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Invited article

A review on current status of municipal solid waste management in India

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ABSTRACT

Municipal solid waste management is a major environmental issue in India. Due to rapid increase in urbanization, industrialization and population, the generation rate of municipal solid waste in Indian cities and towns is also increased. Mismanagement of municipal solid waste can cause adverse environmental impacts, public health risk and other socio-economic problem. This paper presents an overview of current status of solid waste management in India which can help the competent authorities responsible for municipal solid waste management and researchers to prepare more efficient plans.

Introduction

Human activities create waste and these wastes are handled, stored, collected and disposed of, which can pose risks to the environment and to public health (Saxena et al., 2010; Zhu et al., 2008). Economic development, urbanization and improved living standards in cities increase the quantity and complexity of generated solid waste (Gidde et al., 2008; Rathi, 2007). In discussing solid waste, generally and traditionally certain categories of wastes are well recognized as they are very common. For example, solid wastes include domestic, commercial, industrial, (due to construction and demolition), agricultural, institutional and miscellaneous. Many times domestic and commercial wastes cannot be differentiated and are considered together as urban wastes (Syed, 2006).

Municipal solid waste is generally a combination of household and commercial refuse which is generated from the living community (Rajkumar et al., 2010). The continuous indiscriminate disposal of municipal solid waste is accelerating and is linked to poverty, poor governance, urbanization, population growth, poor standards of living, low level of environmental awareness (Rachel et al., 2009; Ogu, 2000) and inadequate management of environmental knowledge. Municipal solid waste generally includes degradable (paper, textiles, food waste, straw and yard waste), partially degradable (wood, disposable napkins and sludge) and non-degradable materials (leather, plastics, rubbers, metals, glass, ash from fuel burning like coal, briquettes or woods, dust and electronic waste) (Jha et al., 2011; Herat, 2009; Tchobanoglous et al., 1993). Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which generate thousands of tons of MSW daily. Poor collection and inadequate transportation are responsible for the accumulation of MSW at every nook and corner (Bundela et al., 2010; Gidde et al., 2008; Sharholy et al., 2007). The management of municipal solid waste is going through a critical phase, due to unavail-

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ability of suitable facilities to treat and dispose of the larger amounts of MSW generated daily in metropolitan cities. Adverse impact on all components of the environment and human health occurs due to scientific disposal of MSW (Gupta et al., 2007; Rathi, 2006; Ray et al., 2005; Sharholy et al., 2005; Jha et al., 2003).

Improper management of solid waste has been reported by several researchers in different cities of developing countries (Mohanty et al., 2014; Das and Bhattacharya, 2013; Noorjahan et al., 2012; Jafari et al., 2010; Chatterjee, 2010; Imam et al., 2008; Chung and Carlos, 2008; Berkun et al., 2005). Due to improper solid waste management, waste has become one of the

Table 1 – Municipal solid waste generation rates in different cities of India.

