognizance of the deficiencies in earlier methodologies and incorporation of the above mentioned measures have improved the chances of successful MSW management in Delhi in the future.

6.2. Involvement of local community and NGOs

Success of the waste management plan includes significant cooperation from the public, not only in policy formulation but also active involvement in waste management and disposal operations. In the recent past, several RWAs in different low, middle and high income group colonies have taken the initiative for effective MSW management. Source segregation and on-site composting has been started in cooperation with MCD, NGOs and private collectors. The private collectors are hired at salaries ranging from US$1.50 to US$4 per day. In addition to the salaries, waste collectors are provided protective gloves, proper footwear and aprons by the NGOs. Land for on-site composting was selected with the consensus of the residents and equal participation from site level municipal staff. The compost is either applied in the colony parks or sold to the residents to be used in personal gardens. NGOs like Toxic Link and Vatavaran have helped to achieve 'zero garbage' in 29 Delhi colonies using such schemes. The successful achievement of the 'zero garbage' objective has encouraged the residents of these colonies to aim at 'dustbin-free' colonies.

Vatavaran and Naya Savera manage MSW at some residential educational institutes such as the Indian Institute of Technology Delhi (IITD), Jawaharlal Nehru University (JNU), Delhi University's South Campus and Miranada House to achieve 'zero-waste campuses'. Sristhi and Chintan are also Delhi based NGOs, working remarkably in the training of waste collectors for collection and towards establishing private partnerships. These NGOs also assist the Government of Delhi in spreading awareness by organising door-to-door meetings, cluster meetings, awareness generation programmes, rallies, school programmes, etc. ACORD, another NGO, uses radio for creating mass awareness of MSW management and for motivating residents to practice waste segregation.

These programs have achieved considerable success in the case of institutions and middle and high income colonies. However, it has been observed that the authorities and residents remain motivated until an NGO is actively involved or a campaign or drive takes place. The success of these pilot level projects can be emulated at a bigger arena only by creating awareness about the advantages of proper MSW management among the residents.

7. Conclusions

With an ever increasing population and a rapid pace of urbanization, the effects of poor waste management practices on human health and the environment have never been more pronounced. The study concludes that the present policy and infrastructure are inadequate in dealing with the enormous quantity of MSW generated by the city of Delhi. With an almost 3-fold increase in MSW generation by 2021, the situation may reach critical proportions. MCD and the Government of Delhi have realized the seriousness of the situation and framed guidelines in the form of the Master Plan (2005–2021) for disposal and treatment of MSW for the entire state of Delhi. MCD took a big step towards improving MSW management practices by privatizing the collection, segregation, transportation and disposal of waste. NGOs, with the assistance from RWAs, have played an important role in establishing an infrastructure for DTDC services and segregation of waste at the source in certain areas of Delhi; this kind of cooperation needs to be replicated at a larger scale. The Bhagidari scheme initiated by the Government of Delhi has been instrumental in promoting citizen-government partnerships in the field of MSW management. More such initiatives need to be taken towards educating people about correct practices of solid waste disposal. Initiatives taken by policy makers never yield results unless matched by proper implementation at every level. It is clear that any substantial change in the present scenario is not possible without a three-way partnership of the government, the private sector and the citizens.

Acknowledgements

Vikash Talyan thanks the University Grants Commission (UGC) Delhi for providing financial support. The authors are also thankful to the anonymous reviewers who through their comments helped to improve the present article.

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