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Municipal solid waste management in India – Current status, management practices, models, impacts, limitations, and challenges in future

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Abstract. Pollution, climate change, and waste accumulation are only some of the new problems that have arisen because of the exponential population growth of the past few decades. As the global population expands, managing municipal solid trash becomes increasingly difficult. This is by far the most difficult obstacle for governments to overcome, especially in less developed nations. The improper open dumping of trash, which is causing mayhem across the country, has two immediate effects: it contaminates groundwater and surface water. Air pollution and the accumulation of greenhouse gases are both exacerbated by the release of methane and other harmful waste gases. Leachate from the landfill leaks underground and pollutes groundwater. In most cases, leachate moves into the groundwater zone and pollutes it after forming in association with precipitation that infiltrates via waste. This has far-reaching effects on people's health and disturbs the natural environment. This review article critically examines the current state of Solid Waste Management (SWM), addressing both the highlighted concerns and the government management solutions that have been put in place to address these issues. In addition, the constraints, and difficulties that India will face in the future in terms of solid waste management and the role of models for such a system are discussed.

Keywords: landfilling; leachate; municipal solid waste; waste generation; waste management models; waste-to energy

1. Introduction

As the result of increasing urban population and the influx of people into cities, a substantial amount of waste is being generated. It is very important that we investigate the causes of the worrying rise in trash production around the world. The rates at which waste is generated is becoming higher and higher around the entire globe. This is the most difficult obstacle that governments in nations that are still in the process of developing must overcome. The most recent statistics indicate that between 80 and 90% of MSW is disposed of in landfills without any kind of

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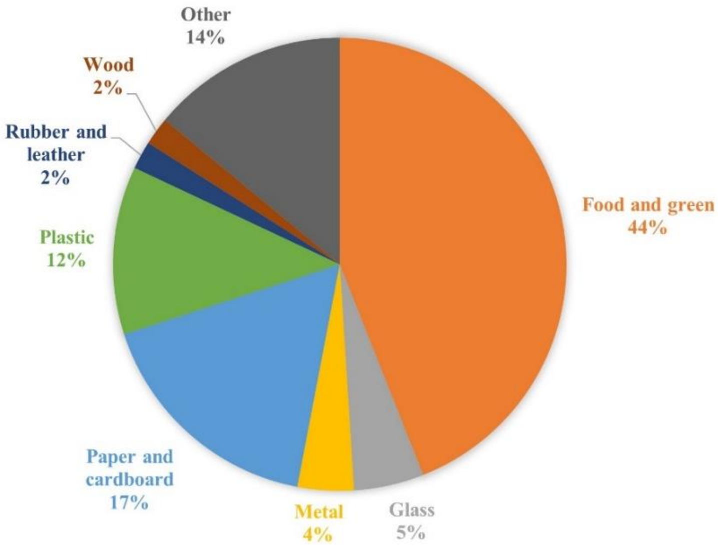

Fig. 1 Global Solid waste composition

scientific supervision being exercised over it. When garbage is discarded without any type of waste management system being in place, it has a significant influence on the quality of the air we breathe, the land we farm, and the water we drink (Joshi and Ahmed 2016, Ahluwalia and Patel 2018). The most significant risks associated with disposing of MSW in landfills are leachate formation, which contributes to the deterioration of groundwater quality, and the creation of harmful greenhouse gases (Ngwabie *et al*. 2019). For this reason, it's important to treat toxic landfill gases and the leachates production by landfills.

2. Status of waste generation at the global level

Based on estimates, there will be 3.40 billion metric tons of garbage produced year by the year 2050, a 70 percent increase over 2016's waste output. This increase is mostly attributable to rising urbanization rates at the same time as the world's population. According to projections by 2050, daily per capita trash creation is estimated to climb by 19% in high-income nations and by 40% or more in low- and middle-income countries. Fig. 1 shows the global distribution of common waste elements (World Bank 2019). Fig. 2 shows depiction of a tiny percentage of garbage which is now properly treated and safely overseen in landfills, with the vast majority being dumped in fields or open areas and transported to hidden disposal locations (World Bank 2019. Koppiahraj *et al.* 2019).

