A Review of Municipal Solid Waste: Its Generation, Composition, Impacts, Management and Challenges in Urban Areas with Special Focus on India

Kanchan Deoli Bahukhandi and Saswat Ollemman

Abstract Municipal Solid waste (MSW) is a rapidly growing issue in the world of today along with countless number of other issues as well in all grounds. The trend of urbanization, growth of industrialization, advancements in technology etc. seen in urban areas of the world are some of the perks that attract the population towards living an urban life for more income, better comfort and improved lifestyles. But the same has led to a number of issues over the years as well, including a very high generation rate of MSW (with varied compositions) due to certain and ever-growing urban lifestyles and also ever-increasing demands of the population to adjust to the modern way of living. Today, these generation rates have reached such high levels that proper and effective management has become a huge challenge for the urban areas of the world. The developing nations of the world like India are suffering quite a lot due to it compared to certain developed nations despite generating comparatively lesser amounts of MSW, reasons being both economical as well as various social grounds too. An effort to describe MSW along with its generation and composition figures in various parts of the world has been made through this paper keeping a primary focus towards India. Studies have also been made about the various impacts MSW could have towards people, other living beings and also the environment along with the means for its management. Different steps like: waste segregation, collection, transportation, recycling, treatment and disposal are involved in the process of MSW management and the same needs to be executed effectively in order to call the MSW management which has been or is being performed as a proper one. But doing so is easier said than done as various challenges are faced along the way towards MSW management of an area/city/country. Several factors may be responsible for it ranging from economic, political and even social, all of which have been discussed by means

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of this review work. Once again, special attention has been given towards the nation of India while doing the same.

Keywords Municipal solid waste (MSW) · MSW management · Urbanization · Generation and composition

1 Introduction

The wastes which are generally solid in nature and generated as a result of certain deeds of human beings and also animals could be termed as Municipal Solid Wastes (MSW). They are usually regarded as futile and having no purpose in daily life [13]. Various terms like "trash" or "garbage" are seen to be in common use to denote Municipal Solid Waste which might include even several categories of waste products ranging from durable, non-durable, packaging and other household or even office refuses. MSW could also range from the refuse generated by various household jobs to certain industrial/manufacturing ventures. Some examples are: plastic cups/plates, wrappers, food wastes etc. while other types like industrial, constructional or toxic wastes do not fall under this category [1, 18]. The rise of industrialization has been a major reason for the increase in the solid waste amounts in developing countries like India [38]. Vast rise in industrialization has led to the movement of more and more of the population from rural to urban areas thus leading to the increase in the amounts of MSW which is produced and the same is expected in the future as well [8, 9, 12, 92, 22]. The amounts of solid wastes produced in China has increased due to rise in population over the decades and also due to its economic development as a result. The rise in the amounts of solid wastes produced hasn't been observed in any other nation such as in China [7, 32, 48].

According to Hoornweg and Bhada-Tata [49], urbanized areas of the world generate as much as over a billion tonnes of MSW annually with that figure predicted to rise up to over 2.2 billion by the year 2025 with no signs of lowering down anytime soon. Such kind of results are not just adversely affecting the lands and water bodies by causing pollution, but certain other aspects as well. Methane gas could be produced in higher fractions from solid waste products with is a Green House Gas thus resulting in air pollution and a contributor towards global warming as well. Along with that, un-managed or poorly managed MSW could lead to issues like floods in the cities, adverse health effects such as dengue, diarrhoea, respiratory issues etc. According to [10, 74, 77, 119, 125], the issues related to management of MSW in developing countries are enhanced by factors like extreme rates of generation which is a resultant of sharp increases in population and the preferred practice of urban dwelling by people in today's world. Along with that, lack of education and poor economic conditions leading to insufficient financial aid towards waste management also act as contributing factors for the same.

The generated solid wastes in households could vary up to nine different types with food/vegetable wastes being the most common and highest generated category

and that a number of issues could be faced in proper management of the same by the municipal corporations who bear the responsibility of MSW management in urban cities. This is a common issue in highly populated developing countries [104]. The biggest issue related to MSW management in developing nations is lack of proper means for treatment and discarding of the gigantic amounts of solid wastes that are produced in their urban areas. Along with that, lack of ample facilities for collection and means of transportation of the wastes further adds to the already existing issues. As a result of all, the management and discarding of the wastes is done in various unscientific or rather absurd manners which in turn affects the health and well-being of residents of the city and also its surrounding environment [44, 59, 62, 87]. The above-mentioned issues are the prime reasons for the designing of a proper waste management system in developing nations to satisfy both economy and environment being an extremely challenging job [3].

2 Review of Literature

Sharholy et al. [96], have highlighted how generation of municipal solid waste in developing countries like India is rapidly increasing stating various reasons behind it. It has also been claimed that such wastes can adversely affect human health if not managed effectively and doing so by various irrational means like dumping in open grounds surrounding public areas. It has also been claimed that as much as 90% wastes are being managed by such manners adversely affecting human health. Various treatment and disposal methods of MSW have been discussed while also throwing light on waste management rules existent in India. Suggestions on spreading awareness among general public encouraging participation on MSW management via NGOs have also been made. Shekdar [98], has primarily focus his study about waste management in Asian countries arguing that the various approaches made towards management of MSW should be adaptable with the surroundings or environment in which they are performed as different areas with different conditions require different management techniques. Various situations have been analysed throughout the study to know the reasons for high waste generation rates in Asian countries which are quite complex and varying in terms of culture. Finally, discussions on various integrated approach methods have been discussed which could be followed by all Asian countries in order to achieve sustainable solid waste management while also pointing towards the importance of "sustainable development".

Imam et al. [54], focussed on the study in management of solid waste in the city of Abuja, Nigeria. Rates of waste generation, its increase and the problems arising due to it in the entire nation of Nigeria with prime focus on Abuja have been discussed along with the means of managing wastes that are followed. Finally, it has been argued that improvements are required in the fields of waste management also suggesting that developing certain management techniques like waste composting plants (small-scale) could also turn out to be a means of employment and a source of income for the public. Zhang et al. [126], made a review study on the management of MSW in

the largest population of the world China having put forward generation rates and composition of wastes that are seen in China. Along with that, the various methods for management of MSW in the nation and issues in the management processes have also been discussed. At last, certain ways or methods have also been studied and put forward about potential opportunities of future improvemens in the management of MSW in China.

Minghua et al. [70], have also made a study on solid waste management methods followed in China with prime focus on the "Pudong New Area". The different solid waste management techniques followed in Pudong have been discussed in a very detailed manner with special attention towards the collection, transportation and treatment techniques of the generated waste. It was brought into light that a geographic information system (GIS) was also in place in the waste management system of Pudong. This provided easier access of routes for trucks and helped reduce fuel consumption. A prominent focus upon the separation of source of the wastes to reduce the requirement for its disposal and also the need to utilize more and more of recycled items have been recommended. Wilson et al. [124], analysed the management of waste in 20 different cities from varied continents all around the world and made a comparative study by means of integrated and sustainable waste management (ISWM). Comparative study about the area, population and its growth rate etc. of the 20 cities along with population size, GNI per capita etc. of the respective countries to which they belonged was done thus recognizing the respective income levels of the different cities (categorized as: High, Upper-middle, Lower-middle and Low). Per capita waste generation and also its composition were calculated based on the income levels. Certain major indicators or dimensions were made use to carry out the comparative study of waste management and hence concluding that a certain type of management system doesn't work for all and that the prime strength is the usage of diverse methods.