Sample no.	Name of city	Population (as per 2001 census)	Area (Km^2)	Waste quantity (TPD)	Waste generation rate (kg/(cap · day))	Compostables (%)	Recyclables (%)	C/N ratio	HCV* (Kcal/kg)	Moisture (%)
1.	Kavaratti	10119	4	3	0.30	46.01	27.20	18.04	2242	25
2.	Shillong	132867	10	45	0.34	62.54	17.27	28.86	2736	63
3.	Shimla	142555	20	39	0.27	43.02	36.64	23.76	2572	60
4.	Agartala	18998	63	77	0.40	58.57	13.68	30.02	2427	60
5.	Gandhinagar	195985	57	44	0.22	34.30	13.20	36.05	698	24
6.	Dhanbad	199258	24	77	0.39	46.93	16.16	18.22	591	50
7.	Pondicherry	220865	19	130	0.59	46.96	24.29	36.86	1846	54
8.	Imphal	221492	34	43	0.19	60.00	18.51	22.34	3766	40
9.	Aizwal	228280	117	57	0.25	54.24	20.97	27.45	3766	43
10.	Jammu	369959	102	215	0.58	51.51	21.08	26.79	1782	40
11.	Dehradun	424674	67	131	0.31	51.37	19.58	25.90	2445	60
12.	Asansol	475439	127	207	0.44	50.33	14.21	14.08	1156	54
13.	Kochi	595575	98	400	0.67	57.34	19.36	18.22	591	50
14.	Raipur	605747	56	184	0.30	51.40	16.31	223.50	1273	29
15.	Bhubaneswar	648032	135	234	0.36	49.81	12.69	20.57	742	59
16.	Tiruvanantapuram	744983	142	171	0.23	72.96	14.36	35.19	2378	60
17.	Chandigarh	808515	114	326	0.40	57.18	10.91	20.52	1408	64
18.	Guwahati	809895	218	166	0.20	53.69	23.28	17.71	1519	61
19.	Ranchi	847093	224	208	0.25	51.49	9.86	20.23	1060	49
20.	Vijaywada	851282	58	374	0.44	59.43	17.40	33.90	1910	46
21.	Srinagar	898440	341	428	0.48	61.77	17.76	22.46	1264	61
22.	Madurai	928868	52	275	0.30	55.32	17.25	32.69	1813	46
23.	Coimbatore	930882	107	530	0.57	50.06	15.52	45.83	2381	54
24.	Jabalpur	932484	134	216	0.23	58.07	16.61	28.22	2051	35
25.	Amritsar	966862	77	438	0.45	65.02	13.94	30.69	1836	61
26.	Rajkot	967476	105	207	0.21	41.50	11.20	52.56	687	17
27.	Allahabad	975393	71	509	0.52	35.49	19.22	19.00	1180	18
28.	Vishakhapatnam	982904	110	584	0.59	45.96	24.20	41.70	1602	53
29.	Faridabad	1055938	216	448	0.42	42.06	23.31	18.58	1319	34
30.	Meerut	1068772	142	490	0.46	54.54	10.96	19.24	1089	32
31.	Nashik	1077236	269	200	0.19	39.52	25.11	37.20	2762	62
32.	Varanasi	1091918	80	425	0.39	45.18	17.23	19.40	804	44
33.	Jamshedpur	1104713	64	338	0.31	43.36	15.69	19.69	1009	48
34.	Agra	1275135	140	654	0.51	46.38	15.79	21.56	520	28
35.	Vadodara	1306227	240	357	0.27	47.43	14.50	40.34	1781	25
36.	Patna	1366444	107	511	0.37	51.96	12.57	18.62	819	36
37.	Ludhiyana	1398467	159	735	0.53	49.80	19.32	52.17	2559	65
38.	Mumbai	1437354	286	574	0.40	52.44	22.33	21.58	1421	43
39.	Indore	1474968	130	557	0.38	48.97	12.57	29.30	1437	31
40.	Nagpur	2052066	218	504	0.25	47.41	15.53	26.37	2632	41
41.	Lucknow	2185927	310	475	0.22	47.41	15.53	21.41	1557	60
42.	Jaipur	2322575	518	904	0.39	45.50	12.10	43.29	834	21
42.	Surat	2433835	112	1000	0.41	56.87	11.21	42.16	990	51
44.	Pune	2538473	244	1175	0.46	62.44	16.66	35.54	2531	63
45.	Kanpur	2551337	267	1100	0.43	47.52	11.93	27.64	1571	46
46.	Ahmedabad	3520085	191	1302	0.37	40.81	11.65	29.64	1180	32
47.	Hyderabad	3843585	169	2187	0.57	54.20	21.60	25.90	1969	46
48.	Bangalore	4301326	226	1669	0.39	51.84	22.43	35.12	2386	55
49.	Chennai	4343645	174	3036	0.62	41.34	16.34	29.25	2594	47
50.	Kolkata	4572876	187	2653	0.58	50.56	11.48	31.81	1201	46
51.	Delhi	10306452	1483	5922	0.57	54.42	15.52	34.87	1802	49
52.	Greater Mumbai	11978450	437	5320	0.45	62.44	16.66	39.04	1786	54

Source: CPCB, 2005.

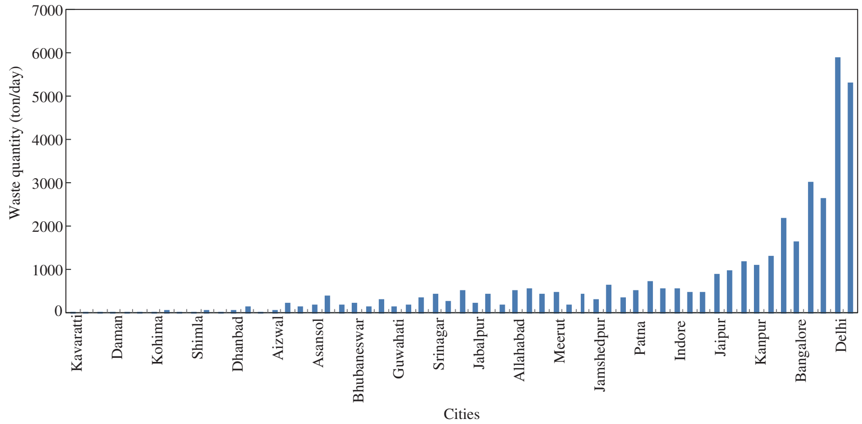

Fig. 1 – Waste quantity generation rate (ton/day) *vs.* cities.

pollution sources that has caused diverse environment impacts as well as detrimental towards human health and safety (Shazwin and Nakagoshi, 2010). India is one of the least urbanized countries of the world, yet its urban population is second largest amongst the countries of the world. Metropolitan cities (Delhi, Mumbai, Kolkata and Chennai) account for more than 42% of India's urban population (Ghosh and Kansal, 2014) and been a top producer of MSW in India due to its high occupancy. In the present study, an attempt has been made to provide a comprehensive review of MSWM for Indian cities to evaluate the current status and identify the problems of MSWM. A review of literature of SWM in India highlights institutional/financial issues as the most important ones limiting improvements in SWM (Parthan and Milke, 2009). Hanrahan et al., 2006 specifically note that "There is an urgent need for much improved medium term planning at the municipal and state level so that realistic investment projections can be developed and implemented."