3. Current status of India in solid waste generation

India now ranks among the top ten countries contributing the most to municipal solid trash worldwide. According to the most recent data on solid waste from the Central Pollution Control Board (CPCB), the nation produces 160.038 TPD (tonnes per day). Overall, this amounts to a

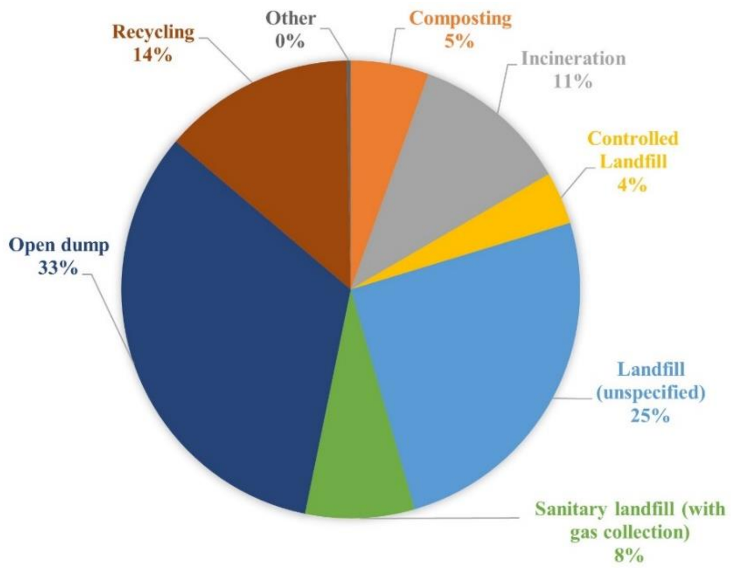

Fig. 2 Global treatment and disposal of waste

Table 1 Solid waste per capita

Year	Solid waste generation per capita (gm/day)
2015-16	118.68
2016-17	132.78
2017-18	98.79
2018-19	121.54
2019-20	119.26
2020-21	119.07

collection efficiency of 95.4%, with 152.7495 kTPD (kilotonns per day) of waste being collected, of which 79.9563 kTPD is treated and 29.4272 kTPD is dumped in landfills. Nevertheless, there exists a substantial disparity of 50.6554 kilotons per day (kTPD) or 31.7% of the overall waste generated, which remains unattributed. Table 1 shows that during the last five years, there has been a modest decrease in the amount of waste produced per person (CPCB, 2020-21). Delhi has the highest rates of solid waste production per resident in India, followed by Lakshadweep and Mizoram. In addition, there has been an increased trend in the percentage of processed solid waste, with that figure projected to rise from 19% in 2015-16 to 49.96% in 2020-21 (CPCB, 2020-21). According to the latest data from the Central Board of Pollution Control, the states of Maharashtra, Uttar Pradesh, and Tamil Nadu produce the most solid garbage in India (Fig. 3). The state of Chhattisgarh stands out as the only one in India where the quantity of garbage produced is exactly equal to the amount processed. In terms of total trash treated, Maharashtrais in the lead, followed by Tamil Nadu and Gujarat (Fig. 4). There has been a gradual decline in the amount of trash sent to landfills during the previous six years. From 54% in 2015-16 to 18% in 2020-21(CPCB, 2020-21), landfill disposal of solid waste has decreased dramatically. Most India's known waste disposal

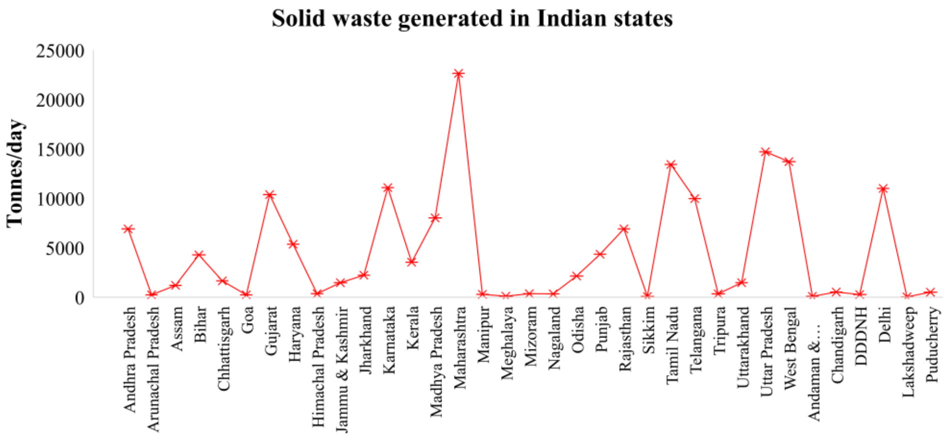

Fig. 3 Solid Waste Generation in India

Fig. 4 Solid Waste Treated in India

sites (221) are in the states of Maharashtra (382 sites), Madhya Pradesh (341 sites), and Karnataka (275 sites). In addition, the two Indian states with the most active landfills are Maharashtra (137 sites) and Karnataka (52).