Tanskanen [106], discussed the concept of integrated municipal solid waste management (MSWM) by usage of computer-based model designed for the Helsinki Metropolitan Area (HMA) with the goal of designing strategies for waste separation to achieve the intended recovery rate of municipal solid waste that was in place for the country of Finland. The developed HMA model, consisting of different stages (six to be precise) and certain formulas to calculate various components, proved to be fruitful in achieving the intended goals, thus qualifying to be an ideal tool for the integrated municipal solid waste management planning strategies. Demirer et al. (2005), performed a case study about the life cycle assessment of municipal solid waste management in the Turkish capital of Ankara by means of integrated waste management (IWM) model. Certain scenarios were under consideration in the course of study and the various types of wastes produced as well as the amounts of waste managed in different scenarios were compared. This helped attain the most suitable system for MSW in the city of Ankara in terms of its effect towards the environment.

3 MSW Generation and Composition: A Global Scenario

According to Guerrero et al. [43], the management of solid wastes in urban areas is a great challenge for officials responsible for its management in city areas of developing countries due to various reasons such as: increment in waste generation, lower capital available with the authorities and complexity in the processes involved in waste management, improper knowledge and understanding of factors which can affect the waste management process etc. A study depicting the GDP and solid wastes produced from certain cities of various countries along with its area of origin was presented and is shown in Table 1.

In 2015, the total population of the earth was predicted to be about 7.3 billion out of which the total strength that resided in urban areas was calculated to be around 49% [112]. Due to this, the exact amounts of MSW produced globally is very complicated to be known precisely. According to World Bank data [61], in the year 2016 the amount of MSW that was produced globally ranged to accounted for around 2 billion tonnes. Most of that generated waste (about 33%) was managed in an unsuitable manner which affected both people and environment. Around 115 tonnes of organic waste are produced by just 37 megacities in the world every year. Urban areas of the world play vital roles in both the development as well as production of maximum amounts of MSW all over the world. An estimate of total waste generation performed by World Bank is shown in Figs. 1a–b and 2.

In Canada, the households were reported to generate around 12.9 million tonnes of MSW in the year of 2008, out of which about 8.5 million tonnes were sent for disposal while the remaining 4.4 million tonnes were recycled. Due to this, the disposal rate of MSW reduced by 4% between the years of 2006–2008 [72]. The total amount of MSW produced in USA amounted to about 238 million tonnes accounting for about 2.02 kg per capita/day in the year 2015. Out of this, about 28% of the waste produced was organic forms of waste [89]. According to a US-EPA report (EPA 2021), the total MSW generation in USA increased to 292.4 million tonnes in 2018 or the per capita produce increasing to 2.2 kg/day. 69 million tonnes of waste out of this were sent for recycle process. Like other areas of the world, the MSW generated in USA came in varied compositions of different products or items. The MSW which was generated with varied compositions in the year 2018 has been shown in Fig. 3. The European Union has 27 member nations generating wastes of different forms and in different quantities based on varied factors like total consumption by its population and also the economic conditions of the different nations. It could also depend upon the ways in which waste collection and management is done. Based on such factors the MSW produced vary in amounts such as 280 kg per capita in the nation of Romania while countries like Denmark producing up to 844 kg per capita in the year 2019 [35]. Figure 4 shows the total MSW generated in different nations of the European Union as well as comparisons between the difference in amounts produced in 2005 and 2019.

The total generated waste in Australia between 2016 and 2017 amounted to be around 67 million tonnes out of which 54 million tonnes accounted for core waste.

Table 1 Waste generation rate and area of origin in various cities with the numbers indicating different areas as follows: 1: household, 2: offices, schools, 3: construction, 4: health care, 5: agriculture, 6: industry and 7: shops

Continent	Country	GDP (In US Dollars)	Year of study	City	Waste origin arriving at the official disposal site	Waste generation rate (kg/capita/day)
Africa	Ethiopia	344	2009	Adis Ababa	1,2,4,6,7	0.32
	Kenya	738	2009	Nakuru	1,2,3,4,5,6,7	0.50
	Malawi	326	2009	Lilongwe	1	0.50
	South Africa	5786	2009	Pretoria	1,2,3,4,7	0.65
	South Africa	5786	2009	Langeberg	1,3,4,5,6,7	0.65
	South Africa	5786	2009	Emfuleni	1,3,6	0.60
	Tanzania	509	2010	Dar es Salam	1,2,4,5,6,7	0.50
	Zambia	985	2010	Lusaka	1,2,3,4,6,7	0.37
Asia	Bangladesh	551	2007, 2008, 2009	Gazipur	1,4	0.25
	Bhutan	1805	2010	Thimphu	1,2,3,7	0.54
	China	3744	2010	Beijing	1,3,4,7	0.80
	India	9232	2010	Doddaballapur	1,2,3,6,7	0.28
	Indonesia	2349	2009, 2010	Banda Aceh	1,4	0.90
	Indonesia	2349	2009, 2010	Ambon	1,4	0.90
	Indonesia	2349	2010	Jogjakarta	1,2,5,7	0.90
	Nepal	364	2007	Kathmandu	1,2,6,7	0.35
	Pakistan	495	1995	Lahore	1,2,6,7	0.84
	Philippines	1995	2009	Quezon City	1,2,3,4,7	0.67
	Sri Lanka	2068	2010	Balangoda	1,2,3,4,6,7	0.83
	Sri Lanka	2068	2010	Hambantota	1,2,3,4,7	0.81
	Thailand	4043	2009, 2010	Bangkok	1,2,3,4,6,7	1.10
	Turkey	8215	2010	Kutahya	1,2,4,6,7	0.60
	Turkey	8215	2010	Bitlis	1,2,3,4,5,6,7	0.90
	Turkey	8215	2010	Amasya	1,2,4,7	1.20
Central & South America	Costa Rica	4084	1985, 1995	Cartago	1,2,3,4,5,7	0.7–0.8
	Costa Rica	6386	2011	San Jose	1,2,3,4,6,7	1.10
	Costa Rica	3370	1991	Talamanca	1,7	0.30
	Costa Rica	4084	1992, 1995	Tarcoles	1,7	0.30–0.50
	Costa Rica	5529	2001	Tuis	1,7	0.30

(continued)

Table 1 (continued)

Continent	Country	GDP (In US Dollars)	Year of study	City	Waste origin arriving at the official disposal site	Waste generation rate (kg/capita/day)
	Ecuador	1771	1995	Pillaro	1,7	0.50
	Ecuador	1771	1995	El Carmen de los Colorados	1,7	0.50
	Nicaragua	1069	2008, 2009, 2010	Managua	1,2,3,4,5,6,7	0.48
	Nicaragua	1069	2009, 2010	Masaya	1,2,4,7	0.40
	Peru	4447	2008, 2009, 2010	Canete	1,2,3,4,5,6,7	0.47
	Suriname	5888	2008, 2009	Paramaribo	1,7	0.47
	Suriname	5888	2008	Asidonhopo	–	0.28

Source Guerrero et al. [43]

Out of that total amount of core waste, about 13.8 of municipal solid waste was produced from different areas in different parts of the country. This amounted for around 560 kg per capita of waste which was generated (Grant et al. 2018). A sharp increase of 145% in waste generation rate has been observed in Australia between the years of 1997 to 2012 which was much higher than the rate of population increase [6].

