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Status and challenges of municipal solid waste management in India: A review

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Abstract: The abysmal state of and challenges in municipal solid waste management (MSWM) in urban India is the motivation of the present study. Urbanization contributes enhanced municipal solid waste (MSW) generation and unscientific handling of MSW degrades the urban environment and causes health hazards. In this paper, an attempt is made to evaluate the major parameters of MSWM, in addition to a comprehensive review of MSW generation, its characterization, collection, and treatment options as practiced in India. The current status of MSWM in Indian states and important cities of India is also reported. The essential conditions for harnessing optimal benefits from the possibilities for public private partnership and challenges thereof and unnoticeable role of rag-pickers are also discussed. The study concludes that installation of decentralized solid waste processing units in metropolitan cities/towns and development of formal recycling industry sector is the need of the hour in developing countries like India.

Subjects: Civil, Environmental and Geotechnical Engineering; Engineering Management; Environment & Agriculture

Keywords: urbanization; biodegradable; population; solid waste; rag-pickers; recycling

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PUBLIC INTEREST STATEMENT

Like other developing countries in India, also the common man's perception about solid waste management suffer "not in my backyard" syndrome and leave waste to be taken care by urban local municipal bodies only. There is complete lack of at-source segregation and management of solid waste. Thus it becomes really difficult to manage burgeoning waste without active participation of the people. It is also important to develop and implement an integrated solid waste management approach taking advantages of existing unorganized sector (rag-pickers) for its cost-effective and sustainable management. There is urgent need to promote such disposal techniques which have option for resource recovery as well as energy generation. Awareness towards safe disposal of waste, public–private partnership, and selection of appropriate technology according to waste characteristics is important. This paper gives a picture about the municipal solid waste management scenario in India including challenges and possible solutions.

1. Introduction

India is rapidly shifting from agricultural-based nation to industrial and services-oriented country. About 31.2% population is now living in urban areas. Over 377 million urban people are living in 7,935 towns/cities. India is a vast country divided into 29 States and 7 Union Territories (UTs). There are three mega cities—Greater Mumbai, Delhi, and Kolkata—having population of more than 10 million, 53 cities have more than 1 million population, and 415 cities having population 100,000 or more (Census, 2011a). The cities having population more than 10 million are basically State capitals, Union Territories, and other business/industrial-oriented centers. India has different geographic and climatic regions (tropical wet, tropical dry, subtropical humid climate, and mountain climate) and four seasons (winter, summer, rainy, and autumn) and accordingly residents living in these zones have different consumption and waste generation pattern. However, till date, no concrete steps had been taken to analyze regional and geographical-specific waste generation patterns for these urban towns and researchers have to rely on the limited data available based on the study conducted by Central Pollution Control Board (CPCB), New Delhi; National Engineering and Environmental Research Institute (NEERI), Nagpur; Central Institute of Plastics Engineering and Technology (CIPET), Chennai; and Federation of Indian Chambers of Commerce and Industry (FICCI, 2009), New Delhi.

Municipal solid waste management (MSWM), a critical element towards sustainable metropolitan development, comprises segregation, storage, collection, relocation, carry-age, processing, and disposal of solid waste to minimize its adverse impact on environment. Unmanaged MSW becomes a factor for propagation of innumerable ailments (Kumar et al., 2009).

In the developed countries, solid waste management (SWM) belongs to prominent thrust areas for pursuing research (Dijkgraaf & Gradus, 2004; Ferrara & Missios, 2005) and economic and technological advancements have initiated responsiveness of stakeholders towards it (Shekdar, 2009). High population growth rates, rapidly varying waste characterization and generation patterns, growing urbanization and industrialization in developing countries (Troschinetz & Mihelcic, 2009) are the important reasons for paying attention towards MSWM as more area is required to accommodate waste (Idris, Inane, & Hassan, 2004).

Several studies suggest that reutilizing of solid waste is not only a viable option to MSWM (Kasseva & Mbuligwe, 2000; Sudhir, Muraleedharan, & Srinivasan, 1996) but also desirable—socially, economically, and environmentally (Kaseva & Gupta, 1996; Misra & Pandey, 2005; Schoot Uiterkamp, Azadi, & Ho, 2011). One of the significant problems in urban India is almost no segregation of MSW and disposal of construction and demolition debris (C&D), plastic wastes, commercial and industrial refuses, and e-waste (Buenrostro & Bocco, 2003; CPCB, 2000a; Position paper on the solid waste management sector in India, 2009).

Annually, about 12 million tons of inert waste are generated in India from street sweeping and C&D waste and in the landfill sites, it occupies about one-third of total MSW. In India, MSWM is governed by Municipal Solid Waste (Management and Handling) Rules, 2000 (MSWR) and implementation of MSWR is a major concern of urban local bodies (ULBs) across the country.

2. Urbanization and solid waste generation in India

2.1. Urbanization

The consequences of burgeoning population in urban centers are more noticeable in developing countries as compared to the developed countries. The population of urban India was 377 million (Census of India, 2011a), which accounts for 31% of the total population. Global case histories reveals that when a country's urban population extends beyond 25% of the overall population (as in the present case), the pace of urbanization accelerates (Kumar & Gaikwad, 2004). The population residing in urban regions increased from 18 to 31.2% from 1961 to 2011 respectively (Census of India, 2011b).

Table 1. Per capita waste generation rate

Population size	Waste generation* (kg/capita/day)	Waste generation** (kg/capita/day)
>2000000	0.43	0.55
1000000–2000000	0.39	0.46
500000–1000000	0.38	0.48
100000–500000	0.39	0.46
<100000	0.36	–

Source: CPCB Report (2000b)* and Calculated from R.K. Annepu (2012)**.