4. Sources and composition of municipal solid waste (MSW)

An overabundance of MSW is now the world's most pressing environmental issue. Both the community as a whole and its individual members have a stake in the proper disposal of this kind of waste. Their responsibility extends to creating and maintaining a solid waste management infrastructure. However, municipal solid waste management efforts are typically hampered by a wide variety of obstacles that are beyond the purview of local authorities (Sujauddin *et al.* 2008).

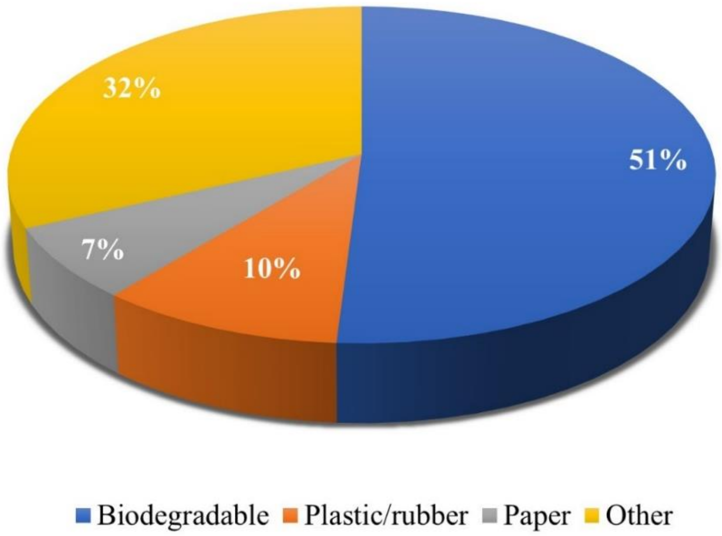

Fig. 5 MSW composition in India

Multiple sources contribute to the complexity of MSW (municipal solid waste) management. The lack of resources typically explains why management, structure, and complexity aren't given enough care. Depending on variables including population density, economic condition, structure of industries, and waste management regulations, MSW varies greatly through cities and nations. Effective management of MSW requires a thorough knowledge of its volume and composition. Understanding the MSW's energy content and its fundamental makeup may help engineers and scientists evaluate the waste's viability as a power source. Such information is useful for forecasting the composition of gaseous emissions arising from gasification and incineration, two key energy conversion methods used for MSW treatment. This data will be important in the design of plants that will be used to generate power from municipal garbage. Garbage collection is essential to the informal economy. The majority, or 70% of garbage, is recyclable, whereas just 30% is made up of non-recyclable items like dirt and old food. The development of efficient waste management methods and the promotion of sustainable practices need an awareness of these factors (Kumar and Agarwal 2020). In India, MSW is composed of around 40%–60% biodegradable material, 30%–50% inert material, and 10%–30% recyclable material. Indian trash contains 0.64 ± 0.8% Nitrogen, 0.67 ± 0.15% Phosphorus, and 0.68 ± 0.15% Potassium with a C: N ratio of 26:5 (Gupta *et al.* 2015, Joshi and Ahmed 2016). The typical composition of Indian MSW is given in Fig. 5 (Ahluwalia *et al*. 2018).

5. Major effects of MSW on health and environment

Economic, institutional, regulatory, technological, and operational restrictions plague solid waste management in developing nations (Imam *et al.* 2008). As a direct consequence of these issues, waste like paper scraps, plastic bags, paper-plastic containers, plastic bottles, and piles of deteriorating garbage in drains and streets accumulate. Furthermore, the lack of essential infrastructure such as collecting trash, adequate sanitation, and sanitary water supply has exacerbated the problem (Rathi 2007). Solid waste management is particularly difficult in underdeveloped countries owing to a lack of resources and infrastructure (Imam *et al*. 2008). This leads to a buildup of trash in the form of discarded paper, plastic bags, paper-plastic containers, plastic bottles, and rotting rubbish in the streets and drains. Critical infrastructure, such as garbage collection, sufficient sanitation, and access to clean water, is lacking, making the situation much worse (Rathi 2007). Improper waste management methods, the commingling of diverse waste kinds with municipal solid waste (MSW), insufficient waste segregation and treatment facilities, and the dumping of waste in open areas and landfills are all major problems that need to be addressed. Leachates, offensive smells, and the release of poisonous compounds into the soil, air, and water are all the result of these variables, and they have a devastating effect on local and global ecosystems as well as human health (Abba *et al.* 2010). As a result, solid waste will continue to play a substantial role in amplifying the effects of global warming and climate change (Li *et al*. 2011).

