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Towards Sustainable Municipal Solid Waste Management in India: Challenges, Trends, and Innovations

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Abstract

In developing economies like India, the need for efficient management of Municipal Solid Waste (MSW) and sustainable development is growing. In India about 1,50,847 tonnes of MSW generated daily with decomposable waste accounting for 50% of this total. The non-decomposable portion of this waste is either sent to open dumps or unsanitary landfills. Only 47% of this waste is processed and about 27% is sent to sanitary landfills. But the waste composition is shifting towards less organic and more non-biodegradable portion due to growing economy and purchasing power of individuals. Existing methods of municipal solid waste management such as composting, bio-methanation, incineration etc. treat specific type of wastes leaving behind a considerable proportion of rejects and inert which are to be disposed using sanitary/engineered landfills. With the goal of developing Smart Cities in India having smart waste management; appropriate waste processing and disposal facility needs to be developed. This paper analyzes the trajectory of MSW quantities and composition trends in Indian Smart Cities, highlighting the need for sanitary/engineered landfills in MSW management. It emphasizes the critical parameters that influence the performance of these landfills and identifies the challenges inherent in MSW management. By shedding light on these challenges, the paper lays the groundwork for potential solutions to improve the overall performance of MSW management.

Keywords: MSW, Sanitary Landfill, Leachate, Modeling, Smart City

Introduction

In India, MSW generation stands at 1,50,847 tonnes per day. Efficient disposal of Municipal Solid Waste (MSW) is a challenging issue in developing countries. Over the years, the collection efficiency of the waste has improved to more than 90% (Sharholy, M., Ahmad, K., Mahmood, G. Trivedi, 2008; CPHEEO, 2016; CENTRAL POLLUTION CONTROL BOARD, 2021). The composition of MSW in India comprises 45-50% organic waste, 18-23% recyclables, and the remainder is destined for landfill disposal.(Central Pollution Control Board, 2017a, 2017b) (Fig. 1).

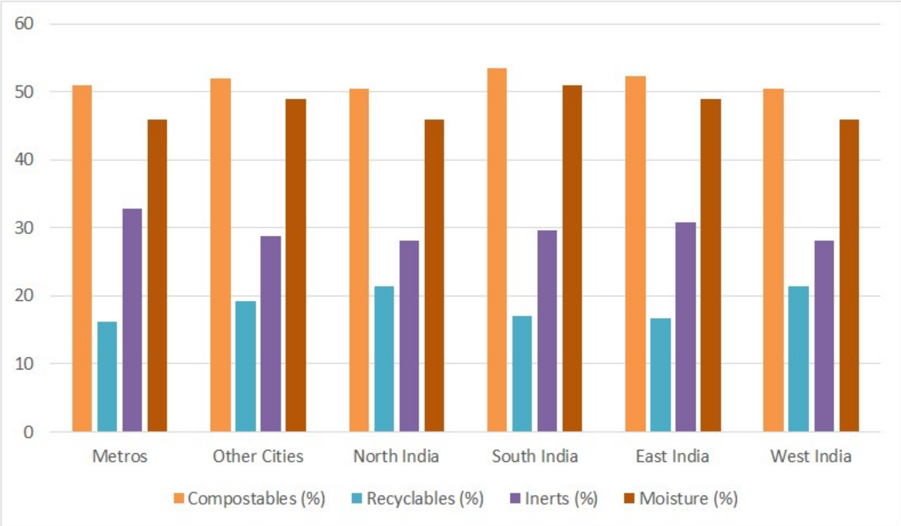

Figure 1: Composition of MSW in different regions of India (Annepu, 2012)

Growing population, economy and education level directs towards production of more per capita waste a

Table 1: The per capita waste generation of the cities depending on the population ranges

Population in millions	No. of cities	Waste generation in kg/capita/day (Kumar et al., 2009)	Waste generation in kg/capita/day (Annepu, 2012)
<0.1	8	0.17 - 0.54	-
0.1 to 0.5	11	0.22 - 0.59	0.46
1 to 2	16	0.19 - 0.53	0.46
>2	13	0.22 - 0.62	0.55

Table 2: Municipal Solid Waste Generation Trend in India (Gupta, M., 2016; Patel, R., & Gupta, 2018; Sharma and Singh, 2020)

Year	Organic Waste (%)	Inorganic Waste (%)
2010	60	40
2012	55	45
2014	50	50
2016	45	55
2018	40	60
2020	35	65

Table 3: Variation in waste composition with population(Gupta et al., 2015)

Population (in lakh)	MSW Composition (%)					
	Biodegradable	Paper	Rubber, Leather and synthetics	Metals	Glass	Inert
1-5	44.57	2.91	0.78	0.33	0.56	43.59
5-10	40.04	2.95	0.73	0.32	0.56	48.38
10-20	38.95	4.71	0.71	0.49	0.46	44.73
20-50	36.57	3.18	0.48	0.59	0.48	49.07
≥50	30.84	6.43	0.28	0.80	0.28	53.90

Table 2 and Table 3 presents trend in MSW composition in Indian cities with population. Biodegradable portion follows declining trend whereas paper, metals and inert follow rising trend.