Table 2. Statistics of MSW generated in different states in India

S. No.	States	Municipal Solid Waste (TPD) 2000	Municipal Solid Waste (TPD) (2009–2011)	Collected (TPD) (2009–2011)	Treated (TPD) (2009–2011)	Growth (%)
1	Andhra Pradesh	4376	11500	10655	3656	163
2	Assam	285	1146	807	73	302
3	Delhi	4000	7384	6796	1927	85
4	Gujarat	NA	7379	6744	873	–
5	Karnataka	3278	6500	2100	2100	98
6	Kerala	1298	8338	1739	4	542
7	Madhya Pradesh	2684	4500	2700	975	68
8	Maharashtra	9099	19204	19204	2080	111
9	Manipur	40	113	93	3	182
10	Meghalaya	35	285	238	100	713
11	Orissa	655	2239	1837	33	242
12	Punjab	1266	2794	NA	Nil	121
13	Puducherry	69	380	NA	Nil	451
14	Rajasthan	1966	5037	NA	Nil	156
15	Tamil Nadu	5403	12504	11626	603	131
16	Tripura	33	360	246	40	991
17	Uttar Pradesh	5960	11585	10563	Nil	94
18	West Bengal	4621	12557	5054	607	172

Source: CPCB (2000b, 2013).

2.2. Generation and collection

In India, rapid urbanization and uncontrolled growth rate of population are main reasons for MSW to become an acute problem. According to population size per capita waste generation rate and its growth during a decade are indicated in Table 1 (Annepu, 2012). It is anticipated that population of India would be about 1,823 million by 2051 and about 300 million tons per annum of MSW will be generated that will require around 1,450 km^2 of land to dispose it in a systematic manner, if ULBs in India continue to rely on landfill route for MSW management (Position paper on the solid waste management sector in India, 2009). However, these projections are on conservative side, keeping 1.33% annual growth in per capita generation of MSW (Bhide & Shekdar, 1998; CPCB, 2000a; Pappu, Saxena, & Asolekar, 2007; Shekdar, 1999). Therefore, with 5% annual growth in per capita generation landfill area required for disposal of waste could be many folds (CPCB, 2013).

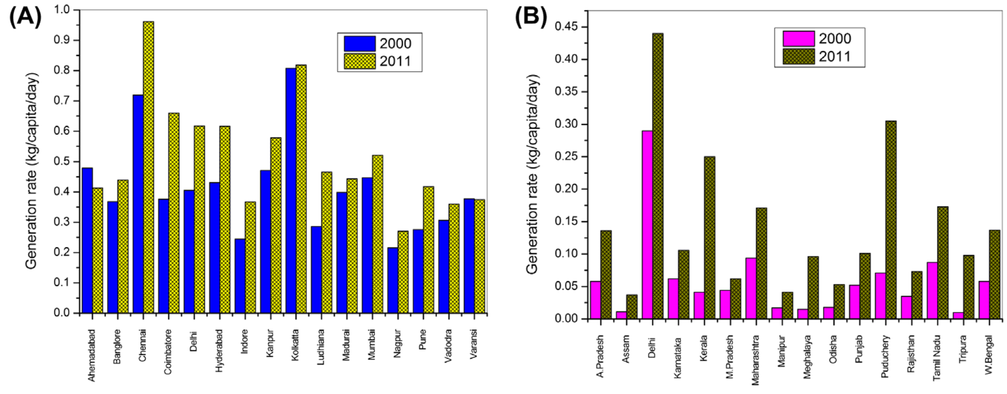


Figure 1. (a) Per capita generation of MSW selected Indian cities in 2000 and 2011, (b) Per capita generation of MSW in selected Indian states in 2000 and 2011.

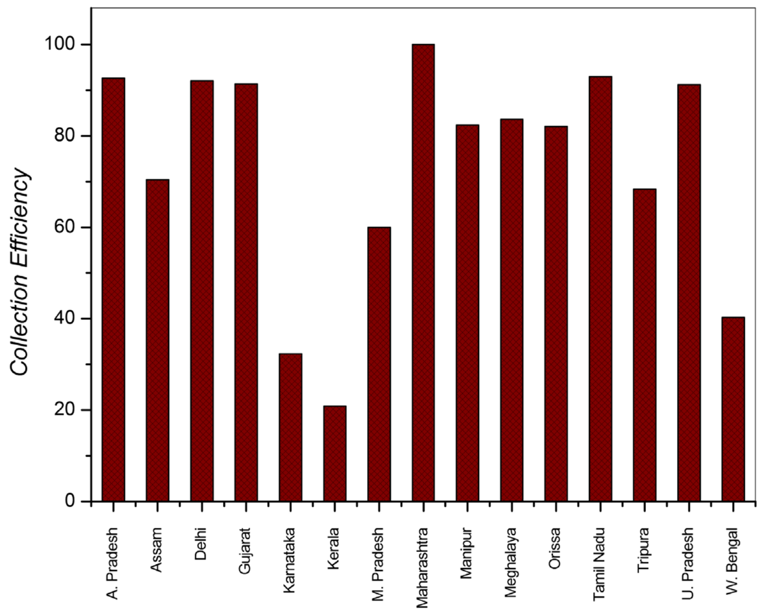


Figure 2. Collection efficiency of selected Indian states (CPCB, 2013).

Planning Commission Report (2014) reveals that 377 million people residing in urban area generate 62 million tons of MSW per annum currently and it is projected that by 2031 these urban centers will generate 165 million tons of waste annually and by 2050 it could reach 436 million tons. To accommodate this amount of waste generated by 2031, about 23.5×10^7 cubic meter of landfill space is required and in terms of area it would be 1,175 hectare of land per year. The area required from 2031 to 2050 would be 43,000 hectares for landfills piled in 20 meter height. These projections are based on 0.45 kg/capita/day waste generation. In India, due to lack of availability of primary data on per capita waste generation, inadequate data on waste characteristics, and influence of informal sectors, different reports give different values and projections. Therefore, it is difficult to assess the land requirement and select appropriate treatment/disposal techniques. The study carried out in 59 cities (35 Metro cities and 24 State Capitals) by the National Environmental Engineering Research Institute (NEERI) reveals that 39,031 TPD of MSW was generated from these cities/towns during the year 2004–2005. For the same 59 cities, a study was again carried out by CIPET during 2009–2010 for CPCB wherein it was seen that these cities are generating 50,592 TPD of waste (CPCB, 2013). During the year 2011, about 1,27,486 TPD MSW was generated from across the country, out of which only 89,334 TPD (i.e. 70%) was collected and 15,881 TPD (i.e. 12.45%) processed or treated (CPCB, 2013). During the last decade, solid waste generation has increased 2.44 times (CPCB, 2013).