The World Health Organization (WHO) has also stressed the repercussions of incorrect solid waste disposal in terms of soil, water, and air pollution, as well as the health effects on populations living near the impacted regions (WHO 2015). The health impact of solid waste varies depending on a number of factors, including the type of waste management systems, characteristics, and habits of the exposed population, duration of exposure, and preventative and mitigating measures (Di Bell and Vaccari 2014, Ferronato and Torretta 2019, Ziraba *et al*. 2016). Various waste treatment methods lead to the emission of distinct compounds, some of which could consist of environmental components associated with transportation and exposure pathways. For example, waste incineration releases substances into the air, becoming an important environmental transport route. Moreover, waste management practices, such as landfill or dumpsite waste disposal, have the potential to contaminate groundwater through the leakage of leachate (Vaccari *et al*. 2018), potentially exposing people to toxic or carcinogenic compounds in the water (Negi *et al*. 2020).

One of the most severe consequences on the environment in developing countries is the leaching of toxic chemicals and heavy metals from unlined landfill sites. Disposal of solid waste on and near water bodies leads to disturbance in the water quality, as shown by several studies (Table 2). Regarding the characteristics of the water bodies that surround landfill sites, the authorities should correctly handle the waste in order to prevent further damage.

6. Solid waste management in India

Controlling, collecting, processing, reusing, and disposing of solid wastes affordably while protecting human health and the environment and satisfying the demands of those who benefit from the system are the primary objectives of solid waste management. The US EPA established a waste management hierarchy in 1989 to help deal with this problem (Fig. 6).

In the beginning stages of solid waste management in India, prioritization was not well understood. However, there have been major shifts in the way solid waste is handled in recent years. There is much work to be done before efficient methods of trash disposal can be implemented. Even now, just a small percentage of the world's solid waste is being properly dealt with. Solid waste management cannot be implemented successfully without first properly segregating waste (Nandan *et al.* 2017). Critical components of any SWM system, waste collection, storage, and transportation face challenges (Guria and Tiwari 2010, Das and

Table 2 Previous studies on the impact of MSW on water and soil

Samples	Interpretation	Reference
Leachate	Physiochemical analysis of leachate samples from northern India confirmed its danger. Since the concentration of measured factors declines with distance from the dump, leachate is a potential source of groundwater pollution, and elevated levels of ammoniacal nitrogen and chloride were found in most samples.	Negi *et al*. (2020)
	Recent research in Iraq looked at how seasonal changes in leachate from an open dumpsite affected groundwater quality. The leachates' primary characteristics were their toxicity owing to the presence of heavy metal concentrations and their extreme amounts of organic and inorganic components. The dump site leachate has dramatically higher levels of almost every physicochemical parameter.	Rashid *et al.* (2022)
	Seasonal shifts, human activity, leachate migration, agricultural runoff, and local geology are just some of the causes of water quality decline in landfill locations. High levels of sulfate and nitrate were found in the hazardous leachate from chemical effluent.	Alam *et al.* (2021)
	Leachates had total heavy metal concentrations around 2- 50 times higher than dissolved heavy metal concentrations in the leachates' liquid section, indicating that roughly 50-99% of the heavy metal components in the leachates are partitioned in the suspended particles.	Xaypanya *et al*. (2018)
	Zn was found to be the highest followed by Cu, Mn, Cr, Pb, Ni, and Hg as the sequence of heavy metal concentrations at the landfill site. When compared to the other metals, Zn, Cu, and Mn displayed the greatest mobility potential. Leachate from a landfill has different heavy metal concentrations than leachate from a borehole. A rise in the number of heavy metals, especially Cu, Cr, and Ni, in the leachate discharge has been linked to the presence of an optimal moisture level within the landfill waste, which in turn has influenced the pace of organic acid formation.	Prechthai *et al.* (2008)
	Extremely prominent levels of almost all physicochemical parameters, including heavy metals, were detected in leachate. This means that the aquifer that provides the ground and surface water below is potentially at risk from the leachate, which is likely to contain significant amounts of toxins. Understanding the leachate's chemical makeup is crucial for ensuring the safety of water supplies farther downhill.	Nta *et al.* (2020)
Groundwater	Dissolved components are released into streams and groundwater from both natural and human-made sources, and as a result, neither is safe for human consumption.	Alemayehu *et al*. (2019)
Leachate, Groundwater	Leachate seeping into the groundwater around dumping sites was determined to be very hazardous, clearly not safe enough for human consumption.	Pande *et al.* (2015)
	All metrics in leachate were found to be beyond acceptable limits, and the concentration of heavy metals was high in some but not all analyses. The concentration of the measurable parameters is greatest in the borewell. The more away the borehole is from the landfill, the better the groundwater quality will be.	Dharmarathne and Gunatilake (2013)
Surface water	The introduction of solid waste into water systems is a major contributor to water pollution. Water quality differs across places with and without landfills. The inhabitants living along the river are also affected. Water pollution may be prevented by scientific management and the isolation of pollution sources.	Singh and Dey (2014)
	Waste sites, ponds, and open wells were all found to have dangerously elevated levels of heavy metals. Physical and chemical analyses both found significant levels of contamination in organic and inorganic components. The low levels of heavy metals suggest that the debris was mostly municipal trash. After conducting a series of physicochemical tests, it was concluded that the water was not safe for human consumption.	Naveen *et al*. (2018)
Soil	In three out of the six drills that were conducted, the highest concentrations of heavy metals were discovered at depths that were greater than 2.5 meters. The distribution of heavy metals in the soil of the landfill was significantly influenced by the organization and buildup patterns of municipal and industrial waste. The heavy metal content was found to be lesser in samples that comprised debris and innocuous excavation waste from surrounding construction worksites. These samples were taken from nearby construction sites.	Kasaasi *et al*. (2008)
	The study found that the soil had a lot of heavy metals like Cu, Cr, Mn, Ni, Pb, and Zn. Also, the soil didn't have clear horizons, had a high pH, high levels of natural and organic carbon, low levels of nitrogen, and a high C/N ratio.	Remon *et al*. (2005)