4 Waste Generation in India

The urban dwelling population of India is in the range of over 370 million which accounts for over 31% of the total population of the country that was estimated to be about 1.2 billion [17]. With a population strength accounting for 18% of the total population of the entire world, India is predicted to overcome China in becoming the most populated nation in the world by 2022 and by 2050, the figures predicted to be as high as 1.6 billion [81]. India being second largest populated nation of the world and with an ever-increasing population has seen an increase in the rates of MSW generation in recent years. An estimated generation of over 147,000 metric tonnes (MT) of MSW was calculated from over 84,000 wards in January of 2020 by India. The figures for MSW generation by India are predicted to increase for in future as: 276,342 tonnes per day (in 2021); 450,132 tonnes per day (in 2031); 1,195,000 tonnes per day (in 2050). An increase of 1.3% has been observed in the per capita waste

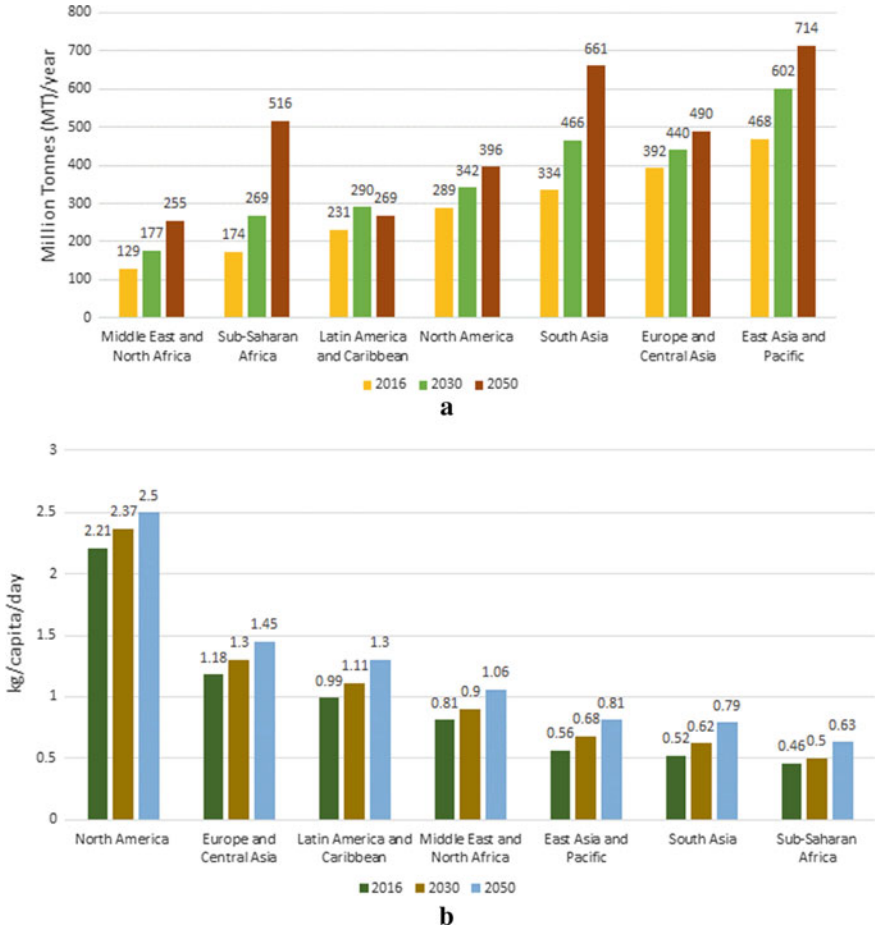

Fig. 1 **a** Global waste generation figures. (*Source* Kaza et al.[61]), **b** Global Waste Generation per capita figures. (*Source* Kaza et al. [61])

generation ate in India per annum [100]. Waste Generation in India was estimated as 100,000 MT for the year 2000 as per the Ministry of Urban Development. Survey conducted by the Central Pollution Control Board over the period of 1999 to 2016 in various parts of India has shown the amounts of waste which was generated by various cities/urban areas of the country, some of which has been provided in Table 2 [20] (Fig. 5).

The MSW that is generated from a particular city, state or even area can be linked with its population. In India, the Northern portion has been found to contribute the most (around 30%) whereas the Eastern portion has been found to contribute the least (around 17%) of MSW generated in the entire country with figures of its components varying with different classes of cities [5].

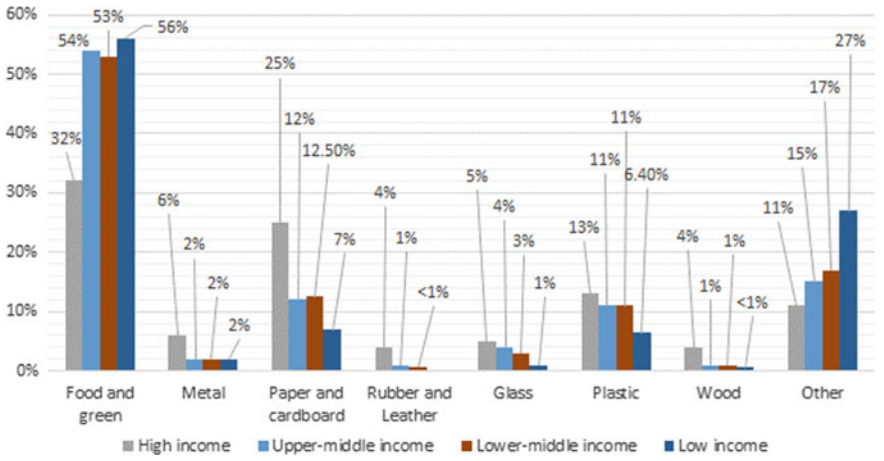

Fig. 2 Compositions of Waste in different income categories. (*Source* Kaza et al. [61])

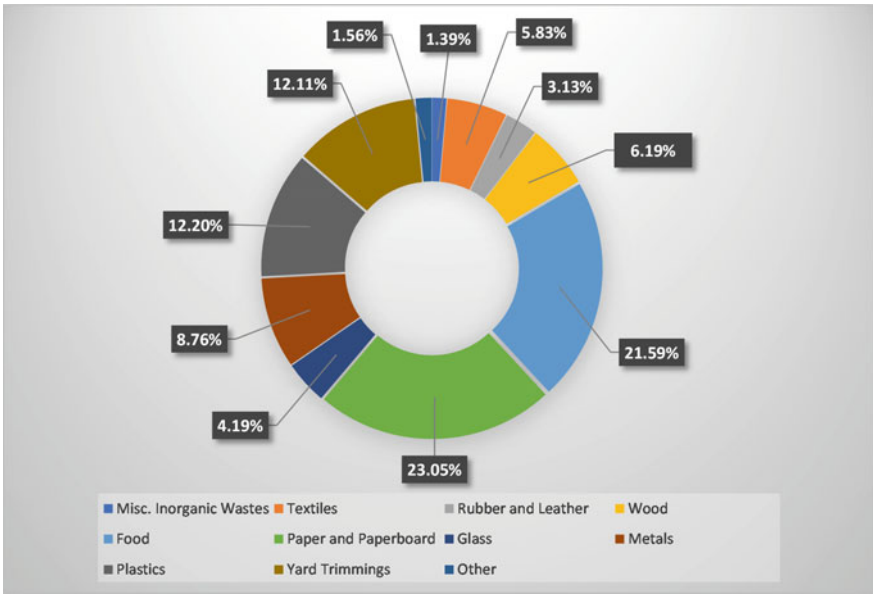

Fig. 3 MSW Generated in 2018 by USA with varied compositions. (*Source of data* EPA 2021)

The solid wastes containing organic fragments that could be decomposed via microorganisms can be termed as compostable wastes [94]. A recycling process is one where previously utilized material (waste products) could be processed into newer products considering that the life cycle of the material does not get aborted

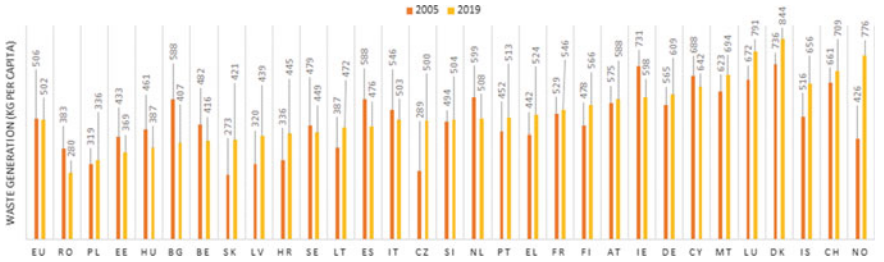

Fig. 4 MSW generated in European Union Nations. (*Source* Eurostat [35])

Table 2 Waste generation in 11 most populated cities of India

City	Population (as of 2011)	Waste generation			
		1999–00 (TPD)	2004–05 (TPD)	2010–11 (TPD)	2015–16 (TPD)
Mumbai	12,442,373	5355	5320	6500	11,000
Delhi	11,034,555	400	5922	6800	8700
Bangalore	8,443,675	200	1669	3700	3700
Chennai	7,088,000	3124	3036	4500	5000
Hyderabad	6,731,790	1566	2187	4200	4000
Ahmedabad	5,577,940	1683	1302	2300	2500
Kolkata	4,496,694	3692	2653	3670	4000
Surat	4,467,797	900	1000	1200	1680
Pune	3,124,458	700	1175	1300	1600
Jaipur	3,046,163	580	904	310	1000
Lucknow	2,817,105	1010	475	1200	1200

Source of data CPCB [20]

upon consumption and such wastes could be termed as recyclable wastes (Ramos et al. 2013) (Figs. 6, 7, 8 and 9).