Table 3. Change in composition of municipal solid waste with time (in %)

Year	Biodegradables	Paper	Plastic/rubber	Metal	Glass	Rags	Others	Inert
1996	42.21	3.63	0.60	0.49	0.60	–	–	45.13
2005	47.43	8.13	9.22	0.50	1.01	4.49	4.02	25.16
2011	42.51	9.63	10.11	0.63	0.96	–	–	17.00

Source: Planning Commission Report.

Various studies reveal that small towns have paid more attention and performed more responsibly regarding generation rate of MSW (Bhide & Shekdar, 1998; Kansal, 2002; Kansal, Prasad, & Gupta, 1998; Rao & Shantaram, 1993). The comparative quantity of MSW generated by selected states of India in years 2000 and 2011 is shown in Table 2. Comparative status of per capita generation of MSW for the year 2000 and 2011 is plotted with respect to selected cities and states of India in Figure 1(a) and (b), respectively (CPCB, 2000a, 2013).

The survey conducted by FICCI reveals MSW realization at dumpsite varies from 16 to 100%, like in Kozhikode it is 16% and in Greater Mumbai it is 100%. Greater Mumbai (Maharashtra) and Ludhiana (Punjab) have 100% waste disposal, in Delhi and Surat (Gujarat) around 95% of MSW reached its landfill sites, and in the rest of the cities/town less than 90% waste reached dumpsites (CPCB, 2013; FICCI, 2009). The variation in collection efficiency (i.e. 100% waste collected/waste generated) of selected Indian States in the year 2011 is shown in Figure 2 (CPCB, 2013).

2.3. Composition and characteristics of Indian municipal solid waste

Following major categories of waste are generally found in MSW of India:

- *Biodegradable Waste*: Food and kitchen waste, green waste (vegetables, flowers, leaves, fruits) and paper.
- *Recyclable Material*: Paper, glass, bottles, cans, metals, certain plastics, etc.
- *Inert Waste Matter*: C&D, dirt, debris.
- *Composite waste*: Waste clothing, Tetra packs, waste plastics such as toys.
- *Domestic Hazardous Waste* (also called “household hazardous waste”) and toxic waste:

Waste medicine, e-waste, paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer and pesticide containers, batteries, and shoe polish.

MSW in India has approximate 40–60% compostable, 30–50% inert waste and 10% to 30% recyclable. Analysis carried out by NEERI reveals that in totality Indian waste consists of Nitrogen content (0.64 ± 0.8) %, Phosphorus (0.67 ± 0.15)%, Potassium (0.68 ± 0.15)%, and C/N ration (26 ± 5) %. Change in the physical and chemical composition of Indian MSW with time is shown in Table 3.

3. Solid waste management practices and challenges in India

In India, MSWM is governed by MSWR. However, majority of ULBs do not have appropriate action plans for execution and enactment of the MSWR (CPCB Report, 2013). Unfortunately, no city in India can claim 100% segregation of waste at dwelling unit and on an average only 70% waste collection is observed, while the remaining 30% is again mixed up and lost in the urban environment. Out of total waste collected, only 12.45% waste is scientifically processed and rest is disposed in open dumps (CPCB Report, 2013). Existing and future land requirement for disposal of MSW along with growth in population and MSW generation is shown in Figure 3. Environment friendliness, cost effectiveness, and acceptability to the local community are major attributes to achieve efficient solid waste management system. Critical examination of important parameters of MSWM practice with respect to Indian Scenario is delineated below:

3.1. Segregation
There is no organized and scientifically planned segregation of MSW either at household level or at community bin. Sorting of waste, is mostly accomplished by unorganized sector and seldom practiced by waste producers. Segregation and sorting takes places under very unsafe and hazardous conditions and the effectiveness of segregation is reasonably low as unorganized sector segregates only valuable discarded constituents from waste stream which can guarantee them comparatively higher economic return in the recycling market (Kaushal, Varghese, & Chabukdhara, 2012). On a number of occasions, due to improper handling the segregated constituents got mixed up again during transportation and disposal (CPCB Report, 2013). Lack of segregation deprive proper scientific disposal of waste (Singhal & Pandey, 2000).

3.2. Collection
Waste produced by houses is usually transferred into communal bins that are fabricated from metal, made from concrete or in combination of both. Street sweepings also find its way to community bins. These community waste bins are also used by other essential commercial sectors in the vicinity of disposal bins along with household waste except where some commercial complexes or industrial units engage municipal authorities for transfer of their waste to disposal site by paying some amount (Kumar et al., 2009).

3.3. Reuse/recycle
This entails activities like collecting those materials from the waste, which could be gainfully retrieved and utilized for making new products. Since unsegregated waste is dumped at community bins, its optimal recycling is not possible. However, rag-pickers usually sorted out and took and sell recyclable material like plastics, glass, etc. In Pondicherry, almost all recyclable material is sorted out by rag-pickers and absorbed in material stream through recycling (Pattnaik & Reddy, 2010).

3.4. Transportation
Modes of transportation for MSWM practised in India are: bullock carts, hand rickshaws, compactors, trucks, tractor, trailers, and dumpers. In smaller towns trucks having 5–9 ton capacity are used without adequate cover system. Stationary compactors, mobile compactors/closed tempos, and tarpaulin-covered vehicles are used in the transportation of MSW and about 65, 15, and 20% of waste is transported through these compacters, respectively. The maintenance of vehicles used in for transportation of waste is usually done in workshop run by ULBs but most of these workshops can do minor repairs only. No wonder, in the event of breakdown of these vehicles, the overall collection, transportation, and disposal efficiency reduces drastically. Only few transfer stations can be found in some metropolitan e.g. Mumbai (Joseph, 2002).

3.5 Disposal
In India, almost every city, town, or village adopted unscientific disposal of MSW. The existing practice and technology availability for MSWM for 59 cities have been indicated in Figure 4 (Kumar et al., 2009). Among these cities, 40 cities have shown increase in waste generation, 7 cities shows reduction, and it was more or less same for 6 cities. Though there was an increase in population during the decade for these cities, no significant reason was indicated by author for reduction as well as equal amount in waste generation for these cities. However, the possible reason for reduction could be that the waste generated could not reach the designated dumping site and was lost in the cities peripherals, outskirts, along the road, low lying area, along the drain, green areas, etc. Data reveal that uncontrolled open dumping is a common feature in almost all cities (Kumar et al., 2009). The following disposal practices are in use in hierarchy.