Bhattacharya 2014). In India, local governments must collect refuse and are often provided with containers for sorting recyclables from nonrecyclables. They are routinely mixed, spilled, and burned in the open despite these efforts (USEPA 2002).

The 2016 Solid Waste Management (SWM) Rules in India have been updated by the Union Ministry of Environment, Forests, and Climate Change (MoEF&CC). After 16 years, the Municipal Solid Waste (Management and Handling) Rules, 2000 have been superseded by this new set of regulations.

7. Municipal solid waste management (MSWM) processes in India and challenges faced

7.1 Segregation and collection

In the present context, waste segregation is a rare practice. The daily collection of unsorted rubbish is handled by government agencies, who don't have enough staff. According to CPHEEO (2016), this manual rubbish collection occurs from congested and small streets. In accordance with SWM Rules 2016, over 70% of the trash generated is collected (or 43 million tons), of which only 12 million tones receive suitable treatment while the rest 31 million tones are carelessly deposited in landfills (MSW 2016). Municipal solid waste (MSW) collection techniques include house-to-house collection and community bin collection, both of which adhere to set timetables and are frequently accompanied by the ringing of the vehicle's bell. But there are still a number of important problems with these MSW collection systems: First off, a sizable portion of families do not use community trash cans, which results in rubbish being dumped on the side of the road. Second, a lot of trash cans in the neighborhood frequently overflow, creating unhealthy circumstances. Finally, people who hunt for recyclables close to community trash cans unintentionally cause garbage to pour nearby. Even though there are frequent waste collection services, much of the trash is left on the streets until the next day's collection, leading to significant littering across the metropolitan environment. (Joseph 2014).

7.2 Transport and storage

Municipal waste is often collected by city-owned trucks in the traditional waste management system, while in certain major cities, private businesses are hired to supplement the government fleet. For the transportation of waste, major cities often use open-body, multipurpose trucks with a capacity range of 5 to 8 tones. Rural towns, on the other hand, rely on tricycles, bullock wagons, tow trucks, power tillers, and other vehicles for garbage transportation. trash compactors, container carriers, and dumper placers are increasingly frequently used with community bins because of recent changes in trash management procedures. Transfer stations are used to speed up the waste collection process, where waste is moved from smaller vehicles to larger ones. To ensure that the operations are conducted in a sanitary manner, these transfer stations need considerable changes (Pariatamby *et al.* 2014).

7.3 Treatment and disposal

The lack of well-managed waste treatment systems is one of the key issues in the field of solid waste management. As a result, solid waste treatment techniques such as bio-methanation, waste-to-energy conversion, and composting confront substantial challenges, particularly in the preliminary stages of development. The typical practice of improper rubbish disposal, often