The total generation of MSW in the city of Pune is estimated to be about 1600 MT per day which could be categorized into certain types but broadly as biodegradable and non-biodegradable waste as shown in Table 4 [101]. The average figures of MSW generation of the country are around 450 gms/per capita/day compared to over 1 kg/per capita/day generated by many developed nations. The waste generated by India also has the capability of being a potential source of (electrical) energy with potential up to 500 megawatts (MW) of electricity generation which is predicted to keep increasing in the future [110] (Fig. 10).

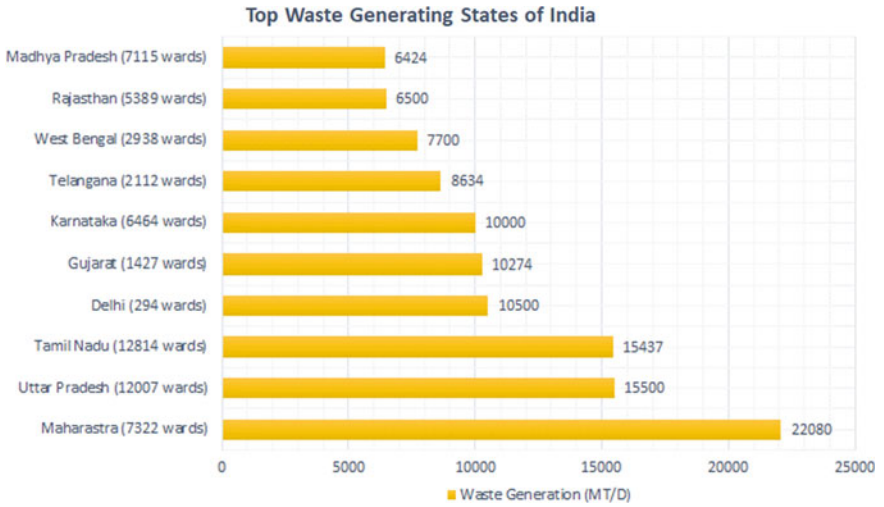

Fig. 5 Top 10 most waste generating states of India [here, MT = Metric tonnes]. (*Source of data*: [100])

Table 3 MSW components with compositions in different classes of cities

City or Region	MSW (TPD)	Compostables (%)	Recyclables (%)	Inerts (%)	Moisture (%)	Cal. Value (MJ/kg)	Cal. Value (kcal/kg)
Metros	51,402	50.89	16.28	32.82	46	6.4	1,523
Other cities	2,723	51.91	19.23	28.86	49	8.7	2,084
East India	380	50.41	21.44	28.15	46	9.8	2,341
North India	6,835	52.38	16.78	30.85	49	6.8	1,623
South India	2,343	53.41	17.02	29.57	51	7.6	1,827
West India	380	50.41	21.44	28.15	46	9.8	2,341
Overall Urban India	130,000	51.3	17.48	31.21	47	7.3	1,751

Source Annepu [5]

5 Impact of Municipal Solid Waste Generated

So far, details on the enormous amounts of solid wastes that are generated or were generated at certain periods of time has been observed. Such amounts of solid waste

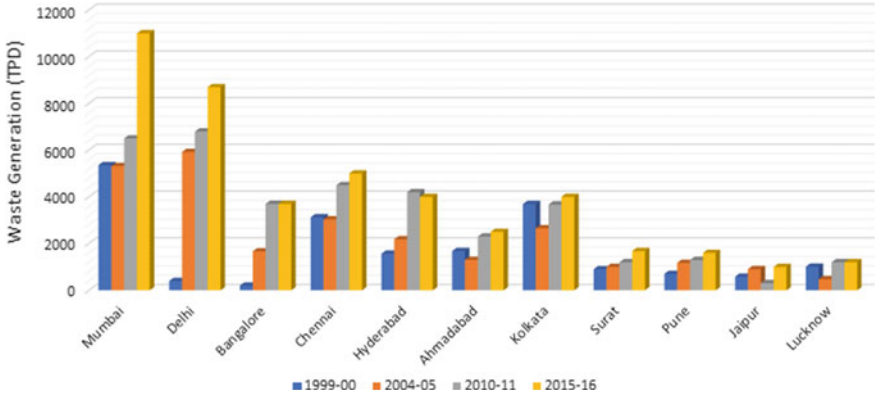

Fig. 6 Comparison of total waste generated over different time periods in the top 11 most populated cities in India (as per Table 2)

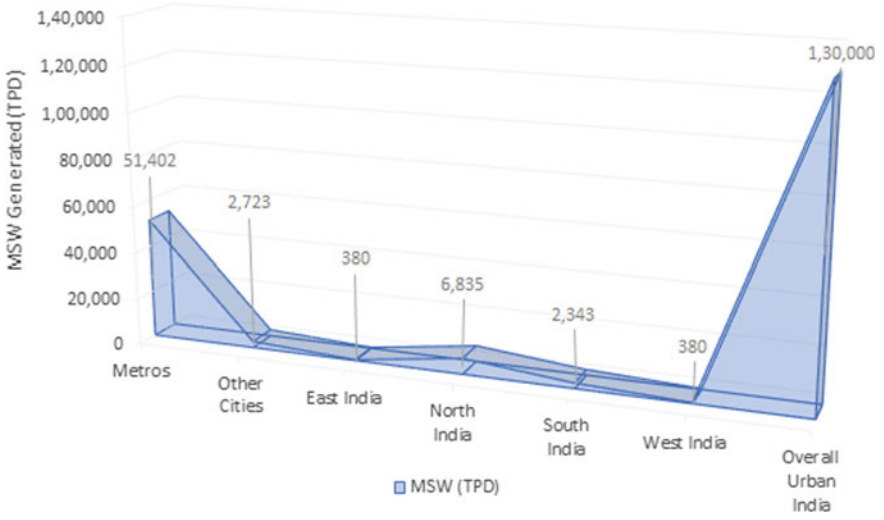

Fig. 7 Comparison of MSW generated in different classes of cities (as per Table 3)

could bring about adverse effects to the public, the surroundings as well as atmosphere if not fruitfully and efficiently managed. Effects of MSW could be varied and may depend mostly on the amounts generated and also how it is managed or what techniques are being utilized for its management. The study put forward by Vergara and Tchobanoglous [118] lists the major impacts that solid waste could have as follows:

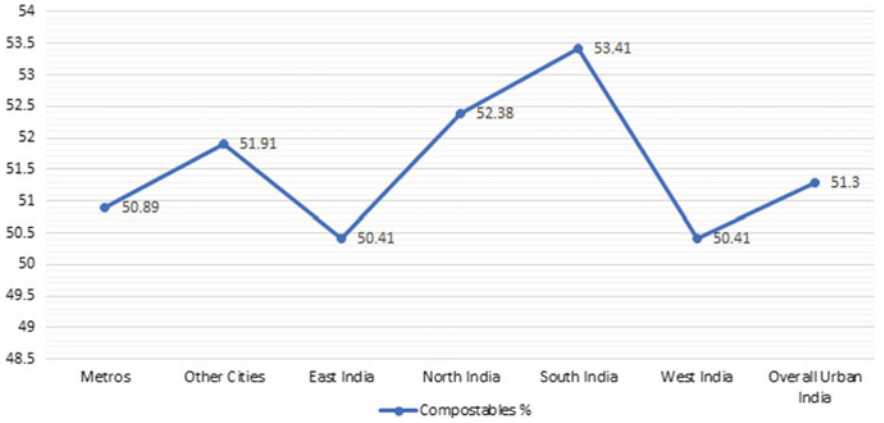

Fig. 8 Comparison of % compostables in different classes of cities (as per Table 3)

Fig. 9 Comparison of % recyclables in different classes of cities (as per Table 3)

Table 4 Types of MSW generated in Pune city

Biodegradable waste (720 MT/D)	Non-biodegradable waste (880 MT/D)
Organic waste-400 MT	Inorganic waste-560 MT
Household waste-320 MT	Inert waste–320 MT

Source Soni et al. [101]

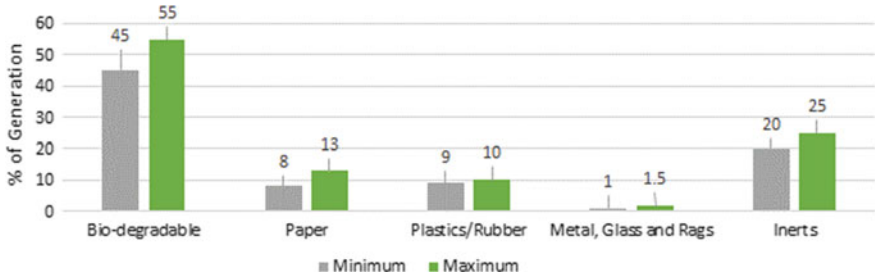

Fig. 10 Comparison of generated MSW compositions in India (as per Table 5)

Table 5 Composition of MSW generated in India

Type of waste generated	% of Generation
Bio-degradable	45–55
Paper	8–13
Plastics/Rubber	9–10
Metal, glass and rags	1–1.5
Inerts	20–25

Source of data Tripathy [110]

5.1 Pollutant Emission to the Environment

Pollutants of varying sizes, properties, types and proportions could get released into the environment and adversely affect its various components like air, water bodies or land leading to their pollution if the generated MSW is not effectively managed. Sometimes certain management techniques could also result in release of pollutants. According to Cheng et al. [23], the burning of MSW in the open could be hazardous and release gaseous pollutants like CO, CO_2, SO_2 etc. into the atmosphere. According to Bahukhandi and Aaron [8], generation of MSW in very high rates along with its poor management has led to pollution of underground water which is a major source for drinking purposes for large sections of population in the country of India. An increase in amounts of TDS, SO_4, NO_3, total hardness etc. of water beyond permissible limits has been an outcome for the same reasons.

5.2 Climate Change and Rise in Average Temperature

Improperly managed solid waste could be a source of Green House Gases (GHGs) which could get released into the air and could be a prime factor leading up to possible climate change although not at a rapid pace [15]. Climate change could lead to issues like increment in the average temperatures, rise in sea level, global warming, glacier melting, harsh weather conditions etc. thus affecting humans as well as the nature

[53]. Decrease in GHG emissions, which can aid in avoiding the above conditions, can be achieved either by reduction in the generation of waste or by practicing better management methods such as recycling [25].

5.3 Adverse Effect on Public Health

Improperly managed waste could affect human/public health in different ways. The prime reasons behind this include attraction of disease spreading vectors due to its mass accumulation, blockage of drainage systems serving as habitat for those vectors etc. [52]. Sometimes even waste management techniques could end up affecting the health of the public, such as birth defects observed in people with work or habitat near landfills, respiratory issues observed in people living or inhaling the air in the proximity of composting zones etc. [39]. It has been observed that the economically weaker sections of the society are affected more by wastes as they reside in close proximities to the waste dumping areas or disposal grounds. Along with them, waste workers also remain at high risk of getting affected by the ill-effects of solid waste generated [111]. The unethical export activity of certain toxic wastes to another country or region also puts their population at greater risks to face its ill-effects [24, 95, 122].

5.4 Adverse Effect on Ecological Health

The management and disposal of waste acts as a kind of alteration in the use of a particular land or zone which in turn could remould the livelihood/dwellings of certain species belonging to that zone. Exposure to hazardous wastes cause ill-effects on plants, animals and also water bodies like oceans upon direct release to the environment [118]. MSW like plastics get released into the ocean bodies in the range of "millions of tons" which has resulted in the ratio between plastic and other marine wastes to be around 6:1 [42], Moore et al. [71]. Plastic wastes have showcased its effects on about 267 kinds of species who get affected by either its consumption or entanglement by it, thus leading to health issues and fatal conditions of the species [31, 42]. Plastics can also serve as disease carrying vectors within the food chain as it has the ability for absorption of organic pollutants and harmful toxins [66].

6 Management of Municipal Solid Waste

The management of MSW has been a big issue for almost all parts of the world, be it developed or in a developing stage. Improper handling or management of solid wastes has proved to be one of the chief sources of causing adverse effects on human

health while also affecting the environment by polluting the air, water bodies and also bringing about climatic changes by causing overall rise of average Earth temperature thus leading towards global warming as discussed previously. This makes proper and effective management of MSW a necessity in the world of today. According to Rajput et al. [83], the figures of collection of generated wastes in many major cities of the world being performed effectively is as low as 25–55% with about 60% of the of the world's nations facing major issue related to environmental due to inefficient management and disposal of waste.

The practice of control over the generation of waste along with its storage, collection, transportation and discarding can be termed as solid waste management. Meanwhile reducing the overall amount of waste generation by virtue of re-using or recycling of goods could be termed as waste minimization [108]. Pollution of the environment is a possibility if any of those factors aren't performed effectively [65]. Ensuring proper health conditions of the general public, especially the poorer sections of the society is the primary focus of Municipal Solid Waste Management (MSWM). Along with that, maintenance of proper environmental conditions, economic stability, overall sustainability, efficient productivity as well as generation of employment are also some of major goals which are aims by MSWM and could only be achieved by the virtue of practicing proper and effective systems for MSWM [93]. History has been evidence of waste management being an engineering function. Advancement in technology in the modern society has led to amounts of solid waste generation reach big figures thus making MSWM the need of the hour [107].

There are quite a lot of differences observed between the developing and developed countries of the world when it comes to waste management. This difference could also be observed in regards to management in urban or rural areas or whether the area of generation is residential or an industrial one [28]. A waste management process is hugely influenced by the composition of waste that is being generated, which also differs largely according to income levels of the population. MSW such as paper, glass, plastics etc. are generated in more amounts among the communities with higher income as usage of packaged items are more common in those areas [102]. According to Joshi and Ahmed [57], waste management practice in India has always faced various issues with urban local bodies not taking necessary steps towards its proper implementation and also due to inefficiencies observed in other grounds like collection and processing of wastes as well. In order for a successful MSWM programme to take place, the following practices with solid wastes are compulsory to be performed in an efficient manner:

- Segregation
- Collection
- Recycle/Reuse
- Disposal

6.1 Segregation of MSW

Waste segregation could be described as source separation and is generally the method of separating items which could prove to be of some utility from the MSW which has been generated. This method could prove beneficial in many ways such as reducing the overall amounts of waste which would require further management thus saving time and energy during the waste management process. Segregation also helps keep the environment clean thereby also aiding towards well-being of the public health conditions [68]. The cost as well as complications in waste management could be reduced to a greater extent by the segregation process [37]. Segregation also acts as an important agent for the recycling process. Waste management is improved by a large scale if various items amidst the generated MSW could be treated as resources with economic values and be re-utilized for other activities while ensuring that sustainability is being maintained in the process [115].