Significant advances in the treatment and disposal of MSW have been made as a result of the growing emphasis on sustainable waste management on a worldwide scale, ushering in a new era of waste handling procedures that are ecologically friendly. Notably, techniques like composting have become effective instruments for managing organic waste sustainably, as shown by the works of Chefetz et al., 1996, Mbuligwe et al., 2002, and Castaldi et al., 2005.

Similar to this, biomethanation has shown its potential to transform organic waste into valuable biogas in research by Bhattacharyya et al., 2008, Neves et al., 2008, Dhar et al., 2015, Li et al., 2011 and Baghel and Bafna, 2021. Others methods for MSW treatment include waste-to-energy (Tozlu et al., 2016; Karmakar et al., 2023; Saha and Handique, 2023;), incineration (Tillman et al., 1989; Abd Kadir et al., 2013), pyrolysis (Williams and Besler, 1992; Buah et al., 2007; Bhatt et al., 2022) and gasification (Tanigaki et al., 2012; Zhang et al., 2012).

Additionally, the investigation of resource and material recovery techniques, such as those described by Allegrini et al., 2015, Bueno et al., 2015, and Nanda and Berruti, 2021, underlines the possibility of deriving value from organic waste. Refuse Derived Fuel (RDF) and recycling strategies, as discussed in studies by Jackson, 1985, Ismail and AL-Hashmi, 2009, Merrild et al., 2008, Farzadkia et al., 2012, Brás et al., 2017 and Singh et al., 2017, significantly contribute to waste reduction by producing usable energy and recycled materials. Despite these excellent developments, it is important to recognize the constraints imposed by these processing and treatment techniques. The treatment of various waste streams is difficult since some solutions are designed for particular types of waste. Additionally, a lot of procedures create unwanted rejects, which raises questions regarding how they will affect the whole waste management process. (Table 4).

Gasification of MSW is suitable all kind of waste but it highly energy intensive, costly and produces tar (Knox, 2005; Matsakas et al., 2017). Material/Resource Recovery from MSW is suitable only for waste of larger size and free from soil rejecting soiled waste (Prechthai et al., 2008). Recycling paper requires higher energy, and produces more solid residues and CO2 compared to production of virgin paper. Similarly, recycling of plastic (HDPE) and metals (Steel) respectively produces more solid residues and requires more resources as compared to production of virgin materials.

Table 4: Preferred and Rejected Waste Type for MSW Management Methods

S.No.	MSWM Method	Rejects	Rejects by weight percent	Preferred waste type	Reference
	Composting	Inerts mainly sand and bones, particles of size > 80 mm and < 15 mm, compost of size > 15 mm	22 % - 32 %	Food and organic wastes of particle size 15 mm to 80 mm free from heavy metals and other toxic substances	(Colazo et al., 2015; Glenn, 1992; Montejo et al., 2011)
	Biomethanation/Biogas	Inerts mainly sand and bones, particles of size > 80 mm and < 15 mm, compost of size > 15 mm	23 % - 33 %	Food and organic wastes of particle size 15 mm to 80 mm free from heavy metals and other toxic substances	(Colazo et al., 2015; Montejo et al., 2011)
	Incineration	Ashes, non-combustibles	15 % non-combustibles, and 30 %-37 % ash	Combustible, low moisture content, high calorific value waste like plastic and rubber	(Knox, 2005; Lam et al., 2010; Montejo et al., 2011)
	Pyrolysis	Solid residues, non-combustibles	15-20 %	Combustible, low moisture content, high calorific value waste like plastic and rubber	(Knox, 2005; Velghe et al., 2011)
	RDF	Wastes that are non-combustibles, have high heating value, high moisture content(>20%), chlorine or sulphur content	-	high content in plastics, paper/cardboard, polymeric containers textiles, wood and other organic matter	(Garg et al., 2007; Pohl et al., 2008)

Finally, MSW is to be disposed in sanitary/engineered landfills. But the landfillable waste is still dumped or burnt in open areas unscientifically (Kumar et al., 2009; Triassi et al., 2015). This waste when ignites and spread, causes fire. These fires emit dangerous fumes containing dioxins/ furans, CO, $PM_{2.5}$, PM_{10}, SO_x and NO_x due to combustion of wide range of materials including hydrocarbons, pesticides and chlorinated materials(Shih et al., 2016; Kumari et al., 2019;). Such contamination due to open dumps needs innovative and cost effective methods for rehabilitation (Datta et al., 2017; Singh et al., 2018). The major cause for open dumping or unsanitary landfilling of waste is issues associated with setting up of sanitary/engineered landfill which include availability of suitable site, running and maintenance, cost involved and risk of groundwater contamination (Belevi, H; Baccini, 1989; Sumathi et al., 2008; Abd Kadir et al., 2013).

