

Renewable and Sustainable Energy Reviews

An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations

--Manuscript Draft--

Manuscript Number:	RSER-D-20-04221R2
Article Type:	Review Article
Section/Category:	Waste to Energy
Keywords:	Municipal Solid Waste; waste to energy; Landfill; Anaerobic Digestion; life cycle assessment
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Abstract:	<p>In developing countries, urbanization and rapid population growth has resulted in a substantial increase in generation of Municipal Solid Waste (MSW). Safe collection, transportation and treatment of MSW are among the major issues facing medium to large Indian cities. Poor MSW management practices have negative impact on public health, environment and climate change. India currently only treats 21% of MSW while the remainder disposed in unsanitary landfill sites with no recycling and treatment technologies. This paper reviews the existing MSW management practices, challenges and provides recommendations for improving MSW management for the city of Jaipur in Rajasthan state. Major challenges faced by Indian cities include uncontrolled landfilling, failings in the implementation of MSW (management and handling) legislation and inadequate public participation in management. Recommendations for improvement include public awareness campaigns, Public-Private Partnership (PPP), investment in lined landfills, recycling, waste to energy techniques (incineration, gasification, pyrolysis, anaerobic digestion), landfill gas recovery from MSW, improved optimization models to minimize cost as well as resources utilized in the MSW management and the use of life cycle assessment tools to minimize environmental impact. This study will provide policy makers and private sector stakeholders to develop strategies for future planning, investment and execution of improved MSW management in Indian cities.</p>
Response to Reviewers:	<p>Dear Editor, 20th Aug, 2021 RSER</p> <p>Thank you very much for the detailed review of our manuscript (Ms. Ref. No.: RSER-D-20-04221R1).</p> <p>Please find attached the revised version of our manuscript entitled "An overview of municipal solid waste management in Jaipur City, India - Current status, challenges and recommendations" for kind consideration.</p> <p>Authors are grateful for the suggestions and comments given by reviewers which has helped to improve the quality of the paper. Kindly consider our detailed response to the reviewer's comments given below.</p> <p>The changes made in the manuscript are obvious being in 'Track change mode'. Page</p>

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3

4 Kishan Kumar Prajapati¹, Monika Yadav¹, Rao Martand Singh², Priti Parikh³, Nidhi Pareek⁴,
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10 Technology (NTNU), Trondheim 7034, Norway

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26 **ABSTRACT**

27 In developing countries, urbanization and rapid population growth has resulted in a
28 substantial increase in generation of Municipal Solid Waste (MSW). Safe collection,
29 transportation and treatment of MSW are among the major issues for Indian cities. Poor
30 MSW management practices have negative impact on public health, environment and climate
31 change. India currently only treats 21% of MSW while the remainder disposed in unsanitary
32 landfill sites with no recycling and treatment technologies. This paper reviews the existing
33 MSW management practices, challenges and provides recommendations for improving MSW
34 management for the city of Jaipur in Rajasthan, India.

35 Despite being the state capital as well as the top tourist destination in northern part of India,
36 there is no detailed study which reviews the waste management strategies of this city along
37 with identifying the key challenges. The study reveals that the major challenges for MSW
38 management in Jaipur include uncontrolled landfilling, inadequate public participation as
39 well as failings of implementation of MSW legislation and waste conversion.

40 Recommendations for improvement include public awareness campaigns, public-private
41 partnership, investment in lined landfills, recycling and waste to energy techniques.

42 Optimization models and life cycle assessment tools should be employed to minimize cost
43 and the environmental impact of MSW management. This study will provide policy makers
44 and private sector stakeholders to develop strategies for future planning, investment and
45 execution of improved MSW management in Indian cities.

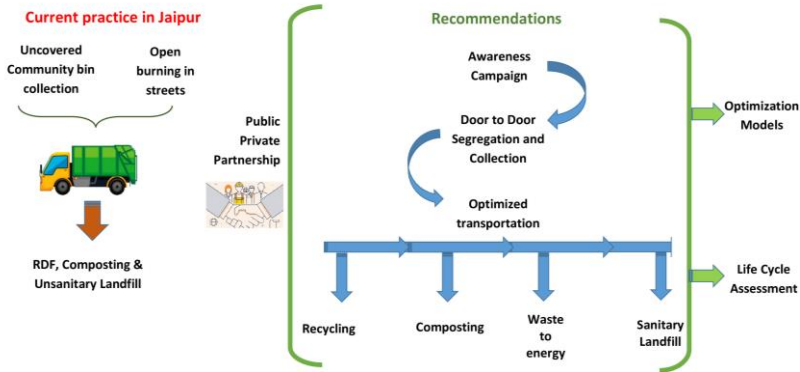
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47 **Keywords:** Municipal solid waste; Waste to energy; Landfill; Anaerobic digestion;
48 Optimization models; Life cycle assessment

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51 Graphical Abstract



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68 **List of abbreviations**

AD	Anaerobic digestion
BLF	Bioreactor landfilling
CPCB	Central Pollution Control Board
CDC	Centre for Communication Development
GIS	Geographic information systems
GHG	Greenhouse gas
JMC	Jaipur Municipal Corporation
LFGR	Landfill gas recovery
LCA	Life cycle assessment
MoEF	Ministry of Environment and Forests
MSW	Municipal solid waste
MSWM	Municipal solid waste management
NGO	Non-governmental organizations
PPP	Private-public partnership
RDF	Refused derived fuel
SEG	Socio-economic group
SPCB	State Pollution Control Board
TPD	Tonne per day
ULB	Urban local bodies
VS	Volatile solid

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73 **1. Introduction**

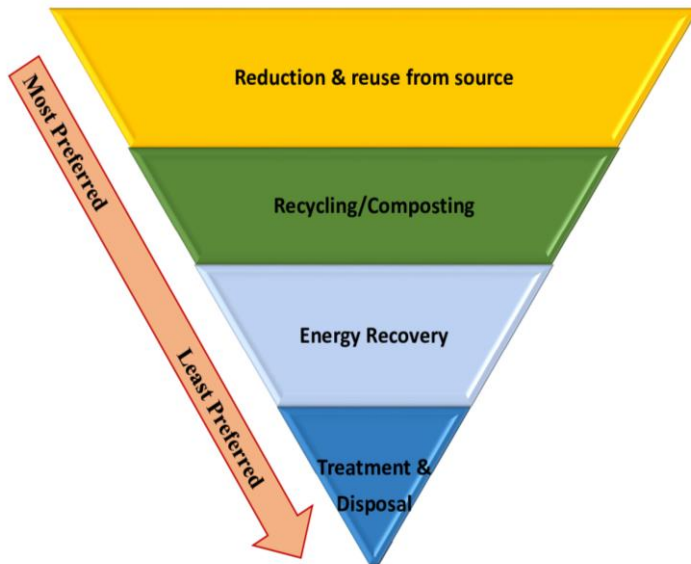
74 Rapid urbanization, industrialization, and population growth have resulted in substantial
75 increase in rates of solid waste generation in urban centers. As per United Nations, the 52%
76 population of world was urban in 2011 and it is estimated to reach to 67.2% till 2050 [1].
77 This increase will transform the social structure, living standards, resource utilization as well
78 as waste generation by people. The generation rate of municipal solid waste (MSW) can be
79 directly correlated to the economic growth of a country i.e., gross domestic product and
80 population density [2, 3]. Annual worldwide total solid waste generation is approximately 17
81 billion tonne per year, and this sector contributes to 16% greenhouse gas (GHG) emissions
82 responsible for global warming [2, 4].

83 In developing countries such as India, typical per capita, MSW generation rate is
84 about 0.49 kg/day which is lower than the 1-2.5 kg/day waste generation rates in developed
85 countries. In future, waste consumption and generation patterns in developing countries will
86 replicate those in developed nations. Currently, India handles 62 million tonne MSW per year
87 [5]. However, the collection and treatment efficiency of the country is around 90% and 27%
88 respectively. Remaining untreated MSW at present itself is a major problem which would
89 sustain in a disastrous way [6]. Jaipur city having 3.04 million population, is the capital of
90 Rajasthan state where a rise in infrastructure development and living standards has led to
91 waste generation amounting to 1000 tonne per day (TPD) [7, 8]. This quantity of waste is
92 one-third of the total waste generated by entire Rajasthan state.

93 Most of the Indian cities failed to have the desired level of municipal solid waste
94 management (MSWM) due to the shortage of financial resources and technology, and lacking
95 in sustainable planning and execution. MSWM effectiveness in a city should keep pace with
96 the growth of that city [9, 10]. Increase in waste generation in Indian cities makes the
97 management of MSW and its handling a critical problem. This needs targeted action from

98 key stakeholders involved in the management of MSW in any city including Municipal
99 Corporation of city, MSW generators i.e., public and private institutions (offices, hotels,
100 restaurants, markets and other commercial sectors), non-governmental organizations (NGOs)
101 and private contractors. Waste generated in large quantity requires a system of collection,
102 segregation, storage, transportation, treatment, and disposal. There are several MSWM
103 method to cut down the volume of the waste such as its minimization from source itself,
104 waste 3 R's ("Reduce, Reuse and Recycle") strategy, incineration, composting and anaerobic
105 digestion (AD); however, unscientific or unsanitary landfilling is the most adopted approach
106 for MSW disposal nationwide as it has been a relatively simple and economical mode of
107 MSW disposal [11, 12].

108 Figure 1 shows a four-tiered integrated solid waste management hierarchy to guide
109 MSWM decision-making according to the type of waste. Knowledge of composition of MSW
110 is important for selecting the suitable waste processing and disposal practices since MSW
111 volume and its composition differs considerably with the places having changes in food
112 habits, cultural traditions, lifestyles, socio-economic conditions, and climate [4, 13].
113 Integrated MSWM based on varying MSW composition is required to recover materials,
114 compost and renewable energy from MSW and residues to reduce the quantity of MSW
115 reaching landfill sites [12].



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117 Figure 1. Integrated solid waste management hierarchy [14]

118 This study reviews the present status of MSWM for Indian cities more broadly and
119 specifically for Jaipur city and provides recommendations for improvement. Further, the
120 study provides the list of waste management technologies adopted in the other cities of India
121 as well as around the globe to convert the waste to energy. The review further compares these
122 technologies in terms of energy potential and economic feasibility. The life cycle assessment
123 (LCA) and optimization done by other studies have also been summarized to elaborate the
124 applicability of these tools for predicting the most suitable method for implementing the
125 waste conversion technologies resulting in highest energy yield with minimum emission and
126 cost. This review would enable regulatory bodies such as the State Pollution Control Board
127 (SPCB), Urban Development Authority and Municipal Corporation to improve the waste
128 management processes in the Jaipur city and tackle the issues in systems. Moreover, this
129 study may also be helpful for the other cities of developing countries around the world which

130 are facing the similar issues to tackle the accumulating waste due to lack of proper treatment
131 method as well as policies regarding them.

132 **2. Current scenario of MSW in India**

133 '*Solid waste*' includes solid or semi-solid domestic waste, sanitary waste, commercial waste,
134 institutional waste, catering and market waste, and other non-residential wastes, street
135 sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture,
136 dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-
137 waste, battery waste, and radioactive waste" [15]. MSW (Management and Handling) Rules,
138 2000 issued by Ministry of Environment and Forests (MoEF), Government of India, regulates
139 appropriate collection, segregation, transportation, treatment and disposal of solid waste.
140 Under these rules, Municipalities are authorized to implement measures for improving MSW
141 and submit annual reports to the Central Pollution Control Board (CPCB). Parameters such as
142 the quality of ambient air and groundwater, leachate, compost and standards of incineration
143 are required to comply with respective standards and monitored by CPCB as well as SPCB.
144 Currently there is a gap between regulation and enforcement in most Indian cities. [10, 16,
145 17].

146 Key features in revised rules i.e. solid waste management rules 2016, extended to
147 urban and industrial areas, are mandating the solid waste source segregation to have its
148 recovery, reuse and recycle; integration of informal system i.e. unauthorized rag pickers and
149 waste dealers into the formal system; prohibition of waste throwing, burning, and burying in
150 public spaces, if violation of rules found, generator will have to pay 'spot fine'; manufactures
151 of sanitary products should provide the suitable wrapping material with it for its safe
152 disposal; introducing partnership concept for bulk waste producers (hotels, institutions,
153 restaurants, event organizers, new townships and societies) to segregate, sort and handle the
154 generated waste by associating with local bodies; all brand owners or manufactures shall

155 have to provide the required financial aid to local authorities for MSWM; non-recyclable
 156 waste (Calorific Value \geq 1500kcal/kg) should be used directly for energy production or as
 157 input for generating refused derived fuel (RDF) [15].

158 Being one of the fastest growing economies and the second most populated country in
 159 the world, India is facing the upsurge in MSW generation in the cities. With changing
 160 lifestyles, Indian cities are now generating more MSW with an estimated increase of 1-1.33%
 161 per annum. Currently in India, only 15-20% of MSW is segregated, 21.45% of MSW is
 162 processed or treated and remaining 78.55% MSW disposed at unsanitary landfills. Open
 163 dumping was 90% in 2008 and showed only 11.45% waste diversion from open dumping in
 164 last decade [10, 18]. Moreover, the projection of MSW generation for urban inhabitants
 165 revealed that the MSW generation rate (kg/capita/day) is approximately two times of the
 166 urban agglomeration rate [19].

167 MSW contains 50-60% organic fraction composed of majorly food waste and its
 168 untreated disposal i.e., uncontrolled decomposition causes rotting, severe impacts on local
 169 public health and foul odor due to methane generation which is a GHG [20,21]. Reliable
 170 characterization of MSW requires a large number of MSW samples being analyzed over the
 171 cities of India. Physical composition of MSW for Indian scenario is shown in Table 1. MSW
 172 collected from different cities of India contains approximately 40-62% biodegradable content
 173 and 11-24% recyclable content [17]. Average household MSW composition consists of
 174 around 70% organic fraction [22-24].

175 Table 1: Physical composition (%) of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio

1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	45	12	43	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

176

177 MSW generations in [major35](#) metro cities of India are reported by CPCB are shown
 178 in Figure 2. It exhibits trend of waste generation per day in last [105](#) years (in the year of
 179 2004-05, [2010-11](#) and 2015-16) in [major35](#) metro cities. Larger metro cities such as Mumbai
 180 and Delhi have a very high rate of waste generation and are currently leading in waste
 181 generation with up to 11000 and 8700 TPD waste generation respectively. In Delhi, openly
 182 dumped MSW was observed to be the highest in the low socio-economic neighborhood with
 183 61 kg per capita per person per year [25].

184 Socio-economic conditions i.e., education level, family income, occupation and
 185 household size play significant role in MSW generation in the society. A study performed in
 186 Dhanbad city, India regarding these factors divided society into five socio-economic group
 187 (SEG) based on above mentioned four factors. It concluded that middle and lower middle
 188 SEG has the highest per capita waste generation due to comparatively more family members.
 189 Comprehensive study of waste composition in different SEGs shows high food and plastics
 190 wastes generation from higher SEG, whereas lower SEG generates lesser food waste due to

191 different standard of living [267]. Impact of socio-economic factors on MSW generation in
192 Bangalore city shows positive relation with family income, whereas negative relation with
193 education level and household size [23].

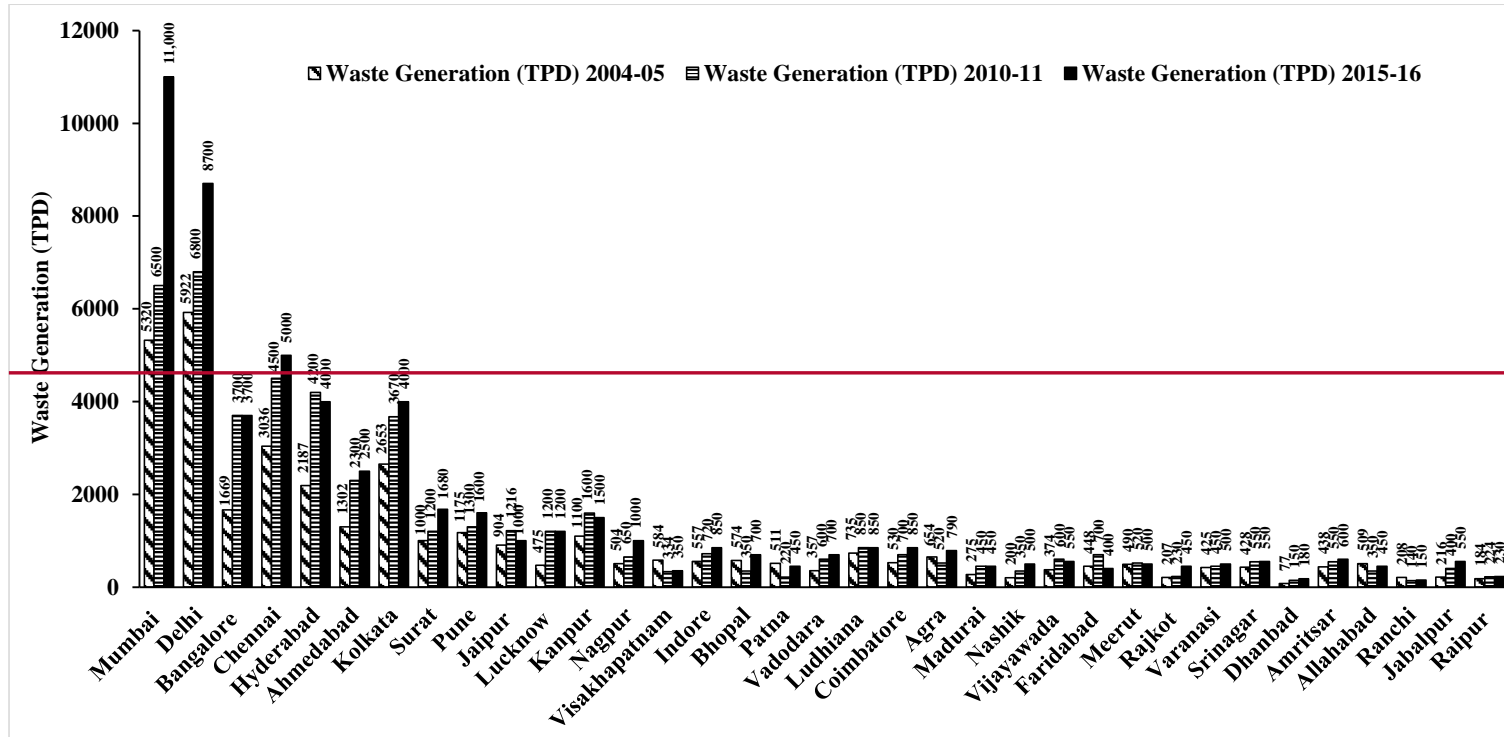
194 In Indian system, the residential solid waste in the household is stored in a single
195 plastic container (16-20 L capacity) in a mixed form including both dry and wet waste. The
196 collected waste is then dumped by the residents to the nearby community bins (4.5-6 m³
197 capacity, metallic or concrete) without segregation. The door-to-door collection is practiced
198 only in few wards of metro cities, through handcarts or tricycle with the help of NGOs.
199 Residential and market waste is also dumped on the open roads either due to negligence of
200 waste generator or inadequate presence and capacity of community bins. All street and road
201 wastes are collected by sweepers using wheelbarrows and thereafter dumped it into nearby
202 community bin. Community bins are mostly uncovered i.e., easily accessible to rag pickers
203 and animals, they litter the waste around the bin in the search of recyclable waste and food
204 respectively, thereby dispersed waste on the street and creating the unhygienic conditions.
205 The dispersed waste sometimes reaches to the nearby drainage system causing it to be
206 blocked. The major problem for municipality arises from low and middle-income residential
207 areas where the waste is dumped on narrow streets, or behind houses instead of putting it in
208 nearby bins [24, 278, 289]. Due to this poor-practice, these areas remain inaccessible to waste
209 collecting workers for some days.

210 Private contractors are involved in metro cities for transportation of MSW from
211 community bins to dumping sites. Tractors, ordinary trucks, pay loader, compactors, tippers
212 and dumper placer vehicles are usually used for waste transportation. Though many of them
213 are outlived which run with low efficiency and high fuel consumption [19, 2930, 304].

214 Except few cities like Delhi, Pune and Hyderabad, all Indian cities transport MSW to the
215 dumping sites where uncontrolled landfilling is practiced (Table 2).

216 Current management strategies adopted for handling MSW in some major Indian
217 cities are highlighted in Table 2. Almost all cities have no source segregation of MSW while
218 some cities perform MSW segregation by engaging workers. Few cities have poor collection
219 efficiency and no source segregation is performed except Bangalore and Pune. Composting
220 and unsanitary landfilling is a very common strategy practiced for waste management in most
221 of the Indian cities. Pune is the only city where waste management practice is appreciably
222 effective by integrating segregation, composting, waste to energy plants and scientific
223 landfilling. There are less significant research updates regarding MSWM of Northeast Indian
224 cities. In Dibrugarh town of Assam, open dumping site is located near the Brahmaputra river
225 contaminating the river ecosystem as well as affecting the health of humans and animals. The
226 health hazards become more severe during rainy seasons causing water pollution and water-
227 borne diseases [[2930](#)].