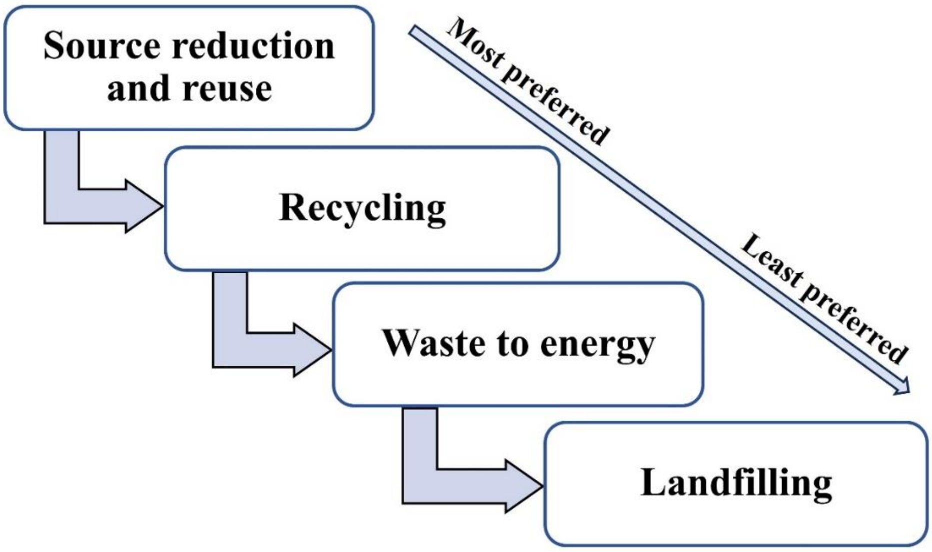

Fig. 6 Waste management hierarchy

Fig. 7 Current practices for MSW management in India

witnessed in open dumps, remains a problem, with 90% of all waste still being thrown in open locations indiscriminately. The creation of sealed sanitary landfill facilities is uncommon, and as a result, dump sites in major cities are rapidly running out of accessible space (Kumar and Agrawal 2020). Furthermore, the proper disposal of sanitary, battery, E-waste, and other hazardous waste must be integrated into various treatment procedures independently (Lv *et al.* 2018, Rarotra *et al*. 2020). The dumping of SWMs in India has reached an unacceptable level. Therefore, infrastructure must be put in place to treat and dispose of ever-increasing MSW volumes (Sharholy *et al*. 2007). According to the United Nations Environment Programme (UNEP), a landfill can be defined as the controlled deposition of municipal solid waste (MSW) on terrestrial surfaces. The reduced necessity for waste removal necessitates the establishment of a designated landfill site. Therefore, through the implementation of an efficient landfill system, municipal solid waste (MSW) can be effectively and securely deposited on land, mitigating concerns related to instability and averting the contamination of surface water caused by odors and wind-borne trash.

Additionally, this approach helps to minimize air emissions, greenhouse gas (GHG) emissions, fires, as well as potential disturbances to animals and wildlife (MoEFCC 2015). In India, dumps should be replaced with well-managed designed landfills, which will significantly reduce waste's impact on the environment. Therefore, ideally, the following steps should be adhered to for the implementation of an efficient waste management system (Malav *et al*. 2020) (Fig. 7).

8. Waste-to-energy processes in India

Global energy consumption is expected to reach 17 billion tonnes of oil equivalent (toe) by 2035, while CO2 emissions are expected to rise to between 29 and 43 Gt/year, according to the IEA (Chu and Majumdar 2012). The government of India, like many other developing countries, is striving to reduce the negative effects of global warming by enacting laws that encourage renewable energy development (Paulraj *et al.* 2019). Most of the country already has infrastructure in place to harness renewable energy sources like solar, biomass, hydropower, wind, and biogas. However, alternative energy sources and the efficient utilization of existing natural resources are both crucial (Malav *et al.* 2020). To obtain renewable energy, waste-to-energy (WtE) technology is the best option. Potentially alleviating several pressing environmental issues connected with solid waste management, these cutting-edge technologies have the potential to produce substantial amounts of heat and electricity from trash (Lipu *et al.* 2013) as well as lowering the use of fossil fuels, which emit greenhouse gases (GHGs), which contribute to global warming and climate change (Srivastava *et al.* 2020). Information provided by SPCBs/PCCs indicates that eleven waste-to-energy facilities are currently functioning in India two in Andhra Pradesh, one each in Goa, Haryana, Madhya Pradesh, Maharashtra, and Uttar Pradesh, and two in Uttarakhand, and three in Delhi (CPCB, 2020-21). The distinct types of waste-to-energy processes are mentioned in Fig. 8.

9. Role of model development in solid waste management

A model is a depiction of an item, system, or idea that is not identical to reality (Qureshi *et al*. 1999). Risk analysis, cost-benefit analysis, environmental impact assessment, multicriteria decision analysis, and life cycle assessment were among the decision-making methodologies and tools incorporated in the models. The primary objectives of models in waste management encompass the optimization of garbage collection routes for trucks and the more intricate task of evaluating the comparative advantages of different waste management methodologies (Morrissey and Browne 2004). Considering this, waste management services have recently emphasized on the use of innovative and modern information technology to improve MSWM and boost the efficiency of trash sorting and recycling (Nowakowski and Pamula 2020, Rahman *et al.* 2020, ASME 2020).