By looking at the changing MSW management scenario in India, this paper aims to address these urgent challenges. It seeks to contribute to a greater understanding of sustainable waste management practices and serve as a roadmap for future research and policy decisions by examining trends, problems, and innovations.

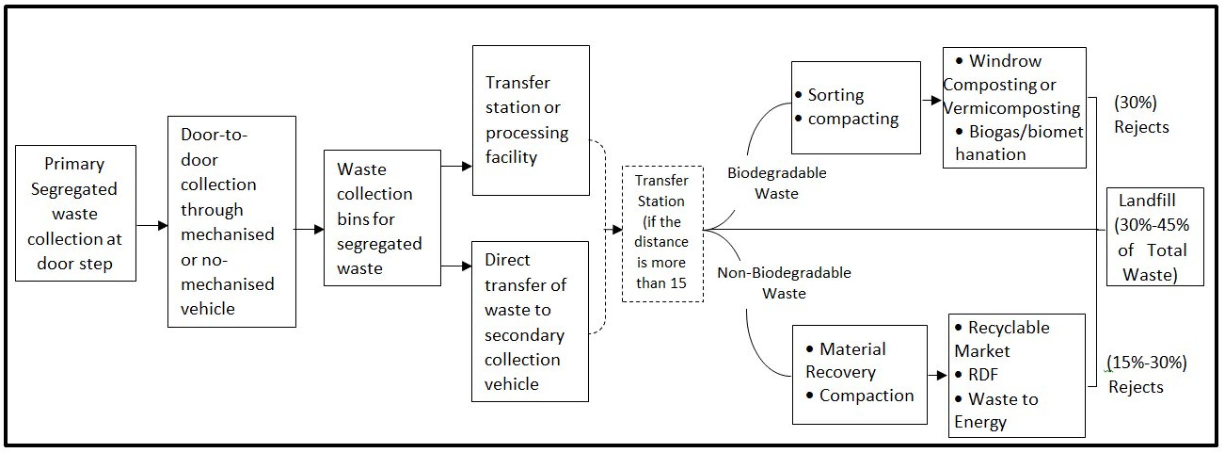

Figure 2: MSW management flowchart (CPHEEO, 2016)

Typical flow of MSWM in India to be followed as per Municipal Solid Waste Management Rules, 2016 is presented in Fig. 2. Presently, out of total MSW generated in India, 96.8% (1,46,053 TPD) is collected, 47% (70,973 TPD) is processed, 27.08% (40, 863 TPD) is sent to sanitary landfills and 25.8% (39,010 TPD) is unaccounted (Chand Malav et al., 2020; MNRE, 2018; CENTRAL POLLUTION CONTROL BOARD, 2021). Rejects data presented in Table 4. has been mapped into Fig 2., showing that even if the waste collection and processing reaches 100%, sanitary landfills will be receiving 30-45% of MSW in the form of rejects.

As much as 1,175 hectare land per year will be required by 2031 for landfill sites with better pollution control design if the current MSWM focussing on recycling, composting and biomethanation as best methods followed by disposal in sanitary landfill is adopted(Planning commission, 2014).

Municipal Solid Waste Management in Indian Smart Cities

In 2015, Ministry of Housing and Urban Affairs, allocated 100 smart cities to states/UT of India with Solid Waste Management as one of the important components (Smart cities mission, Ministry of Housing and Urban Affairs, GOI, 2015). Table 5 shows waste generation and Fig 3. shows MSW composition in smart cities located in different regions in India based on data collected from field.

Table 5: Area Wise Average MSW Generation in Smart Cities

Region	Waste Generation(Tonnes/Day)	Daily Waste Generation Per Capita (Kg/capita/day)	Moisture (%)	Recyclables(%)
North India	1500	0.45	58-60	16-17
East India	4500	0.30	45-46	11-12
South India	350-548	0.33-0.37	45-46	17-18
Central India	450-750	0.33-0.51	58-62	25-26
West India	1600-4000	0.43-0.52	40-42	10-12