228



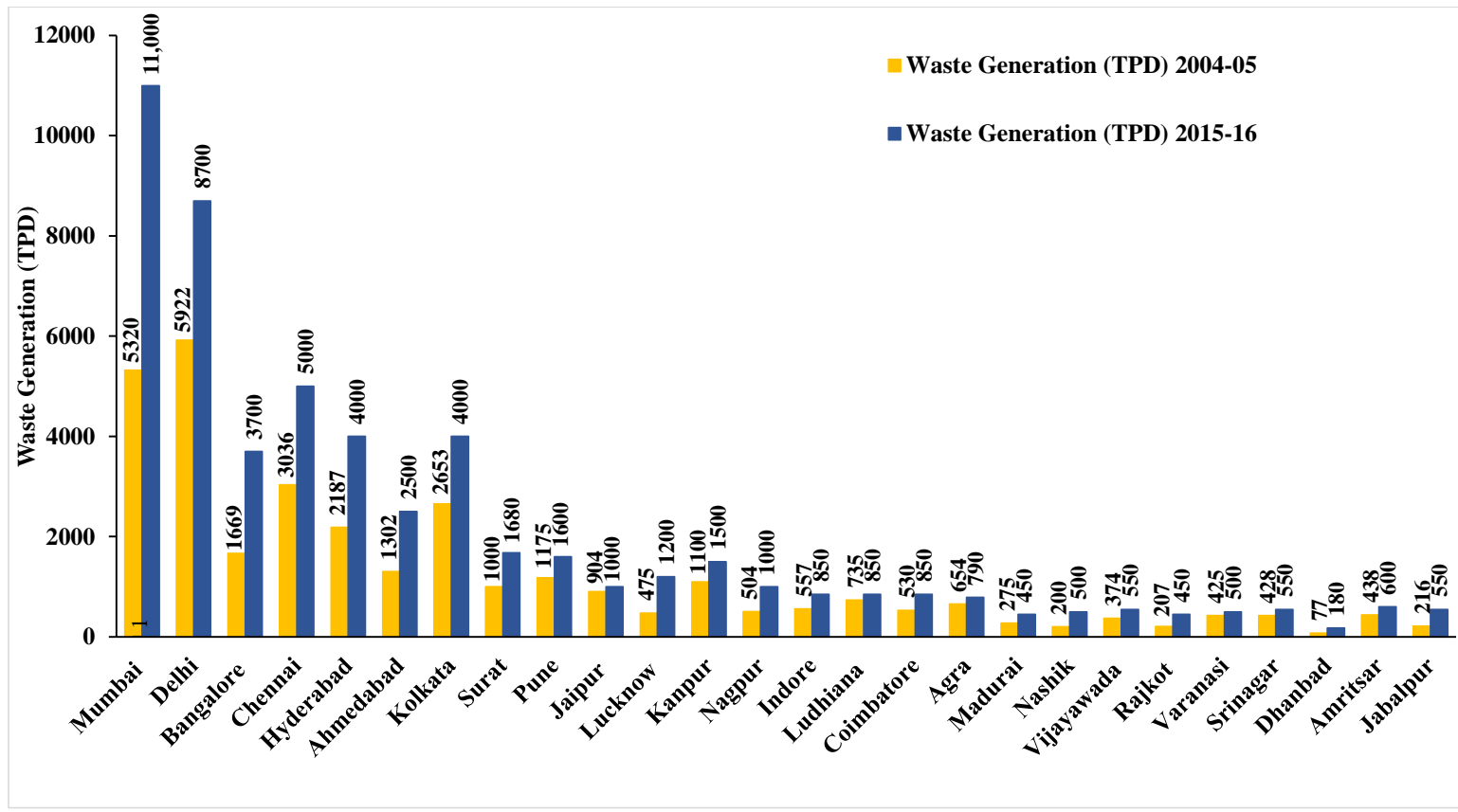


Figure 2. MSW generation trend in major Indian cities [7]

232

233

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235

236

Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,27 8]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,31 2]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R's hierarchy of management and waste to energy technology	[32 3]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[33 4 ,34 5]

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Delhi	Y	Y	Y	R-Informal, C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[356,367]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[378,389]
Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[3940]
Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[404]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[412]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[423]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[434,445]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[456]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]

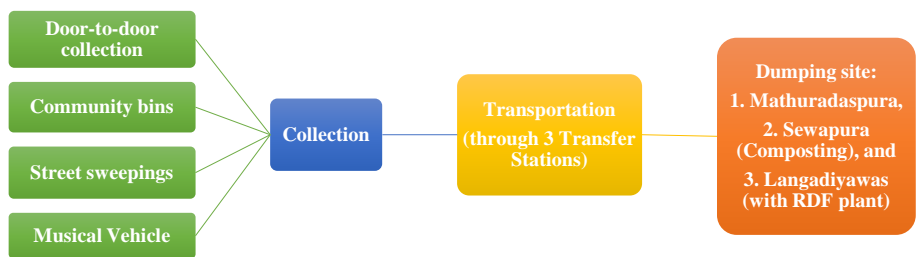
Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[467]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[478]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[312,489]
Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[4950]
Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[312]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[312,504]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,267]

237 Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary
238 Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective
239 strategy, (no.) –number in the bracket represents the number of respective facilities.

240 **3. Municipal waste management in Jaipur city**

241 The previous section provided status of waste management in some of the significant cities of
242 India. The waste management strategies followed by these cities are largely based on the
243 MSW composition which in turn vary according to the lifestyle and eating habits of citizens,
244 food resources as well as the climate of the city [51]. While, these studies of other cities of
245 India are helpful in solving the specific waste management issues; the MSWM model of one
246 city cannot be implemented as it is to another city of India due to varying climate conditions
247 and lifestyle which changes drastically in India.

248 Jaipur city, capital of Rajasthan the largest state of India, is one of the future smart cities of
249 India and famous for its tourism and hospitality. In 2019, the city has been declared as
250 UNESCO world heritage site. As shown in Figure 2, It is also a major city in north India
251 along with Delhi, Kanpur and Lucknow with high waste generation rate. With an area of 467
252 km² and the entire city is divided into 91 wards. Since 2011, the wards are distributed in 8
253 Municipal Corporation zones: Vidhyadhar Nagar, Civil Lines, Mansarovar, Sanganer, Moti
254 Dungri, Hawa Mahal East, Hawa Mahal West and Amer. Jaipur Municipal Corporation
255 (JMC) has the constitutional responsibility of collection, transportation, treatment and safe
256 disposal of MSW generated in the city. Currently, Jaipur city has MSW flow in its
257 management process as shown in Figure 3.



258
259 Figure 3. MSW flow in Jaipur [278]

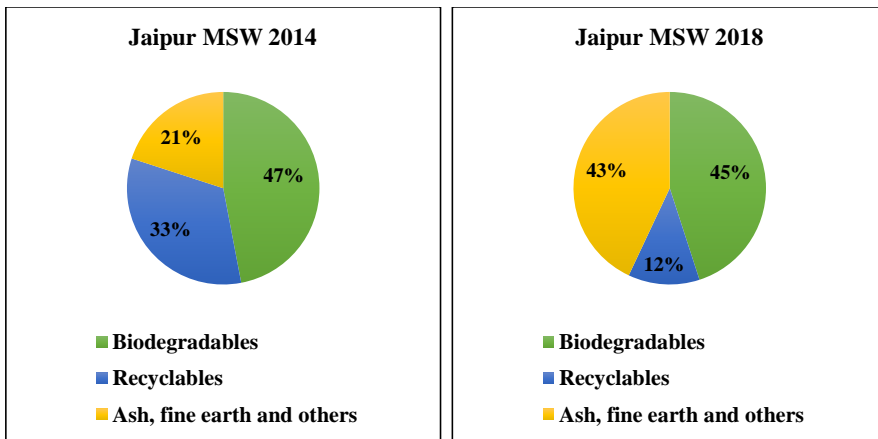
260 **3.1.MSW composition and characteristics**

261 MSW in Jaipur comprises three key components [334, 52]:

- 262 1. Biodegradable (organic waste): Food waste, garden waste (grass, fallen leaves and
263 tree trimmings), wood etc.
- 264 2. Recyclable waste: Paper (paper is classified as organic only when it is tainted -by
265 organic material), cardboard, plastics, metals, glass etc.
- 266 3. Inert and other wastes: Textiles, leather, paints, rubber, multi-laminates, medicines,
267 sanitary products and inert materials (stones, silt, ash and inorganic material).

268 MSW composition and chemical characteristics viz. moisture content, volatile solids (VS),
269 calorific value and elemental composition etc. of MSW in Jaipur city are shown in Figure 4
270 and Table 3 respectively. As shown in Figure 4, approximately 45% portion of MSW
271 collected in Jaipur was reported in 2018 to be biodegradable while 43% content was
272 composed of ash and fine earth particles [17].

273
274



275
276 Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

277 Table 3: Chemical characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV	C	H	N	S	O	P	Potash
			(kCal/kg)						(P ₂ O ₅)	K ₂ O
Values (%)*	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

278 *Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids,
279 CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen,
280 P=Phosphorus.

281

282 3.2.Cleaning and collection

283 The door-to-door waste collection method is not adopted in Jaipur city by JMC, and rather
284 some wards are implementing it through informal sectors by paying them reasonable amount
285 per month. Sometimes, a portion of MSW left unattended and remained as open dumped
286 waste. Jaipur city has collection efficiency of MSW around 85% [11, 12]. In this collected
287 MSW, 18-24% contents are recyclable including paper, plastic, rubber, ferrous and non-
288 ferrous metals. However, 15% out of total recyclable waste is collected by rag pickers for
289 their livelihood and traded to scrap buyer informally [10].

290 JMC staff require more health inspectors and sweepers for respective wards as per a
291 study conducted [11]. Permanent and temporary street sweepers on daily wage basis are
292 deployed for cleaning the city. Street sweeping and community bins are the primary
293 collection methods of the waste. Total 1794 community bins of 3 sizes i.e., 1.1 m³, 3 m³ and
294 7 m³ capacity have been installed [11]. Still, many wards are left without having any garbage
295 container causing more disorder with respect to waste collection.

296 It has been observed that the ~~citytown~~ does not segregate the waste at source and dump
297 it into the municipal bins, open spaces and drains. Many of the community bin's waste are
298 scattered around by animals which causes unhygienic conditions. Some ward's road cleaning
299 is performed daily while remaining wards are cleaned periodically i.e., once or twice a week.

300 Street waste cleaning, de-silting the surface drains and collection tasks performed by
301 sweepers using a wheelbarrow and transferred to community bins. Since recyclable waste
302 segregation is not practiced, it is usually found mixed in the community bins [11].

303 **3.3.Transfer station and transportation**

304 The collected garbage from community bins is transported to the secondary storage points or
305 transfer station and then to the disposal sites using dumper placer and compactor vehicles.

306 Currently, Jaipur has 3 transfer station at Lal Dungri, Vidhyadhar, and Jhalana having
307 capacity of 400, 250, and 150 TPD respectively. Uncovered or open body type trucks tend to
308 spill waste gradually on the road causing unhygienic conditions on the roads. A vehicle's
309 waste collection frequency is around 2-4 times daily due to lack of transfer stations in other
310 zones. Therefore, 3 more transfer stations are proposed in Mansarover, Bambala Pulia and
311 Sushilpura to cover the zones which are far away from disposal sites and to minimize the
312 time, money and fuel consumption during waste transportation. Transportation system alone
313 consumes more than 60% funding from the total fund assigned for the MSWM [11, 12].

314 **3.4.Treatment and disposal facilities**

315 For MSW disposal, Jaipur city has currently 3 dumping sites: Mathuradaspura,
316 Langadiyawas, and Sewapura as shown in Figure 5 on Jaipur map and main features are
317 discussed below [11, 12].

- 318 1. Mathuradaspura dumping site: It is located at 17 km distance from the main city,
319 having capacity up to 400 TPD of MSW with total area 0.285 km².
- 320 2. Sewapura dumping site: It is situated at 20 km from the city, with site area 0.324 km²
321 having a capacity of 300 TPD. It has a compost processing facility of 350 TPD
322 operated by Infrastructure Leasing & Financial Services Limited.
- 323 3. Langadiyawas dumping site: It has a total area of 0.782 km² out of which 0.065 km²
324 is allotted for RDF processing facility and 0.16 km² for Sanitary Landfilling (under

325 construction). M/s Grasim Industries constructed an RDF processing facility
326 producing 150 TPD RDF from 500 TPD MSW at Langadiyawas and transported to a
327 company UltraTech Cement Limited in Neemuch, Madhya Pradesh, to generate
328 energy for cement production.

329 MSW undergoes many transformations before converting to RDF such as removal of
330 dangerous and large items (i.e., big stones, batteries, dead animals, machines) by workers and
331 then load into pre shredder to have granular size of 0-200 mm. Subsequently, the shredded
332 waste is sent into an integrated conveyor installed magnetic separator removing all metals
333 from waste. Further separation of sand and grit from organic waste is carried out by trommel
334 screen. The heavier pieces like glass and ceramics are passed through the ballistic separator.
335 Thereafter, organic portions are sent for further size reduction up to 0-50 mm, resulting in
336 mixed waste as raw materials for RDF. This garbage for RDF has low calorific value, so
337 plastics purchased from Sainath Enterprises are added. This RDF application in cement plant
338 brings carbon credit to the firm and 9-15% saving of coal burning. This facility recovers 5-
339 6% RDF instead of 30% from MSW received because of the inadequate technology and
340 mixing of construction debris with the MSW [278].



341
342 Figure 5. The landfill locations in Jaipur city [11, 12]

343 Currently, total 500 MSW TPD i.e., 50% of total MSW treated either as composting or
344 converted into RDF. JMC proposed a waste to energy plant in Mathuradaspura site for
345 remaining MSW which is being disposed unscientifically at this moment [11]. Uncontrolled
346 dumping is practiced in all of 3 disposal sites, prone to leachate production which can cause
347 ground and ground water pollution and may create vectors for propagating various diseases.
348 Moreover, these sites are without pollution monitoring facilities, proper fencing and fly
349 control [12]. Ground water from eight sites near Mathuradaspura were sampled and some of
350 them show high content of naturally available fluoride and total dissolved solid which may
351 cause fluorosis and gastro intestinal irritation respectively to the nearby residents [11, 12].

352 **3.5.Private-public partnership (PPP)**

353 JMC has been using PPPs model to sub-contract some of its MSWM responsibilities to
354 individual corporations (NGOs or private companies). Two private companies are handling
355 composting and RDF treatment facility in Jaipur MSWM [11]. Two NGOs the Centre for
356 Communication Development (CDC) and Satya were engaged on MSWM related activities.

357 Satya provided labor in Jaipur to lead a successful program in handling the waste and
358 dumping the MSW. Satya was also engaged in door-to-door collection in Vaishali Nagar,
359 Chitrakoot and ward no.20 with charging INR 20-30 a household per month in 2005-07.
360 However, due to poor facilitation from JMC, difficulties in payments, inadequacy in
361 management, the partnership was discontinued after two years of the contract. Another NGO,
362 CDC started few projects for better urban MSWM regarding collection and transportation.
363 Again, JMC could not support their projects financially and hence CDC ceased their work
364 and focused on other social services in Jaipur city [278].

365 **3.6.Case studies**

366 Singh [12] carried out a survey of two regions of Jaipur city viz. Tonk Phatak and Malviya
367 Nagar and concluded that stronger social network or high-income areas have better MSWM
368 or living condition than low-income societies. Here, social network means friendship, social
369 contacts and interactions among the influencing people and common people. Dissatisfaction
370 level found to be high in Tonk Phatak area as a result of lack of community bins and waste
371 collection system with respect to MSWM. While, Malviya Nagar was found to be more
372 socially connected and where MSW was carried away daily. Tonk Phatak area people were
373 willing to pay some money to get their locality clean and hygienic. On the other hand,
374 Malviya Nagar locality somewhat disagreed for the same. The survey in these two areas
375 found that 90% peoples do not have awareness ~~among people~~ about the fate of waste.

376 A case study performed by Gandhi et al. [20] in Jaipur metropolitan revealed the
377 amount of food waste generated from hotel sectors. The study reported that food waste (14.9
378 kg/day) generation from 4-5 star rated hotels is almost threefold as compared to 2-3-1 star
379 rated and unrated hotels. Only 34% hotels out of surveyed 70 hotels perform segregation of
380 food waste, out of which 84% are of 3-5 rated hotels. An educational institute survey study
381 revealed that MSW generated from the campus consisted of food waste, plastics, paper,

382 metal, glass, and garden trimming etc [53]. Total collected waste was directly transported to
383 the city's dumping site. Segregation was not performed and waste treatment facility have not
384 been adopted within the campus [53]. A feasibility study of organic waste energy potential in
385 another institutional campus shows that the mixed food and green waste has biogas potential
386 of 400-660 mL/g VS of mixed substrate [54]. The study suggested that there was a need for
387 developing composting and AD plant for the organic waste generated within the campus,
388 with segregation of recyclable waste. Another study performed the multi feed anaerobic co
389 digestion of mung bean husk and wheat straw with organic fraction of MSW. The co-
390 digestion was observed to increase 37% methane production with respect to AD of organic
391 fraction of MSW only [55].

392

393 **4. Challenges pertaining to MSWM in Jaipur**

394 The main difficulties with MSWM in Jaipur city are firstly the social negligence from
395 public side to have segregation and proper disposal of solid waste due to either lack of
396 knowledge of its long-term harmful impacts on habitats and environment or their
397 irresponsibility towards their fundamental duty of protecting environment. The second major
398 challenge is governance as the municipal corporation continues to practice waste dumping at
399 the outskirts of the city with no planning and safe waste treatment practices. Unlined and
400 uncovered landfilling is the worst option when accounting its groundwater contamination,
401 land degradation and environmental and health impacts causing from breeding infectious
402 diseases majorly due to leachate and landfill gas. Sometimes, Jaipur city also faces burning of
403 MSW piled in streets or grounds, producing highly toxic gases composed of dioxins, CO,
404 hydrocarbons, volatile organic compounds, oxides of sulfur, and hazardous fumes etc.
405 Municipality and public have not been sensitized about the increasing adverse effects of

406 wastes on local environment i.e., contaminating air, water and land making hard for living
407 beings to survive [17, 56].

408 Major technical problem for MSW treatment is mixed MSW i.e., non-segregation of
409 organic waste for its utilization into biogas and compost production which is the most
410 suitable waste management technique for Indian Scenario. In 2008, India's installed energy
411 recovery from waste was 86.32 MW and currently in 2021, it is 168.64 MW, which is very
412 less in comparison to MSW generation rate within the same time period [57, 58]. Biomass
413 power generation (4831.33 MW in March 2016 to 10145.92 MW in March 2021) by
414 combustion route and biomass cogeneration in sugar mills in India is highly progressive. On
415 the other hand, there is no substantial focus on waste to energy conversion techniques in last
416 13 years even though MSW increment rate has been high [57, 58]. Even many installed
417 composting, RDF and waste to energy plants have been failed due to insufficient waste
418 segregation, inefficient management, operational problems like deficient logistical planning
419 and adequate financing. Other problems in prospects of energy recovery facility are feasible
420 technologies, inadequate financial support and quality of waste i.e., contamination occurs
421 during collection and transportation, lack of appropriate storage facility, and lack of expertise
422 in government. These problems were listed and recognized after consultation with urban local
423 bodies (ULBs), industries, and academics [20, 59]. Since most of the Indian cities are rapidly
424 developing, there is a pressing need of effective and sustainable waste management practices
425 in every city.

426 **5. Recommendations**

427 Various feasible and well-practiced techniques in some cities of India as well as at global
428 scale are recommended in this section to tackle challenges of Jaipur city as well as other
429 Indian cities having similar scenario of MSW quantity and composition.

430 **5.1. Awareness campaigns to increase public participation**

431 A most prominent stakeholder is community or public and their inclusion at various levels of
432 waste management process will lead to effective as well as efficient MSWM [304]. In
433 general, “Waste” is supposed to be not useful for people which need to be thrown away.
434 Therefore, the opinion on waste needs to be changed and it should be considered as a
435 resource rather than waste [278]. For this, firstly JMC needs to organize awareness programs
436 assisted from NGOs and educational institutes for reducing the MSW at source, making
437 residents aware of waste categories i.e., organic, recyclable, non-biodegradable and other
438 hazardous waste, so that community would start segregating domestic MSW into
439 biodegradable and non-biodegradable waste. Further, people can be encouraged to start home
440 composting for gardening purpose along with educating them with potential health impacts
441 from poor MSW management. Awareness programs can be arranged through public group
442 meetings, seminar, workshops, newspapers, media, radio, and television networks involving
443 active participation from local bodies [12, 389].

444 Food waste generation in different hospitality sectors at hotels and restaurants is high
445 in a city like Jaipur which is well known for tourism and hospitality. Strategies for mitigating
446 food waste from hospitality sector include: making customers and staff aware through
447 showing signage and posters regarding reducing the food wastage, imposing fine over food
448 leftovers (possibly well-mentioned in the food menu), management of serving size, serving
449 smaller plates that avoids people to take extra food, serving again leftovers if food is not
450 spoiled, often revising the menu based on most of the food leftovers and offering the non-
451 consumed food to food banks and low-income communities through support of NGOs.
452 Segregated food waste provides the chance to recover energy from it such as biogas and
453 compost production. Food waste management from hospitality sector also needs to be

454 improved in terms of reducing food waste and its handling i.e., segregation, and effective
455 subsequent utilization [20].

456 Door-to-door collection in pre-organized time slots with gentle alarming sound, is
457 essential even though this will require more manpower and wheel barrows or handcarts
458 containing 2-3 different colored bins. Door-to-door collection must be stringent and should
459 strictly collect the properly segregated waste. Once household waste collection is improved,
460 concepts like “Bin free city” or “Zero dustbin city” may be introduced in Jaipur which have
461 been successfully implemented in Ambikapur city of Chhattisgarh. Similarly, Maharashtra’s
462 Nagpur city has also reduced the community bins number to 80% of total to encourage door-
463 to-door collection of MSW [22, 2930]. Government can introduce the competitions and
464 winning rewards in different zones in the same city for sanitation and cleanliness which
465 would encourage the public participation. Moreover, MSW collectors and sweepers should be
466 provided training, steady disinfection of the dhalaos (transfer station), safety uniforms, and
467 equipments and regular monthly wages. They must be provided with personal protective
468 equipment like gloves, shoes and air filter masks while cleaning and handling the wastes to
469 prevent eosinophilia, respiratory disorders and infection or contagious diseases [504, 60].

