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Tailoring Solid Waste Management in India

Learnings from Cities with a Million-plus Population

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Report | March 2025

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ceew.in

Improving solid waste management in India is crucial, as it aligns with more than half of the 17 Sustainable Development Goals (SDGs).

Image: iStock

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MINISTRY OF HOUSING AND URBAN AFFAIRS

FOREWORD

India has implemented various national initiatives and programmes aimed at improving sanitation and waste management. **Swachh Bharat Mission (SBM)**, launched in 2014, is one of the most transformative interventions that has become the world's largest sanitation initiative. In the last 10 years, SBM has significantly improved urban cleanliness, waste segregation, and processing in Indian cities. Under the second phase of the SBM, the Government of India envisions achieving 'garbage-free cities' by ensuring 100% waste processing and scientific disposal of legacy waste.

Many cities across India have made significant improvement in waste management, setting valuable lessons for urban centres nationwide. There is a need for how cities can effectively learn from each other and adopt solutions tailored to their unique requirements. The Council on Energy, Environment and Water (CEEW) has undertaken a study from eight cities that are consistently performing well in the Swachh Survekshan and developed a **challenge-root cause-solution (CRS) framework**. The approach will allow cities to design and implement localised waste management solutions.

The insights and case studies from this report will be invaluable in helping municipal authorities adopt **context-specific solutions** to strengthen governance mechanisms and improve their waste management efforts. I commend CEEW for this timely and well-researched study, which provides a unique framework for tailoring solid waste management strategies in India's rapidly growing urban centres.

This report's findings and recommendations can be leveraged by cities to enhance their waste management ecosystems and share learnings for collective progress. I extend my best wishes to the team at CEEW for their efforts in advancing waste management research and hope that this report serves as a valuable resource for policymakers, practitioners, and city administrators across the country and the world.

(Roopa Mishra)

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The *Solid Waste Management Rules, 2016*, mandate waste generators to segregate waste at the source, enhancing waste minimisation, cost efficiency, and operational effectiveness across the waste supply chain.

Image: Vishesh/Waste Warriors

About CEEW

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses **data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources**. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW is a strategic/ knowledge partner to 11 ministries for India's G20 presidency.

The Council's illustrious Board comprises Mr Jamshyd Godrej (Chairperson), Mr S. Ramadorai, Mr Montek Singh Ahluwalia, Dr Naushad Forbes, Dr Janmejaya Sinha, Dr Suresh Prabhu, and Ms Vinita Bali. The 330+-strong executive team is led by Dr Arunabha Ghosh. CEEW has repeatedly featured among the world's best managed and independent think tanks.

In over 14 years of operations, The Council has engaged in 500+ research projects, published 460+ peer-reviewed books, policy reports and papers, created 220+ databases or improved access to data, advised governments around the world 1400+ times, promoted bilateral and multilateral initiatives on 160+ occasions, and organised 610+ seminars and conferences. In July 2019, Minister Dharmendra Pradhan and Dr Fatih Birol (IEA) launched the CEEW Centre for Energy Finance. In August 2020, Powering Livelihoods — a CEEW and Villgro initiative for rural start-ups — was launched by Minister Piyush Goyal, Dr Rajiv Kumar (then NITI Aayog), and H.E. Ms Damilola Ogunbiyi (SEforAll).

The Council's major contributions include: Informing India's net-zero goals; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for India's G20 presidency, the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the first independent evaluation of the *National Solar Mission*; India's first report on global governance, submitted to the National Security Advisor; support to the National Green Hydrogen and Green Steel Missions; the 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; irrigation reform for Bihar; the birth of the Clean Energy Access Network; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); India's largest multidimensional energy access survey (ACCESS); critical minerals for *Make in India*; India's climate geoengineering governance; analysing energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka, and Viet Nam. CEEW published *Jobs, Growth and Sustainability: A New Social Contract for India's Recovery*, the first economic recovery report by a think tank during the COVID-19 pandemic.