3.5.1. Open dumping
In India, MSW generated is usually directly disposed on low lying area in routine way violating the practices of sanitary landfilling. Almost no ULBs have adequate sanitary landfilling facility and MSW is dumped in the outskirts of town along the roads. Unscientific dumping is prone to flooding and

Figure 3. Prediction Plot for MSW generation, land requirement, and population from 2001 to 2051.

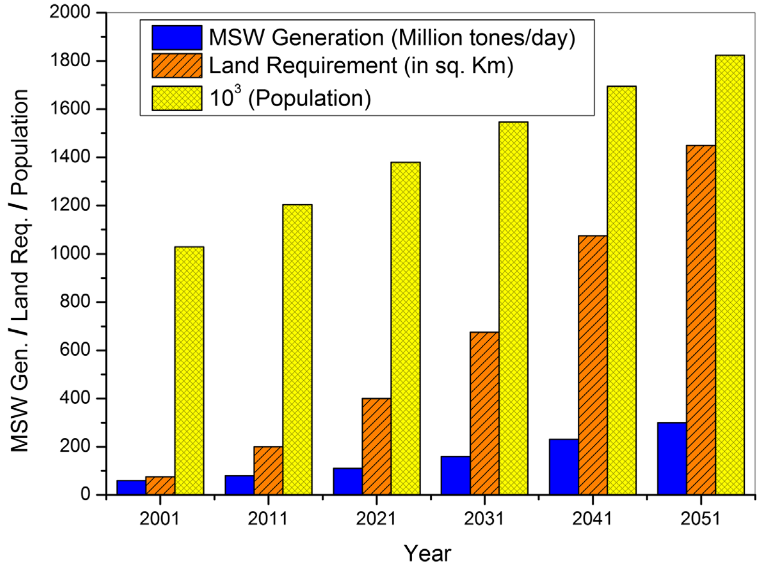
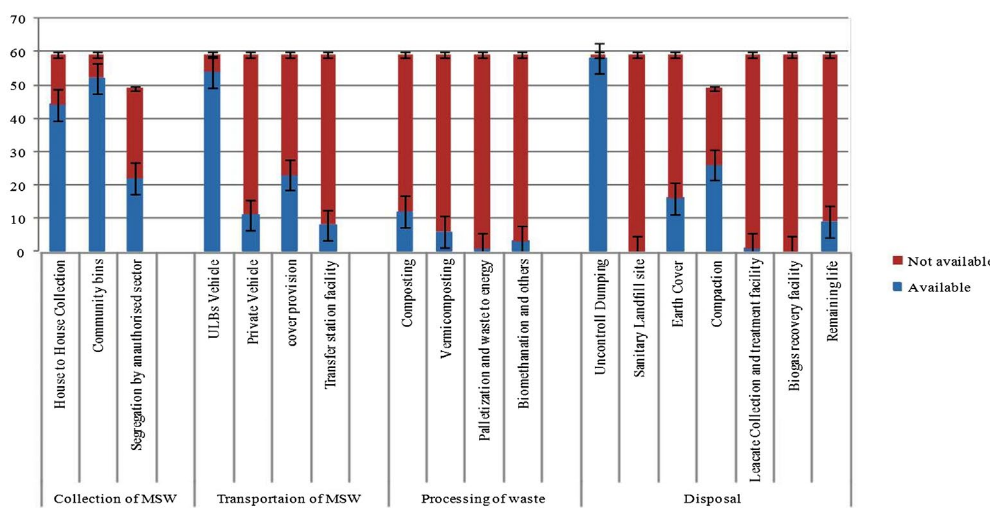


Figure 4. MSWM practices in selected Indian cities (Kumar et al., 2009).



major source of surface water contamination during monsoon and ground water contamination due to percolation of leachate (Lo, 1996; Mor, Ravindra, Dahiya, & Chandra, 2006).

3.5.2. Landfilling

Landfilling would continue to be extensively accepted practice in India, though metropolitan centers like Delhi, Mumbai, Kolkata and Chennai have limited availability of land for waste disposal and designated landfill sites are running beyond their capacity (Sharholy, Ahmad, Mahmood, & Trivedi, 2008). The development of new sanitary landfills/expansion of existing landfill are reported in the states such as Andhra Pradesh (Vijianagaram), Delhi (Bhalswa, Okhla and Ghazipur), Goa, Gujarat (8 sites), Haryana (Sirsaand Ambala), Karnataka (12 sites.), Madhya Pradesh (Gwalior and Indore), Maharashtra (Nashik, Sonpeth, Ambad, Pune, Navapur and Navi Mumbai), Punjab (Adampur), Rajasthan (Jodhpur), and West Bengal (17 sites) (CPCB, 2013). According to CPCB, 2013 report, till date, India has 59 constructed landfill sites and 376 are under planning and implementation stage. Apart from this, 1305 sites have been identified for future use.

3.5.3. Landfill gas-to-energy plants

From landfills mainly methane (CH_4) and carbon dioxide (CO_2) gases are produced. These gases have significant greenhouse effect. CH_4 emission from landfill is about 13% of global CH_4 emission and is about 818 million metric tons per annum in terms of CO_2 equivalent (Rachel, Damodaran, Panesar, Leatherwood, & Asnani, 2007). In India, estimated methane emission is about 16 million metric CO_2 equivalents per annum through landfills (International Energy Agency, 2008). The energy potential from landfill gas available at selected sites in Delhi (Balswa, Gazipur and Okhla) is 8.4 MW, Mumbai (Deonar and Gorai) 5.6 MW, Ahmadabad (Pirana) 1.3 MW, and Pune (Urli) had 0.7 MW annually (Siddiqui & Khan, 2011). Planning Commission Report (2014) indicated that 62 million tons of annual MSW generated in urban area can produce 439 MW of power from combustible component and RDF, 72 MW of electricity from landfill gas and 5.4 million metric tons of compost for agriculture use as CH_4 has 23 times higher global warming potential than CO_2. The utilization of landfill gas, particularly CH_4 for energy production is important as it finally converts into primary constituents (i.e. CO_2 and H_2O). A study conducted by United Nations Environmental Program (UNEP) has shown that green house gas emission from landfill can be significantly reduced by following environmentally sound management of hazardous and other wastes (UNEP, 2008, 2010):

(1) Waste minimization.