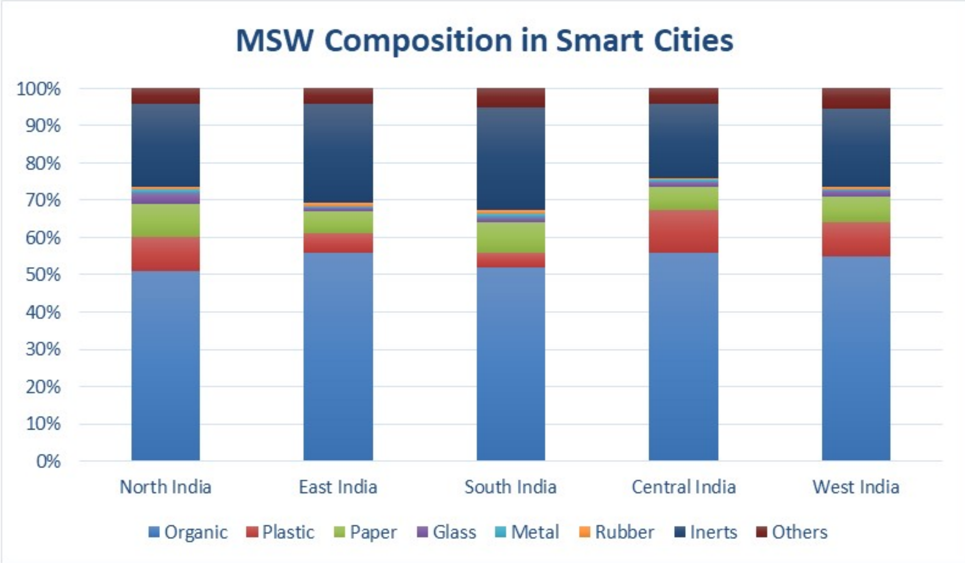

Figure 3: MSW composition in smart cities located in different regions in India

Currently, average waste generation Indian Smart Cities is 0.43 kg per capita per day and total MSW generated is approximately 61,500 TPD. Of the total MSW generated in these cities, about 15, 500 TPD is inert. The average collection efficiency in these cities in 88%. Out of this waste, about 80% is processed and disposed (Ministry of Housing and Urban Affairs, 2020). **Table 6.** presents MSW collection and processing data for 15 Indian Smart Cities.

Table 6: Current MSWM status of Indian Smart Cities

Smart City	% Collection and Transportation	% Processing and Disposal
Indore	100	97
Surat	100	94
Navi Mumbai	98	94
Ahmadabad	100	93
Chennai	68	51
Bengaluru	74	56
Jabalpur	100	91
Ludhiana	75	36
Rajkot	99	90
Tirupati	100	96
New Delhi	100	89
Lucknow	92	88
Chandigarh	91	58
Gandhinagar	96	79
Bhopal	99	89

The MSW in Indian smart cities is composed of 45-60% compostable matter, 10-26% of recyclables and 23-34% of inerts as presented in Fig. 3. For efficient and sustainable management of this MSW, the process flow is proposed as shown in Fig. 4.

The proposed process flow addresses following lacunae from MSWM adopted currently:

- Waste collection and segregation is limited to wet waste and dry waste only (and recyclables in some cases). Proposed MSWM emphasizes on segregation of solid waste into Organic, paper/plastics, metals/glass and others at source. Further sorting into sub-categories: Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS), Polyethylene Terephthalate (PET) for plastics; cardboard, tissue paper, packaging paper, news print for paper; Ferrous and Non-Ferrous for Metals; and colored and non-colored for Glass at Transfer station.

- Present Municipal solid waste management does not take into account the rejects generated from various waste processing methods.

- Recycling of waste like colored glass, certain type of plastics and metals incurs higher cost and energy than their actual production. Hence, it has limited applications.

- Inerts constitutes almost 23-24% of the total waste; yet no specific methodology has been outlined.

- The Sanitary Landfill plays an important role in disposal of wastes along with the rejects and inerts. Current MSWM neglects the importance or sanitary Landfill. Proposed method estimates the quantity of rejects (10,100 TPD), inerts and suggest their disposal by sanitary landfills.

- As predicted by reports of Planning commission, 2014, large area of land would be required for setting up landfill sites.