470 A study in Jaipur highlights that the placement of community bins should be equitable
471 in terms of regional coverage and not just be based on social connections [12]. Bigger bins
472 must be placed near the party venues, marriage halls and institutions, which generate larger
473 volumes of MSW in a day. All community bins must be covered so that it would be
474 accessible to humans only avoiding waste dispersion by animals. ~~Transportation of MSW is~~
475 ~~energy intensive with significant emissions. For transportation, old and inefficient vehicles~~
476 should be ~~avoided/discarded and also transporting vehicles should be~~ covered properly to
477 prevent waste scattering on roads.

478 **5.2. Improvement in existing composting and landfill facilities**

479 The biological conversion of organic fraction existing in MSW into a compost/humus
480 through bacterial activity i.e., oxidizing the organic compounds in the presence of air, is
481 called composting. In anaerobic composting, microorganisms break down the organic
482 compounds in the absence of air through reduction process while metabolizing the nutrients
483 [61]. This compost has good fertilizer quality for agriculture application. Many metro cities
484 have MSW composting capacity between 150-500 TPD. Vermicomposting is also practiced
485 in Mumbai, Bangalore and Faridabad where organic waste is decomposed by aerobic
486 microorganisms followed by disintegration through earthworms [10]. Similar measures can
487 be adopted for Jaipur city as well. Organic feedstocks in vermicomposting are generally
488 animal, agricultural, food waste, and sewage waste. The processing periods for
489 vermicomposting may be ranged between 28-120 days and conditions for the process can be
490 varied between 18-67°C temperature, 5.9-8.3 pH and moisture content 11-80%, yielding
491 compost as bio-fertilizer rich in nitrogen, phosphorous and potassium [62].

492 Many studies highlighted the irreparable damage caused through uncontrolled open
493 landfilling sites and suggested sanitary landfill for final MSW disposal [323, 401, 63]. Jaipur
494 city must have sanitary landfill provisions for safe disposal of MSW by either transforming
495 the existing open landfills to sanitary landfill or establishing waste to energy plant [301].
496 Sanitary landfill design must follow the procedures of MSW 2016 guidelines regarding site
497 selection, environmental examination i.e., environmental impact assessment-, near to the
498 treatment facility if possible, and away from dwelling areas and water bodies. There must be
499 urgent cessation of existing dumping sites near rivers or any water storage facility like well,
500 pond, lakes.

501 Advancement in landfill technology may lead to the development of bioreactor landfilling
502 (BLF), which serves as storage as well as treatment of waste. BLF facilitates rapid

503 degradation of organic waste through microbial action due to increase in moisture content via
504 leachate recirculation. The process may achieve faster landfill gas generation to have energy
505 production from it. This type of landfilling also enhances the waste stabilization and its
506 features such as waste degradation, storage, landfill gas collection and faster stabilization
507 make it an environmentally sound landfill as compared to other landfill systems. Diversion of
508 MSW streams to recycling, composting and waste to energy technologies may avoid the
509 possibility or development of landfill gas recovery (LFGR) system as no organic waste
510 reaches to landfill site avoiding biological actions for gas production [19, 63].

511 **5.3. Informal sector integration and public private partnerships**

512 The efficient MSWM in Jaipur city also calls for the provisions of a governing body to
513 administer rag pickers and scrap dealers. The rag pickers can be integrated with the formal
514 system by providing training and facility of precautionary measures as well as the regular
515 monthly wages along with preventing the scrap dealers to take any advantage of rag pickers.
516 Their incorporation with the formal system would enhance the recovery of the recyclable
517 materials [12, 50]. Recently, a study in Brazil has advocated the socio-economic inclusion
518 of scavengers for addressing the challenge of MSW management through their active
519 participation in waste collection and increasing their quality of life through income
520 generation as well as ensured health and safety at work [64].

521 Due to lack of investment and experts in waste treatment field, responsibilities like
522 collection, transportation, treatment and disposal can be shared between NGOs, private
523 companies and municipality. For instance, collection and segregation can be handled by
524 NGOs, ~~using resources provided by municipality while~~ transportation ~~can be handled~~ by
525 municipality ~~and~~. ~~Similarly,~~ design, construction and operation of treatment and disposal
526 facilities ~~may be handled by~~ a private company ~~esy~~. This model has been followed by Delhi
527 by collaborating with 3 different companies for MSWM in six zones of Delhi [278]. PPP

528 model is a significant way and profitable business for private investors which have adequate
529 planning, experts and infrastructures to have well-organized MSWM. For instance, Praj
530 Industries Ltd, Pune has introduced the safer production of biodiesel, fuel ethanol, bio-CNG
531 (Compressed Natural Gas) and liquid manure from the organic content of MSW by solvent
532 extraction, fermentation, and biomethanation in an integrated manner [445].

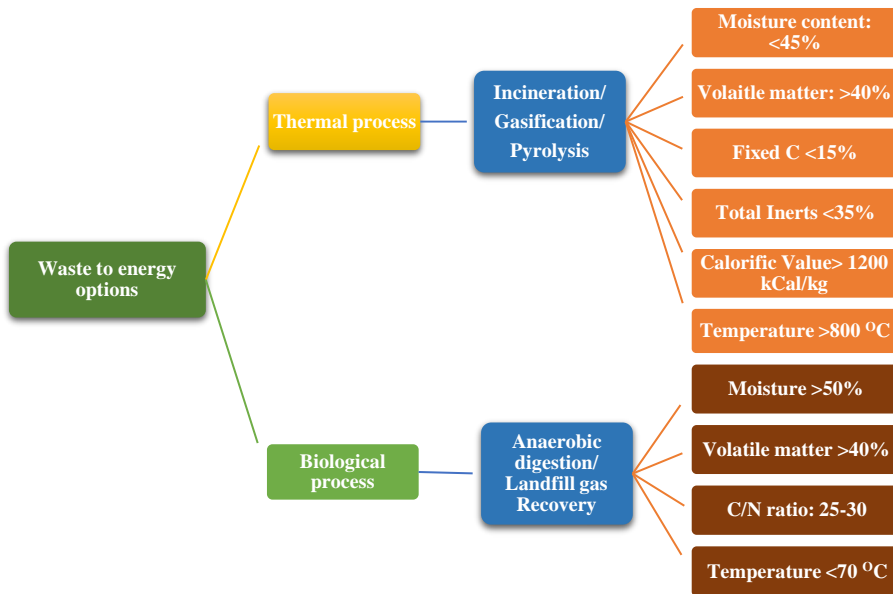
533 Circular resource efficiency can be achieved by using recyclables from MSW as raw
534 materials for recycled new products. Increasing cost of new materials and non-renewable
535 energy makes that case for recovery of material from waste as an economical and sustainable
536 way for recycling. Recyclables can include newspapers, plastics, glass, aluminium, metals,
537 construction and demolition debris. Recovery of recycling materials mainly consists of
538 screening of undersize material and shredding followed by magnetic separation for ferrous
539 metal. Getting some revenue from recyclables may ease the waste management budget as
540 well as cut down the cost regarding its treatment and disposal, thereby reducing the landfill
541 burden. ~~Engagement of private sector into manufacturing industry has huge potential in
542 having recyclables as input raw materials. This can be a perfect trade mechanism for
543 generating job opportunities as well as minimizing the dependence on non-renewable
544 resources.~~ Overall, recycling alone is the most economical and energy efficient process that
545 avoids the enormous embodied energy of a virgin new material and also evades the GHGs
546 emissions due to the virgin material energy consumption [9, 19].

547 **5.4. Adoption of waste to energy techniques**

548 For a developing country like India, rapid economic development requires energy and
549 resources to progress. With depleting fossil reserves, future energy demand can be addressed
550 through the alternative sources of energy i.e., renewable energy. At present, India has 2554
551 MW potential as renewable energy potential from waste generated i.e., MSW and waste
552 water [334, 65]. Waste to energy can play effective role in production of renewable and

553 sustainable energy. In Jaipur, the MSW consisting organic and inorganic portions may be
554 utilized for biofuel and power generation.

555 MSW's quantity, characteristics, composition, physical properties, land availability,
556 environmental safety, financing, stakeholder's involvement, and capability of organizations
557 are major criteria for selection of appropriate technology. Cities alone generating more than
558 1000 TPD (like Jaipur) should opt for waste to energy technologies as it would be sustainable
559 as well as economical. If the thermal route is to be adopted, the enhanced calorific value of
560 waste should be ensured by proper segregation of MSW [66]. The recovery of energy from
561 waste offers many additional benefits i.e., total waste quantity gets reduced by 60-90%
562 depending upon the waste composition and adopted technology; demand for land for
563 landfilling would reduce; the cost of transportation to far-away landfill sites would reduce;
564 and most importantly net environmental pollution would be minimized [11]. Further, the pros
565 and cons of individual waste to energy technologies are shown in Table 5. Recommendations
566 for making waste to energy technologies viable in Indian cities are to introduce contracts for
567 waste collections and deliveries, control on storage sites preventing contamination, increase
568 the public participation by educating and making aware, more funds to ULBs or municipality
569 authority to support waste to energy projects [59].



570

571 Figure 6. Waste to energy options with operating parameter's desired ranges [18]

572 **5.4.1. Thermal conversion**

573 Thermal conversion process entails thermal decomposition of MSW to produce either heat
 574 energy or fuel oil or gas. The objectives of thermal waste to energy are recovering the energy
 575 potential from the waste, destroying toxic substances in organic and inorganic waste, saving
 576 the natural energy resources for energy production, reducing the waste quantities for disposal
 577 and transforming the residuals into reusable secondary products to save material resources.
 578 Thermal treatment plants require high installation and operational cost as well as the experts
 579 in the field [10]. It is convenient to have waste as a fuel resource containing a high
 580 percentage of non-biodegradable matter and low moisture content. The main technological
 581 options under this category include incineration, pyrolysis and gasification. Main operating
 582 parameters during thermal conversion to energy require desired ranges for proper functioning
 583 are shown in Figure 6. Moisture content, volatile content and temperature are the crucial
 584 parameters for incineration, pyrolysis, gasification and AD as well. Though the thermal

585 conversion techniques require much higher temperature (>800°C) as compared to biological
586 conversion method. The volatile matter in the waste should be at least 40% in order to be
587 feasible for waste to energy conversion.

588 **5.4.1.1.Incineration**

589 Incineration is a similar process like the combustion i.e., complete burning of solid waste in
590 presence of sufficient air at 980 to 2000°C, converting MSW's chemical energy into heat
591 energy and generating electricity through turbine-generator system [10, 11]. Raw MSW is
592 generally preferred. Incineration depends on the characteristics of waste which in turn
593 affected by the socio-cultural, seasonal and demographic differences [67]. However,
594 segregated combustible non-biodegradable waste having calorific value greater than 1000
595 kcal/kg should be selected for this treatment. Moisture content and inert waste reduce the
596 calorific value of MSW and affect its combustibility. Stages in incineration process are -
597 drying, incineration, energy recovery from combustion, and flue gas cleaning for air pollution
598 control. Ash produced, in the end, can be utilized in road construction and building materials
599 like fly ash brick. Through this treatment process, incineration of 1 tonne of MSW is capable
600 of generating 544 kWh of energy and 180 kg of solid residues [68]. In General, around 0.7-
601 1.2 mg CO₂ is released from incineration of 1 mg MSW incineration [69]. Though, it may be
602 different for Indian MSW incineration scenario due to dissimilar compositions. Indian cities
603 hardly practice this technique due to undesirable characteristics i.e., high moisture content,
604 high inert content and low calorific value of MSW [10, 18].

605 **5.4.1.2.Gasification**

606 Gasification is the combustion of solid waste into gas mixture (H₂, CO, CO₂, CH₄, H₂O and
607 inert gases) under deficient oxygen conditions at high temperature 800-900°C. Syngas
608 (majorly H₂ and CO), the main product of gasification, can be used to produce renewable
609 energy and as a feedstock for production of chemicals like methanol and liquid fuels. This

610 system mainly includes the gasifier, gas cleaning configuration and energy recovery system.
611 Generally, it is installed for agricultural residues and forest wastes in India. However, it can
612 also be used for MSW by drying, inert removal and chopping prior to gasification of MSW
613 [10, 334, 70]. Its integration with combined cycle, where conversion of gaseous fuel to
614 electricity by gas turbine have overall high conversion efficiency ranges 40-50% for 30-60
615 MW capacity plant [71]. The process is widely used in Japan with 85 MSW operating
616 gasification plants as well as at a smaller scale in USA, Germany, Norway, UK and Italy
617 [68]. This technology is comparably better than incineration in terms of cost, flue gas
618 cleaning and output products and can be explored for MSW management in Jaipur city.

619 **5.4.1.3. Pyrolysis**

620 Pyrolysis is another thermal conversion technology in which biomass converted to liquid
621 (bio-oil or bio-crude) and gases, in devoid of oxygen at 400-800°C temperature range. The
622 process parameters are temperature, the rate of heating, residence time, waste composition,
623 and waste particle size. Lower temperature pyrolysis products are pyrolysis oil, wax and tar.
624 However, quality pyrolysis gases (CO, H₂, H₂O, N₂, hydrocarbons) are produced at a higher
625 temperature (>700°C). Some developed countries like Japan, UK and France are operating
626 MSW pyrolysis plants successfully. Integration of MSW pyrolysis with a gas turbine for
627 energy recovery may lead to a net conversion efficiency of 28-30% [68].

628 **5.4.2. Biological conversion**

629 The biological conversion process is based on the enzymatic decomposition of organic matter
630 by microbial action to produce biofuel i.e., biogas, bioethanol, and bio-diesel. Biological
631 processes are preferred for waste having a high percentage of biodegradable matter and high
632 level of moisture content, which aids microbial activity. The main technological options
633 under this category are AD (or bio-methanation) to produce biogas and fermentation to
634 produce biofuel like ethanol [11, 18].

635 **5.4.2.1. Anaerobic Digestion**

636 Organic matter is degraded by bacteria in controlled anaerobic conditions to generate biogas
637 i.e., mixture of CH₄ and CO₂ and traces of water vapor, H₂S, NH₃, etc. The AD process is
638 composed of series of 4 stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis
639 [72]. Controlling parameters are volatile content, temperature, pH, and carbon to nitrogen
640 (C/N) ratio. The lignocellulosic organic matter is undesirable for AD process without
641 adequate pretreatment, as its hydrolysis is difficult due to the presence of lignin [66, 73, 74].
642 It is capable of generating 300-400 m³ biogas per tonne of VS of organic fraction of MSW
643 [18]. One tonne of MSW composed of 60% organic matter and remaining is moisture which
644 may produce 150 kg of methane through AD process. Purified biogas after removing CO₂
645 and H₂S gas can be used as transportation fuel, called as Bio-CNG [68]. AD of untainted
646 food waste has attractive option of management, nutrient recycling and bio-methanation
647 having potential of 410-530 ml biogas/g VS of food waste [75].

648 **5.4.2.2. Landfill Gas Recovery**

649 Complex biological and chemical decomposition of organic matter of MSW dumped results
650 in landfill gas production. Landfill gas emissions composed of mainly methane and carbon
651 dioxide gases. Waste composition (primly organic fraction), moisture content, waste age, ash
652 content, temperature and precipitation are major factors affecting the rate of methane gas
653 production. Landfill gas has methane potential of 100 m³/tonne of organic fraction of MSW
654 which is capable of being trapped and utilized as green energy production [76]. Landfill
655 accounts for 13% of global CH₄ emission considered as one of the major anthropogenic
656 methane emissions [289]. Its reduction and recovery consequently reduce GHG emission. If
657 landfill gas could be recovered, it is capable of generating 72 MW of electricity in India [5].
658 Since most of the landfill sites are not designed considering recovery of landfill gas, it is
659 infeasible to trap landfill gas and therefore its on-site burning is chosen [289,76,77].

660 Standard protocols used internationally for landfill gas estimation are first order
661 decomposition models i.e., LandGEM, mass balance model, modified triangular method
662 developed by Intergovernmental Panel on Climate Change. These models need to incorporate
663 meteorology data for site specific estimation. The on-field methods are flux chamber
664 technique, vertical radial plume mapping and differential absorption LiDAR techniques
665 [77,78]. Flux chamber method has been used for estimating CH₄ and CO₂ emission fluxes
666 which are 68 and 92 mg/min/m² respectively, which are severe in summer in comparison to
667 winter season for northeast city Guwahati [77]. A specific model has been developed for
668 methane estimation from landfill sites in Indian climatic conditions, which is validated in
669 three different climatic cities: Shillong, Jaipur and Kolkata [78].

670 RDF, waste to energy and LFGR methods involve renewable energy recovery from
671 MSW through clean development mechanism projects, as they can result into 40,308-
672 1,252,206 tonne of CO₂ equivalent reduction in GHG emission, which will bring carbon
673 credits and make the projects financially attractive [79].

674

675 **5.4.3. Energy and economic aspects of waste to energy techniques**

676 The specific energy potential of waste to energy technologies have been summarized in Table
677 4 [55, 68, 80]. On the basis of these energy potentials, further calculations were done to
678 estimate the total saving of diesel fuel as well as GHG emissions for using the energy from
679 these plants to replace the diesel for power generation. As reported by Prajapati et al. [55], 1
680 tonne of organic fraction of MSW has the potential to generate 192.582 m³ biogas through
681 AD. 1 m³ of biogas generates 2.04 kWh electricity with 35% efficiency [80]. Utilizing diesel
682 for heat and power generation results in GHG emissions of 2.68 kg CO₂ per L of diesel
683 burned [81]. These emissions can be saved by replacing the diesel from biofuel generated
684 from organic fraction of municipal waste. Similarly, GHG emission from landfill of MSW is

685 1230 kg of CO₂ per tonne of MSW [82]. These GHG emissions from landfills can be saved
 686 by using waste to energy technology.

687

688 Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy

689 Technologies

Technology	Specific Energy potential (kWh _e /tonne)	GHG emissions and cost savings				
		Diesel Fuel saved (L)	USD (\$)	GHG from Diesel Generator (kg of CO ₂)	GHG from landfill (kg/tonne)	Total GHG saved (kg of CO ₂)
AD	393*	90.36	106.62	242.16	1230.00	1472.16
Incineration / RDF	544	125.12	147.64	335.32	1230.00	1565.32
Gasification	400	92.00	108.56	246.56	1230.00	1476.56
LFGR	163	37.54	44.29	100.60	1230.00	1331.60

690 *kWh/tonne of Organic fraction of MSW

691 For cost analysis of these technologies, the key parameters to be considered are: cost
 692 of land acquisition, technology installation, feedstock, operation and maintenance cost as
 693 well as labor cost. From economic assessment perspective, incineration technique is the more
 694 suitable choice as compared to complex gasification technology as it requires low cost for

695 implementation and installation. Gasification has the operational cost of around 0.250 million
696 USD/day. Still, gasification is the most attractive technology considering environmental
697 assessment as it can reduce more than 3208 TPD of carbon emissions [83]. In India, most of
698 the gasifiers uses coal, agricultural, and agro-industrial waste. Therefore, the MSW with
699 similar energy content can also be used as a co-fuel in appropriate blend for energy
700 production. However, further research and optimization of this strategy is required to reduce
701 its capital cost. Hybrid technologies can also be explored for combining MSW conversion
702 with other renewable energy technologies for making MSW viable as fuel. A recent study
703 suggested a hybrid solar-biomass system in which AD of MSW was combined with
704 concentrated photovoltaic to generate heat and power from the system [84].

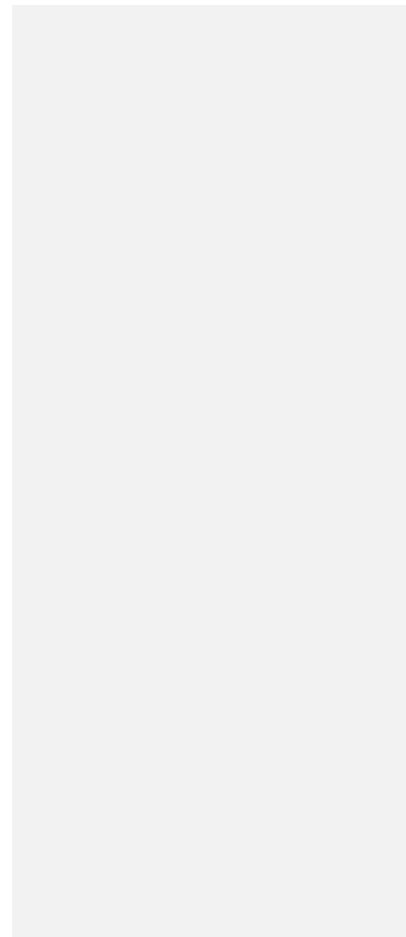
705 A biomass RDF plant feasibility was evaluated with net present value as profitability
706 method and also sensitivity analysis performed to evaluate critical factors like pellet price,
707 capacity utilization and annual working hours for plant economy. The study concluded a
708 minimum selling price as USD 120 per tonne of pellet for plant feasibility [85].

709 In developing countries like India, the economic viability of waste to energy technology
710 requires comprehensive study of cost parameters for initial investment, cash inflow and
711 outflow estimation as well as sensitivity analysis of influencing parameters. There is a scope
712 of techno-economic evaluation of waste to energy technologies using economic metrics net
713 present value and levelized cost of energy considering economic value of produced
714 electricity, thermal energy and products, and specially accounting ecological benefits,
715 reduction in current MSWM costs.