Inappropriate, low scale or even absence in the practice of source segregation process is a prime reason for the various issues which are observed in many developing Asian countries like India, Bangladesh, Sri Lanka, Malaysia etc. during the practice of MSW management. Another issue is the loss of ability of a lot of generated wastes to be re-utilized the reason being it getting mixed with certain other hazardous wastes [46]. While carrying out segregation in countries like India, no scientific method is technique is generally observed at any level. Also, the conditions under which it takes place has been observed to be unhygienic for human health and the overall process hasn't proven to be very much fruitful due to it not being performed by experts and thus only items with visible economic value in the market being segregated [60].

6.2 Collection and Transportation of MSW

Waste collection which could be the first step towards management is performed via diverse means by different nations considering various factors with health concerns of public, economic issues, political conditions etc. being some of them. Generated waste could present adverse effects towards health and nature on the basis of the way it has been stored, handled, collection or managed [121]. The process of waste collection could end up being the largest cut out of the total expenditure bill of the entire MSW management process. This is usually the case in city/urban dwellings with to the large concentrations of the generated waste. Quite a few nations in Asia still struggle for possession of effective and efficient waste collection systems [120]. The methods of waste collection observed in European nations could be termed as perfect due to the diverse methods being utilized as well the effectiveness in collection of MSW in fractions [34]. In certain huge and developed cities of Latin America and the Caribbean regions waste collection methods observed have also been satisfactory even though there exist various cities that struggle to do the same [113].

According to Olukanni et al. [78], various challenges are encountered during waste collection process in various nations of the African continent owing to certain factors like insufficient capital for proper techniques to be practised, low knowledge of the general population about threats posed by untreated waste etc. The major waste collection methods described in the study are:

- Mode of Operation based waste collection: The major systems discussed under this category include:
  - Haul container system
  - Stationary container system
- Type of Waste based waste collection: Here, the systems of collection described are:
  - Collection of unseparated waste
  - Collection of separated waste

According to Hui et al. [51], a fruitful way to attain "Integrated Solid Waste Management (ISWM)" is the source separation of the MSW which is collected, but is not at practice in Chongqing, China. The major collection mechanisms of MSW in practice at Chongqing are said to be the following:

- Wastes by residential areas: Household wastes are collected in all towns/villages in dumping vessels which is transferred to waste collection stations. The Chongqing Municipal Administration Commission's (CMAC) department of Environmental Sanitary Protection takes on the responsibility to further transport it to waste treating zones.
- Wastes by institutions: The particular institution generating the waste is held responsible its transfer to treatment zones for which private parties could be hired by them as well.
- Wastes by Commercial areas: Here the job is mainly carried out by the management office of that commercial area who transfers the generated waste to treatment sites.
- Wastes by cleaners of public places: In this case well, CMAC is held responsible for the waste generated to be transferred to treating locations.
- Wastes by construction sites: The organization whose construction activity is in progress is given the responsibility of transferring non-recyclable wastes to treatment zones generally without involvement of a third party.

According to Jin et al. [55], the responsibility for the collection of generated MSW in Macao lies on the shoulders of the Government who in turn had appointed privately owned waste service company (WSC) for the same purpose from the year 1992. The activities like collection of wastes generated in households, various institutions, industries, commercial areas etc. and its transportation is carried out by the WSC. A total of 380 appointed staff members, 25 waste collection trucks, 4 high pressure water jet vehicles and 6 sweeping vehicles are under the possession of WSC who

utilizing the same collects about 500 tpd of solid waste. The Port Authority of the SAR Government of Macao are the ones responsible for removal of refuse in water bodies of Macao.

According to Nandan et al. [73], the responsibility of collection of generated waste in India is to be taken up by the Government's Municipality Department. Collection of waste from different households has to be performed by the Municipal Authority by virtue of:

- Collection of MSW in Community containers
- Household to household collection
- Waste collection in regular intervals
- Provision of collecting vehicles with ringing bells to alert the public

The collected waste is then transferred into treatment zones in time intervals of generally two times in a week.

Community vessels constructed out of different materials ranging from concrete, metals etc. act as collection means for wastes which is generated from different households in a city/town/area. Along with that, wastes generated from industries, commercial areas, roadside garbage etc. also makes its way into these community waste collecting containers/vessels with the exception of any organization/body who may make payments to municipal authorities for transferring the generated waste directly from their premises to treatment zones [64].

Gonzàlez-Torre et al. [41], have discussed about the various types of container systems that could be utilized for collection of MSW in urban cities. Some of them are:

- *Household Containers:* Comprises of plastic vessels received by families for collecting wastes. Each household may receive a single container to store all wastes or multiple colour coded ones to store wastes of different compositions accordingly which later helps in easier to sort up the waste.
- *Neighbourhood Containers:* A common vessel/storage container for a group of people to collect all their generated waste together. Generally seen in flats/apartments.
- *Zone Containers:* Larger sized collection containers placed in particular areas outside one's premises to collect waste generated by a number of societies or neighbourhoods of people and could be easily collected again by waste collecting vehicles who transfers it to appropriate locations.

6.3 Recycling of MSW

The process by virtue of which goods discarded off as refuse or waste is remodelled or re-utilized for other purposes is termed as recycling. Examples include: paper recycling to avoid cutting down of trees, reduction in mining jobs by re-utilization of refused metals etc. [80]. Recycling could be achieved through different means, either by reusing a refused item for the same or some different purpose and also

by re-modelling the wastes generated into other products, like composting [47]. In recent times, a "throwaway mentality" has been instilled in the minds of the society with the advancements in the fields of industrialization and progress in economic grounds as well. Recycling process has also become complicated and got limited to just industrial wastes [11]. The increased usage of plastics in the world of today has become a big issue due to it being a chief source of non-biodegradable waste. The cities with very high plastic (single-use) waste generation figures face problems like floods as a result of drainage systems getting choked and pollution of marine bodies [4].

Carrying out recycling process by virtue of mechanical means may be reasonable for some certain wastes such as bioplastic polymers like PLA but it could become less efficient due to limited supply of such polymers in required amounts [27]. The barrier properties of various biopolymers may require to be intensified for usage in certain areas such as packaging of food items, multilayer lamination etc [69]. Countries like India are coming up in the face of the world as to having one of the most prominent markets in the sector of waste recycling but still it is not being performed up to satisfiable levels [14]. In the Indian city of Pondicherry, a lot of the recycling activities are performed by waste/rag-pickers who separate useful goods like glass, metals, plastics etc. from the refuse collected from community containers and makes an earning out of it [82].

6.4 Treatment and Disposal of MSW

The disposal process could also be termed as the final step towards the completion of an MSW management process. It could be the biggest decisive factor of how successful or efficient the solid waste management performance of a country, city or even area has been which could also have an influence on the public health, environmental conditions etc. of the particular place. According to Hamer [45], waste disposal has an inevitable relation with pollution. Since waste is referred as unnecessary remnants with adversely affecting characteristics and on the other hand, pollution can be termed as the introduction of objects that could adversely affect the environment, hence disposal of waste is seemed to always have some kind of pollution associated with it. According to Williams [123], effective waste treatment and proper disposal became a necessity with the rise of urbanization and increasing communities of people in city areas, which has led to higher waste generation rates and quantities which turned into a serious issue with passing time.

The disposal of solid wastes into open grounds by virtue of irrational practices is very commonly seen in India without any proper management methods being followed which as a reuslt has displayed many adverse effects on both public and environment [20]. Methane gas in the range of around 48% is emitted from the waste dumping grounds of just about seven megacities of India due to ineffective waste management techniques that are practiced [67, 86]. Therefore, it has become the need of the hour to practice some scientific and efficient waste management techniques

so that adverse effects as such could be avoided for the present as well as future generations. Some of the commonly followed methods for achieving proper waste management are as follows.