Machine learning (ML) approaches have been effectively used to ecologically linked domains such as wastewater, air pollution, and solid waste treatment due to their superior capacity to simulate complicated systems (Joharestani *et al*. 2019, Ye *et al.* 2020). Modeling, prediction, and optimization of MSW-related challenges are projected to rely heavily on ML approaches. Models are developed to solve various waste-related problems. Some examples of different machine learning models are discussed in Table 3.

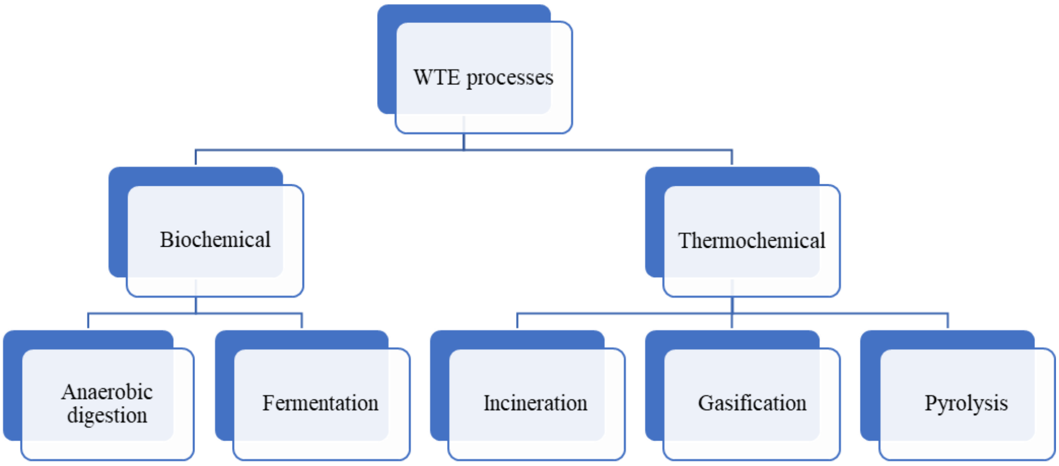

Fig. 8 Waste to energy practices

Table 3 Applications of various waste management models

Applications	Model applied	Reference
Facility location problem- Appropriate transfer station selection for segregated and non-segregated wastes	FLP models- MIP	Rathore and Sarmah (2019)
Increase the total annual profit	MIP	Ayedimir-Karadag (2018)
Appropriate site locations for healthcare waste	MIP	Gergin *et al.* (2019)
Decrease the overall cost of transportation and facility location	MILP	Asefi *et al.* (2019)
Municipal solid waste management strategies	MOLP	De souza and Coelho (2019)
Identify the best locations for MSW recycling and disposal facilities and optimize landfill capacity allocation to transfer stations and population areas.	MOOM	Habibi *et al.* (2017)
Plastic waste generation rate	ANN, SVM, RF	Kumar *et al.* ((2018)
MSW classification	CNN, SVM	Togacar *et al.* ((2020)
MSW generation	ANN, DT	Kannangara *et al.* (2018)
Biogas production	SVM, RF, KNN	Wang *et al.* ((2020)
Landfill surface temperature	ANN	Abu Qdais and Shatnawi (2019)
Landfill gas prediction	ANN	Abushammala *et al.* (2014). Fallah *et al.* ((2020)
Prediction of heating value MSW	ANN	Olatunji *et al.* ((2019)
Waste generation amounts on different time scales	ANN	Vu *et al.* ((2019a)
Waste collection route optimization	ANN	Vu *et al.* ((2019b)
Optimization of biomethane production from solid-state co-digestion	ANN	Saghouri *et al.* (2020)

Note: MIP- Mixed Integer Programming; MILP- mixed integer linear programming; ANN-Artificial Neural Networks; ARNN- Auto-regressive neural network; SVM- Support Vector Machine; RF- Random Forest; CNN- convolutional neural networks; DT- decision tree; KNN- k-nearest neighbor. MOLP- Multi-objective linear programming; MOOM- Multi-objective optimization model

10. Future challenges, limitations, and opportunities in solid waste management in India

The most challenging difficulty that many countries are now experiencing is solid waste management (Malav *et al*. 2020). Lack of energy recovery from waste and inadequate recycling techniques are one of the key issues which disrupt the waste to energy processes (Mohan *et al*. 2020). Many technological, political, and economic challenges have hampered the growth of the waste-to-energy business, including a lack of financing, poor data collecting and analysis, and inconsistent rules and regulations. In the future, it will be essential and beneficial for all sorts of organizations to discuss and analyze such constraints (Pandey *et al*. 2021, Rajmohan *et al*. 2020).