716 Table 5: Pros and cons of different waste to energy techniques [10, 334, 68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	<ul style="list-style-type: none"> • Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume 	<ul style="list-style-type: none"> • Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	<ul style="list-style-type: none"> • Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning 	<ul style="list-style-type: none"> • Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	<ul style="list-style-type: none"> • Production of fuel oil 	<ul style="list-style-type: none"> • Heterogeneity in MSW • Char removal is important • Yield stream is complex

Biological conversion	AD	<ul style="list-style-type: none"> • Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent) • Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer • Control GHG emissions, with net environmental gains are positive • Potential for co-digestion with agricultural and industrial organic wastes • Less monitoring is required • Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill 	<ul style="list-style-type: none"> • Requires organic waste segregation • Not suitable for complex organics, oily, or lignocellulosic materials • GHGs, fouling, and fire threats if leakage is present
	LFGR	<ul style="list-style-type: none"> • Least cost option • Collected gas can be used power generation, and thermal application • Reduce environmental and health impact, reduce GHG emissions 	<ul style="list-style-type: none"> • Expertise and monitoring required • Higher transportation cost and need larger land area • Leachate problem if landfill is not scientific



718
719

5.5.Application of optimization models

720 Mathematical and optimization models robustly used for planning and optimizing the
721 MSWM infrastructure to make MSWM as sustainable management reducing usage of fossil
722 fuels. Extrapolation of past data is inaccurate and unreliable way for forecasting of waste
723 generation rate, as it greatly affected by socioeconomic factors whose selection should be
724 significant to the local situation. Mathematical modeling methods of solid waste streams for
725 the precise prediction of waste generation and its rate have been benefitted the MSWM in
726 terms of viable future planning. Models concerning generation of waste having key variables
727 of socioeconomic factors like household size, waste volume, education level of households,
728 income level of households, and environmental awareness, etc. in a district area, and in a
729 similar way over the country. Linear regression technique is used to develop model the
730 forecasting of biodegradable and non-biodegradable waste generation rate and also analyzing
731 the accountable variables in Dhanbad city [86]. Waste collection streams data: mixed waste,
732 source separated waste, and treatment decisions also used for modeling of waste prediction.
733 Models include mostly correlation and regression models, single regression analysis and
734 multiple regression analysis, system dynamic, and artificial intelligent system (genetic
735 algorithm, artificial neural network, and fuzzy logic) for multivariable analysis [87].

736 Nganda [88] developed a mathematical model actings as a technique to optimize the
737 use of management facilities (like number of trucks, incineration plants, landfill capacity,
738 etc.) to reduce total waste management cost and ensuring optimal use of resources. It results
739 to provide suitable information in decision-making to have a planned and efficient waste
740 management system. Same model was used in Hong Kong, waste streams between collection
741 centers, replacement truck warehouse, incinerators, and landfill were formulated using mixed
742 integer programming for identifying the number of trucks required between two points and
743 same in the whole system and waste amount reduced by 42% in landfill with their present

744 strategy [89]. In a similar way, management facilities can be minimized by using
745 mathematical models in Jaipur scenario with existing operating facilities.

746 An integrated model of geographic information systems (GIS), equation-based model
747 and agent-based model effectively used to minimize collection cost by 11.3%, by reducing
748 travel length and time making efficient collection and transportation system [90]. Das and
749 Bhattacharyya [91] proposed an effective MSWM in Bidhan Nagar municipality under
750 metropolitan Kolkata city, by optimizing length route in its transportation using travelling
751 salesman problem. Travelling salesman problem can be robustly used for optimizing the path
752 length for waste transportation amongst the waste source, collection points, transfer stations,
753 treatment facility or landfill, will majorly reduce the management cost and emissions from the
754 transportation part. Cost effective collection and transportation process considering the
755 locations of dustbin, transfer station, road network, composting unit and dumping site, is
756 optimized with help of GIS and remote sensing in Vellore city of India, and achieving 59.12%
757 reduction in travel distance in the transportation [92]. Thus, reducing natural resource
758 consumption and making the management as sustainable approach.

759 **5.6. Application of life cycle assessment tools**

760 Different MSWM strategies can be compared and evaluated by using LCA tool which helps
761 in determining the environmental implications, energy consumption and cost of the different
762 combination of management strategies [93-95]. LCA makes it easier to identify the processes
763 which have a significant impact on the environment. SimaPro, GaBi, WISARDTM and
764 EASEWASTE are widely used software for LCA.

765 Babu et al. [63] evaluated 4 disposal scenarios in Bangalore city: open dumping,
766 landfilling without gas recovery, landfilling with gas recovery and BLF to find out
767 sustainable and economical disposal using LCA tool. The study revealed BLF as best option
768 with least Global Warming Potential (3335 kg CO₂) and photochemical ozone creation
769

770 potential (0.379 kg) per tonne of waste, and faster waste stabilization inducing more energy
771 recovery from MSW and also with lesser payback period (50 years) than others. Another
772 study assessed the cost and environmental impacts of 4 management options under LCA tool
773 in the selected wards of Bangalore: 1. Existing system i.e., recycling, composting and rest of
774 MSW transported to landfill site; 2. With optimal route transportation; 3. Vermicomposting
775 of 62% MSW (biodegradable) and rest landfilling; 4. Incineration of entire waste. The results
776 of the study showed that the second option with optimal route transportation and least amount
777 required USD 409750 per annum was the best on the basis of ecological, economic and social
778 aspects [96].

779 LCA performed for integrated MSWM in Delhi concluded that the recycling facility
780 has negligible emissions and energy consumption. Landfilling has comparatively less
781 negative environmental impacts in the beginning year as compared to incinerators. However,
782 it produces highest GHG emissions among all MSWM afterwards [367]. For the same city,
783 Bohra et al. [97] compared 12 different integrated MSWM scenarios involving RDF, AD,
784 composting and sanitary landfilling including existing MSWM i.e., 9% composting and rest
785 to landfill site as baseline scenario. While the global warming potential (226.92 kg CO₂ eq.)
786 was revealed to be least for the scenario having major diversion of organic waste from
787 landfilling to treatment facilities to RDF pelletisation (16%), AD (16%) and composting
788 (10%).

789 A study in Mumbai city compared six different scenarios including the current
790 practice of open dumping with partial BLF and other five integrated approaches of different
791 combinations of recycling, AD, composting, incineration and landfilling with 50% gas
792 recovery. The study reported least GHG (930.01 kg CO₂ eq. per tonne) emission for the
793 combination of recycling, AD and landfilling [323]. LCA study carried out in non-metro city
794 Dhanbad compared four management strategies of collection + transportation + landfilling;

795 recycling + open burning + open dumping + landfilling without energy recovery (LFWER);
796 composting + LFWER; and recycling, composting and LFWER. It concluded that the
797 management strategies comprising recycling, composting and landfilling without energy
798 recovery had the least environmental impacts (global warming potential - 3430 kg CO₂;
799 terrestrial ecotoxicity - 0.872 kg C₂H₄ eq.; acidification - 4.63 kg SO₂ and eutrophication 1.99
800 kg PO₄³⁻ per tonne of MSW) as recyclables, organic and inert materials subjected to
801 respective treatment or disposal facility [56].

802 The outcomes of the environmental evaluation of different MSWM scenarios in a city
803 provides crucial information to decision makers when planning sustainable waste
804 management strategies. LCA study of MSWM in Jaipur city will greatly help to identify and
805 quantify the environmental impacts caused either by waste or different treatment processes.
806 This may help the managing authorities to choose the best and environmentally appropriate
807 process among the possible treatments.

808 **6. Conclusions**

809 Jaipur city faces significant problems including unregulated landfilling, inability to enforce
810 MSW (management and handling) regulations and insufficient public involvement in the
811 management process. The study inferred that composting and unsanitary landfilling are the
812 most prevalent method for waste disposal in Jaipur as well as other Indian cities with no
813 proper installed facilities for waste conversion. Even the installed facilities are less suitable
814 and inefficient due to the lack of segregation of waste during collection.

815 On the basis of this review, the key conclusions and recommendations for MSW
816 management for Jaipur cities can be summarized as below:

- 817 • Different stakeholders (municipality, private sectors, public and informal sectors) are
818 required to work together by taking specific responsibility in MSWM stages aiming to
819 have maximum material and energy recovery from MSW.

- 820 • There is a need to actively work with local communities to raise awareness for waste
821 segregation processes.
- 822 • There is a large scope and urgent need of development of recycling plants, feasible
823 waste to energy technology and scientific landfill in Jaipur complying environmental
824 standards regarding emissions.
- 825 • The mathematical or optimization model can be applied in Jaipur MSWM robustly,
826 which would optimize the resource utilization, minimize management facilities, time
827 and expenditure.
- 828 • LCA study in Jaipur city of practicing or possible MSWM scenarios would be helpful
829 to identify the technology or treatment process having least impact on the
830 environment which should be favored first.
- 831 • More research is required regarding the economic and environmental gains from
832 recycling and energy generation facilities in the context of Jaipur city.

833 **Acknowledgements**

834 Authors are thankful to Department of Science and Technology, (Grant No: Grant No.
835 ECR/2016/000989) and Department of Biotechnology (Grant No. BT/RLF/Re-
836 entry/04/2013) Government of India for providing the financial support to carry out the
837 present study. The fourth author is also grateful to the Royal Academy of Engineering,
838 BBOXX and UCL for supporting her five-year fellowship.

839 **Conflict of interest:**

840 The authors declare that they have no conflict of interest. The authors alone are responsible
841 for the content and writing of the paper.

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1 **An overview of municipal solid waste management in Jaipur City, India - Current**
2 **status, challenges and recommendations**

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26 **ABSTRACT**

27 In developing countries, urbanization and rapid population growth has resulted in a
28 substantial increase in generation of Municipal Solid Waste (MSW). Safe collection,
29 transportation and treatment of MSW are among the major issues for Indian cities. Poor
30 MSW management practices have negative impact on public health, environment and climate
31 change. India currently only treats 21% of MSW while the remainder disposed in unsanitary
32 landfill sites with no recycling and treatment technologies. This paper reviews the existing
33 MSW management practices, challenges and provides recommendations for improving MSW
34 management for the city of Jaipur in Rajasthan, India.

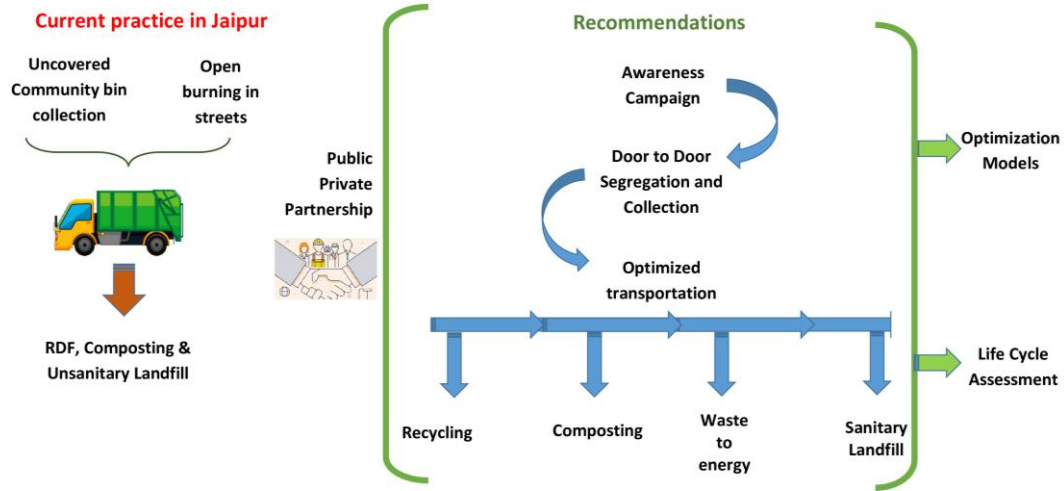
35 Despite being the state capital as well as the top tourist destination in northern part of India,
36 there is no detailed study which reviews the waste management strategies of this city along
37 with identifying the key challenges. The study reveals that the major challenges for MSW
38 management in Jaipur include uncontrolled landfilling, inadequate public participation as
39 well as failings of implementation of MSW legislation and waste conversion.

40 Recommendations for improvement include public awareness campaigns, public-private
41 partnership, investment in lined landfills, recycling and waste to energy techniques.

42 Optimization models and life cycle assessment tools should be employed to minimize cost
43 and the environmental impact of MSW management. This study will provide policy makers
44 and private sector stakeholders to develop strategies for future planning, investment and
45 execution of improved MSW management in Indian cities.

46
47 **Keywords:** Municipal solid waste; Waste to energy; Landfill; Anaerobic digestion;
48 Optimization models; Life cycle assessment

51 **Graphical Abstract**



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68 **List of abbreviations**

1		
2	AD	Anaerobic digestion
3		
4	BLF	Bioreactor landfilling
5		
6		
7	CPCB	Central Pollution Control Board
8		
9		
10	CDC	Centre for Communication Development
11		
12	GIS	Geographic information systems
13		
14	GHG	Greenhouse gas
15		
16		
17	JMC	Jaipur Municipal Corporation
18		
19	LFGR	Landfill gas recovery
20		
21		
22	LCA	Life cycle assessment
23		
24	MoEF	Ministry of Environment and Forests
25		
26	MSW	Municipal solid waste
27		
28		
29	MSWM	Municipal solid waste management
30		
31	NGO	Non-governmental organizations
32		
33		
34	PPP	Private-public partnership
35		
36	RDF	Refused derived fuel
37		
38		
39	SEG	Socio-economic group
40		
41	SPCB	State Pollution Control Board
42		
43		
44	TPD	Tonne per day
45		
46	ULB	Urban local bodies
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49	VS	Volatile solid

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1. Introduction

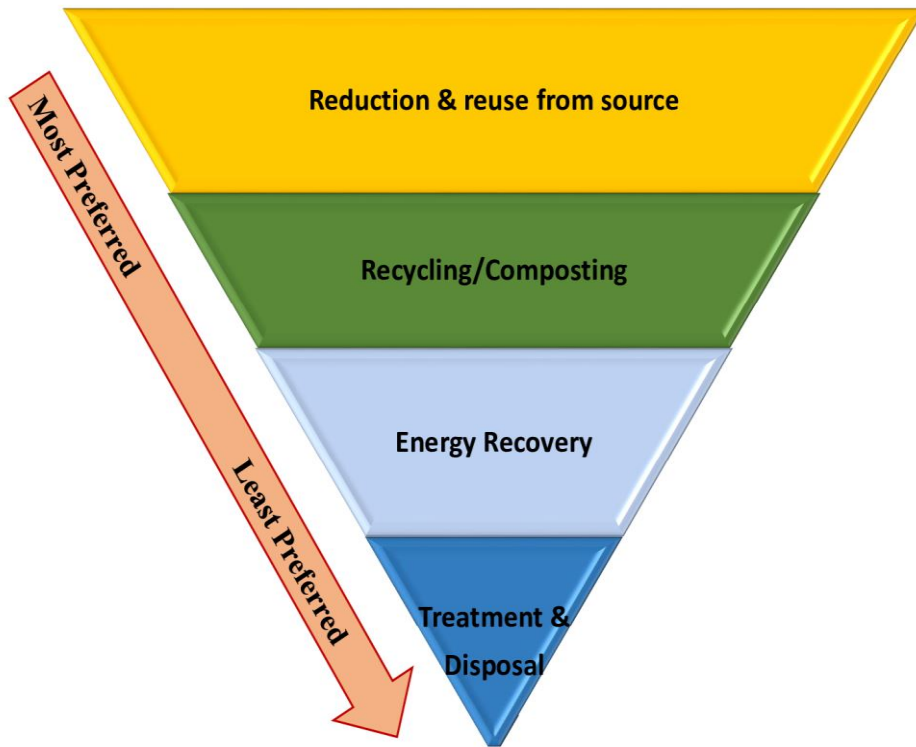
Rapid urbanization, industrialization, and population growth have resulted in substantial increase in rates of solid waste generation in urban centers. As per United Nations, the 52% population of world was urban in 2011 and it is estimated to reach to 67.2% till 2050 [1]. This increase will transform the social structure, living standards, resource utilization as well as waste generation by people. The generation rate of municipal solid waste (MSW) can be directly correlated to the economic growth of a country i.e., gross domestic product and population density [2, 3]. Annual worldwide total solid waste generation is approximately 17 billion tonne per year, and this sector contributes to 16% greenhouse gas (GHG) emissions responsible for global warming [2, 4].

In developing countries such as India, typical per capita, MSW generation rate is about 0.49 kg/day which is lower than the 1-2.5 kg/day waste generation rates in developed countries. In future, waste consumption and generation patterns in developing countries will replicate those in developed nations. Currently, India handles 62 million tonne MSW per year [5]. However, the collection and treatment efficiency of the country is around 90% and 27% respectively. Remaining untreated MSW at present itself is a major problem which would sustain in a disastrous way [6]. Jaipur city having 3.04 million population, is the capital of Rajasthan state where a rise in infrastructure development and living standards has led to waste generation amounting to 1000 tonne per day (TPD) [7, 8]. This quantity of waste is one-third of the total waste generated by entire Rajasthan state.

Most of the Indian cities failed to have the desired level of municipal solid waste management (MSWM) due to the shortage of financial resources and technology, and lacking in sustainable planning and execution. MSWM effectiveness in a city should keep pace with the growth of that city [9, 10]. Increase in waste generation in Indian cities makes the management of MSW and its handling a critical problem. This needs targeted action from

1 98 key stakeholders involved in the management of MSW in any city including Municipal
2 99 Corporation of city, MSW generators i.e., public and private institutions (offices, hotels,
3
4 100 restaurants, markets and other commercial sectors), non-governmental organizations (NGOs)
5
6
7 101 and private contractors. Waste generated in large quantity requires a system of collection,
8
9 102 segregation, storage, transportation, treatment, and disposal. There are several MSWM
10
11 103 method to cut down the volume of the waste such as its minimization from source itself,
12
13 104 waste 3 R's ("Reduce, Reuse and Recycle") strategy, incineration, composting and anaerobic
14
15 105 digestion (AD); however, unscientific or unsanitary landfilling is the most adopted approach
16
17 106 for MSW disposal nationwide as it has been a relatively simple and economical mode of
18
19 107 MSW disposal [11, 12].
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24 108 Figure 1 shows a four-tiered integrated solid waste management hierarchy to guide
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26 109 MSWM decision-making according to the type of waste. Knowledge of composition of MSW
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28 110 is important for selecting the suitable waste processing and disposal practices since MSW
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30 111 volume and its composition differs considerably with the places having changes in food
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32 112 habits, cultural traditions, lifestyles, socio-economic conditions, and climate [4, 13].
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34 113 Integrated MSWM based on varying MSW composition is required to recover materials,
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36 114 compost and renewable energy from MSW and residues to reduce the quantity of MSW
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39 115 reaching landfill sites [12].
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117 Figure 1. Integrated solid waste management hierarchy [14]

118 This study reviews the present status of MSWM for Indian cities more broadly and
 119 specifically for Jaipur city and provides recommendations for improvement. Further, the
 120 study provides the list of waste management technologies adopted in the other cities of India
 121 as well as around the globe to convert the waste to energy. The review further compares these
 122 technologies in terms of energy potential and economic feasibility. The life cycle assessment
 123 (LCA) and optimization done by other studies have also been summarized to elaborate the
 124 applicability of these tools for predicting the most suitable method for implementing the
 125 waste conversion technologies resulting in highest energy yield with minimum emission and
 126 cost. This review would enable regulatory bodies such as the State Pollution Control Board
 127 (SPCB), Urban Development Authority and Municipal Corporation to improve the waste
 128 management processes in the Jaipur city and tackle the issues in systems. Moreover, this
 129 study may also be helpful for the other cities of developing countries around the world which

130 are facing the similar issues to tackle the accumulating waste due to lack of proper treatment
131 method as well as policies regarding them.

132 **2. Current scenario of MSW in India**

133 ‘*Solid waste*’ includes solid or semi-solid domestic waste, sanitary waste, commercial waste,
134 institutional waste, catering and market waste, and other non-residential wastes, street
135 sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture,
136 dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-
137 waste, battery waste, and radioactive waste” [15]. MSW (Management and Handling) Rules,
138 2000 issued by Ministry of Environment and Forests (MoEF), Government of India, regulates
139 appropriate collection, segregation, transportation, treatment and disposal of solid waste.

140 Under these rules, Municipalities are authorized to implement measures for improving MSW
141 and submit annual reports to the Central Pollution Control Board (CPCB). Parameters such as
142 the quality of ambient air and groundwater, leachate, compost and standards of incineration
143 are required to comply with respective standards and monitored by CPCB as well as SPCB.
144 Currently there is a gap between regulation and enforcement in most Indian cities. [10, 16,
145 17].

146 Key features in revised rules i.e. solid waste management rules 2016, extended to
147 urban and industrial areas, are mandating the solid waste source segregation to have its
148 recovery, reuse and recycle; integration of informal system i.e. unauthorized rag pickers and
149 waste dealers into the formal system; prohibition of waste throwing, burning, and burying in
150 public spaces, if violation of rules found, generator will have to pay ‘spot fine’; manufactures
151 of sanitary products should provide the suitable wrapping material with it for its safe
152 disposal; introducing partnership concept for bulk waste producers (hotels, institutions,
153 restaurants, event organizers, new townships and societies) to segregate, sort and handle the
154 generated waste by associating with local bodies; all brand owners or manufactures shall

155 have to provide the required financial aid to local authorities for MSWM; non-recyclable
 156 waste (Calorific Value ≥ 1500 kcal/kg) should be used directly for energy production or as
 157 input for generating refused derived fuel (RDF) [15].