1. Waste generation and characteristics

The quantity and characteristics of solid waste vary from place to place. Factors that influence the quantity and composition are the average income level, the sources, the population, social behavior, climate, industrial production and the market for waste materials (Late and Mule, 2013; Yadav and Devi, 2009). The present annual quantity of solid waste generated in Indian cities has increased from 6 million tons in 1947 to 48 million tons in 1997 and to 90 million tons in 2009 and it is expected to increase to 300 million tons by 2047 (TEDDY, 2010; Sharholy et al., 2006). CPCB with the assistance of NEERI has conducted survey of solid waste management in 59 cities (35 metro cities and 24 state capitals: 2004–05). Quantities and waste generation rate in 59 cities are given in Table 1. Waste generation rate in ton/day and kg/cap/day of different cities are depicted as Fig. 1 and Fig. 2 respectively.

It can be seen from Table 1 that per capita generation rate is high in some cities (Port Blair, Kochi, Chennai, Vishakhapatnam, Pondicherry, Kolkata, Jammu, Delhi and Hyderabad). This may be due to high living standards, the rapid economic growth and the high level of urbanization in these cities. However, the per capita generation rate is observed to be low in other cities (Kohima, Nashik, Imphal, Rajkot and Guwahati).

Table 1 also shows the differences in the municipal solid waste characteristics indicate the effect of urbanization and development. In urban areas, the major fraction of municipal solid waste is compostable materials (40%-60%) and inerts (30%-50%). The relative percentage of organic waste in municipal solid waste is generally increasing with the

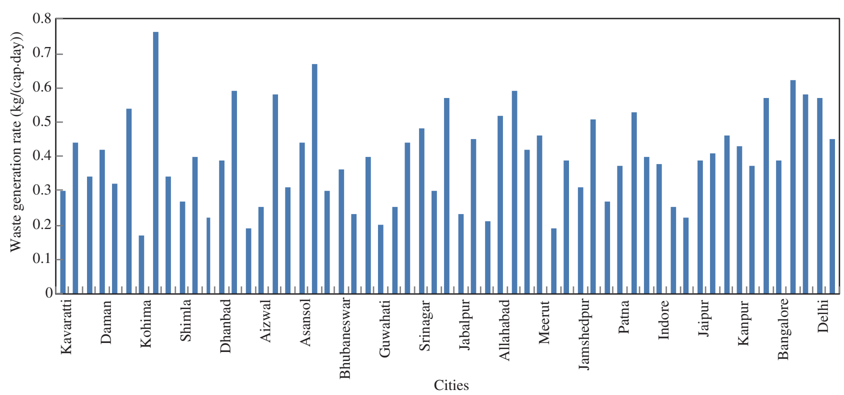

Fig. 2 – Waste generation rate (kg/cap/day) *vs.* cities.

Table 2 – Physical characteristics of municipal solid wastes in Indian cities.

Population range (in million)	Number of cities surveyed	Paper	Rubber, leather and synthetics	Glass	Metal	Compostable matter	Inert material
0.1–0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5–1.0	15	2.95	0.73	0.56	0.32	40.04	48.38
1.0–2.0	9	4.71	0.71	0.46	0.49	38.95	44.73
2.0–5.0	3	3.18	0.48	0.48	0.59	56.57	49.07
5.0 and above	4	6.43	0.28	0.28	0.80	30.84	53.90

All values are in percent and are calculated on wet basis.
Source: Manual on Municipal Solid Waste Management, Ministry of Urban Development, GoI.

Table 3 – Chemical characteristics of municipal solid wastes in Indian cities.

Population range (in million)	Number of cities surveyed	Moisture %	Organic matter %	Nitrogen as total nitrogen %	Phosphorous as P_2O_5 %	Potassium as K_2O %	C/N ratio	Calorific value [a] in kcal/kg
0.1–0.5	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5–1.0	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0–2.0	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2.0–5.0	3	21.03	25.60	0.56	0.69	0.78	22.45	907.18
5.0 and above	4	38.72	39.07	0.56	0.52	0.52	30.11	800.70

All values, except moisture, are on dry weight basis.
Source: Manual on Municipal Solid Waste Management, Ministry of Urban Development, GoI.
[a] Calorific value on dry weight basis.

decreasing socio-economic status; so rural households generate more organic waste than urban households. Also, it has been noticed that the percentage of recyclables (paper, glass, plastic and metals) is very low, because of rag pickers who segregate and collect the materials at generation sources, collection points and disposal sites. Tables 2 and 3 shows the physical and chemical characteristics of municipal solid waste in Indian cities. Fig. 3 illustrates the percent of compostable and recyclable waste generated by different cities of India.