Major limitation in Indian cities is that they do not conduct scientific and systematic trash storage at the source. Typically, waste is dumped in uninhabited areas, abandoned government land, drains, and roads. Despite regular cleaning by Municipal Workers, the city cannot stay clean for more than two or three hours after garbage has been put on the street. The city's open drains grow clogged with trash because residents dump their trash in them. Regular dumping causes major drain diameters to shrink and diminish. Separate storage facilities for biodegradable and non-biodegradable trash are not already in place, which is another barrier. Most urban areas lack adequate waste management services. In most Indian towns, unprotected landfilling is a common practice with serious environmental repercussions (Kumar and Pandit 2013).

Awareness among the public is also equally important for proper waste management. The first step to managing waste is source reduction which is the most preferred step and to successfully follow this step awareness is especially important. Lack of awareness is mainly due to the reason that most people are unaware of the toxic effects of discarded waste and due to negligence about this issue by the people. Most people generally mix all kinds of waste like E-waste with municipal solid waste. Therefore, there is a big need to conduct awareness programs and surveys to make people aware of recycling and other sustainable management processes. Another issue with this respect there should be proper segregation of waste of different kinds and then different management processes can be applied. Segregation is a very big issue in waste management and is a global issue as well. This condition arises because of a lack of effective societal organization and planning (Ye *et al*. 2021). Moreover, the irresponsible disposal of MSW pollutes surface and groundwater, whereas the unscientific removal of MSW has a negative environmental impact (Istrate *et al*. 2020).

Due to its complicated structure and sluggish biodegradability, biogas production from diverse feedstocks remains constrained (Kainthola *et al*. 2019). This issue can be solved by employing various pre-treatment procedures (Prajapati *et al*. 2021). Future technologies and trends such as microbial fuel cell technology, are environmentally benign since it turns municipal solid waste into high energy output and hydrogen gas. Due to the increasing depletion of fossil fuels, the world requires alternative energy sources such as Waste to Energy (WtE) to avert future energy crises. (Ye *et al*. 2021).

11. Conclusions

Worldwide, the amount of waste produced is growing at an alarming rate. Furthermore, a large quantity of MSW is deposited and dumped in open dumps and landfill every single day creating havoc around the surrounding areas by creating a major impact on health and the environment which includes leaking out of landfill leachate, which is directly involved in the contamination of groundwater, production of toxic landfill gases which increases the concentration of GHGs in the environment and many such major effects of improper dumping of wastes. Long-term solutions are needed for the issues associated with achieving effective solid waste management. The use of planned landfills and other waste management strategies, such as waste reduction, recycling, processing, on-site segregation, and correct disposal, are all viable options for handling MSW properly. In the current context, it is imperative to enhance the waste collection, treatment, and disposal protocols in order to optimize the proficient administration of solid waste. Presently in India, there exists a multitude of focal points in the realm of municipal solid waste management. One such area of emphasis revolves around the development of innovative waste management technologies that can be readily embraced by small and medium scale enterprises. The overarching objective of this endeavor is to enhance their overall productivity and bolster their standing in the global arena of competitiveness. In light of the notable achievements realized through the 'Swachh Bharat Abhiyan', India is now directing its efforts towards the establishment of a 'Waste to Wealth Authority'. This esteemed entity will harness cutting-edge technologies on a nationwide scale to effectively tackle the pressing issue of waste generation, while simultaneously fostering socio-economic remedies for the nation. The primary objective of this mission is to discern, examine, authenticate, and implement cutting-edge technologies that can effectively process waste materials to produce sustainable energy, facilitate material recycling, and extract valuable resources.

Additionally, it endeavors to establish a comprehensive database encompassing both domestic and international technological advancements, which will serve as a valuable resource for Urban Local Bodies in their efforts to tackle waste-related predicaments. At present, considerable emphasis has been placed on the strategic implementation of decentralized waste processing sites within urban areas, with the primary objective of addressing the challenges associated with the management of both newly generated municipal solid waste (MSW) and pre-existing legacy waste. The Indian government has also promulgated policies and disbursed financial assistance to bolster the Waste to Energy sector initiatives. The advancement and propagation of the Bioenergy industry in India is effectively regulated by a multitude of policies and incentive frameworks implemented by the esteemed Biogas technology development group of the Ministry of New and Renewable Energy (MNRE). More study is needed to eliminate the drawbacks and restrictions of current waste-to-energy methods. Local governments should educate the public on the need of minimizing waste at its source, sorting it into dry and wet materials, and disposing of waste in an ecologically sound manner, as well as other measures that may be taken to improve waste management nationwide.

Declaration

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

Ethical responsibilities of authors

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors".

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Data availability statement

All data generated or analysed during this study are included in this published article.

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