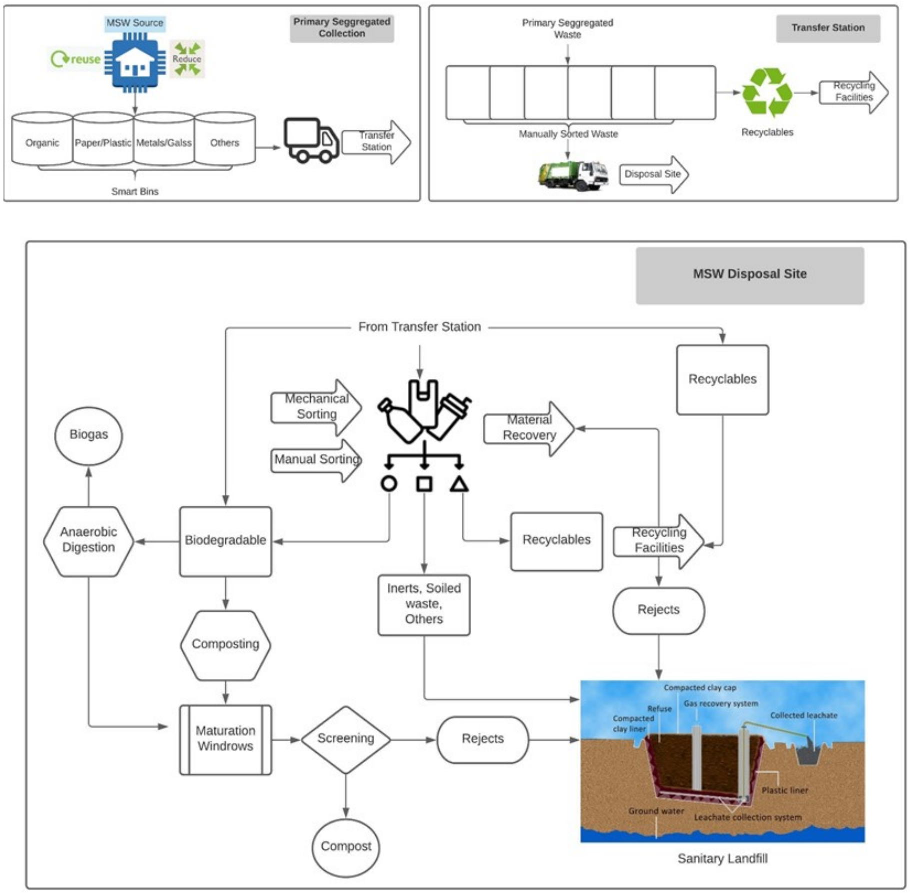

Figure 4: Proposed MSWM flowchart for smart cities

Factors affecting MSWM by Sanitary Landfills

There are number of factors that affect performance of Sanitary Landfills like Composition of MSW, Location of Disposal Site, Management of Leachate, Design of Landfill, Rehabilitation measures for landfill site etc. Out of these, three factors namely waste composition, landfill siting and leachate management play very important role in Indian conditions because:

- Waste data available is insufficient and limited to populated cities only as we have seen in previous sections.
- There are 3,075 dumpsites which needs rehabilitation, 91 dumpsites have been capped and 14 dumpsites have been converted into sanitary landfills(CENTRAL POLLUTION CONTROL BOARD, 2021). 994 landfill sites identified for construction and area of 1,175 hectare land per year is required by 2031 for landfill sites (Planning commission, 2014; CENTRAL POLLUTION CONTROL BOARD, 2018;).
- Although, there are approximately 59 landfills in 59 cities in India, many of these face problem of excessive leachate and risk of groundwater contamination (Mishra et al., 2017; Sachin Mishra, Dhanesh Tiwary, 2017).

Waste Composition

Uncontrolled and unconsolidated disposal of MSW in dumping sites is prominent problem which possess health risks and causes groundwater pollution (Kumar et al., 2009; Zurbrugg, 2003). In India, almost each class I and class II city have dumpsite which needs to be converted into sanitary landfill(Federation of Indian Chambers of Commerce and Industry (FICCI), 2009). Many sites for sanitary landfilling have been identified and many of these of started construction while rest are in planning stage(CPCB, 2013). Details of MSW Landfills and Dumpsites is presented in Table 7.

Table 7: Status of MSW Dumpsites and Landfills in India(CENTRAL POLLUTION CONTROL BOARD, 2021, 2018)

Total number of existing dumpsites	3,075
Dumpsites reclaimed/capped	91
Dumpsites converted to sanitary landfill	14
Landfill site identified	994
Landfill Constructed	104
Landfill under construction	77
Landfill in operation	204

But major issue for setting up a sanitary landfill is waste composition analysis and its quantification. The characteristics of landfill waste as well as the operational activities at the landfill site is required for optimization of landfill cost (Owusu-Nimo et al., 2019). Operational activities at landfill site include leachate management which is again affected by waste composition (Adhikari et al., 2014). Researchers have found that MSW have great recyclables potential (Raharjo et al., 2018), identifying which will reduce load on landfill performance.

The amount and composition of waste generated is affected by various factors which are climate, living habits, religious, public attitudes and socio-economic factors such as household size, income and education (Bandara et al., 2007; Trang et al., 2017; Ramachandra et al., 2018). Waste characterization greatly affects extent of resulting soil, air (greenhouse gases) and water pollution (leachate) (Ranjan et al., 2014). It is also very essential in landfill design and assessment. There have been researches on characterization of MSW but these have classified waste into lesser number of categories (Sharholy, M., Ahmad, K., Mahmood,

G. Trivedi, 2008; Planning commission, 2014; Kumar et al., 2017; Ramachandra et al., 2018;). This leads to waste having energy potential or which can be recycled/reuse being dumped(Kumar et al., 2017). Elaborative characterization of MSW have been done in various countries, classifying waste into as many as 36 categories (Gidarakos et al., 2006; Burnley et al., 2007; Staley and Barlaz, 2009; Baawain et al., 2017).

Landfill Siting

Setting up of landfill demands site selection out of available alternatives. Numerous methodologies based on spatial multi criteria decision support, Geographic Information System (GIS), Analytical Hierarchy Process (AHP), DRASTIC method and Multi--criteria evaluation (Sener et al., 2006; Wang et al., 2009; Ersoy and Bulut, 2009; Moeinaddini et al., 2010; Şener et al., 2011; Gorsevski et al., 2012; Rahmat et al., 2017; G. A., Adeyemi, M., Markus, O. G., Gbolahan, S. O., 2018; Santhosh and Sivakumar Babu, 2018; Yousefi et al., 2018; Demesouka et al., 2019;) have already developed. Optimizing distance from collection point is major criteria to minimize transportation cost which have been worked in India (Majumdar et al., 2017). But the method is suitable for only one-point collection situation which is not the case in various cities.