2. Composition of municipal solid waste

Waste composition depends on a wide range of factors such as food habits, cultural traditions, climate and income (Srivastava et al., 2014; Patle et al., 2014; Naveen et al., 2013; Gupta et al., 2013; Kumar et al., 2009). Many categories of municipal solid waste are found such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. Municipal solid waste contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, *etc.*), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) (Kausal et al., 2012; Upadhyay et al., 2012; Reddy and Galab, 1998). Of these, papers, plastics, yard debris, food waste, wood, textiles, disposable diapers, bones, leather and other organics are combustible materials although glass, metal and aluminium are non-combustible materials (Srivastava et al., 2014; Denison and Ruston, 1990). The composition of municipal solid waste at generation sources and collection points was determined on a wet weight basis and it consists mainly of a large organic fraction (40%–60%), ash and fine earth (30%–40%), paper (3%–6%) and plastic, and glass and metals (each less than 1%). The C/N ratio ranges between 800 and 1000 kcal/kg (Sharholy et al., 2008).

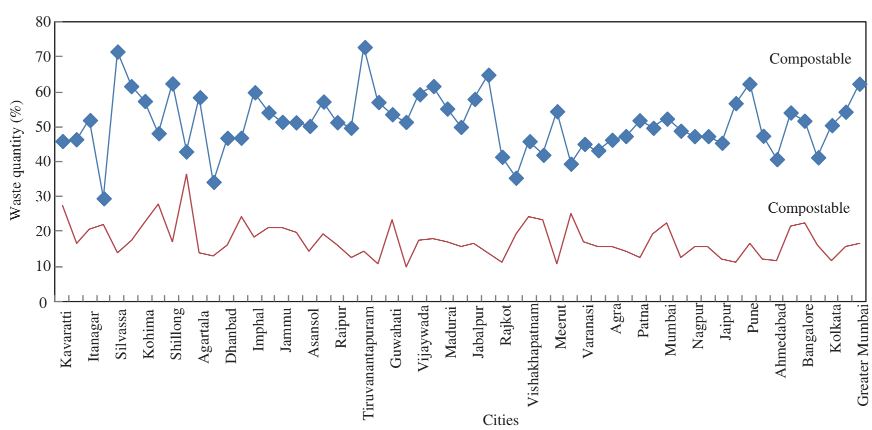

Fig. 3 – Waste category *vs.* cities.

Table 4 – General characteristics of Indian mega-cities and their solid waste management.

Parameter	Year	Mega cities			
		Chennai	Delhi	Kolkata	Mumbai
Area (km^2)		174	1484	187.33	437.71
Population (million)	1971	2.47	4.07	3.15	5.97
	1981	4.28	6.22	4.13	8.23
	1991	5.42	8.42	11.02	12.6
	2001	6.56	12.87	13.20	16.43
Waste generation (kg/capita/day)	1971/73	0.32	0.21	0.5	0.49
	1994	0.66	0.48	0.32	0.44
	1999	0.61	1.1	0.545	0.52
Waste collection (Gg per day)	1999	3.124	5.327	3.692	6.0

Source: Jha et al., 2007.

2.1. MSW compositional changes reported for India since 1971

Municipal solid waste components like paper, plastic and glass are having the increasing trend from 4.1%, 0.7% and 0.4% respectively in 1971 to 8.18%, 9.22% and 1.01% respectively in 2005, metals are also having the increasing trend during the same period while inert materials and compostable matter are having the decreasing trend from 49.2% and 41.3% respectively in 1971 to 25.61% and 40% in 2005. Increasing trend suggests that the establishment of the formal recovery and recycle facilities will be economically a viable option (Kausal et al., 2012).

Table 5 – Variation in MSW composition characteristics in mega-cities over past decades.

MSW Characteristics	City	% Composition variation over years				
		1971–1973	1990–1993	1995	1997–1998	2000–2002
Compostable matter	Chennai	47.97	44	44	49.6	47.24
	Delhi	35.42	–	65–84	47.07	–
	Kolkata	40.37	41	40	47	46.58
	Mumbai	59.78	–	40	–	37.5
Rags	Chennai	4.85	4.27	5	4.5	–
	Delhi	4.7	4	4	–	–
	Kolkata	3.6	–	3	–	–
	Mumbai	2.48	–	3.6	–	–
Rags and textiles	Chennai	4.85	4.59	10	–	3.14
	Delhi	–	8	8	–	0.52
	Kolkata	3.6	2.9	3	–	–
	Mumbai	–	–	7.2	–	–
Papers	Chennai	7.75	4.69	10	4.5	6.45
	Delhi	6.29	–	6.6	4.8–9	3.62
	Kolkata	3.18	5.2	10	–	–
	Mumbai	4.89	–	10	–	15
Leather and rubber	Chennai	–	<1	5	1	1.45
	Delhi	–	–	0.6	–	1.83
	Kolkata	0.86	2	1	–	–
	Mumbai	–	–	0.2	–	–
Plastics	Chennai	0.88	<1	3	2.5	7.04
	Delhi	0.85	–	1.5	4.1–8.65	4.17
	Kolkata	0.65	3.5	8	0.65	1.54
	Mumbai	2.92	–	2	–	–
Metals	Chennai	0.95	<1	<1	0.04	0.03
	Delhi	1.21	–	2.5	–	0.45
	Kolkata	0.66	–	<1	–	0.66
	Mumbai	2.46	–	<1	–	0.8
Glass	Chennai	0.97	<1	<1	–	–
	Delhi	0.57	–	1.2	0.85–2.9	0.49
	Kolkata	0.38	–	3	0.66	0.24
	Mumbai	0.72	–	0.2	–	0.4
Ash, fine earths and others	Chennai	–	33	33	38.9	34.65
	Delhi	36	–	51.5	–	36.56
	Kolkata	51.18	46.95	47	–	35
	Mumbai	44.2	–	44	–	35

Source: Jha et al., 2007.