158 Being one of the fastest growing economies and the second most populated country in
 159 the world, India is facing the upsurge in MSW generation in the cities. With changing
 160 lifestyles, Indian cities are now generating more MSW with an estimated increase of 1-1.33%
 161 per annum. Currently in India, only 15-20% of MSW is segregated, 21.45% of MSW is
 162 processed or treated and remaining 78.55% MSW disposed at unsanitary landfills. Open
 163 dumping was 90% in 2008 and showed only 11.45% waste diversion from open dumping in
 164 last decade [10, 18]. Moreover, the projection of MSW generation for urban inhabitants
 165 revealed that the MSW generation rate (kg/capita/day) is approximately two times of the
 166 urban agglomeration rate [19].

167 MSW contains 50-60% organic fraction composed of majorly food waste and its
 168 untreated disposal i.e., uncontrolled decomposition causes rotting, severe impacts on local
 169 public health and foul odor due to methane generation which is a GHG [20,21]. Reliable
 170 characterization of MSW requires a large number of MSW samples being analyzed over the
 171 cities of India. Physical composition of MSW for Indian scenario is shown in Table 1. MSW
 172 collected from different cities of India contains approximately 40-62% biodegradable content
 173 and 11-24% recyclable content [17]. Average household MSW composition consists of
 174 around 70% organic fraction [22-24].

175 Table 1: Physical composition (%) of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio

1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	45	12	43	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

176

MSW generations in major metro cities of India are reported by CPCB are shown in Figure 2. It exhibits trend of waste generation per day in last 10 years (in the year of 2004-05 and 2015-16) in major metro cities. Larger metro cities such as Mumbai and Delhi have a very high rate of waste generation and are currently leading in waste generation with up to 11000 and 8700 TPD waste generation respectively. In Delhi, openly dumped MSW was observed to be the highest in the low socio-economic neighborhood with 61 kg per capita per person per year [25].

Socio-economic conditions i.e., education level, family income, occupation and household size play significant role in MSW generation in the society. A study performed in Dhanbad city, India regarding these factors divided society into five socio-economic group (SEG) based on above mentioned four factors. It concluded that middle and lower middle SEG has the highest per capita waste generation due to comparatively more family members. Comprehensive study of waste composition in different SEGs shows high food and plastics wastes generation from higher SEG, whereas lower SEG generates lesser food waste due to

191 different standard of living [26]. Impact of socio-economic factors on MSW generation in
192 Bangalore city shows positive relation with family income, whereas negative relation with
193 education level and household size [23].

194 In Indian system, the residential solid waste in the household is stored in a single
195 plastic container (16-20 L capacity) in a mixed form including both dry and wet waste. The
196 collected waste is then dumped by the residents to the nearby community bins (4.5-6 m³
197 capacity, metallic or concrete) without segregation. The door-to-door collection is practiced
198 only in few wards of metro cities, through handcarts or tricycle with the help of NGOs.
199 Residential and market waste is also dumped on the open roads either due to negligence of
200 waste generator or inadequate presence and capacity of community bins. All street and road
201 wastes are collected by sweepers using wheelbarrows and thereafter dumped it into nearby
202 community bin. Community bins are mostly uncovered i.e., easily accessible to rag pickers
203 and animals, they litter the waste around the bin in the search of recyclable waste and food
204 respectively, thereby dispersed waste on the street and creating the unhygienic conditions.
205 The dispersed waste sometimes reaches to the nearby drainage system causing it to be
206 blocked. The major problem for municipality arises from low and middle-income residential
207 areas where the waste is dumped on narrow streets, or behind houses instead of putting it in
208 nearby bins [24, 27, 28]. Due to this poor-practice, these areas remain inaccessible to waste
209 collecting workers for some days.

210 Private contractors are involved in metro cities for transportation of MSW from
211 community bins to dumping sites. Tractors, ordinary trucks, pay loader, compactors, tippers
212 and dumper placer vehicles are usually used for waste transportation. Though many of them
213 are outlived which run with low efficiency and high fuel consumption [19, 29, 30]. Except

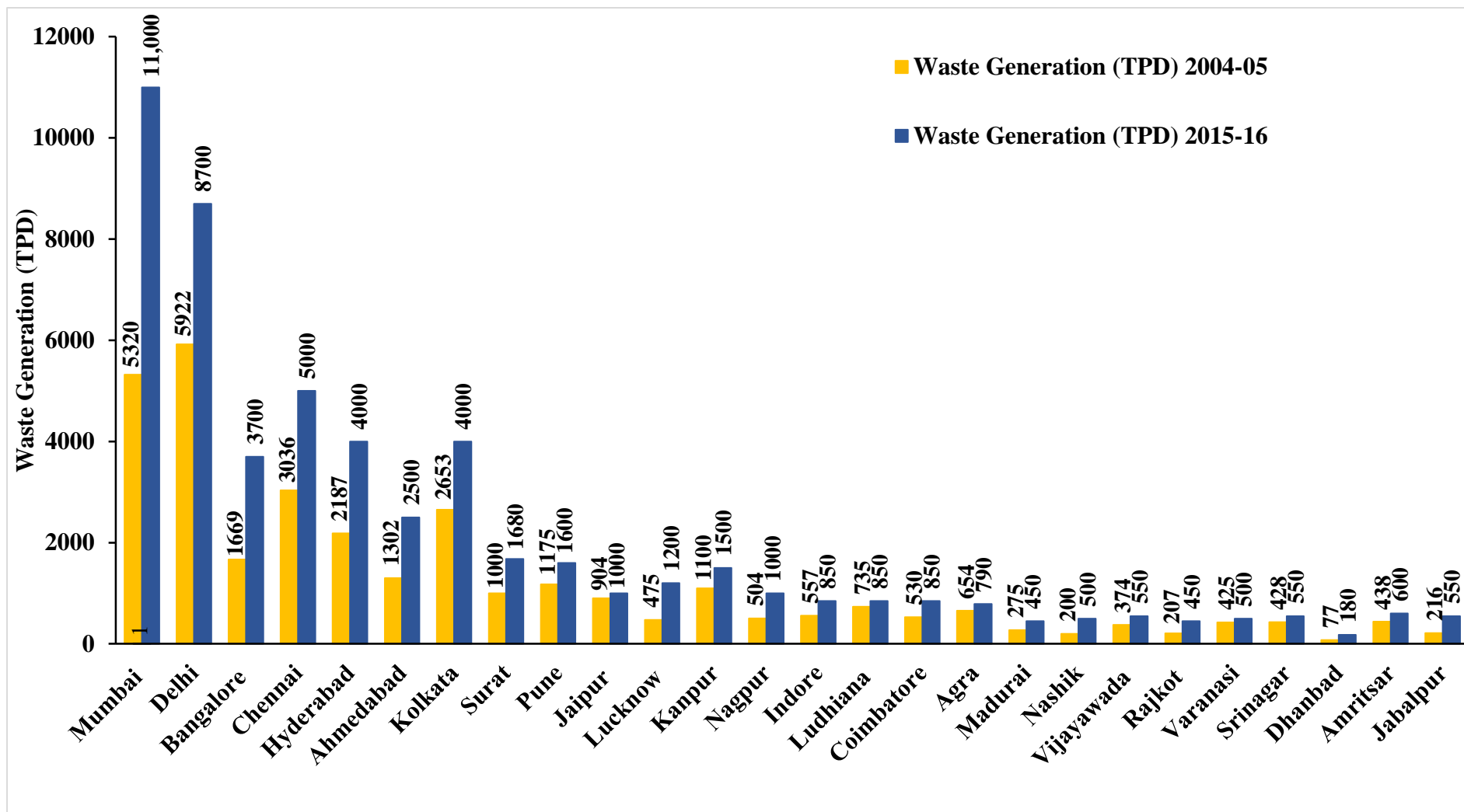
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214 few cities like Delhi, Pune and Hyderabad, all Indian cities transport MSW to the dumping
215 sites where uncontrolled landfilling is practiced (Table 2).

216 Current management strategies adopted for handling MSW in some major Indian
217 cities are highlighted in Table 2. Almost all cities have no source segregation of MSW while
218 some cities perform MSW segregation by engaging workers. Few cities have poor collection
219 efficiency and no source segregation is performed except Bangalore and Pune. Composting
220 and unsanitary landfilling is a very common strategy practiced for waste management in most
221 of the Indian cities. Pune is the only city where waste management practice is appreciably
222 effective by integrating segregation, composting, waste to energy plants and scientific
223 landfilling. There are less significant research updates regarding MSWM of Northeast Indian
224 cities. In Dibrugarh town of Assam, open dumping site is located near the Brahmaputra river
225 contaminating the river ecosystem as well as affecting the health of humans and animals. The
226 health hazards become more severe during rainy seasons causing water pollution and water-
227 borne diseases [29].

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230 Figure 2. MSW generation trend in major Indian cities [7]

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231 Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,27]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,31]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R's hierarchy of management and waste to energy technology	[32]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[33,34]
Delhi	Y	Y	Y	R- Informal, C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[35,36]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[37,38]
Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[39]

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Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[40]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[41]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[42]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[43,44]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[45]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]
Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[46]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[47]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[31,48]
Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[49]

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Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[31]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[31,50]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,26]

232 Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary
 233 Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective
 234 strategy, (no.) –number in the bracket represents the number of respective facilities.

3. Municipal waste management in Jaipur city

The previous section provided status of waste management in some of the significant cities of India. The waste management strategies followed by these cities are largely based on the MSW composition which in turn vary according to the lifestyle and eating habits of citizens, food resources as well as the climate of the city [51]. While, these studies of other cities of India are helpful in solving the specific waste management issues; the MSWM model of one city cannot be implemented as it is to another city of India due to varying climate conditions and lifestyle which changes drastically in India.

Jaipur city, capital of Rajasthan the largest state of India, is one of the future smart cities of India and famous for its tourism and hospitality. In 2019, the city has been declared as UNESCO world heritage site. As shown in Figure 2, It is also a major city in north India along with Delhi, Kanpur and Lucknow with high waste generation rate. With an area of 467 km² and the entire city is divided into 91 wards. Since 2011, the wards are distributed in 8 Municipal Corporation zones: Vidhyadhar Nagar, Civil Lines, Mansarovar, Sanganer, Moti Dungri, Hawa Mahal East, Hawa Mahal West and Amer. Jaipur Municipal Corporation (JMC) has the constitutional responsibility of collection, transportation, treatment and safe disposal of MSW generated in the city. Currently, Jaipur city has MSW flow in its management process as shown in Figure 3.

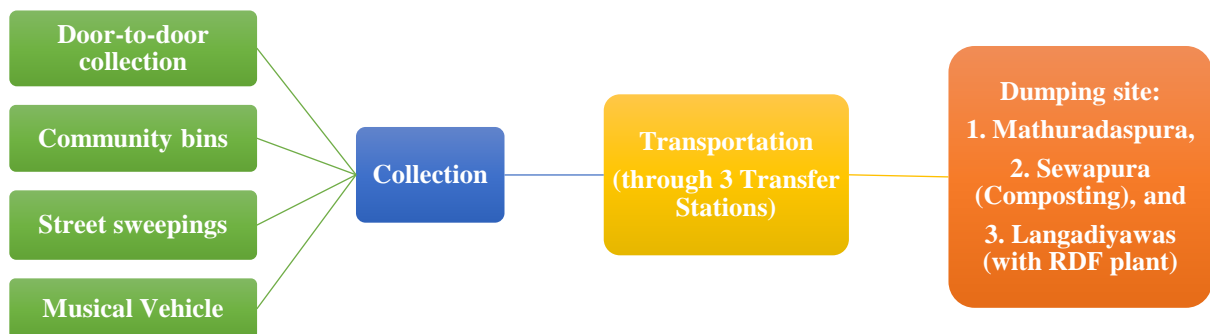


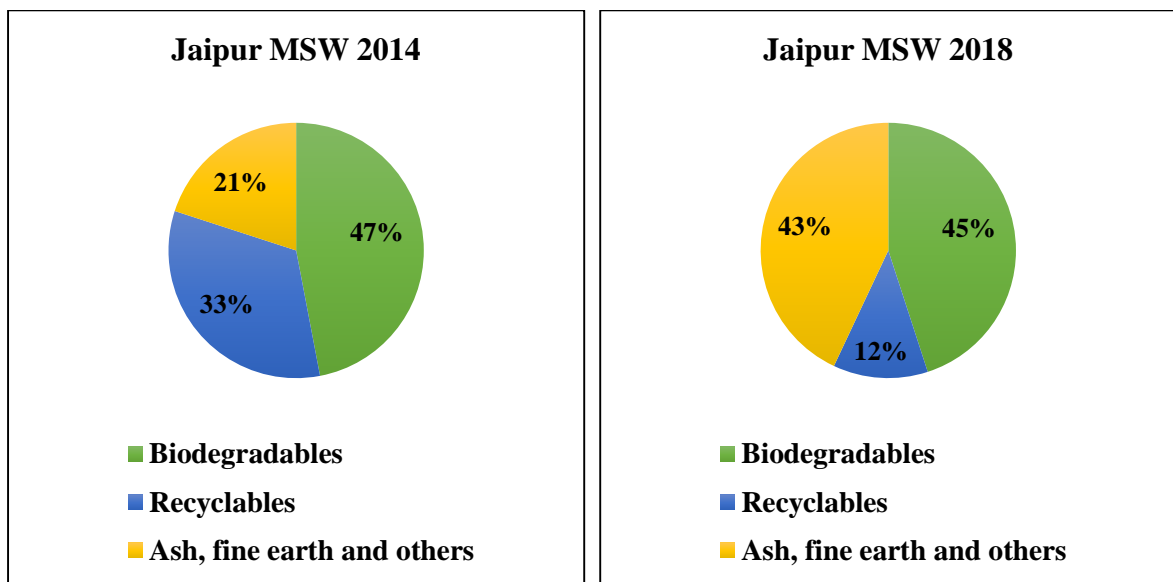
Figure 3. MSW flow in Jaipur [27]

255 **3.1.MSW composition and characteristics**

256 MSW in Jaipur comprises three key components [33, 52]:

- 257 1. Biodegradable (organic waste): Food waste, garden waste (grass, fallen leaves and
258 tree trimmings), wood etc.
- 259 2. Recyclable waste: Paper (paper is classified as organic only when it is tainted by
260 organic material), cardboard, plastics, metals, glass etc.
- 261 3. Inert and other wastes: Textiles, leather, paints, rubber, multi-laminates, medicines,
262 sanitary products and inert materials (stones, silt, ash and inorganic material).

263 MSW composition and chemical characteristics viz. moisture content, volatile solids (VS),
264 calorific value and elemental composition etc. of MSW in Jaipur city are shown in Figure 4
265 and Table 3 respectively. As shown in Figure 4, approximately 45% portion of MSW
266 collected in Jaipur was reported in 2018 to be biodegradable while 43% content was
267 composed of ash and fine earth particles [17].



271 Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

272 Table 3: Chemical characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV	C	H	N	S	O	P	Potash
			(kCal/kg)						(P ₂ O ₅)	K ₂ O
Values (%)*	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

*Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids, CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen, P=Phosphorus.

3.2.Cleaning and collection

The door-to-door waste collection method is not adopted in Jaipur city by JMC, and rather some wards are implementing it through informal sectors by paying them reasonable amount per month. Sometimes, a portion of MSW left unattended and remained as open dumped waste. Jaipur city has collection efficiency of MSW around 85% [11, 12]. In this collected MSW, 18-24% contents are recyclable including paper, plastic, rubber, ferrous and non-ferrous metals. However, 15% out of total recyclable waste is collected by rag pickers for their livelihood and traded to scrap buyer informally [10].

JMC staff require more health inspectors and sweepers for respective wards as per a study conducted [11]. Permanent and temporary street sweepers on daily wage basis are deployed for cleaning the city. Street sweeping and community bins are the primary collection methods of the waste. Total 1794 community bins of 3 sizes i.e., 1.1 m³, 3 m³ and 7 m³ capacity have been installed [11]. Still, many wards are left without having any garbage container causing more disorder with respect to waste collection.

It has been observed that the city does not segregate the waste at source and dump it into the municipal bins, open spaces and drains. Many of the community bin's waste are scattered around by animals which causes unhygienic conditions. Some ward's road cleaning is performed daily while remaining wards are cleaned periodically i.e., once or twice a week.

295 Street waste cleaning, de-silting the surface drains and collection tasks performed by
296 sweepers using a wheelbarrow and transferred to community bins. Since recyclable waste
297 segregation is not practiced, it is usually found mixed in the community bins [11].

298 **3.3.Transfer station and transportation**

299 The collected garbage from community bins is transported to the secondary storage points or
300 transfer station and then to the disposal sites using dumper placer and compactor vehicles.

301 Currently, Jaipur has 3 transfer station at Lal Dungri, Vidhyadhar, and Jhalana having
302 capacity of 400, 250, and 150 TPD respectively. Uncovered or open body type trucks tend to
303 spill waste gradually on the road causing unhygienic conditions on the roads. A vehicle's
304 waste collection frequency is around 2-4 times daily due to lack of transfer stations in other
305 zones. Therefore, 3 more transfer stations are proposed in Mansarover, Bambala Pulia and
306 Sushilpura to cover the zones which are far away from disposal sites and to minimize the
307 time, money and fuel consumption during waste transportation. Transportation system alone
308 consumes more than 60% funding from the total fund assigned for the MSWM [11, 12].

309 **3.4.Treatment and disposal facilities**

310 For MSW disposal, Jaipur city has currently 3 dumping sites: Mathuradaspura,
311 Langadiyawas, and Sewapura as shown in Figure 5 on Jaipur map and main features are
312 discussed below [11, 12].

- 313 1. Mathuradaspura dumping site: It is located at 17 km distance from the main city,
314 having capacity up to 400 TPD of MSW with total area 0.285 km².
- 315 2. Sewapura dumping site: It is situated at 20 km from the city, with site area 0.324 km²
316 having a capacity of 300 TPD. It has a compost processing facility of 350 TPD
317 operated by Infrastructure Leasing & Financial Services Limited.
- 318 3. Langadiyawas dumping site: It has a total area of 0.782 km² out of which 0.065 km²
319 is allotted for RDF processing facility and 0.16 km² for Sanitary Landfilling (under

320 construction). M/s Grasim Industries constructed an RDF processing facility
1
2 321 producing 150 TPD RDF from 500 TPD MSW at Langadiyawas and transported to a
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4 322 company UltraTech Cement Limited in Neemuch, Madhya Pradesh, to generate
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7 323 energy for cement production.
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9 324 MSW undergoes many transformations before converting to RDF such as removal of
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11 325 dangerous and large items (i.e., big stones, batteries, dead animals, machines) by workers and
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13 326 then load into pre shedder to have granular size of 0-200 mm. Subsequently, the shredded
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15 327 waste is sent into an integrated conveyor installed magnetic separator removing all metals
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17 328 from waste. Further separation of sand and grit from organic waste is carried out by trommel
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19 329 screen. The heavier pieces like glass and ceramics are passed through the ballistic separator.
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21 330 Thereafter, organic portions are sent for further size reduction up to 0-50 mm, resulting in
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23 331 mixed waste as raw materials for RDF. This garbage for RDF has low calorific value, so
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25 332 plastics purchased from Sainath Enterprises are added. This RDF application in cement plant
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27 333 brings carbon credit to the firm and 9-15% saving of coal burning. This facility recovers 5-
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29 334 6% RDF instead of 30% from MSW received because of the inadequate technology and
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31 335 mixing of construction debris with the MSW [27].
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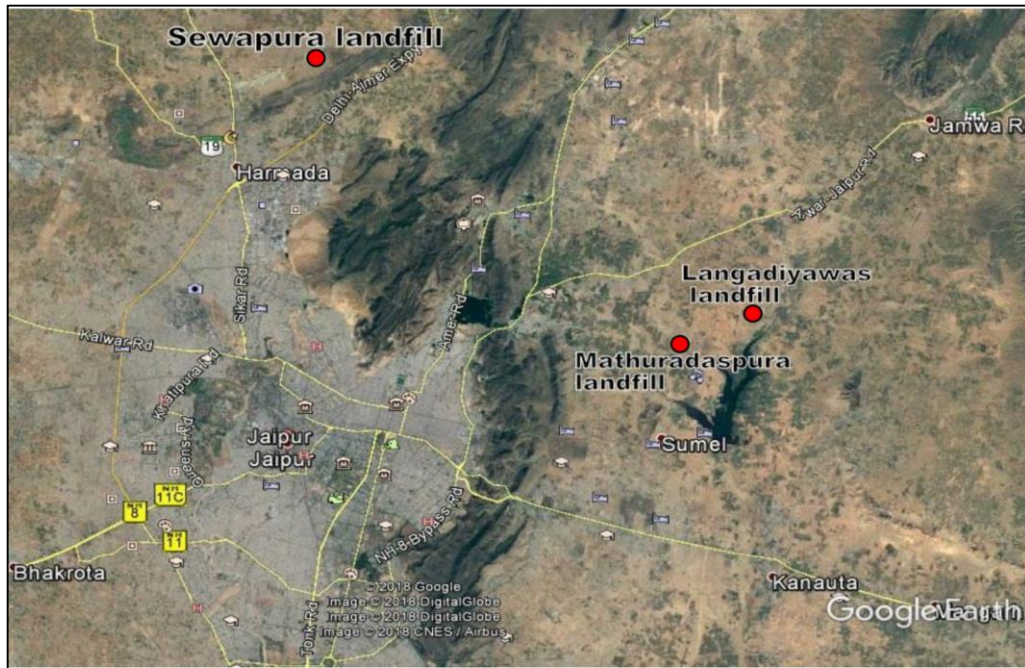


Figure 5. The landfill locations in Jaipur city [11, 12]

Currently, total 500 MSW TPD i.e., 50% of total MSW treated either as composting or converted into RDF. JMC proposed a waste to energy plant in Mathuradaspura site for remaining MSW which is being disposed unscientifically at this moment [11]. Uncontrolled dumping is practiced in all of 3 disposal sites, prone to leachate production which can cause ground and ground water pollution and may create vectors for propagating various diseases. Moreover, these sites are without pollution monitoring facilities, proper fencing and fly control [12]. Ground water from eight sites near Mathuradaspura were sampled and some of them show high content of naturally available fluoride and total dissolved solid which may cause fluorosis and gastro intestinal irritation respectively to the nearby residents [11, 12].