(2) Recycling and reuse.

(3) Reductions in fossil fuel by substituting energy recovered from waste combustion.

(4) Energy derived by CH_4 from landfill site can be used for *in situ* energy requirement.

Non-availability of requisite quality of MSW at plant site, presence of low calorific matter in MSW i.e. inert and C&D waste, reservation to use compost generated from MSW by farmers, lack of appropriate market policy for use of RDF, and compost makes such projects economically non-viable. Ministry of New and Renewable Energy (MNRE), Government of India installed 3 Mega Watt (MW) capacity plant at Solapur, Maharashtra, 16 (MW) capacity at Okhla, Delhi, and planned to support few more waste to-energy projects at Bangalore (8 MW), Hyderabad (11 MW), Pune (10 MW), and Delhi at Gazipur (12 MW) (MNRE Annual Report, 2014–2015) also in Delhi, Narela (24 MW) waste-to-energy plant is under installation.

Though, in developed countries to acquire enhanced biodegradation and gas recovery, the leachate/liquid/supplemental water is added/recirculated in landfill sites (Barlaz, Ham, & Schaefer, 1990; Reinhart, McCreanor, & Townsend, 2002). But unfortunately, MSWR does not permit leachate recirculation in India. Hence, a vast opportunity for enhanced energy recovery from landfill remains untapped.

3.5.4. Biological treatment of organic waste

The waste generated in India has more organic content—about 50%—as compared to 30% generated by developed countries. Following composting methods are commonly adopted in India:

3.5.4.1. Aerobic composting. Composting is defined as the phenomenon under which biological conversion of organic matter existing in MSW takes place in the presence of air under humid and warm environment. The end product of composting, having high nutrient value, is humus (compost). Composting could be either labor-intensive or mechanical. In smaller towns labor-intensive composting is carried out. However in big Indian cities, power-driven composting units have been installed (Bhide & Shekdar, 1998). A MSW composting center installed at Indore City (Madhya Pradesh) is one of the best maintained facilities. In Bengaluru, Vadodara, Mumbai, Delhi, and Kanpur, mechanical composting units of 150 to 300 tons/day capacities were also installed (Sharholy, Ahmad, Vaishya, & Gupta, 2007).

3.5.4.2. Vermi-composting. Vermicomposting is carried out by introducing earthworms on semi-decomposed organic waste. Earthworms can consume five times of organic matter per

Table 4. Number of composting/vermi-composting plants in some states

State	Number of plants (composting/ vermicomposting)	State	Number of plants (composting/ vermicomposting)
Andhra Pradesh	32	Madhya Pradesh	4
Chhattisgarh	15	Maharashtra	125
Delhi	3	Meghalaya	2
Goa	5	Orissa	3
Haryana	2	Punjab	2
Gujarat	86	Rajasthan	2
Himachal Pradesh	13	Tripura	13
Karnataka	5	Uttarakhand	3
Kerala	29	West Bengal	9

Source: CPCB (2013).

Table 5. Number of energy recovery plants in some states

State	No. of RDF plants/ waste to energy plant (PP)/Biogas (BG)	State	No. of RDF plant/ Waste to Energy Plant/Biogas (BG)
Andhra Pradesh	3-RDF, 4 PP	Delhi (UT)	1-RDF, 1PP
Chandigarh (UT)	1-RDF	Gujarat	2-RDF
Chhattisgarh	1-RDF	Kerala	2-BG
Maharashtra	19-BG		

Source: CPCB (2013).

day as compared to their body weight. Initially, biodegradable organic matter is decomposed through microbial enzymatic activity. India's largest vermin-composting plant of 100 Million Tons/day capacity is located in Bengaluru, while there are smaller plants in Hyderabad, Bangalore, Mumbai, and Faridabad. Details of composting and vermin-composting plants installed in different states are shown in Table 4.

3.5.4.3. Anaerobic digestion. Anaerobic decomposition of waste is also known as biomethanation process. It is one of the important and sustainable techniques for treatment of the biodegradable part of MSW in subtropical climates. In this process, stabilization occurs and biogas is liberated by the conversion of organic matter, which in turn can be used as energy. The biogas has 55–60% methane and it can be used as fuel for power generation. Government of India encourages biomethanation technology by utilizing industrial, agricultural and municipal wastes. A number of schemes for biomethanation are under planning and inception stage for some cities such as Delhi, Bangalore, and Lucknow to utilize waste generated from vegetable market and yard wastes. (Ambulkar & Shekdar, 2004).

3.5.5. Thermal treatment

Thermal treatment of solid wastes can be accomplished by Incineration, Pyrolysis and Plasma Arc gasification. Incineration of Indian MSW is not suitable as the MSW has high organic constituents, moisture content, or inert content in the waste in the range of 30% to 60% each and calorific value in the range of 800–1,100 kcal/kg in MSW (Jalan & Srivastava, 1995; Joardar, 2000; Kansal, 2002; Sudhir et al., 1996). If waste has high dampness or has low calorific value, incineration is not feasible without the help of extra fuel. Usually in India, for burning hospital waste, small incinerators are used (Sharholy, Ahmad, Mahmood, & Trivedi, 2005). A 300 TPD capacity MSW incineration plant at

Timarpur, Delhi, built in 1987, was the first large-scale plant. However, the plant could not run for a long time and had to be decommissioned due to non-availability of waste having required calorific value for incineration (Sharholy et al., 2007). Currently, there is no large-scale working MSW incinerator in India.