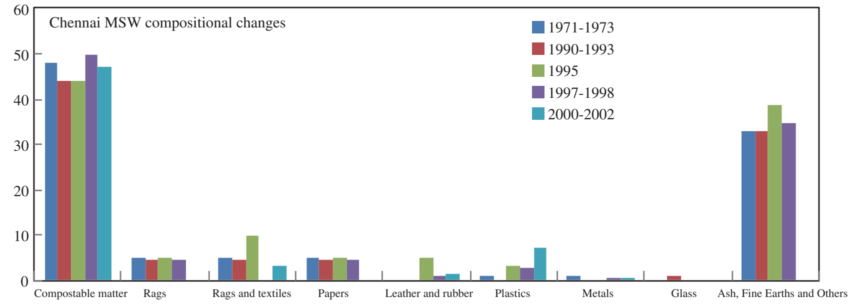

Fig. 4 – MSW compositional changes in Chennai.

2.2. MSW composition changes of four mega cities in India

From Table 4, population of Mumbai increased from 8.23 million in 1981, to 12.6 million in 1991, a growth of about 49%. In Chennai, the population increase was about 21% between 1991 and 2001, while waste generation increased by about 61% from 1996 to 2002 waste generation increased by about 61% from 1996 to 2002. Table 5 and Figs. 4-7 shows the variation in composition of MSW of four mega cities i.e. Chennai, Delhi, Kolkata and Mumbai over past century respectively.

3. Collection and storage of MSW

The waste collection in India is very unorganized. Most of the urban areas are lacking in MSW storage at the source, significantly. The collection bins used in various cities are neither properly designed nor properly located and maintained. This has resulted in the poor collection efficiency. The average collection efficiency for MSW in Indian cities and states is about 70% (Saxena et al., 2010; Rathi, 2006; Siddiqui et al., 2006; Gupta et al., 1998; Maudgal, 1995 and Khan, 1994). The bins are common for both decomposable and non-decomposable waste (no segregation of waste is performed) and the waste is disposed at a communal disposal center. Storage bins can be classified as movable bins and fixed bins. The fixed bins are more durable but their positions cannot be changed once they have been constructed, while the movable bins are flexible in transportation but lacking in durability (Sharholy et al., 2008; Nema, 2004; Malviya et al., 2002). The MSW management steps are depicted in Fig. 8.

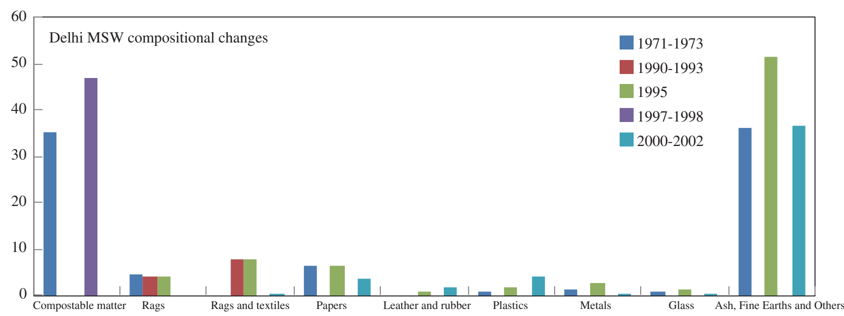

Fig. 5 – MSW compositional changes in Delhi.

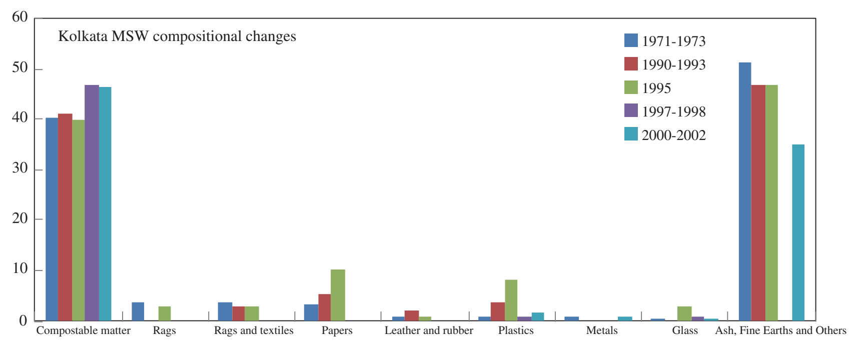

Fig. 6 – MSW compositional changes in Kolkata.