The AHP is a structured technique for organizing and analyzing complex decision-making, such as landfill site selection (Rahmat et al., 2017). In the site selection process, AHP determines the relative weight or priority of criteria to each other and allows comparing elements to each other in a consistent manner (Vahidnia et al., 2009; Şener et al., 2010). AHP divides the decision problems into understandable parts; each of these parts is analyzed separately and integrated in a logical manner (Demesouka et al., 2013). AHP process contains various steps such as selection of criterion, use of pairwise comparison matrix for setting priority or weighting of criterion and to get an overall score of each criterion (Ahmad et al., 2016). Selection of criteria includes identifying its attributes and possible alternatives for landfill site for each criterion, computation of linguistic variables for the importance weight of each criteria and decision maker's choice for importance weight of the criteria (Singh and Vidyarthi, 2008). The various criterion or factors include geo-environmental factors like such as land use/cover, surface water/river, distance to settlement areas, geology, soil, slope, lineament and roads (Fagbohun and Aladejana, 2016; TÜdeş and Kumlu, 2017; Ghazifard et al., 2018). Further, geopolitical, social and economic factors also effects waste management (Parvathamma, 2014). One of the way to evaluate these factors is using Saaty's 9 points scale where each value represents a state (Moeinaddini et al., 2010; Fagbohun and Aladejana, 2016).

The Geographical Information System (GIS) helps to quantify the relationship between the demands and supply of suitable land for waste disposal over time and plays a significant role in decision making for planning and management of solid wastes (Khan and Samadder, 2014). The advantages of applying GIS in the landfill siting process include selection of objective zone according to the set of provided screening criteria, zoning and buffering, performing 'what if' data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of the various influencing factors etc., handling and correlating large amounts of complex geographical data and visualization of the results through graphical representation (Sumathi et al., 2008). GIS is a tool that not only reduces time and good spatial site selection but also provides a digital data bank for future monitoring of the site. It can be utilized for thematic maps of base map, drainage map, geomorphology, land use/land cover and lineaments, soil and geology maps which can be intersected to get output (Neela, 2013). Application of GIS-based multi-criteria evaluation approach for characterizing and assessing potential favorable landfill sites has proved effective in developing countries where urbanization, poor planning, and lack of adequate resources contribute to the poor state of solid waste management practices (Gorsevski et al., 2012).

Leachate Management

Leachate Modelling

Numerous chemical and biological approaches are available to identify pollutants present in leachate and assess risk from the contaminants (Christensen et al., 1994; Mikac et al., 1998; Butt and Oduyemi, 2003; Butt et al., 2008; Adeolu et al., 2011; Baderna et al., 2011). But the precision of these methods in pollutants concentration is still a concern. The fate of all the pollutants leachate can be predicted by solute transport model developed by Huyakorn et al., 1987 based on a two-dimensional, advection-dispersion equation. The model have been used with modifications by researchers (Liu et al., 2004). The use of model with improvisation according to Indian conditions will provide effective tolls for risk assessment due to leachate. Other models based on finite element flow and geo-informatics are also available with sufficient scope for modelling plume in groundwater (Ashraf and Ahmad, 2008). Various Leachate Pollution Index (LPI) available are helpful in estimation extent of contamination by leachate. But the indexes cover very less parameters), are site specific (Kumar and Alappat, 2005; Arunbabu et al., 2017; Mor et al., 2018) or have errors (Lothe and Sinha, 2017). These indexes have been modified and implemented to get better results in India in very few areas (Mor et al., 2018). Supplementing groundwater contamination with GIS will provide better understanding of contamination plume behavior (Mishra et al., 2018).

Leachate Treatment

Leachate generated from landfill varies in terms of quantity and characteristics from region to region. Typical characteristics of leachate generated from MSW landfill is presented in Table 8.

Table 8: MSW leachate characteristics (Kjeldsen et al., 2002; Xiaoli et al., 2007; Karthik et al., 2007; Bhalla et al., 2012; Ghosh et al., 2015; Kalamdhad, 2018; Rani et al., 2019; Mandal et al., 2020; Mounaim Halim El Jalil et al., 2020; Pandey et al., 2014; Sharma et al., 2020; Tenodi et al., 2020; Wai et al., 2020;)