3.5. Private-public partnership (PPP)

JMC has been using PPPs model to sub-contract some of its MSWM responsibilities to individual corporations (NGOs or private companies). Two private companies are handling composting and RDF treatment facility in Jaipur MSWM [11]. Two NGOs the Centre for Communication Development (CDC) and Satya were engaged on MSWM related activities.

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352 Satya provided labor in Jaipur to lead a successful program in handling the waste and
353 dumping the MSW. Satya was also engaged in door-to-door collection in Vaishali Nagar,
354 Chitrakoot and ward no.20 with charging INR 20-30 a household per month in 2005-07.
355 However, due to poor facilitation from JMC, difficulties in payments, inadequacy in
356 management, the partnership was discontinued after two years of the contract. Another NGO,
357 CDC started few projects for better urban MSWM regarding collection and transportation.
358 Again, JMC could not support their projects financially and hence CDC ceased their work
359 and focused on other social services in Jaipur city [27].

360 **3.6. Case studies**

361 Singh [12] carried out a survey of two regions of Jaipur city viz. Tonk Phatak and Malviya
362 Nagar and concluded that stronger social network or high-income areas have better MSWM
363 or living condition than low-income societies. Here, social network means friendship, social
364 contacts and interactions among the influencing people and common people. Dissatisfaction
365 level found to be high in Tonk Phatak area as a result of lack of community bins and waste
366 collection system with respect to MSWM. While, Malviya Nagar was found to be more
367 socially connected and where MSW was carried away daily. Tonk Phatak area people were
368 willing to pay some money to get their locality clean and hygienic. On the other hand,
369 Malviya Nagar locality somewhat disagreed for the same. The survey in these two areas
370 found that 90% people do not have awareness about the fate of waste.

371 A case study performed by Gandhi et al. [20] in Jaipur metropolitan revealed the
372 amount of food waste generated from hotel sectors. The study reported that food waste (14.9
373 kg/day) generation from 4-5 star rated hotels is almost threefold as compared to 2-3-1 star
374 rated and unrated hotels. Only 34% hotels out of surveyed 70 hotels perform segregation of
375 food waste, out of which 84% are of 3-5 rated hotels. An educational institute survey study
376 revealed that MSW generated from the campus consisted of food waste, plastics, paper,

377 metal, glass, and garden trimming etc [53]. Total collected waste was directly transported to
378 the city's dumping site. Segregation was not performed and waste treatment facility have not
379 been adopted within the campus [53]. A feasibility study of organic waste energy potential in
380 another institutional campus shows that the mixed food and green waste has biogas potential
381 of 400-660 mL/g VS of mixed substrate [54]. The study suggested that there was a need for
382 developing composting and AD plant for the organic waste generated within the campus,
383 with segregation of recyclable waste. Another study performed the multi feed anaerobic co
384 digestion of mung bean husk and wheat straw with organic fraction of MSW. The co-
385 digestion was observed to increase 37% methane production with respect to AD of organic
386 fraction of MSW only [55].

4. Challenges pertaining to MSWM in Jaipur

389 The main difficulties with MSWM in Jaipur city are firstly the social negligence from
390 public side to have segregation and proper disposal of solid waste due to either lack of
391 knowledge of its long-term harmful impacts on habitats and environment or their
392 irresponsibility towards their fundamental duty of protecting environment. The second major
393 challenge is governance as the municipal corporation continues to practice waste dumping at
394 the outskirts of the city with no planning and safe waste treatment practices. Unlined and
395 uncovered landfilling is the worst option when accounting its groundwater contamination,
396 land degradation and environmental and health impacts causing from breeding infectious
397 diseases majorly due to leachate and landfill gas. Sometimes, Jaipur city also faces burning of
398 MSW piled in streets or grounds, producing highly toxic gases composed of dioxins, CO,
399 hydrocarbons, volatile organic compounds, oxides of sulfur, and hazardous fumes etc.
400 Municipality and public have not been sensitized about the increasing adverse effects of

1 401 wastes on local environment i.e., contaminating air, water and land making hard for living
2 402 beings to survive [17, 56].
3

4
5 403 Major technical problem for MSW treatment is mixed MSW i.e., non-segregation of
6
7 404 organic waste for its utilization into biogas and compost production which is the most
8
9 405 suitable waste management technique for Indian Scenario. In 2008, India's installed energy
10
11 406 recovery from waste was 86.32 MW and currently in 2021, it is 168.64 MW, which is very
12
13 407 less in comparison to MSW generation rate within the same time period [57, 58]. Biomass
14
15 408 power generation (4831.33 MW in March 2016 to 10145.92 MW in March 2021) by
16
17 409 combustion route and biomass cogeneration in sugar mills in India is highly progressive. On
18
19 410 the other hand, there is no substantial focus on waste to energy conversion techniques in last
20
21 411 13 years even though MSW increment rate has been high [57, 58]. Even many installed
22
23 412 composting, RDF and waste to energy plants have been failed due to insufficient waste
24
25 413 segregation, inefficient management, operational problems like deficient logistical planning
26
27 414 and adequate financing. Other problems in prospects of energy recovery facility are feasible
28
29 415 technologies, inadequate financial support and quality of waste i.e., contamination occurs
30
31 416 during collection and transportation, lack of appropriate storage facility, and lack of expertise
32
33 417 in government. These problems were listed and recognized after consultation with urban local
34
35 418 bodies (ULBs), industries, and academics [20, 59]. Since most of the Indian cities are rapidly
36
37 419 developing, there is a pressing need of effective and sustainable waste management practices
38
39 420 in every city.
40

41 421 **5. Recommendations**

42
43 422 Various feasible and well-practiced techniques in some cities of India as well as at global
44
45 423 scale are recommended in this section to tackle challenges of Jaipur city as well as other
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47 424 Indian cities having similar scenario of MSW quantity and composition.
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425 **5.1. Awareness campaigns to increase public participation**

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2 426 A most prominent stakeholder is community or public and their inclusion at various levels of
3
4
5 427 waste management process will lead to effective as well as efficient MSWM [30]. In general,
6
7 428 “Waste” is supposed to be not useful for people which need to be thrown away. Therefore,
8
9
10 429 the opinion on waste needs to be changed and it should be considered as a resource rather
11
12 430 than waste [27]. For this, firstly JMC needs to organize awareness programs assisted from
13
14 431 NGOs and educational institutes for reducing the MSW at source, making residents aware of
15
16
17 432 waste categories i.e., organic, recyclable, non-biodegradable and other hazardous waste, so
18
19 433 that community would start segregating domestic MSW into biodegradable and non-
20
21
22 434 biodegradable waste. Further, people can be encouraged to start home composting for
23
24 435 gardening purpose along with educating them with potential health impacts from poor MSW
25
26
27 436 management. Awareness programs can be arranged through public group meetings, seminar,
28
29 437 workshops, newspapers, media, radio, and television networks involving active participation
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31
32 438 from local bodies [12, 38].

33
34 439 Food waste generation in different hospitality sectors at hotels and restaurants is high
35
36 440 in a city like Jaipur which is well known for tourism and hospitality. Strategies for mitigating
37
38
39 441 food waste from hospitality sector include: making customers and staff aware through
40
41 442 showing signage and posters regarding reducing the food wastage, imposing fine over food
42
43
44 443 leftovers (possibly well-mentioned in the food menu), management of serving size, serving
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46 444 smaller plates that avoids people to take extra food, serving again leftovers if food is not
47
48
49 445 spoiled, often revising the menu based on most of the food leftovers and offering the non-
50
51 446 consumed food to food banks and low-income communities through support of NGOs.
52
53
54 447 Segregated food waste provides the chance to recover energy from it such as biogas and
55
56 448 compost production. Food waste management from hospitality sector also needs to be
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1
2 449 improved in terms of reducing food waste and its handling i.e., segregation, and effective
3 subsequent utilization [20].

4
5 451 Door-to-door collection in pre-organized time slots with gentle alarming sound, is
6 essential even though this will require more manpower and wheel barrows or handcarts
7 452 containing 2-3 different colored bins. Door-to-door collection must be stringent and should
8 strictly collect the properly segregated waste. Once household waste collection is improved,
9 453 concepts like “Bin free city” or “Zero dustbin city” may be introduced in Jaipur which have
10 been successfully implemented in Ambikapur city of Chhattisgarh. Similarly, Maharashtra’s
11 454 Nagpur city has also reduced the community bins number to 80% of total to encourage door-
12 to-door collection of MSW [22, 29]. Government can introduce the competitions and winning
13 455 rewards in different zones in the same city for sanitation and cleanliness which would
14 encourage the public participation. Moreover, MSW collectors and sweepers should be
15 460 provided training, steady disinfection of the dhalaos (transfer station), safety uniforms, and
16 461 equipments and regular monthly wages. They must be provided with personal protective
17 462 equipment like gloves, shoes and air filter masks while cleaning and handling the wastes to
18 prevent eosinophilia, respiratory disorders and infection or contagious diseases [50, 60].

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39 465 A study in Jaipur highlights that the placement of community bins should be equitable
40 in terms of regional coverage and not just be based on social connections [12]. Bigger bins
41 466 must be placed near the party venues, marriage halls and institutions, which generate larger
42 volumes of MSW in a day. All community bins must be covered so that it would be
43 467 accessible to humans only avoiding waste dispersion by animals. For transportation, old and
44 inefficient vehicles should be discarded and covered properly to prevent waste scattering on
45 470 roads.

472 **5.2. Improvement in existing composting and landfill facilities**

1
2 473 The biological conversion of organic fraction existing in MSW into a compost/humus
3
4 474 through bacterial activity i.e., oxidizing the organic compounds in the presence of air, is
5
6
7 475 called composting. In anaerobic composting, microorganisms break down the organic
8
9
10 476 compounds in the absence of air through reduction process while metabolizing the nutrients
11
12 477 [61]. This compost has good fertilizer quality for agriculture application. Many metro cities
13
14 478 have MSW composting capacity between 150-500 TPD. Vermicomposting is also practiced
15
16
17 479 in Mumbai, Bangalore and Faridabad where organic waste is decomposed by aerobic
18
19 480 microorganisms followed by disintegration through earthworms [10]. Similar measures can
20
21
22 481 be adopted for Jaipur city as well. Organic feedstocks in vermicomposting are generally
23
24 482 animal, agricultural, food waste, and sewage waste. The processing periods for
25
26
27 483 vermicomposting may be ranged between 28-120 days and conditions for the process can be
28
29 484 varied between 18-67°C temperature, 5.9-8.3 pH and moisture content 11-80%, yielding
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31
32 485 compost as bio-fertilizer rich in nitrogen, phosphorous and potassium [62].

33
34 486 Many studies highlighted the irreparable damage caused through uncontrolled open
35
36 487 landfilling sites and suggested sanitary landfill for final MSW disposal [32, 40, 63]. Jaipur
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38
39 488 city must have sanitary landfill provisions for safe disposal of MSW by either transforming
40
41 489 the existing open landfills to sanitary landfill or establishing waste to energy plant [30].
42
43
44 490 Sanitary landfill design must follow the procedures of MSW 2016 guidelines regarding site
45
46 491 selection, environmental examination i.e., environmental impact assessment, near to the
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49 492 treatment facility if possible, and away from dwelling areas and water bodies. There must be
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51 493 urgent cessation of existing dumping sites near rivers or any water storage facility like well,
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53 494 pond, lakes.

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56 495 Advancement in landfill technology may lead to the development of bioreactor landfilling
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58 496 (BLF), which serves as storage as well as treatment of waste. BLF facilitates rapid
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1 497 degradation of organic waste through microbial action due to increase in moisture content via
2 498 leachate recirculation. The process may achieve faster landfill gas generation to have energy
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4 499 production from it. This type of landfilling also enhances the waste stabilization and its
5
6
7 500 features such as waste degradation, storage, landfill gas collection and faster stabilization
8
9
10 501 make it an environmentally sound landfill as compared to other landfill systems. Diversion of
11
12 502 MSW streams to recycling, composting and waste to energy technologies may avoid the
13
14 503 possibility or development of landfill gas recovery (LFGR) system as no organic waste
15
16
17 504 reaches to landfill site avoiding biological actions for gas production [19, 63].
18

19 **5.3. Informal sector integration and public private partnerships**

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21
22 506 The efficient MSWM in Jaipur city also calls for the provisions of a governing body to
23
24 507 administer rag pickers and scrap dealers. The rag pickers can be integrated with the formal
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26
27 508 system by providing training and facility of precautionary measures as well as the regular
28
29 509 monthly wages along with preventing the scrap dealers to take any advantage of rag pickers.
30
31
32 510 Their incorporation with the formal system would enhance the recovery of the recyclable
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34 511 materials [12, 50]. Recently, a study in Brazil has advocated the socio-economic inclusion of
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37 512 scavengers for addressing the challenge of MSW management through their active
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39 513 participation in waste collection and increasing their quality of life through income
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41
42 514 generation as well as ensured health and safety at work [64].
43

44 515 Due to lack of investment and experts in waste treatment field, responsibilities like
45
46 516 collection, transportation, treatment and disposal can be shared between NGOs, private
47
48
49 517 companies and municipality. For instance, collection and segregation can be handled by
50
51 518 NGOs, transportation by municipality and design, construction and operation of treatment
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53
54 519 and disposal facilities by private companies. This model has been followed by Delhi by
55
56 520 collaborating with 3 different companies for MSWM in six zones of Delhi [27]. PPP model is
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59 521 a significant way and profitable business for private investors which have adequate planning,
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1 522 experts and infrastructures to have well-organized MSWM. For instance, Praj Industries Ltd,
2 523 Pune has introduced the safer production of biodiesel, fuel ethanol, bio-CNG (Compressed
3
4 524 Natural Gas) and liquid manure from the organic content of MSW by solvent extraction,
5
6
7 525 fermentation, and biomethanation in an integrated manner [44].
8

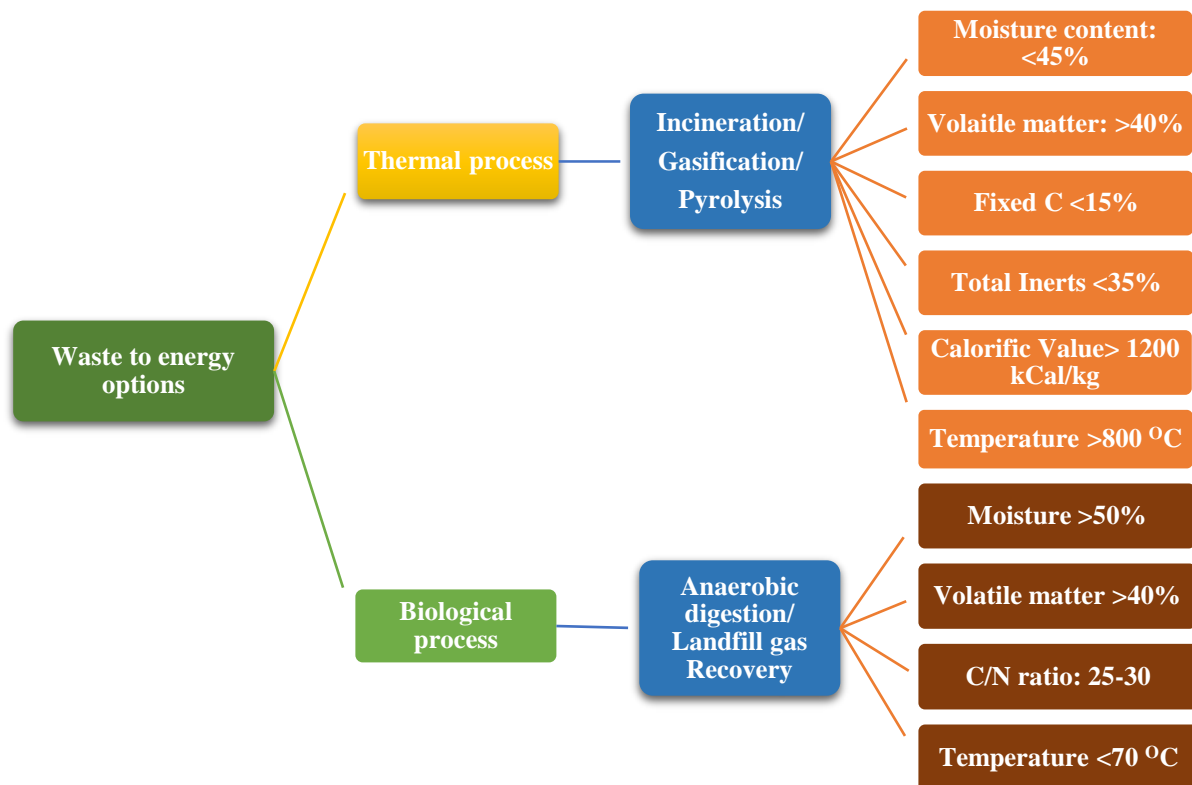
9
10 526 Circular resource efficiency can be achieved by using recyclables from MSW as raw
11
12 527 materials for recycled new products. Increasing cost of new materials and non-renewable
13
14 528 energy makes that case for recovery of material from waste as an economical and sustainable
15
16
17 529 way for recycling. Recyclables can include newspapers, plastics, glass, aluminium, metals,
18
19 530 construction and demolition debris. Recovery of recycling materials mainly consists of
20
21
22 531 screening of undersize material and shredding followed by magnetic separation for ferrous
23
24 532 metal. Getting some revenue from recyclables may ease the waste management budget as
25
26
27 533 well as cut down the cost regarding its treatment and disposal, thereby reducing the landfill
28
29 534 burden. Overall, recycling alone is the most economical and energy efficient process that
30
31
32 535 avoids the enormous embodied energy of a virgin new material and also evades the GHGs
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34 536 emissions due to the virgin material energy consumption [9, 19].
35

36 537 **5.4.Adoption of waste to energy techniques**

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38
39 538 For a developing country like India, rapid economic development requires energy and
40
41 539 resources to progress. With depleting fossil reserves, future energy demand can be addressed
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43
44 540 through the alternative sources of energy i.e., renewable energy. At present, India has 2554
45
46 541 MW potential as renewable energy potential from waste generated i.e., MSW and waste
47
48
49 542 water [33, 65]. Waste to energy can play effective role in production of renewable and
50
51 543 sustainable energy. In Jaipur, the MSW consisting organic and inorganic portions may be
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53
54 544 utilized for biofuel and power generation.
55

56 545 MSW's quantity, characteristics, composition, physical properties, land availability,
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58 546 environmental safety, financing, stakeholder's involvement, and capability of organizations
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547 are major criteria for selection of appropriate technology. Cities alone generating more than
 548 1000 TPD (like Jaipur) should opt for waste to energy technologies as it would be sustainable
 549 as well as economical. If the thermal route is to be adopted, the enhanced calorific value of
 550 waste should be ensured by proper segregation of MSW [66]. The recovery of energy from
 551 waste offers many additional benefits i.e., total waste quantity gets reduced by 60-90%
 552 depending upon the waste composition and adopted technology; demand for land for
 553 landfilling would reduce; the cost of transportation to far-away landfill sites would reduce;
 554 and most importantly net environmental pollution would be minimized [11]. Further, the pros
 555 and cons of individual waste to energy technologies are shown in Table 5. Recommendations
 556 for making waste to energy technologies viable in Indian cities are to introduce contracts for
 557 waste collections and deliveries, control on storage sites preventing contamination, increase
 558 the public participation by educating and making aware, more funds to ULBs or municipality
 559 authority to support waste to energy projects [59].



560
 561 Figure 6. Waste to energy options with operating parameter's desired ranges [18]

562 **5.4.1. Thermal conversion**

1
2 563 Thermal conversion process entails thermal decomposition of MSW to produce either heat
3
4
5 564 energy or fuel oil or gas. The objectives of thermal waste to energy are recovering the energy
6
7 565 potential from the waste, destroying toxic substances in organic and inorganic waste, saving
8
9 566 the natural energy resources for energy production, reducing the waste quantities for disposal
10
11
12 567 and transforming the residuals into reusable secondary products to save material resources.
13
14 568 Thermal treatment plants require high installation and operational cost as well as the experts
15
16
17 569 in the field [10]. It is convenient to have waste as a fuel resource containing a high
18
19 570 percentage of non-biodegradable matter and low moisture content. The main technological
20
21
22 571 options under this category include incineration, pyrolysis and gasification. Main operating
23
24 572 parameters during thermal conversion to energy require desired ranges for proper functioning
25
26
27 573 are shown in Figure 6. Moisture content, volatile content and temperature are the crucial
28
29 574 parameters for incineration, pyrolysis, gasification and AD as well. Though the thermal
30
31
32 575 conversion techniques require much higher temperature (>800°C) as compared to biological
33
34 576 conversion method. The volatile matter in the waste should be at least 40% in order to be
35
36 577 feasible for waste to energy conversion.

38
39 578 **5.4.1.1. Incineration**

40
41 579 Incineration is a similar process like the combustion i.e., complete burning of solid waste in
42
43
44 580 presence of sufficient air at 980 to 2000°C, converting MSW's chemical energy into heat
45
46 581 energy and generating electricity through turbine-generator system [10, 11]. Raw MSW is
47
48
49 582 generally preferred. Incineration depends on the characteristics of waste which in turn
50
51 583 affected by the socio-cultural, seasonal and demographic differences [67]. However,
52
53
54 584 segregated combustible non-biodegradable waste having calorific value greater than 1000
55
56 585 kcal/kg should be selected for this treatment. Moisture content and inert waste reduce the
57
58
59 586 calorific value of MSW and affect its combustibility. Stages in incineration process are -

1 587 drying, incineration, energy recovery from combustion, and flue gas cleaning for air pollution
2 588 control. Ash produced, in the end, can be utilized in road construction and building materials
3
4 589 like fly ash brick. Through this treatment process, incineration of 1 tonne of MSW is capable
5
6
7 590 of generating 544 kWh of energy and 180 kg of solid residues [68]. In General, around 0.7-
8
9
10 591 1.2 mg CO₂ is released from incineration of 1 mg MSW incineration [69]. Though, it may be
11
12 592 different for Indian MSW incineration scenario due to dissimilar compositions. Indian cities
13
14 593 hardly practice this technique due to undesirable characteristics i.e., high moisture content,
15
16
17 594 high inert content and low calorific value of MSW [10, 18].