6.5 *Landfilling*

Landfilling can be simply defined as the deposition of the generated waste on earth (land). It is known by different terms that are used to denote this practice in different parts of the world such as "sanitary landfill" in USA, "controlled tipping" in the United Kingdom but "dumps" in the whole world as common [29]. It could also be described as the waste disposal by means of stuffing it (under pressure) in selected sites or area of land. This is a commonly practiced waste management method in many nations of the world owing to the convenience it offers from a financial point of view. For this reason, landfilling practices for MSWM is very common in developing nations [36, 40, 58, 117], made a study on landfilling practices in many different parts of the world for MSWM and the acquired data has been provided in Table 6.

Landfilling is a common practice for MSWM in many urban areas of India but is also facing issues at the same time due to unavailability of large areas of land required for it to be performed in many major cities [96]. As many as 59 sites for landfill practices have been developed in India with plans of further 1305 more such areas in sight for development in the near future. Many landfilling zones have been either constructed or the pre-existing ones were increased in size in many major states in India such as: Delhi, Maharashtra, Andhra Pradesh, Madhya Pradesh, Punjab etc [21].

Although landfilling process for MSWM seems a very efficient method especially for developing nations, improper practice of the same could lead to adverse effects on both people and environment. According to Vallero et al. [116], there exists a fine line between landfilling and dumping with the latter being a practice of depositing the solid waste without providing a separation from the underlying rock beds and also where excavations made for landfills reach beyond groundwater levels which

Table 6 Disposal of municipal waste by different countries by landfilling method

Country	% MSW managed by landfilling (%)
USA	52.6
Brazil	59.1
Saudi Arabia	85
Malaysia	94.5
China	79
Venezuela	32
Mexico	65
Thailand	27

Table 7 Collection, treatment and landfilling amounts in some high solid waste producing states of India

State	Solid waste generated (TPD)	Waste collected (TPD)	Waste treated (TPD)	Waste landfilled (TPD)
Maharashtra	23,844.551	23,675.7	12,623.33	11,052.37
Uttar Pradesh	17,377.3	17,329.4	4615	0
West Bengal	14,613.3	13,064.63	916	334
Tamil Nadu	13,968	13,968	7196	5654
Karnataka	11,958	10,011	4515	–
Telangana	8497	8360	5747	869
Madhya Pradesh	8000	7500	6100	1400
Rajasthan	6625.56	6475.39	780.18	780.18
Punjab	4634.48	4574.93	917.56	3657.37
Kerala	3903.023	742.23	437.74	–

Source of Data CPCB [19]

results in pollution of the groundwater and subsequently causing ill-effects to the health of people who utilize it. Thus, the concept of "sanitary landfilling" is needed to be practiced for efficient management. According to [16, 88], improper landfilling of MSW in India could rate as high as 90% in total. When groundwater zones are invaded by the waste from landfills, leachate is formed as the wastes come into contact with water. They are generally comprised of both organic and inorganic constituents along with certain metallic components as well forming a complex mixture and having potential to adversely affect the public health and environment as well. According to Hudgins [50], performing landfilling on certain types of wastes like bioplastic polymers along with certain organic waste as well could result in methane gas formation under specific conditions which could affect the environment being a greenhouse gas.

But with the practice of correct methods and application of modern technology, such drawbacks could actually be turned into an advantage by converting the produced "landfill gases" into sources of energy. According to Joshi and Ahmed [57], landfill grounds could act as a potential source of energy as methane emitted from those grounds constitute for about 13% of the global methane. Siddiqui and Khan [99], provided data through their study of various amounts of potential energy that could be generated from landfill zones of various cities in India, which is as follows:

Delhi—8.4 Megawatts
Mumbai—5.6 Megawatts
Ahmadabad—1.3 Megawatts
Pune—0.7 Megawatts.

6.6 Incineration

Incineration is a technique to achieve management of MSW via means of thermal treatment. There exists other process like pyrolysis as well under this category [57]. Thermal treatments methods like incineration are used in very limited countries with a reduction in waste volume and volume of leachate formed being some of the major intensions for its applications [91]. Complete elimination of solid waste is not attained by incineration but rather a reduction of it in terms of both weight and volume, thus aiding in the landfilling process. This is a common practice in Europe and helps greatly in two areas of MSWM: i reduction in weight and volume of MSW; ii use of the method as a potential source of energy such as heat by burning of the wastes. Hence it is feasible in areas where huge land areas aren't available for landfilling [85].

One of the major setbacks offered by waste incineration in the country of Japan is the high amounts of residue which is produced as a result and which ends up requiring separate treatment. Such residue is also signified as "air pollution control residue (AR)" and requires certain treatment before landfilling processes could be performed [33]. In the nation of India, incineration of MSW is not often a suitable waste management technique owing to the large amounts of organic natured wastes that is generated in the country. Also, setbacks towards the method are put forward by the high values of moisture content in the generated waste with 800 to 1100 kcal/kg being a common range of its calorific value (Jalan and Srivastava 1995), [103]. Certain high-capacity incineration plants in the country like a one developed in the Tirampur region of Delhi in 1987 resulted in failure due to unavailability of right amounts of MSW with properties suitable for performing incineration [97].

6.7 Biological Treatment

As the name suggests, this is a waste treatment mechanism which is performed by the aid of certain living organisms. This method is generally suited to the treatment of wastes containing greater fractions of organic constituents. According to Hamer [45], for the treatment of biodegradable wastes, biological treatment has long been a suitable method. This method generally is performed by two means namely: Aerobic and anaerobic treatment. Composting of waste is a very widely known and practiced waste treatment method all over the world. According to Bharadwaj et al. [13], composting is a famous treatment technique seen in the UK where annual waste composting figures reach up to 2 MT/year in more than 300 zones for composting activities which have been developed. Composting is more widely observed in developing countries like India where generation of organic wastes is much higher than in developed countries.

6.8 Aerobic Composting

This is the organic solid waste composting method which is performed in the presence of air (oxygen) with under warm conditions. The end product of the process performed is known as compost and is a commodity which is very rich in nutrients (Bhide and Shekdar, 1998). This is a very widely practiced method in India with composting zones for MSW having been setup in many major urban cities of the country like Delhi, Mumbai, Indore, Bengaluru etc. including composting plants of treating capacities reaching up to 300 tonnes per day in many of those cities [97]. One of the most commonly practiced aerobic composting methods is "vermicomposting", where treatment of MSW is carried out with the aid of earthworms that consume the organic fractions from the solid waste and decomposed to form a nutrient rich product via actions of microorganisms. Major vermicomposting plants are also situated in many major urban areas of India [57].

6.9 Anaerobic Composting

Anaerobic composting which is also referred to as "anaerobic digestion" is the treatment/decomposition of organic wastes without the presence of air (oxygen). The magnitudes of required energy levels in this type of composting are generally lesser compared to aerobic composting [26]. This type of composting method is usually carried out in 2 stages namely: (i) acid formation stage where proteins, lipids or carbohydrates are transformed into certain fatty acids by action of microorganisms and (ii) conversion of the end products of previous stage into methane and CO_2 by the action of special type of bacteria [109]. Another term which can be used for this method is known as "bio methanation" and in India, it is a process often supported well by the Government in the treatment of agricultural and industrial wastes as well along with MSW. Developmental plans for a number of bio methanation plants are underway for many major urban cities of India like Delhi, Bengaluru etc. [2] (Fig. 11).

7 Challenges Faced in MSW Management

Throughout the study, we have come across the waste generation and composition data of various regions of the world and also the needs and techniques for its effective management. But that job is easier said than done. Development of a fully effective technique for MSW management for a particular nation or urban city is very difficult owing to many different reasons. This is an issue faced more often by the developing nations of the world than the developed ones. The reasons behind it might vary from nation to nation with some common points probably shared by them as well.