S.NO.	Parameter	Typical Range
	pH	6.9-9.8
	Turbidity (NTU)	22-80
	Total Hardness (mg/l)	585-1183
	COD (mg/l)	800-29000
	BOD_5 (mg/l)	100-2200
	Total Solids (mg/l)	5000-33000
	Total Suspended solids (mg/l)	600-3100
	Total Dissolved Solids (mg/l)	1000-32000
	Alkalinity (mg/l)	1700-2256
	Conductivity (mS/cm)	1.3-1.6
	Total Organic Carbon (mg/l)	1200-2100
	NO_3^- (mg/l)	4-250
	Total Nitrogen (mg/l)	255-899
	NH_3-N (mg/l)	92-580
	Total Phosphorous (mg/l)	1.2-84

	Cl^- (mg/l)	300-4000
	SO_4^{2-} (mg/l)	44-713
	Fe (mg/l)	3.8-79
	Mn (mg/l)	0.1-9.9
	Zn (mg/l)	0.36-7.0
	Cu (mg/l)	0.09-2.75
	Ni (mg/l)	0.04-0.73
	Cr (mg/l)	0.013-2.1
	Pb (mg/l)	0.08-3.85
	Cd (mg/l)	0.001-0.36
	Sodium (mg/l)	6.2-1465
	Potassium (mg/l)	14.4-2113
	Calcium (mg/l)	14.4-811

There is now extensive scientific research going on the collection, storage and suitable treatment of its highly contaminated leachates, threatening surface and ground waters.

Leachate Recirculation

Recirculation of leachate helps to degrade waste. It has resulted in increased anaerobic decomposition (Sanphoti et al., 2006; Bilgili et al., 2007;). Broad study on variation of operational parameters for leachate recirculation like recirculation ratio, volume, frequency and duration had been performed at laboratory scale for specific type of MSW (Warith et al., 1999; Degueurce et al., 2016; Hussain et al., 2017; Luo and Wong, 2019; Luo et al., 2019). Standard leachate recirculation parameters would help to achieve maximum efficiency of waste degradation.

Challenges and Solutions to Sanitary Landfills

Technological Challenges and Solutions

MSWM by sanitary landfills reduces numerous inconveniences and helps in controlled stabilization of waste over the period of time. But the release of leachate from a sanitary landfill and stricter environmental regulations focused researchers for sustainable treatment of leachate(Renou et al., 2008).

Decomposable matter in the landfill degrades with time leading to settlement of cover. Degradation of waste increases compressibility of waste (Hossain et al., 2003). Laboratory scale methods of decomposing waste by microbes (Fang et al., 2010; Awasthi et al., 2018; Montazer et al., 2018), use of magnetite and Granular activated carbon (GAC) in acidogenesis and methanogenesis respectively (Zhao et al., 2017), acid chlorite for lignin (newsprint) (Stinson and Ham, 1995), Biochar for food waste (Dias et al., 2010) are available, there applicability on field scale is needs to be assessed. Use of Ultraviolet treated soil have proved to enhance degradation of LDPE (Tribedi and Dey, 2017). The methodology can be used to pretreat LDPE portion of segregated waste reaching landfill. Increasing rate of decomposition will help to claim more space in landfill for waste disposal. Degradation of waste containing cellulose and hemicellulose will also result in increasing methane yield (Eleazer, William E., Odle, William S., Wang, Yu-Sheng, Barlaz, Morton A., 1997). Presence of engineered nanomaterials in waste coming from cosmetics and polymers increases toxicity of waste which can inhibit anaerobic decomposition (Lofrano et al., 2017). Their presence in leachate will restrict its recirculation. Treatment of such materials with nanoscale zero-valent iron (Karn et al., 2009; Lacinova et al., 2012), polychlorinated compound (Amin et al., 2014; Ghasemzadeh et al., 2014) and other biosysnthesized nanoparticles (Sharma et al., 2015) have provided acceptable results . Use of MnO_2-TiO_2 photo-catalyst in landfill in mixture with clay-bentonite as liner and intermediate cover proved significantly effective in degradation of non-biodegradable pollutants (Duc, Tran M., Hien, Dang X., 2017). Similarly, use of compacted pozzolanic fly ash as liner increases pH leading to precipitation of heavy metals (Edil et al., 1992). Use of ashes show good potential in covers (Travar et al., 2009). Utilizing modified covers and liners made up of waste products like fly ash, fly ash with sewage sludge (Herrmann et al., 2009), flay ash with bentonite (Mollamahmutoǧlu and Yilmaz, 2001), paper millings with fly ash and plastic clay (Slim et al., 2016), coal gangue (Wu et al., 2017) etc. have good potential to be used on-site but risks associated with them e.g., fly ash have various trace metals needs to be analyzed further. Application of Enterobacter sp. T5 can help to remediate phthalic acid diesters presence in waste (Fang et al., 2010).

Conventional systems of liner and cover utilizes large quantity of soil and claims considerable space (about 2.5 m to 2.7 m). Design optimization of landfills could help to accommodate more volume of waste for the same area. Selection of appropriate geosysntehtic materials will help to reduce thickness of covers and liners e.g., cover system's vegetation layer by Geocells, drainage layer and gas collection layer by Geonet, Geotextile and Geogrid, and liner system's Compacted Clay Liner with Geosynthetic Clay Liner to increase waste storage keeping landfill size same.