Gasification is also one of the thermal treatment techniques which is used for MSW treatment and is capable to decrease pollution and increase heat recovery. In India, limited gasifiers were installed but they are mostly used to burn agro biomass. Two different designs of gasifiers can be seen in India. The first one (NERIFIER gasification unit) has been installed at Nohar, Hanungarh, Rajasthan by Narvreet Energy Research and Information (NERI) for burning of agrowastes, sawmill dust, and forest wastes, while the second one is the Tata Energy Research Institute (TERI) gasifier installed at Gaul Pahari campus, New Delhi (Ahsan, 1999; Sharholy et al., 2007).

Refuse-derived Fuel (RDF) is another upcoming technology, which can be effectively used to produce power/thermal energy from MSW and reduce load on landfill. A few RDF plants were setup at Hyderabad, Guntur, and Vijayawada in Andhra Pradesh. However, the operating cost of the RDF plant is higher. Status of RDF plants in India is presented in Table 5.

3.6. Public–private partnership in MSWM in India

Public private partnership (PPP) mode implementation usually happens at ground level when individually neither public services nor private sector can achieve their respective goals and aspirations of stakeholders. MSWM appears to be fit case for PPP mode for Indian scenario as ULBs alone are unable to accomplice the task assigned as per MSWR. An amount of USD 5 billion annually is required to provide adequate MSWM services to Indian Cities (Hanrahan, Srivastava, & Sita, 2006) and this level of finance can be met through PPP mode only to address MSWM-related challenges.

In India, the PPP mode is still in nascent stage and there is no success story under MSWM. However, many companies took MSWM challenge as a business opportunity and about 40 projects are running under PPP mode for different segments (segregation at community bin, collection, transportation including waste to energy) of MSWM in India. Some Indian companies involved in MSWM are Zen Global Finance Ltd (RDF), ESSEL Infra (MSWM), Enkem Engineers Ltd (biomethanation in collaboration with Entec, Astria), Future Fuel Engineers (India) Pvt. Ltd (biodegestion in collaboration with ECOTEC, Finland), Global Environmental Engineers Ltd (biodigestion in collaboration with PAQUES Pvt., Netherland), Hanzer Biotech (MSWM), Thermax Ltd (Incineration plants in collaboration, ACWA, UK, Danskrodzone, Denmark and Thermal Process, US), Excel Industries (composting), EDL Power (India) Ltd (Sanitary landfill), SELCO international Ltd (RDF, TIFAC, DST), Ramky (Waste Management Services). Some other international companies working in Indian Market in MSWM sector are EISU, UK, Nellemen, Neilsen, and Rauscvenberger of Denmark, Lunde, TBW and BTA of Germany and Entec, Astria, Hitachi Zosen, Japan, etc. However, attributes for successful partnership are efficient implementation, better services, risk sharing, cost saving, and revenue generation. On the other hand, power sharing, loss of control of ULBs, cost enhancement, unaccountability, political risks, and lack of competitiveness are major threat. To overcome the complications associated with MSWM, both public and private sectors should contribute vigorously. Only with the cooperation of both sectors, the efficiency of ULBs in handling SWM can be enhanced. The relations among various components of the PPP system viz. sociological, economical and managerial aspects should be evaluated. The effectiveness of partnership, well defined relationship, and clear demarcation of role, accountability, and adoptability due to dynamics among the various stakeholders are elementary necessities to make PPP work for MSWM (Ahmed & Ali, 2004).

Kerala is one of the few Indian states that took effective measures to address the waste menace by launching Clean Kerala Mission in 2002. Later, in 2007, *Malinya Mukta Keralam* campaign was launched that succeeded in creating the conducive environment for a Mission Mode Action Plan to achieve the goal of Clean Kerala. Mission 2002 Strategy revolves around the time-tested slogan of Reduce, Reuse, Recycle and Recover. Phase-I was implemented in 5 Corporations and 26 Municipalities with participation of Women self-help groups, students, NGOs, and volunteers of "*Kudumbasrees*" along with public servants. Phase-II encompassed another 27 cities and 25 villages. This time it was focused on maximizing recycling as well as recovery of energy and manure using appropriate technological interventions. Clean Kerala Company Ltd collected 187 tons of low-grade plastics from urban local bodies and sent to Neptune Automation for its safe recycling. It has setup a plant to make pyrolysis oil from plastic waste. Further, Kerala is planning to collect and process e-waste—a major urban pollutant. It has entered into MoU with Earth Sense Recycle Pvt. Ltd. Other initiatives to make Kerala plastic free; government has banned use of plastic carry bags/cups/plates/flex boards. Kerala Tourism also launched the "Plastic-Free" campaign at Kovalam beach as part of "Zero-Waste Kovalam," project. Cloth/paper bags have replaced plastic bags. Campaigns have been launched for segregation, collection, and utilization at source with special attention for scientific management of hazardous waste. Implementation of stringent norms for licensing, selection of appropriate technology and development in institutional capacity at ULB level was primary objective "Zero-Waste Kovalam." In addition bins were installed for biodegradable waste/paper in school. Uses of vermin-composed/biogas slurry are gainfully utilized in garden. Training of students for making paper bags, cloth bags, and waste management in school curriculum are also being encouraged (sanitation.kerala.gov.in).

A typical developing country like India has been facing the issue of safe and efficient handling of e-waste ever since the revolution in Information Technology. The availability and affordability of a whole range of electronic equipment coupled with innovations and changing trends have led to rapid rate of obsolescence. India is the fifth biggest generator of e-waste in world (United Nations University, 2014), currently around 15 lakh metric tons (MT) per annum e-waste is generated and its compound annual growth rate is about 25% (ASSOCHAM, 2014). E-waste comprises around 7% of total solid waste generated in India (United Nations University, 2014). Almost 60 per cent of e-waste is a mix of large and small electrical and electronic equipment used in homes and businesses. Indian Ministry of Environment, Forest and Climate Change, notified e-waste rules which came into force with effect from 1st May 2012. Implementation of EPR (Extended Producers Responsibility) and mandatory registration of e-waste recycling firms with Pollution Control Boards are the key salient features of e-waste rules. Bangalore has over 1,200 overseas and domestic electronic industries, which pushes it in the list of cities facing the menace of e-waste hazard. Bangalore generates nearly 86000 MT of e-waste per annum and has 31 registered e-waste recycling/dismantling firms (CPCB, 2014) of which only 3 are actively involved in recycling (Gupta & Shekar, 2009). Trishriya—one such firm, exports e-waste for smelting to recover precious metals to developed nations while the other two E-Parisara and Ash Recyclers are only limited to sorting, dismantling, and shredding (Gupta & Shekar, 2009). Informal sector in this trade has huge limitations when it comes to recovery of precious metals like gold. This sector usually recovers less than 20% and produce emission of precious metals exceeding 400 times that of European threshold (Schluep, 2010). The R&D facility of Swiss Federal Laboratories for Material Testing and Research (EMPA) is actively involved on research in smart materials, material recovery and technology, and provides assistance in implementation of e-waste recycling. State-of-the-art smelters in EMPA have the recovery rate of 95% of gold from e-waste, vis-à-vis other precious metals like palladium, silver, and copper (Schluep, 2010). EMPA also has High-tech off-gas control and treatment system. Recyclers established in Bangalore were provided training by EMPA for deployment of e-waste management strategy.