19 595 ***5.4.1.2. Gasification***

21
22 596 Gasification is the combustion of solid waste into gas mixture (H₂, CO, CO₂, CH₄, H₂O and
23
24 597 inert gases) under deficient oxygen conditions at high temperature 800-900°C. Syngas
25
26
27 598 (majorly H₂ and CO), the main product of gasification, can be used to produce renewable
28
29 599 energy and as a feedstock for production of chemicals like methanol and liquid fuels. This
30
31
32 600 system mainly includes the gasifier, gas cleaning configuration and energy recovery system.
33
34 601 Generally, it is installed for agricultural residues and forest wastes in India. However, it can
35
36
37 602 also be used for MSW by drying, inert removal and chopping prior to gasification of MSW
38
39 603 [10, 33, 70]. Its integration with combined cycle, where conversion of gaseous fuel to
40
41
42 604 electricity by gas turbine have overall high conversion efficiency ranges 40-50% for 30-60
43
44 605 MW capacity plant [71]. The process is widely used in Japan with 85 MSW operating
45
46 606 gasification plants as well as at a smaller scale in USA, Germany, Norway, UK and Italy
47
48
49 607 [68]. This technology is comparably better than incineration in terms of cost, flue gas
50
51 608 cleaning and output products and can be explored for MSW management in Jaipur city.

53 609 ***5.4.1.3. Pyrolysis***

55
56 610 Pyrolysis is another thermal conversion technology in which biomass converted to liquid
57
58
59 611 (bio-oil or bio-crude) and gases, in devoid of oxygen at 400-800°C temperature range. The

1 612 process parameters are temperature, the rate of heating, residence time, waste composition,
2 613 and waste particle size. Lower temperature pyrolysis products are pyrolysis oil, wax and tar.
3
4 614 However, quality pyrolysis gases (CO, H₂, H₂O, N₂, hydrocarbons) are produced at a higher
5
6
7 615 temperature (>700°C). Some developed countries like Japan, UK and France are operating
8
9
10 616 MSW pyrolysis plants successfully. Integration of MSW pyrolysis with a gas turbine for
11
12 617 energy recovery may lead to a net conversion efficiency of 28-30% [68].
13

14 618 **5.4.2. Biological conversion**

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16
17 619 The biological conversion process is based on the enzymatic decomposition of organic matter
18
19 620 by microbial action to produce biofuel i.e., biogas, bioethanol, and bio-diesel. Biological
20
21
22 621 processes are preferred for waste having a high percentage of biodegradable matter and high
23
24 622 level of moisture content, which aids microbial activity. The main technological options
25
26
27 623 under this category are AD (or bio-methanation) to produce biogas and fermentation to
28
29 624 produce biofuel like ethanol [11, 18].
30

31 625 **5.4.2.1. Anaerobic Digestion**

32
33
34 626 Organic matter is degraded by bacteria in controlled anaerobic conditions to generate biogas
35
36 627 i.e., mixture of CH₄ and CO₂ and traces of water vapor, H₂S, NH₃, etc. The AD process is
37
38
39 628 composed of series of 4 stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis
40
41 629 [72]. Controlling parameters are volatile content, temperature, pH, and carbon to nitrogen
42
43
44 630 (C/N) ratio. The lignocellulosic organic matter is undesirable for AD process without
45
46 631 adequate pretreatment, as its hydrolysis is difficult due to the presence of lignin [66, 73, 74].
47
48
49 632 It is capable of generating 300-400 m³ biogas per tonne of VS of organic fraction of MSW
50
51 633 [18]. One tonne of MSW composed of 60% organic matter and remaining is moisture which
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53
54 634 may produce 150 kg of methane through AD process. Purified biogas after removing CO₂
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56 635 and H₂S gas can be used as transportation fuel, called as Bio-CNG [68]. AD of untainted
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636 food waste has attractive option of management, nutrient recycling and bio-methanation
637 having potential of 410-530 ml biogas/g VS of food waste [75].

638 ***5.4.2.2.Landfill Gas Recovery***

639 Complex biological and chemical decomposition of organic matter of MSW dumped results
640 in landfill gas production. Landfill gas emissions composed of mainly methane and carbon
641 dioxide gases. Waste composition (primly organic fraction), moisture content, waste age, ash
642 content, temperature and precipitation are major factors affecting the rate of methane gas
643 production. Landfill gas has methane potential of 100 m³/tonne of organic fraction of MSW
644 which is capable of being trapped and utilized as green energy production [76]. Landfill
645 accounts for 13% of global CH₄ emission considered as one of the major anthropogenic
646 methane emissions [28]. Its reduction and recovery consequently reduce GHG emission. If
647 landfill gas could be recovered, it is capable of generating 72 MW of electricity in India [5].
648 Since most of the landfill sites are not designed considering recovery of landfill gas, it is
649 infeasible to trap landfill gas and therefore its on-site burning is chosen [28,76,77].

650 Standard protocols used internationally for landfill gas estimation are first order
651 decomposition models i.e., LandGEM, mass balance model, modified triangular method
652 developed by Intergovernmental Panel on Climate Change. These models need to incorporate
653 meteorology data for site specific estimation. The on-field methods are flux chamber
654 technique, vertical radial plume mapping and differential absorption LiDAR techniques
655 [77,78]. Flux chamber method has been used for estimating CH₄ and CO₂ emission fluxes
656 which are 68 and 92 mg/min/m² respectively, which are severe in summer in comparison to
657 winter season for northeast city Guwahati [77]. A specific model has been developed for
658 methane estimation from landfill sites in Indian climatic conditions, which is validated in
659 three different climatic cities: Shillong, Jaipur and Kolkata [78].

660 RDF, waste to energy and LFGR methods involve renewable energy recovery from
 661 MSW through clean development mechanism projects, as they can result into 40,308-
 662 1,252,206 tonne of CO₂ equivalent reduction in GHG emission, which will bring carbon
 663 credits and make the projects financially attractive [79].

5.4.3. Energy and economic aspects of waste to energy techniques

664
 665
 666 The specific energy potential of waste to energy technologies have been summarized in Table
 667 4 [55, 68, 80]. On the basis of these energy potentials, further calculations were done to
 668 estimate the total saving of diesel fuel as well as GHG emissions for using the energy from
 669 these plants to replace the diesel for power generation. As reported by Prajapati et al. [55], 1
 670 tonne of organic fraction of MSW has the potential to generate 192.582 m³ biogas through
 671 AD. 1 m³ of biogas generates 2.04 kWh electricity with 35% efficiency [80]. Utilizing diesel
 672 for heat and power generation results in GHG emissions of 2.68 kg CO₂ per L of diesel
 673 burned [81]. These emissions can be saved by replacing the diesel from biofuel generated
 674 from organic fraction of municipal waste. Similarly, GHG emission from landfill of MSW is
 675 1230 kg of CO₂ per tonne of MSW [82]. These GHG emissions from landfills can be saved
 676 by using waste to energy technology.

677
 678 Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy

679 Technologies

Technology	Specific Energy potential (kWh _e /tonne)	GHG emissions and cost savings
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		Diesel Fuel	USD	GHG from	GHG from	Total GHG	
		saved (L)	(\$)	Diesel	landfill	(kg of CO ₂)	
				Generator	(kg/tonne)	saved	
				(kg of			
				CO ₂)			
	AD	393*	90.36	106.62	242.16	1230.00	1472.16
	Incineration	544	125.12	147.64	335.32	1230.00	1565.32
	/ RDF						
	Gasification	400	92.00	108.56	246.56	1230.00	1476.56
	LFGR	163	37.54	44.29	100.60	1230.00	1331.60

*kWh/tonne of Organic fraction of MSW

For cost analysis of these technologies, the key parameters to be considered are: cost of land acquisition, technology installation, feedstock, operation and maintenance cost as well as labor cost. From economic assessment perspective, incineration technique is the more suitable choice as compared to complex gasification technology as it requires low cost for implementation and installation. Gasification has the operational cost of around 0.250 million USD/day. Still, gasification is the most attractive technology considering environmental assessment as it can reduce more than 3208 TPD of carbon emissions [83]. In India, most of the gasifiers uses coal, agricultural, and agro-industrial waste. Therefore, the MSW with similar energy content can also be used as a co-fuel in appropriate blend for energy production. However, further research and optimization of this strategy is required to reduce its capital cost. Hybrid technologies can also be explored for combining MSW conversion with other renewable energy technologies for making MSW viable as fuel. A recent study suggested a hybrid solar-biomass system in which AD of MSW was combined with concentrated photovoltaic to generate heat and power from the system [84].

695 A biomass RDF plant feasibility was evaluated with net present value as profitability
1
2 696 method and also sensitivity analysis performed to evaluate critical factors like pellet price,
3
4 697 capacity utilization and annual working hours for plant economy. The study concluded a
5
6
7 698 minimum selling price as USD 120 per tonne of pellet for plant feasibility [85].
8
9
10 699 In developing countries like India, the economic viability of waste to energy technology
11
12 700 requires comprehensive study of cost parameters for initial investment, cash inflow and
13
14 701 outflow estimation as well as sensitivity analysis of influencing parameters. There is a scope
15
16
17 702 of techno-economic evaluation of waste to energy technologies using economic metrics net
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19 703 present value and levelized cost of energy considering economic value of produced
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22 704 electricity, thermal energy and products, and specially accounting ecological benefits,
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24 705 reduction in current MSWM costs.
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706 Table 5: Pros and cons of different waste to energy techniques [10, 33, 68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	<ul style="list-style-type: none"> • Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume 	<ul style="list-style-type: none"> • Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	<ul style="list-style-type: none"> • Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning 	<ul style="list-style-type: none"> • Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	<ul style="list-style-type: none"> • Production of fuel oil 	<ul style="list-style-type: none"> • Heterogeneity in MSW • Char removal is important • Yield stream is complex

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Biological AD
conversion

- Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent)
- Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer
- Control GHG emissions, with net environmental gains are positive
- Potential for co-digestion with agricultural and industrial organic wastes
- Less monitoring is required
- Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill

LFGR

- Least cost option
 - Collected gas can be used power generation, and thermal application
 - Reduce environmental and health impact, reduce GHG emissions
 - Requires organic waste segregation
 - Not suitable for complex organics, oily, or lignocellulosic materials
 - GHGs, fouling, and fire threats if leakage is present
 - Expertise and monitoring required
 - Higher transportation cost and need larger land area
 - Leachate problem if landfill is not scientific
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1 709 **5.5.Application of optimization models**

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4 710 Mathematical and optimization models robustly used for planning and optimizing the
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6 711 MSWM infrastructure to make MSWM as sustainable management reducing usage of fossil
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8 712 fuels. Extrapolation of past data is inaccurate and unreliable way for forecasting of waste
9
10 713 generation rate, as it greatly affected by socioeconomic factors whose selection should be
11
12 714 significant to the local situation. Mathematical modeling methods of solid waste streams for
13
14 715 the precise prediction of waste generation and its rate have been benefitted the MSWM in
15
16 716 terms of viable future planning. Models concerning generation of waste having key variables
17
18 717 of socioeconomic factors like household size, waste volume, education level of households,
19
20 718 income level of households, and environmental awareness, etc. in a district area, and in a
21
22 719 similar way over the country. Linear regression technique is used to develop model the
23
24 720 forecasting of biodegradable and non-biodegradable waste generation rate and also analyzing
25
26 721 the accountable variables in Dhanbad city [86]. Waste collection streams data: mixed waste,
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28 722 source separated waste, and treatment decisions also used for modeling of waste prediction.
29
30 723 Models include mostly correlation and regression models, single regression analysis and
31
32 724 multiple regression analysis, system dynamic, and artificial intelligent system (genetic
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34 725 algorithm, artificial neural network, and fuzzy logic) for multivariable analysis [87].

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36 726 Nganda [88] developed a mathematical model acting as a technique to optimize the
37
38 727 use of management facilities (like number of trucks, incineration plants, landfill capacity,
39
40 728 etc.) to reduce total waste management cost and ensuring optimal use of resources. It results
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42 729 to provide suitable information in decision-making to have a planned and efficient waste
43
44 730 management system. Same model was used in Hong Kong, waste streams between collection
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46 731 centers, replacement truck warehouse, incinerators, and landfill were formulated using mixed
47
48 732 integer programming for identifying the number of trucks required between two points and
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50 733 same in the whole system and waste amount reduced by 42% in landfill with their present
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734 strategy [89]. In a similar way, management facilities can be minimized by using
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2 735 mathematical models in Jaipur scenario with existing operating facilities.
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5 736 An integrated model of geographic information systems (GIS), equation-based model
6
7 737 and agent-based model effectively used to minimize collection cost by 11.3%, by reducing
8
9 738 travel length and time making efficient collection and transportation system [90]. Das and
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11 739 Bhattacharyya [91] proposed an effective MSWM in Bidhan Nagar municipality under
12
13 740 metropolitan Kolkata city, by optimizing length route in its transportation using travelling
14
15 741 salesman problem. Travelling salesman problem can be robustly used for optimizing the path
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17 742 length for waste transportation amongst the waste source, collection points, transfer stations,
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19 743 treatment facility or landfill, will majorly reduce the management cost and emissions from the
20
21 744 transportation part. Cost effective collection and transportation process considering the
22
23 745 locations of dustbin, transfer station, road network, composting unit and dumping site, is
24
25 746 optimized with help of GIS and remote sensing in Vellore city of India, and achieving 59.12%
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27 747 reduction in travel distance in the transportation [92]. Thus, reducing natural resource
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29 748 consumption and making the management as sustainable approach.
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37 38 750 **5.6. Application of life cycle assessment tools**

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40 751 Different MSWM strategies can be compared and evaluated by using LCA tool which helps
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42 752 in determining the environmental implications, energy consumption and cost of the different
43
44 753 combination of management strategies [93-95]. LCA makes it easier to identify the processes
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46 754 which have a significant impact on the environment. SimaPro, GaBi, WISARDTM and
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48 755 EASEWASTE are widely used software for LCA.
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51 756 Babu et al. [63] evaluated 4 disposal scenarios in Bangalore city: open dumping,
52
53 757 landfilling without gas recovery, landfilling with gas recovery and BLF to find out
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55 758 sustainable and economical disposal using LCA tool. The study revealed BLF as best option
56
57 759 with least Global Warming Potential (3335 kg CO₂) and photochemical ozone creation
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760 potential (0.379 kg) per tonne of waste, and faster waste stabilization inducing more energy
761 recovery from MSW and also with lesser payback period (50 years) than others. Another
762 study assessed the cost and environmental impacts of 4 management options under LCA tool
763 in the selected wards of Bangalore: 1. Existing system i.e., recycling, composting and rest of
764 MSW transported to landfill site; 2. With optimal route transportation; 3. Vermicomposting
765 of 62% MSW (biodegradable) and rest landfilling; 4. Incineration of entire waste. The results
766 of the study showed that the second option with optimal route transportation and least amount
767 required USD 409750 per annum was the best on the basis of ecological, economic and social
768 aspects [96].

769 LCA performed for integrated MSWM in Delhi concluded that the recycling facility
770 has negligible emissions and energy consumption. Landfilling has comparatively less
771 negative environmental impacts in the beginning year as compared to incinerators. However,
772 it produces highest GHG emissions among all MSWM afterwards [36]. For the same city,
773 Bohra et al. [97] compared 12 different integrated MSWM scenarios involving RDF, AD,
774 composting and sanitary landfilling including existing MSWM i.e., 9% composting and rest
775 to landfill site as baseline scenario. While the global warming potential (226.92 kg CO₂ eq.)
776 was revealed to be least for the scenario having major diversion of organic waste from
777 landfilling to treatment facilities to RDF pelletisation (16%), AD (16%) and composting
778 (10%).

779 A study in Mumbai city compared six different scenarios including the current
780 practice of open dumping with partial BLF and other five integrated approaches of different
781 combinations of recycling, AD, composting, incineration and landfilling with 50% gas
782 recovery. The study reported least GHG (930.01 kg CO₂ eq. per tonne) emission for the
783 combination of recycling, AD and landfilling [32]. LCA study carried out in non-metro city
784 Dhanbad compared four management strategies of collection + transportation + landfilling;

1 785 recycling + open burning + open dumping + landfilling without energy recovery (LFWER);
2 786 composting + LFWER; and recycling, composting and LFWER. It concluded that the
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4 787 management strategies comprising recycling, composting and landfilling without energy
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6
7 788 recovery had the least environmental impacts (global warming potential - 3430 kg CO₂;
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9 789 terrestrial ecotoxicity - 0.872 kg C₂H₄ eq.; acidification - 4.63 kg SO₂ and eutrophication 1.99
10
11 790 kg PO₄³⁻ per tonne of MSW) as recyclables, organic and inert materials subjected to
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13
14 791 respective treatment or disposal facility [56].
15

16
17 792 The outcomes of the environmental evaluation of different MSWM scenarios in a city
18
19 793 provides crucial information to decision makers when planning sustainable waste
20
21 794 management strategies. LCA study of MSWM in Jaipur city will greatly help to identify and
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23
24 795 quantify the environmental impacts caused either by waste or different treatment processes.
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26 796 This may help the managing authorities to choose the best and environmentally appropriate
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29 797 process among the possible treatments.
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31 798 **6. Conclusions**

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34 799 Jaipur city faces significant problems including unregulated landfilling, inability to enforce
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36 800 MSW (management and handling) regulations and insufficient public involvement in the
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39 801 management process. The study inferred that composting and unsanitary landfilling are the
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41 802 most prevalent method for waste disposal in Jaipur as well as other Indian cities with no
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44 803 proper installed facilities for waste conversion. Even the installed facilities are less suitable
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46 804 and inefficient due to the lack of segregation of waste during collection.
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48 805 On the basis of this review, the key conclusions and recommendations for MSW
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51 806 management for Jaipur cities can be summarized as below:

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53 807 • Different stakeholders (municipality, private sectors, public and informal sectors) are
54
55 808 required to work together by taking specific responsibility in MSWM stages aiming to
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58 809 have maximum material and energy recovery from MSW.
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- 1 810
- 2 • There is a need to actively work with local communities to raise awareness for waste
- 3 811 segregation processes.
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- 5 812
- 6 • There is a large scope and urgent need of development of recycling plants, feasible
- 7 813 waste to energy technology and scientific landfill in Jaipur complying environmental
- 8 standards regarding emissions.
- 9 814
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- 12 815
- 13 • The mathematical or optimization model can be applied in Jaipur MSWM robustly,
- 14 which would optimize the resource utilization, minimize management facilities, time
- 15 816 and expenditure.
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- 19 818
- 20 • LCA study in Jaipur city of practicing or possible MSWM scenarios would be helpful
- 21 to identify the technology or treatment process having least impact on the
- 22 819 environment which should be favored first.
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- 24 820
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- 27 821
- 28 • More research is required regarding the economic and environmental gains from
- 29 822 recycling and energy generation facilities in the context of Jaipur city.
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32 823 **Acknowledgements**

33

34 824 Authors are thankful to Department of Science and Technology, (Grant No: Grant No.

35 ECR/2016/000989) and Department of Biotechnology (Grant No. BT/RLF/Re-

36 entry/04/2013) Government of India for providing the financial support to carry out the

37 825 present study. The fourth author is also grateful to the Royal Academy of Engineering,

38 BBOXX and UCL for supporting her five-year fellowship.

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46 829 **Conflict of interest:**

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49 830 The authors declare that they have no conflict of interest. The authors alone are responsible

50 for the content and writing of the paper.