Existing dumpsites and sanitary landfill sites after closure needs rehabilitation measures. Aftermath of contaminated soil and groundwater can be prevented by using reactive cut off walls (Guerin et al., 2002; Hong et al., 2017; Yang, Yu-Ling, Reddy, Krishna R., Du, Yan-Jun, Fan, R.D., 2017), electrochemical methods (Ayodele et al., 2018), Iron nano materials (Litter et al., 2018; Soto-Hidalgo and Cabrera, 2018), Carbon nano tube seeds (Song et al., 2017) and some specialized plants species like Thlapsi (Luo and Tu, 2018). The application of these methods on field scale is yet to be investigated to get the best possible solution.

Economic Challenges and Solutions

Cost of MSWM is a function of Collection, Transportation and Disposal. Cost of disposal by Sanitary Landfills is affected primarily by cost of land, and operation and maintenance cost. The combination of recycling with sanitary landfill costs about US$19 per tonne of MSW as compared to combination of recycling, composting and incineration costs about US$38 per tonne of MSW in India. The MSWM by is economically viable as compared to other methods like incineration because of high capital investment for later. Also, sanitary landfill is less sensitive to changes in operation and maintenance cost compared to other methods (Debnath and Bose, 2014; Sharma and Chandel, 2021).

Social challenges and Solutions

MSW collection has reached above 90% in many areas. Still there are cities where waste collection is only 60%-70%. This leads uncontrolled disposal of possessing health risks to the society. MSW segregation is another challenge due to which only 47% of waste is processed. Various social factors affect the quantity and characteristics of MSW generated. The proposed MSWM scheme (Fig.4) will not only address this issue, but also cultivate recycling potential of MSW.

NIMBY (Not In My Backyard) attitude leads to opposition for setting up of disposal site due to which society ends up in a worse situation. The combination of GIS and the Analytic Hierarchy Process (AHP) must replace the traditional method of site selection. It is applied globally at few sites and produced effective results. AHP can be used for scaled weighting of criteria with GIS to locate the suitable sites for the development of landfill. Weighted spatial layers can be created using GIS by factors selected as criteria/sub-criteria and evaluated by experts from different fields using an AHP. Weights can be chosen on 0 to 9 scale or 0 to 10 scale for current and upcoming years of operation of landfill (Chandio and Matori, 2011; Zelenović Vasiljević et al., 2012; Alavi et al., 2013; Deswal and Laura, 2018; Randazzo et al., 2018;).

Conclusion

The article concludes by highlighting the important problems with Municipal Solid Waste Management (MSWM) in India, particularly in light of the country's rising urbanization and economic development. A thorough and effective strategy to waste management is required due to the rising amount of waste being produced. With 100% efficiency and great development in waste processing at 80%, smart cities have emerged as industry leaders in waste collecting. It is clear that the current MSWM techniques, which employ technologies like composting, biomethanation, pyrolysis, gasification, and RDF, have drawbacks and frequently generate undesired rejects. Furthermore, a sizable amount of inert waste is untreated, highlighting the demand for a comprehensive and efficient solution.

The setting up of sanitary landfills stands out among the several suggested solutions as a workable and long-term solution to the problems with the current waste management system. The study offers a thorough framework outlining a suggested MSWM strategy, placing an emphasis on source segregation into various categories such as organic, paper/plastics, metals/-glass, and others. Sub-categorization improves the process by taking into account the intricacies in waste composition, such as different plastic types, variations in paper, and various metal and glass classifications.

The study emphasizes how crucial it is to use sanitary landfills as the basis of this strategy. The study provides a multifaceted strategy to solve difficulties by a careful examination of numerous elements affecting waste management through sanitary landfills, such as waste composition, site selection, leachate management, and modelling. A complete toolset is formed by technological development, economic factors, and societal involvement to manage the complexities of MSWM through sanitary landfills.

The study also calls for a thorough categorization of waste streams and promotes a methodical approach to measuring and characterizing MSW in India. The accuracy of the waste management process is improved by incorporating current tools like ArcGIS and the Analytic Hierarchy Process (AHP) for landfill site selection. Moreover, advanced modelling, recirculation plans, and treatment methods are being used to handle the management of leachate, a byproduct of landfill operations, resulting in a strategy that is both ecologically responsible and operationally effective.

However, it is recognized that India's attempt to achieve sustainable MSWM using sanitary landfills faces a variety of difficulties. The complexity of the work is influenced by a number of variables, including waste degradation, existing infrastructure, leachate generation, land availability, operational expenses, maintenance, and the effectiveness of trash collection and segregation. However, the ideas outlined in this paper provide a hopeful roadmap for establishing sustainable and effective waste management practices across all Indian metropolitan centers, not just in smart cities. By putting the suggested solutions into practice, MSWM might be revolutionized, resulting in a future for the country that is cleaner, healthier, and more environmentally conscious.

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