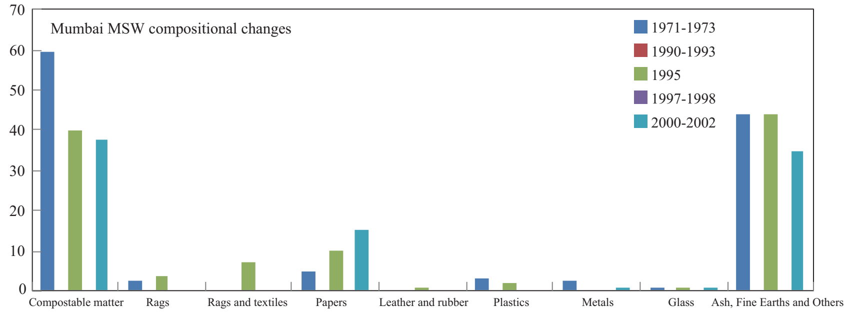

Fig. 7 – MSW compositional changes in Mumbai.
Source: Joseph, 2002.

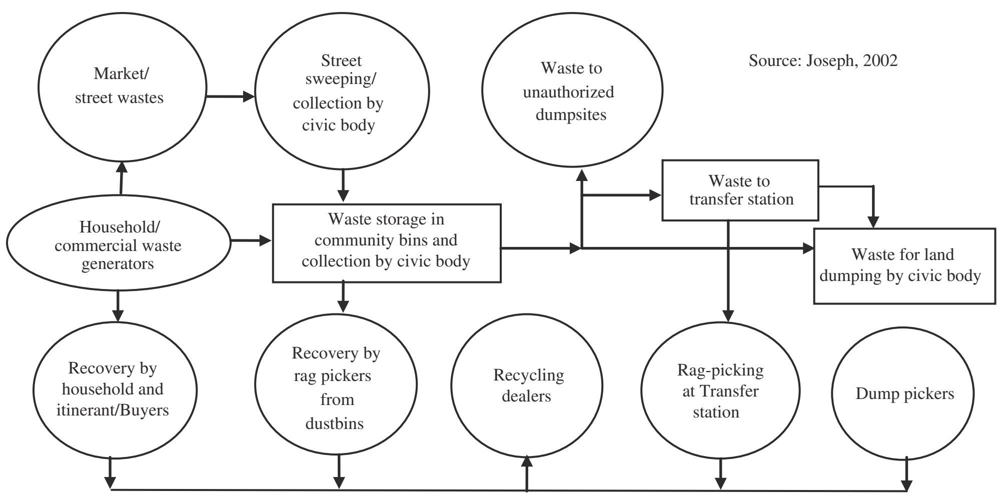

Fig. 8 – Schematic flow chart of common MSW management process.

4. Treatment and disposal of municipal solid waste management

India is facing the lacking of resources or the technical expertise necessary to deal with the disposal of municipal solid waste (Kausal et al., 2012). The two leading innovative mechanisms of waste disposal being adopted in India include composting (aerobic composting and vermi-composting) and waste-to-energy (WTE) (incineration, pelletisation, biomethanation). WTE projects for disposal of MSW are a relatively new concept in India. Although these have been tried and tested in developed countries with positive results, these are yet to get off the ground in India largely because of the fact that financial viability and sustainability are still being tested (Sharholy et al., 2008). A waste-to-energy plant established at Vijaywada by Shriram Energy Systems, Ltd., Hyderabad, with a capacity of about 500 TPD of MSW and a power generating capacity of 6 MW, has been in operation since December 2003. Another plant, with a capacity of about 700 TPD of MSW with a power generating capacity of 6.6 MW, established by M/s SELCO International Ltd., at Gandhamguda near Hyderabad has been in operation since November 2003. M/s Shriram Energy Systems Ltd., Hyderabad, will commission a third waste-to-energy plant at Vishakhapattanam. A waste-to-energy plant (600 TPD capacity) is also underway at Chennai (Kumar et al., 2009).

Only 6%–7% of the MSW is converted into compost in India (Annepu, 2012). Rest MSW is disposed off through landfilling. An incineration and biomethanation type of waste-to-energy system of solid waste disposal has also been introduced in India but contributes at minor level in present scenario (Fig. 9). The status of solid waste disposal in Kerala is depicted in Fig. 10.

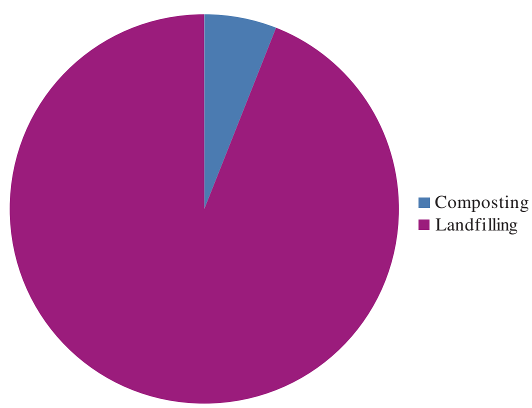

Fig. 9 – Status of solid waste disposal in India.