4. Contribution of rag-pickers in SWM in India

The role of rag-pickers is very important in Indian scenario for MSWM. However, their role in waste management stream had not been given any weightage. They move from one community bin to open dump/landfilling sites in search of recyclable items (paper, plastic, tin, etc.) that can be sold to scrap merchants to enable these urban poor to generate income. Usually, the middle men get the major profit on purchase of recyclable item from rag-pickers on pre-decided rates. Even though rag-pickers save almost 14% of the municipal budget annually, their role is largely unrecognized and they are generally deprived of the right to work (Chintan NGO report). According to an estimate, the rag-pickers reduce up to 20% load on transportation and on landfill (Pappu et al., 2007).

5. General guidelines and policies prevailing in India

For waste management in India, administration and regulation is governed by the Ministry of Environment and Forests and Climate Change (MoEF), the Ministry of Urban Development (MoUD), the National Environmental Engineering Research Institute (NEERI), CPCB, and State Pollution Control Boards (SPCBs) and ground level implementation responsibility lies with ULBs.

The following are major steps taken by GOI for solid-waste management in India during last two and half decades:

- National waste management committee: The main objective of the committee constituted in 1990 was to identify the recyclable contents in solid waste picked up by rag-pickers.
- Strategy Paper: A manual on SWM has been developed by the MoUD in collaboration with the NEERI in August, 1995.
- Policy Paper: MoUD and the Central Public Health and Environmental Engineering Institute prepared a strategy paper for the treatment of wastewater, appropriate hygiene, SWM, and efficacy in drainage system.
- Master plan of Municipal Solid Waste: A stratagem was formulated by the combined efforts of MoEF, CPCB, and ULBs to develop a master plan for SWM with emphasis to biomedical waste in March, 1995.
- High Powered Committee: In 1995, a High Powered Committee constituted under the Chairmanship of Dr. Bajaj, to encompass a long-term strategy for the SWM using appropriate technology.

All the above efforts, culminated into preparation of many acts and regulations to protect the environment, which came into force time to time. The rules relevant to SWM in India are as follows:

Hazardous Waste (Management, Handling and Transboundary movement) Rules (1989, amended January 2003, August 2010): It is to control, manage and handling of hazardous waste.
Biomedical Waste (Management and Handling) Rules (1998): It is related to control, manage, and handling of waste generated from hospital, super speciality centers, and nursing homes.
Municipal Solid Waste (Management and Handling) Rules, 2000: These rules are applicable for MSW and be implemented by ULBs for scientific management.
The Batteries (Management and Handling) Rules (2001): It is applicable to stake holders associated with the manufacturing, handling, and utilization and reuse of batteries or components thereof.
Plastic Waste (Management and Handling) Rules, 2009: It deals with scientific disposal of plastic waste and extended producer responsibility clause has also been incorporate in it.
E-Waste Management and Handling Rules 2011: It is applicable to stake holders associated with the manufacturing, handling, utilizing, processing, and recycling electrical and electronic-related waste items.

Most researchers emphasize that ULBs fails to implement these laws adequately. However, needs and aspirations of stake holders demands for appropriate MSWM and accordingly the GOI is continuously encourages ULBs to implement these rules at ground level and recently draft notification for MSW (Management and Handling rules 2015) is also under formulation (Ministry of Environment, Forest and Climate Change, 2015).

6. Conclusion and recommendations

The aim of this study is to present the status of MSW and other important aspects like challenges for integrated SWM, intricacy of PPP mode, role of rag-pickers, prevailing practices of MSWM, and the rules pertaining to waste management in India. In developing countries like India, it is important to plan and implement sustainable low-cost SWM strategies. Lack of awareness, inappropriate technical knowledge, inadequate funding, unaccountability, implementation of legislation and policies are major reasons for the failure of MSWM. Issues like proper site selection, adequate financial support, and improper human resource management, can be overcome with enhanced capacity, improved procedures and training. The solution to the problems associated with development and adoption of appropriate technologies and lack of trained manpower will require at realistic time frame and not only central government bodies, but state governments also have to take various actions for strengthening MSWM in the country. The intricacies that could arise during implementation should be taken into account, so that decisions and strategies can be based on ground actualities.

Rules of SWM need to be taken in such a way that these take into account the ground realities and allow time for suitable processes and mechanisms to be developed. Unfortunately, role of rag-pickers in SWM has not been adequately recognized till now, who are one of the important stakeholders of the SWM in India. Their role needs to be accommodated in the proper system to upgrade and boost their morale. However, rag-pickers are working for the unorganized sector, therefore proper organized sector for reuse and recycling of waste needs to be put in place to generate more employment and revenue, apart from reducing the load on transportation and landfill.

6.1. Challenges

(1) Awareness to enhance segregation:

Ecological awareness and citizen participation to segregate waste at source, door-to-door collection, and disposal in appropriate collecting bin is imperative. The awareness plays an important role in MSWM and augments the efficiency of waste management stream. It is the most critical phase in the whole process of MSWM, which helps in handling solid waste leading to ultimate success. However, in India, the present scenario reveals that there is almost no segregation of garbage at source which leads to various environmental problems and it becomes very difficult to segregate waste at transfer station or in landfill or treatment site. Also, due to lack of coordination among the residents and lack of planned cities in India, the residents throw garbage improperly. Apart from this, the community bins are not located in the close vicinity and the number of ULBs employees is not adequate as per population residing in that area.