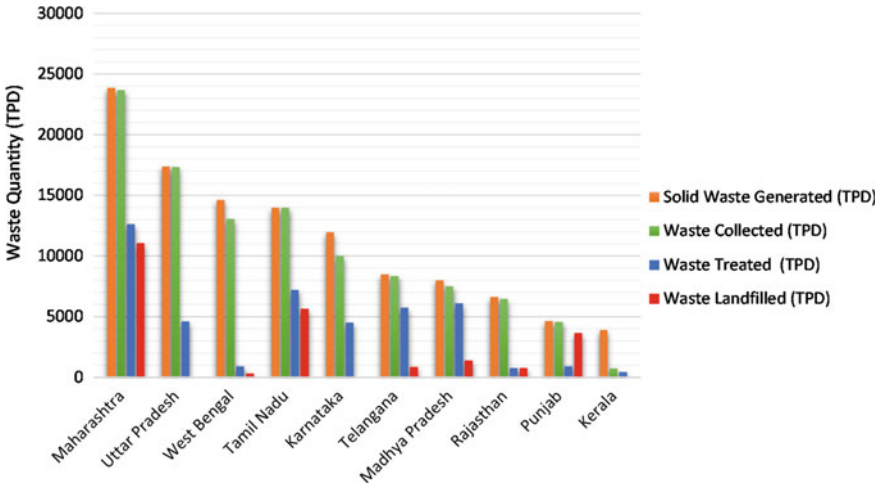

Fig. 11 Comparison of generation, collection, treatment and landfilling quantities of solid waste by some highest solid waste generating Indian States (as per Table 7)

Sulemana et al. [105], through their study have highlighted certain challenges which are commonly encountered by develop nations of the world in the process of waste collection. Some of the issue described are as follows:

Financial Issues: Developing countries often do not receive the required financial assistance from their central or state governments due to which an effective and efficient waste management process cannot be carried out. Governments show unwillingness in providing required funds to carry out the process successful due to which proper waste collecting vehicles like collection trucks could not be bought in required numbers. Because of reasons such as these, collection of MSW do not reach satisfactory figures and most of it gets openly dumped in unscientific manners.

Lacking in willingness and political support: Participation of the public is equally important along with the Government for a proper waste management process to take place. In most developing countries, it has been observed the mentality of people and their responsibility shown towards MSW management is very disappointing. Public awareness towards the importance of proper waste collection is very poor. On top of that, lack of political or governmental support is also very often seen in developing countries due to which an effective waste management process never becomes a reality.

Unsatisfactory schedule for collectors and routing of vehicles: This is perhaps the biggest roadblock in the path towards a proper waste collection system. Waste pickers/collectors aren't provided with proper schedules to perform the collection activities which results in non-uniformity in the process. Along with that the poor quality of waste collection components such as community containers which makes

collection process further difficult. Finally, required number of vehicles are also not available in hand for which waste collection process goes further away from success.

Improper routes towards collection grounds: In many areas of the world, waste dumping areas are very commonly located in very compact or narrow passages. This is a very common scene in developing countries due to which, collection vehicles aren't able to properly reach those sites making the waste collection process an inefficient one.

Low expertise on technical grounds: Unlike many developed nations of the world, the waste collection methods followed by many developing countries are quite simple and most mechanical ones. The people involved in the waste management systems often lack proper technical expertise which could result in a more effective management process with improper infrastructure further contributing to the problems. Compared to developing nations, most developed nations expertise in technicality and also have much better assets and infrastructure which makes their waste management process much better and effective.

Kumar and Agrawal [63], have discussed various issues which faced while MSW management process is practiced in India, which are as follows:

- *Issues of public health and environment:* Methods like landfilling are very commonly utilized in India which results in high rates of leachate formations, high CH_4 emissions into the atmosphere and other factors like pollution of groundwater. The environment gets greatly affected by this which also results in the ill-effects to the public health who are very much dependent upon the environment for their life and activities.
- *Lack of financial aid and proper infrastructure:* Like many other developing nations, the Government of India often fails to provide adequate financial support which is required for an effective waste management process to take place. Although many steps have been taken throughout the years to bring improvement in this factor.
- *Necessary policies not effectively implemented:* Certain national policies are necessary to be formulated and followed for an effective waste management. But very often, a sense of negligence is observed among the people of India when it comes to waste management due to which importance towards certain is not given in required sense.
- *Challenges faced in various MSWM processes:* MSWM consists of many processes as discussed previously ranging from segregation to proper disposal. For the waste management to take place, each of those processes have to be performed effectively. But this could not happen in India due to various reasons like lack of capital and sound infrastructure along with certain social issues as well.
- *Social issues:* Along with financial and infrastructural, MSW management in India faces certain social issues as well du to which it is not as effective as desired. One such issue is lack of proper education and understanding about the importance of MSW management and how it can impact the health of individual and environment as well. Lack of space is also an issue in many urban areas of India due to which

proper disposal could not take place. Along with that, the issue of division of jobs according to classes to people has always existed in India. The ones working in management of wastes are often considered to be at lower levels than those at the upper sections of the society. Hence, the upper classed society often neglects the importance of MSW management considering it a job lower for their standards. Hence, waste management process suffers as a whole.

8 Conclusion and Recommendation

On completion of the study, it could be concluded that MSW generation has become a serious issue all over the world with its generation rates with varied compositions increasing with time and rapid urbanization in the modern day. There is quite a difference observed in the compositions of MSW generated by developed countries compared to developing countries with the former generating more of paper based solid wastes. The adverse effects of MSW could be seen in large extent over the developing nations of the world due to financial grounds and also other social and communal issues. The country of India is a good example of that. Due to this, the practice of MSW management could not be carried out in the urban areas of those nations either due to lack of proper and required funding towards it by the Government, lack of required infrastructure and also lack of a culture where everyone takes active participation towards waste management to mitigate its possible hazards without depending completely on the Government and also without letting any social barriers interfere the same. A few suggestions to overcome various issues and have an efficient MSW management process in order to keep the people and environment free from ill-effects are as follows:

(i) People, especially from the developing countries lacking proper MSW management systems must be provided proper education on the same and its importance and effects if not performed effectively. Waste Management should be made a compulsory course in schools/colleges regardless of whatever line of study a student pursues.

(ii) State as well as central Governments of all nations must make their utmost efforts so that the required funds could be provided for MSW management to be carried out without failure.

(iii) It should be the responsibility of every individual of the country to make an effort towards the reduction in the generation rates of MSW in the first place. More the generation and composition, more complicated and expensive the management process becomes. Hence, unnecessary desires and demands need to be subsidised so and the concept of "re-use" should be promoted and practiced.

(iv) It is also necessary that the correct management techniques for MSW are followed by a certain nation, city, town or area so that the overall process turns out to be effective. For e.g.: In India the generation of organic waste is observed to be in greater amounts than many other developed nations of

the world. On the contrary, there is shortage of free land areas for practicing landfilling. So, the practice of certain biological treatments of waste such as vermicomposting should be practiced and promoted rather than landfilling. This would not only make waste management better but also act as an employment opportunity and potential source of income.

(v) Effective treatment of waste is needed to be done before disposal. Direct disposal of collected waste in open dumping grounds or landfilled is not termed as MSW management. Steps like segregation, incineration etc. need to be carried out before disposal. Otherwise, the disposed waste could lead to pollution of environment and ill-effects on human health

(vi) Recycling process of generated wastes should be given priority all over the world. The 4R policy of: Reduce, Re-use, Recycle and Recover should be given priority. This way, the total volume of waste needed to be disposed decreases which protects the environment and the ones depending on it. On the other hand, this could also become a potential source of income for people.

(vii) Use of plastics should be reduced as it constitutes for highest amounts in MSW generation in all parts of the world, be it developed or developing nations and is non-bio-degradable.

(viii) A focus should be given towards "waste to energy" practices in India, especially for landfilled wastes as methane is extracted in very large amounts and could be converted to biogas making the generated MSW into a potential source of non-conventional energy.

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