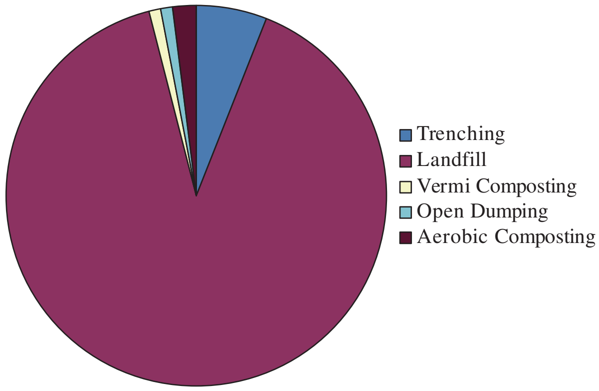

Fig. 10 – Status of solid waste disposal at Kerala. Source: CPCB, 2007.

4.1. *Composting*

The organic content of municipal solid waste (MSW) tends to decompose leading to various smells and odor problems. To ensure a safe disposal of the MSW it is desirable to reduce its pollution potential and several processing methods are proposed for this purpose. Composting is the decomposition of organic matter by microorganism in warm moist, aerobic and anaerobic environment. Composting of MSW is, therefore, the most simple and cost effective technology for treating the organic fraction of MSW (Asnani, 2006). It is suitable for organic biodegradable fraction of MSW, yard (or garden) waste/waste containing high proportion of lignocelluloses materials, which do not readily degrade under anaerobic conditions, waste from slaughterhouse and dairy waste.

Composting can be carried out in two ways *i.e.*, aerobically and anaerobically. During aerobic composting aerobic microorganisms oxidize organic compounds to Carbon di oxide, Nitrite and Nitrate. During anaerobic process, the anaerobic micro organisms, while metabolizing the nutrients, break down the organic compounds through a process of reduction. An anaerobic process is a reduction process and the final product is subjected to some minor oxidation when applied to land (CPHEEO, 2000).

Municipal solid waste composting is being encouraged in many countries of the world and researchers have experienced the benefits of using municipal solid waste compost in the field (Gautam et al., 2010; Porkhrel and Viraraghavan, 2005; Abigail, 1998; John, 1997).

4.2. *Vermi-composting*

Vermicomposting is a system for turning organic waste into nutrient rich soil as it is processed by worms. It cannot really be described as a type of composting, which is a heat producing process that would actually kill worms; whereas vermicomposting should establish environment in which worms can thrive and reproduce. The worms process organic waste excreting them as organic material rich, stable, and plant-available nutrients that look like fine textured soil. Nutrients in vermicompost are often much higher than traditional garden compost (Datar and More).

Vermicompost is an odorless, dark brown bio-fertilizer obtained from the process of vermicomposting (Manyuchi and Phiri, 2013; Manyuchi et al., 2013; Abbasi et al., 2009; Aalok et al., 2008; Chauduri et al., 2000). It is the natural organic manure produced from the excreta of earthworms fed on scientifically semi-decomposed organic waste (Ansani, 2006). Vermicomposting facilities have already entered domestic and industrial marketing in countries like Canada, USA, Italy and Japan. It is now time for India to think about vermitechnology commercially (Aalok et al., 2008).

4.3. *Landfilling*

Landfilling is disposal of waste with different liners and finally with earth cover. It is also the most economical, especially in developing countries where it typically involves pitching refuse into a depression or closed mining site (Daskalopoulos et al., 1998). A landfill is a facility which is designed for the safe disposal of solid wastes. The bottom liners and a top Cover, of the landfill are considered as the most critical components. Penetration of Leachate into the soil is the major problem in landfills (Alekhya et al., 2013). Landfills produce landfill gases and leachate which can harm human and natural systems. Landfill gases (LFGs), produced when methanogens decompose complex molecules, are primarily methane and carbon dioxide (up to 90%), but also include CO, N_2, alcohols, hydrocarbons, organosulfur compounds, and heavy metals (El-Fadel et al., 1997). Leachate can cause surface water and ground water pollution (Smahi et al., 2013; Nagarajan et al., 2012; Aljaradin and Persson, 2012; Akinbile and Yusoff, 2011; Kangsepp and Mathiasson, 2009; Abbas et al., 2009; Lou et al., 2009; Olsson et al., 2009; Adeyemi et al., 2006; Mor et al., 2006; James, 1977).

4.4. *Bio-methanation*

Bio-methanation is the process of conversion of organic matter in wastes to methane and manure by microbial action in the absence of air through a process called anaerobic digestion. The solid wastes from agro-based industries have high organic content and hence its treatment by the process of bio-methanation is most viable as it produces useful products like biogas and enriched manure. The bio-methanation process is a two stage process consisting of acidification and methanation (CPCB, 2007). The process is shown in Fig. 11. Biogas consists of methane and carbon dioxide and can be used as fuel or, by using a generator it can be converted to electricity on-site (Annepu, 2012).