(2) Characterization of municipal solid waste:

India is a vast country divided into different climatic zone, different food habits, and different living standard thereby producing waste of different types. Till date, no comprehensive studies have been conducted to cover almost all cities and towns of India to characterize the waste generated and disposed on landfill. The policy-makers rely on the limited source of information available from few places thereby are unable to provide appropriate solutions for the kind of waste produced for a particular region.

(3) Urbanization and lack of appropriate level funding:

With the population growth, challenge to provide adequate infrastructure in urban area and new landfill site selection is important. Most of the landfill sites are running beyond their capacity in metropolitan cities. Inadequate financial support to cater to waste management problem aggravates it. Due to financial crunch ULBs do not have adequate infrastructure to provide suitable solutions.

(4) Implementation of rules at ground level:

ULBs are not implementing MSWR adequately as revealed by various government reports; thus it is difficult to manage the MSW properly. There is a need to create dedicated group of officers and skilled staff for ULBs with specialization in MSWM. Adequate training and hands-on experiments would enable them to identify bottlenecks at implementation level and take appropriate action.

(5) Financial auditing and work study:

Work study can identify bottlenecks in the whole system and financial auditing can suggest the ways to enhance commitment of the staff engaged. However, no such proactive approach was attempted by ULBs.

(6) Resistance for notification of new landfill site:

There is resistance of local citizen for notification of landfill site in their locality and therefore selection of new site is difficult and all the existing landfill sites are running beyond their capacity.

(7) Lack of coordination among Centre and State:

There is less dialogue between Central and State government. Delay in submission of information from State to Central delays appropriate level implementation at ground level. Such lack of coordination for specific action plan and poor strategy at implementation level by ULBs are main hindrance.

(8) Appropriate technological solution, Outsourcing and PPP:

Environmentally benign practices are the need of the hour to cope with the almost exponential growth of MSW. For this, appropriate technological solutions through PPP are required. However, lack of competency and insufficient financial support are major threats to ULBs for development of MSW infrastructure. There is need for PPP to implement management and handling with the latest technology/know-how with the subject experts firms and companies. Establishment of the good public governance in compliance with secured regulatory framework and appropriate financial support and strict contract implementation is required for the success of PPP. Capacity building and availability of skilled labor, familiarity with new and as well as best practices available for SWM, financial incentives for identifying new techno-feasible solutions, appropriate and quick decision at ULBs level for smooth implementation are real challenges.

(9) Failure of waste-to-energy projects:

India is still struggling to make waste-to-energy project a success story. There is a need to import economically feasible and proven technologies. Apart from this, suitably characterized and segregated waste needs to be provided to waste-to-energy plants as per its requirement.

(10) Involvement of organized sector:

For improving MSW collection efficiency and source segregations, rag-pickers can be engaged through organized sector. However, due to lack of recycling industries and acceptance of society this vast potential has been ignored.

7. Recommendation and conclusion

Following are various recommendations that evolve from this study to improve the existing MSWM practices in India:

(1) The community should pay to augment inadequate resources for MSWM of municipal bodies. Community participation in SWM is the key to sustain a project related to management of solid waste. Till date no such tax has been levied for SWM.

(2) The people should be educated to realize the importance of source segregation at generation point as biodegradables, inert and recyclable material for proper waste management.

(3) Viable decentralized composting plants should be installed to reduce the load on ULBs for collection and transportation of MSW, which subsequently culminates in reduction of the pressure exerted on the landfills.

(4) For large cities, zone-wise decentralized composting units should be setup. Through community participation, segregated biodegradable waste from individual community/units should be collected and disposed into these decentralized composting units.

(5) Characterization of waste at collection and also at disposal point should be made and be available in public domain. Government should take initiative to encourage Universities, technical Institution to take up waste management in its curriculum. Assistance of academic institutions should be solicited in characterization of waste in their vicinity. Thereby most part of India would be covered and location-specific appropriate solutions for waste management can be developed. It can also help to select suitable waste-to-energy technologies for particular regions.

(6) The waste should be treated as resource and formal recycling sector/industries be developed to recycle non-biodegradable recyclable component from the waste thereby providing employment to rag-pickers and absorb them in mainstream. Also a policy, fiscal intensive and development of quality standard for reuse and recycle of C&D waste be developed and notified so that producers dispose/reuse it as per guidelines, thereby reducing burden on landfill.

(7) Manufacturing of non-recyclable polyethylene bags should be banned or research should be initiated to develop biodegradable polyethylene.

(8) In most parts of India, sweeper and rag-pickers are still considered inferior class of citizens despite several laws in place to bring dignity to their profession. To change people's views and perspective, awareness regarding this important service to community should be initiated and manpower engaged in such activities should be named as Green brigade/Crew, and so on.

(9) Though, in India, prevailing MSWR does not permit leachate/water/liquid addition in landfill, biodegradable waste gets mixed again during transportation and finally disposed in landfill. Therefore, practices of leachate/liquid recirculation in landfill should be encouraged to enhance waste stabilization and gas recovery as practiced in developed countries. Modification and provision for it should be made in MSWR accordingly.

(10) Protection of groundwater contamination from leachate percolation from open dump/landfill site should be made compulsory. Appropriate technological solution should be adopted to achieve this goal.

List of abbreviations

CH_4	methane
CO_2	carbon dioxide
C&D	construction and demolition
CPCB	Central Pollution Control Board, New Delhi
CIPET	Central Institute of Plastics Engineering and Technology, Chennai
FICCI	Federation of Indian Chambers of Commerce and Industry New Delhi
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MSWR	Municipal Solid Waste (Management and Handling) Rules, 2000
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forests and Climate Change
MoUD	Ministry of Urban Development
NERI	Narvreet Energy Research and Information
NEERI	National Engineering and Environmental Research Institute, Nagpur
PPP	Public Private Partnership
RDF	Refuse Derived Fuel

SPCBs	State Pollution Control Boards
SWM	Solid Waste Management
TERI	Tata Energy Research Institute
ULBs	Urban Local Bodies
UTs	Union Territories

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