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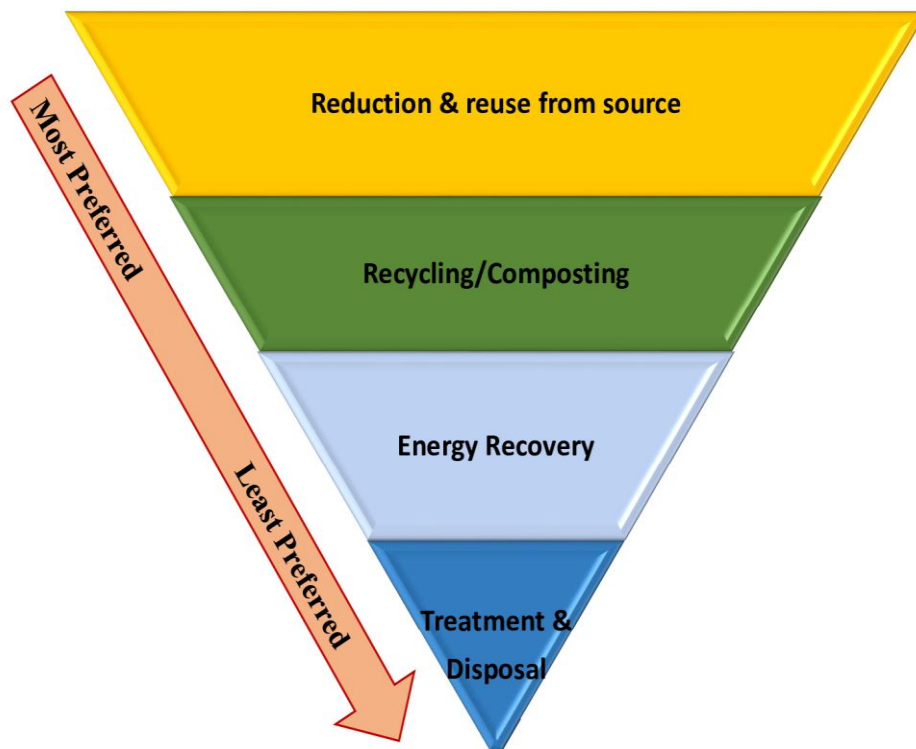


Figure 1. Integrated solid waste management hierarchy [14]

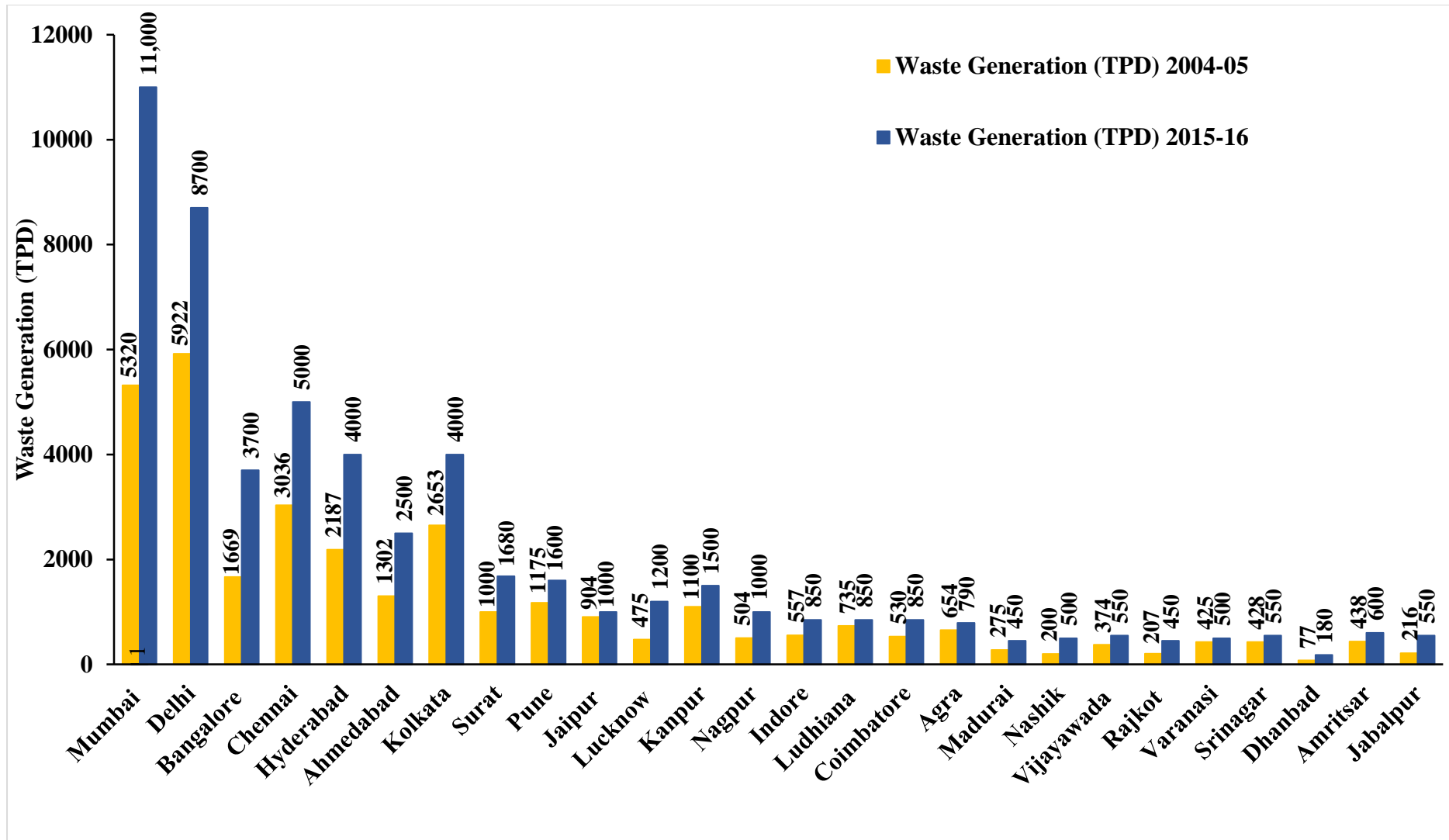


Figure 2. MSW generation trend in major Indian cities [7]

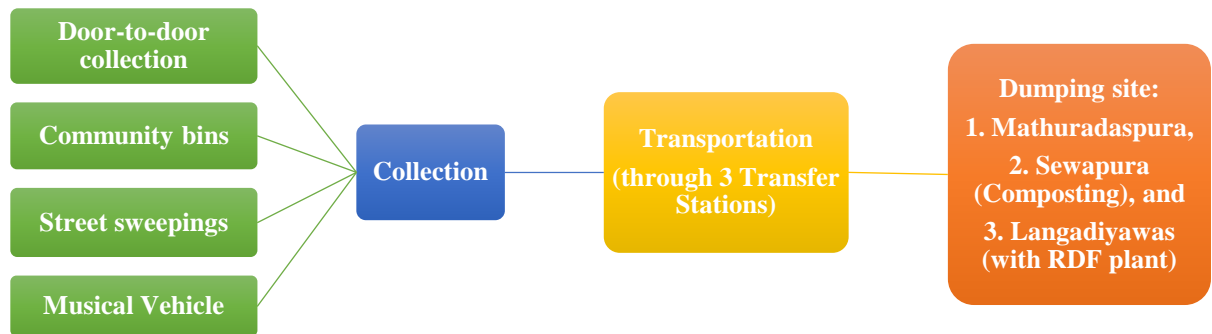


Figure 3. MSW flow in Jaipur [27]

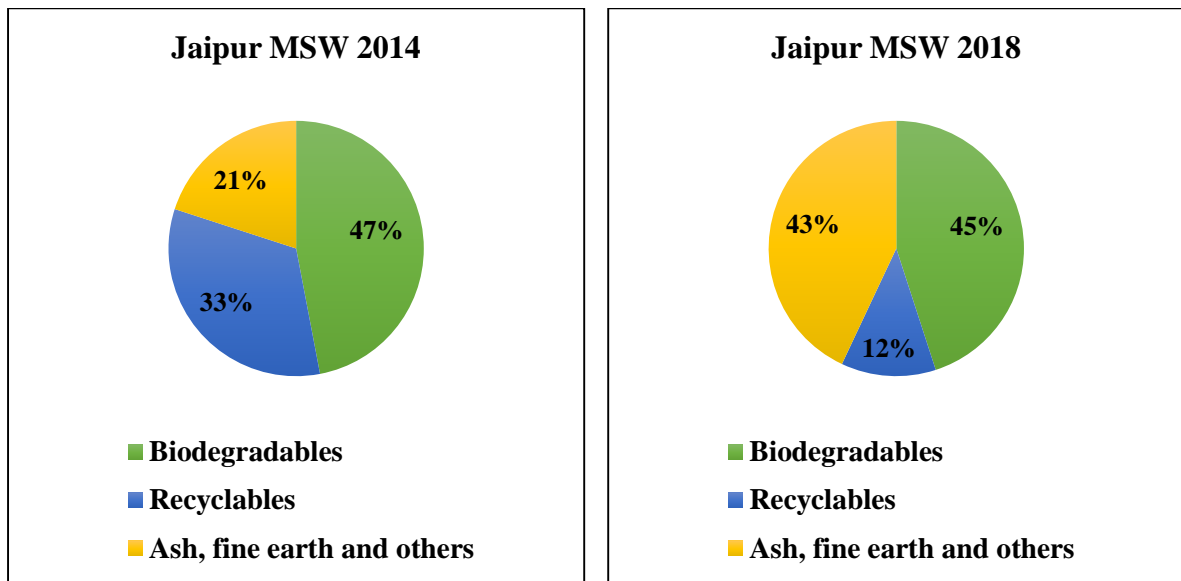


Figure 4. MSW composition in Jaipur city in year of 2014 and 2018 [11, 17]

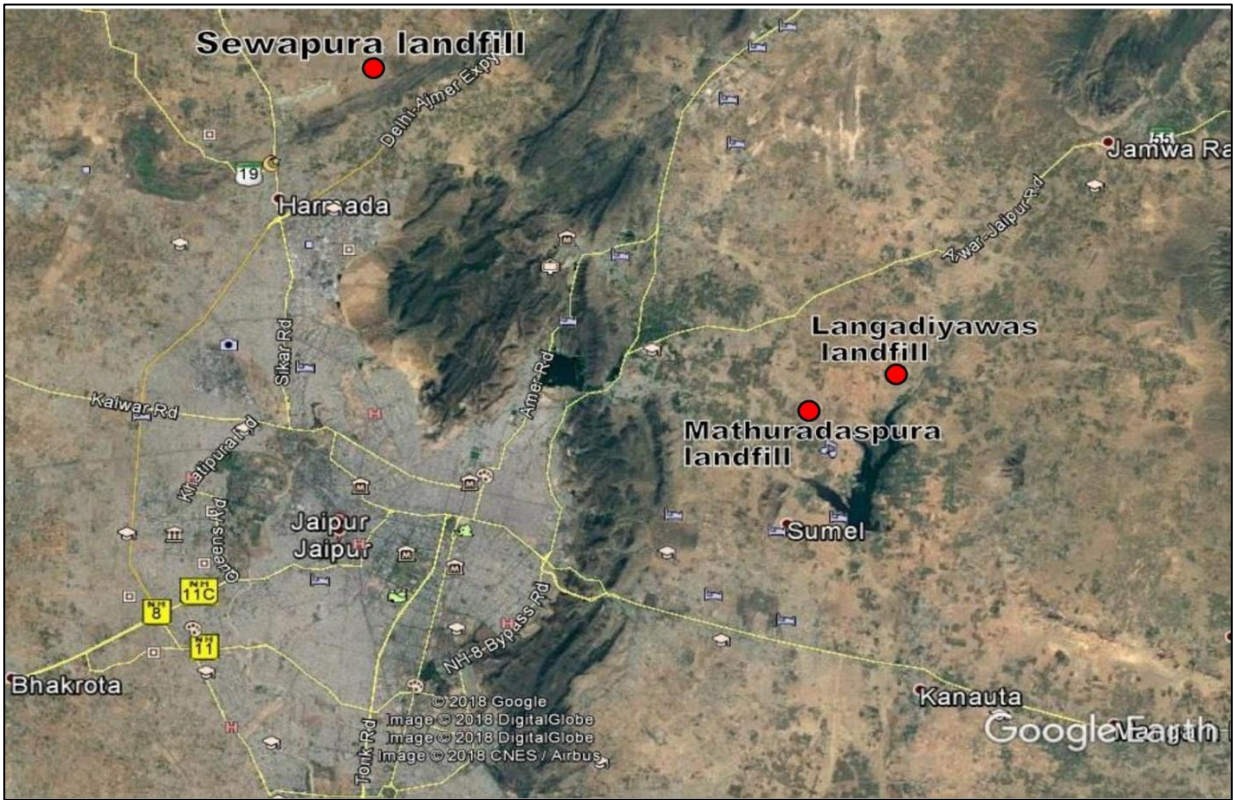


Figure 5. The landfill locations in Jaipur city, India [11, 12].

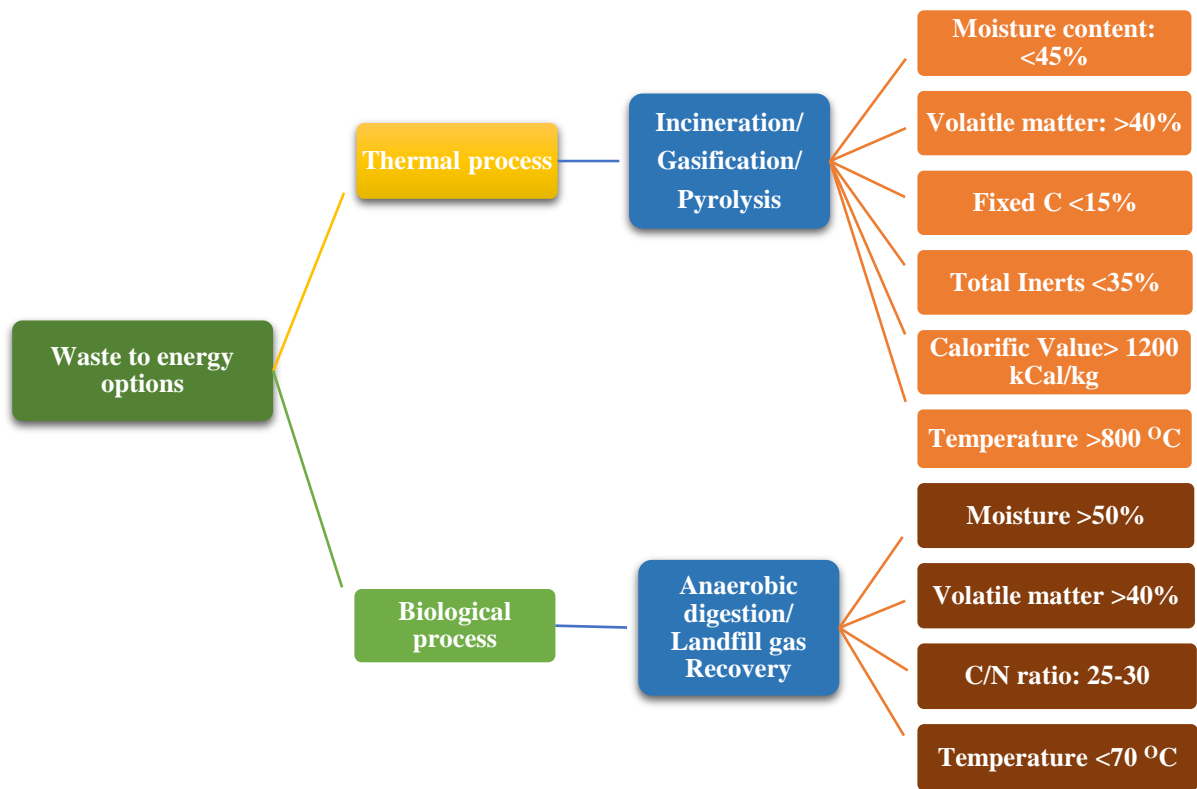


Figure 6. Waste to energy options with operating parameter's desired ranges [18]

Table 1: Physical composition of MSW in Indian cities [17]

S. No.	City	Composition of MSW			
		Compostable (%)	Recyclable (%)	Ash, debris (%)	Carbon nitrogen ratio
1.	Pondicherry	50	24	26	36.86
2.	Raipur	51	16	33	22.35
3.	Chandigarh	57	11	32	20.52
4.	Guwahati	54	23	23	17.71
5.	Bangalore	52	22	26	35.12
6.	Jaipur	46	12	42	43.29
7.	Amritsar	65	14	21	30.69
8.	Madurai	55	17	28	32.69
9.	Hyderabad	54	22	24	25.90
10.	Nagpur	47	16	37	26.37

Table 2: Adopted MSW management strategies in Indian cities

City	Management strategy					Comment	Reference
	Collection	Segregation	Transport	Recycling/ Composting/ Waste to Energy	Landfilling		
Jaipur	Y	N	Y	C & RDF	USLF (3)	Potential of energy recovery techniques	[11,12,27]
Bangalore	Y	N	Y	C & RDF	60% USLF	Pilot AD plants are in operation, lacking SLF	[10,23,31]
Mumbai	Y	N	Y	C	69% USLF (2), 31% BLF	Need 3 R's hierarchy of management and waste to energy technology	[32]
Kolkata	Y	N	Y	N	USLF	Inefficient MSWM	[33,34]
Delhi	Y	Y	Y	R- <i>Informal</i> , C (4), I (3)	SLF (4)	Source reduction and segregation need to adopt, 3 landfill sites exhausted	[35,36]
Lucknow	Y	N	Y	C	USLF (6)	AD plant failed due to lack of segregation	[37,38]

Bhubaneswar	Y	N	Y	N	USLF	Inefficient collection, transportation and waste treatment process	[39]
Guwahati	Y	N	Y	N	USLF	Bio-medical waste mixed in MSW	[40]
Imphal	Y	N	Y	N	USLF (2)	Composting plant not functional	[41]
Aurangabd	Y	N	Y	N	USLF	Need of composting	[42]
Pune	Y	Y	Y	C (2), AD (12)	SLF (1)	Segregation by sweeper during D2D, recycling inert waste	[43,44]
Jodhpur	Y	N	Y	C	USLF	Quality compost and uncontrolled landfilling	[45]
Nagpur	Y	N	Y	C	USLF	Segregated waste mixed in transportation/transfer station, windrow composting, Bioremediation in landfill site	[22]
Gwalior	Y	N	Y	C & RDF	USLF	Only leachate collection tank is present in landfill site	[46]
Varanasi	Y	N	Y	N	USLF	Landfilling is nearby river Ganga, its leachate ruining water quality	[47]
Hyderabad	Y	N	Y	C & RDF	SLF	Source segregation can be encouraged	[31,48]

Mysore	Y (D2D)	N	Y	R and C	USLF	Only treatment residues goes to dumping site	[49]
Vijaywada	Y	N	Y	C, AD, & RDF	USLF	Still, 50% MSW goes to dumping site.	[31]
Chennai	Y	N	Y	N	USLF (2)	No treatment facility	[31,50]
Dhanbad	N	N	Y	N	USLF (2),	60% MSW goes unattended	[24,26]

Y-Yes, N- No (in terms of practice), D2D-Door to Door, R-Recycling, C- Composting, AD-Anaerobic Digestion, I-Incineration, SLF-Sanitary Landfilling, USLF-Unsanitary Landfilling, BLF-Bioreactor Landfilling, RDF-Refuse Derived Fuel facility, % defining efficiency of respective strategy, (N.) –number in the bracket represents the number of respective facilities

Table 3: Chemical Characteristics of MSW in Jaipur [11]

Parameters	Moisture	VS	CV (kCal/kg)	C	H	N	S	O	P (P ₂ O ₅)	Potash K ₂ O
Values (%) *	42.7	49.9	1191	28.7	2.9	0.67	0.2	11.9	0.49	0.93

*Average values are taken from 5 samples of MSW Jaipur, VS= Volatile solids,

CV=Calorific value, C=Carbon, H=Hydrogen, N=Nitrogen, S=Sulfur, O=Oxygen,

P=Phosphorus.

Table 4: Specific Energy and Savings from electricity produced by utilizing Waste to Energy

Technologies

Technology	Specific Energy potential (kWh _e /tonne)	GHG emissions and cost savings				
		Diesel Fuel saved (L)	USD (\$)	GHG from Diesel Generator (kg of CO ₂)	GHG from landfill (kg/tonne)	Total GHG saved (kg of CO ₂)
AD	393*	90.36	106.62	242.16	1230.00	1472.16
Incineration / RDF	544	125.12	147.64	335.32	1230.00	1565.32
Gasification	400	92.00	108.56	246.56	1230.00	1476.56
LFGR	163	37.54	44.29	100.60	1230.00	1331.60

Table 5: Pros and cons of different waste to energy techniques [10,33,68]

Waste to energy techniques		Pros	Cons
Thermal conversion	Incineration	<ul style="list-style-type: none"> • Most reliable & economical • Destruction of toxic waste • Heat and electricity production • Low land area requirement • 80-90% reduction in total waste volume 	<ul style="list-style-type: none"> • Poor waste quality (CV) reduce efficiency, • Ash contains toxic metals needs care in handling and disposal, and higher emissions than other technology • High capital and operation and maintenance costs, and requires skilled personnel for plant operation • Requires intensive flue gas cleaning as emissions are of particulates, SO_x, NO_x, dioxins, etc.
	Gasification	<ul style="list-style-type: none"> • Production of fuel gas • Reduce pollution and increased heat recovery • Less flue gas cleaning 	<ul style="list-style-type: none"> • Heterogeneity in waste • Capital intensive • Hazardous matter in ash needs care in handling and disposal
	Pyrolysis	<ul style="list-style-type: none"> • Production of fuel oil 	<ul style="list-style-type: none"> • Heterogeneity in MSW • Char removal is important • Yield stream is complex

Biological conversion	AD	<ul style="list-style-type: none"> • Better energy recovery efficiency, and less environmental emissions (due to lack of oxygen NOx & SOx are absent) • Energy recovery with byproduct digestate used as soil conditioner/ biofertilizer • Control GHG emissions, with net environmental gains are positive • Potential for co-digestion with agricultural and industrial organic wastes • Less monitoring is required • Prevent dereliction of environment due to the uncontrolled decay of organic content in a landfill, and also reducing the burden on landfill 	<ul style="list-style-type: none"> • Requires organic waste segregation • Not suitable for complex organics, oily, or lignocellulosic materials • GHGs, fouling, and fire threats if leakage is present
	LFGR	<ul style="list-style-type: none"> • Least cost option • Collected gas can be used power generation, and thermal application • Reduce environmental and health impact, reduce GHG emissions 	<ul style="list-style-type: none"> • Expertise and monitoring required • Higher transportation cost and need larger land area • Leachate problem if landfill is not scientific

Highlights

- In Jaipur city 50% MSW is treated while rest is subjected to unsanitary landfilling.
- Indian cities have inadequate MSW management practices treating only 21% of MSW.
- Lack of public participation, proper treatment techniques and sanitary landfill in the city.
- Recycling facilities, waste to energy techniques and sanitary landfilling is required.
- Role of optimization and LCA models in planning suitable MSW management practices.

Declaration of interest statement

The authors declare that there is **No Conflict of interests** for the submitted manuscript.

Sincerely,
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