A 5 MW MSW-based power project was established at Lucknow in December 2003, based on high-rate biomethanation technology. It was executed by Asia Bio-energy Ltd, Chennai on BOOM (Build, Own, Operate and Maintenance) basis. The plant is designed to take care of about 500–600 tons of MSW every day from Lucknow City (Axelsson and Kvarnstrom, 2010). Several schemes have been planned for biomethanation of vegetable wastes and fruit waste in various cities (Prakash and Singh, 2013; Velmurugan and Ramanujam, 2011; Kavitha and Joseph, 2008; Neves et al., 2008; Banu et al., 2007; Bardiya et al., 1996).

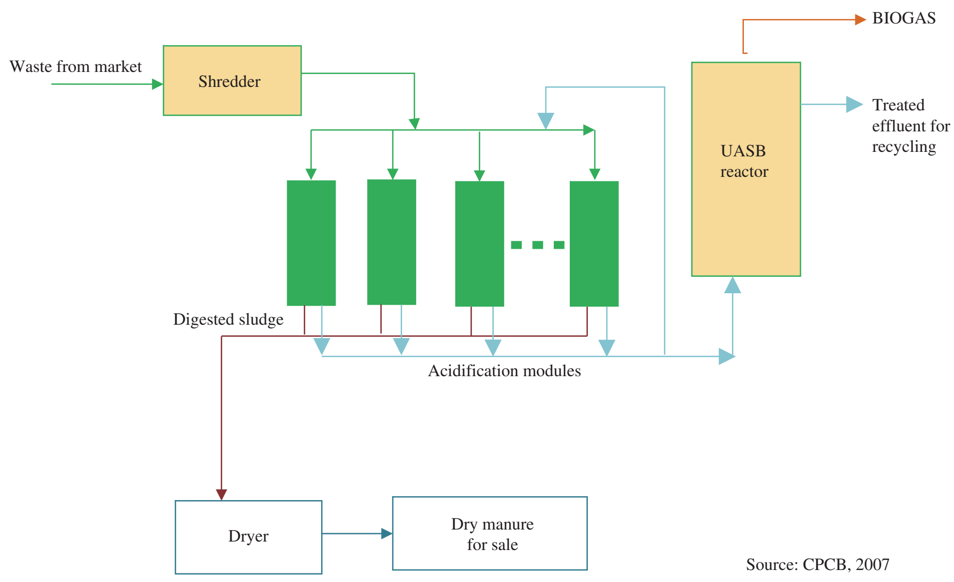

Fig. 11 – Acidification and methanation phase.

4.5. *Incineration*

Incineration is a thermal waste treatment process where raw or unprocessed waste can be used as feedstock (Zaman, 2010). Incineration processes takes place in the presence of air and at the temperature of 850°C and waste are converted to carbon dioxide, water and non-combustible materials with solid residue *i.e.*, bottom ash (Zaman, 2009; DEFRA, 2007). There are various types of incinerators, such as moving grate, fixed grate, rotary-kiln, and fluidized bed (Moustakas and Loizidou, 2010). In Indian cities, incineration is generally limited to hospital and other biological wastes. This may be due to the high organic material (40%–60%), high moisture contact (40%–60%) and low calorific value content (800–1100 kcal/kg) in solid waste (Rajput et al., 2009; Kansal, 2002; Joardar, 2000; Bhide and Shekdar, 1998). Several researches have done on management of municipal solid waste incinerator residues (Sabbas et al., 2003; Sakai and Hiraoka, 2000). An incinerator capable of generating 3.75 MW power from 300 TPD MSW was installed at Timarpur, Delhi in the year 1987. It could not operate successfully due to low net calorific value of MSW. The plant is lying idle and the investment is wasted (Asnani, 2006).

4.6. *Pyrolysis*

Pyrolysis is a thermochemical conversion process where a solid fuel is heated in the absence of an oxidizing agent (in an inert atmosphere). Pyrolysis, as a conversion process, yields 3 products: (i) a gas mixture; (ii) a liquid (bio-oil/tar); and (iii) a solid residue (char). Two technologies exist and differ on the method of heat transfer: fast pyrolysis for production of bio-oil and slow pyrolysis for production of charcoal (Becidan, 2007). The primary disadvantages of pyrolysis processing are: 1) the product stream is more complex than for many of the alternative treatments; 2) the product gases cannot be vented directly in the cabin without further treatment because of the high CO concentrations (Serio et al., 2000). There are several excellent researches on pyrolysis of solid waste for energy generation (Serio et al., 2001, 2002, 2003).

5. Summary

In this paper, an attempt has been made to study the changing trends of quantity and characteristics of MSW. The changing pattern of waste composition emphasizes the importance of segregation for successful operation of waste management facilities. Municipal authorities should maintain the storage facilities in such a manner that they do not create unhygienic and unsanitary conditions. A new survey should be carried out on the generation and characterization of MSW in India. Since the MSW is heterogeneous in nature, a large number of samples have to be collected and analyzed to obtain statistically reliable results.

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