The Council's current initiatives include: State-level modelling for energy and climate policies; consumer-centric smart metering transition and wholesale power market reforms; modelling carbon markets; piloting business models for solar rooftop adoption; fleet electrification and developing low-emission zones across cities; assessing green jobs potential at the state-level, circular economy of solar supply chains and wastewater; assessing carbon pricing mechanisms and India's carbon capture, usage and storage (CCUS) potential; developing a first-of-its-kind Climate Risk Atlas for India; sustainable cooling solutions; developing state-specific dairy sector roadmaps; supporting India's electric vehicle and battery ambitions; and enhancing global action for clean air via a global commission 'Our Common Air'.

The Council has a footprint in over 20 Indian states, working extensively with 15 state governments and grassroots NGOs. Some of these engagements include supporting power sector reforms in Uttar Pradesh, Rajasthan, and Haryana; energy policy in Rajasthan, Jharkhand, and Uttarakhand; driving low-carbon transitions in Bihar, Maharashtra, and Tamil Nadu; promoting sustainable livelihoods in Odisha, Bihar, and Uttar Pradesh; advancing industrial sustainability in Tamil Nadu, Uttar Pradesh, and Gujarat; evaluating community-based natural farming in Andhra Pradesh; and supporting groundwater management, e-auto adoption and examining crop residue burning in Punjab.

The rising generation of waste, coupled with inadequate waste management, can lead to adverse effects.

Image: Adeel Khan/ CEEW

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Without proper waste management, leaks in the waste supply chain result in unaccounted waste being disposed of in open spaces, drains, and water bodies, or burned openly.

Image: iStock

Executive summary

Indian cities will generate approximately 435 million tonnes of solid waste by 2050 (MoHUA 2021). In FY 2021–22, India generated 170,000 tonnes of municipal solid waste per day, about 156,000 tonnes were collected, of which nearly 54 per cent was treated, and 24 per cent was deposited in landfills (CPCB 2024). The remaining 22 per cent was unaccounted for due to leakages in the waste supply chain. Without proper waste management, unaccounted waste is disposed of in open spaces, drains, and water bodies or through open waste burning, all of which result in adverse effects.

India has introduced multiple initiatives through policies and national programmes to address the solid waste management (SWM) crisis. *Swachh Bharat Mission* (SBM), launched in 2014, is the government's ongoing flagship programme. Under *SBM Urban 2.0*, India aims to make all its cities garbage-free by 2026. To achieve this target, cities need to ensure compliance with certain conditions, including scientific management of generated waste, remediation of legacy waste, efforts towards waste reduction, and efforts to promote visible cleanliness (MoHUA 2022). To achieve these targets, city-specific challenges and gaps at each stage of the waste supply chain must be identified and assessed. In recent years, many solutions and best practices have emerged to improve SWM locally and globally. However, replicating best practices from other cities and regions without adapting them to local contexts may not lead to sustainable waste management.

Cities vary significantly in their waste generation and composition, geography, climate, culture, workforce capacity, financial resources, and local legislative framework. **These difference make a one-size-fits-all approach ineffective, as solutions that work in one context may not necessarily work in another**. Therefore, a tailored approach contextualised to each city's unique characteristics is required for developing waste management strategies and plans. Urban local bodies (ULBs) should identify the underlying root causes of city-specific challenges, as local reasons or issues can vary significantly from one city to another.

Challenge–root cause–solution matrix for customising waste management practices

This study introduces a challenge–root cause–solution (CRS) matrix that allows city administrations to explore, facilitate, and adopt tailored solutions that address the local 'root causes' of specific urban waste challenges. We have focused on cities with populations exceeding one million, as they account for roughly half of India's urban waste. These cities also benefit from dedicated funding allocated through the *Million-Plus Challenge Fund* issued under the *Fifteen Finance Commission* (FC-XV).

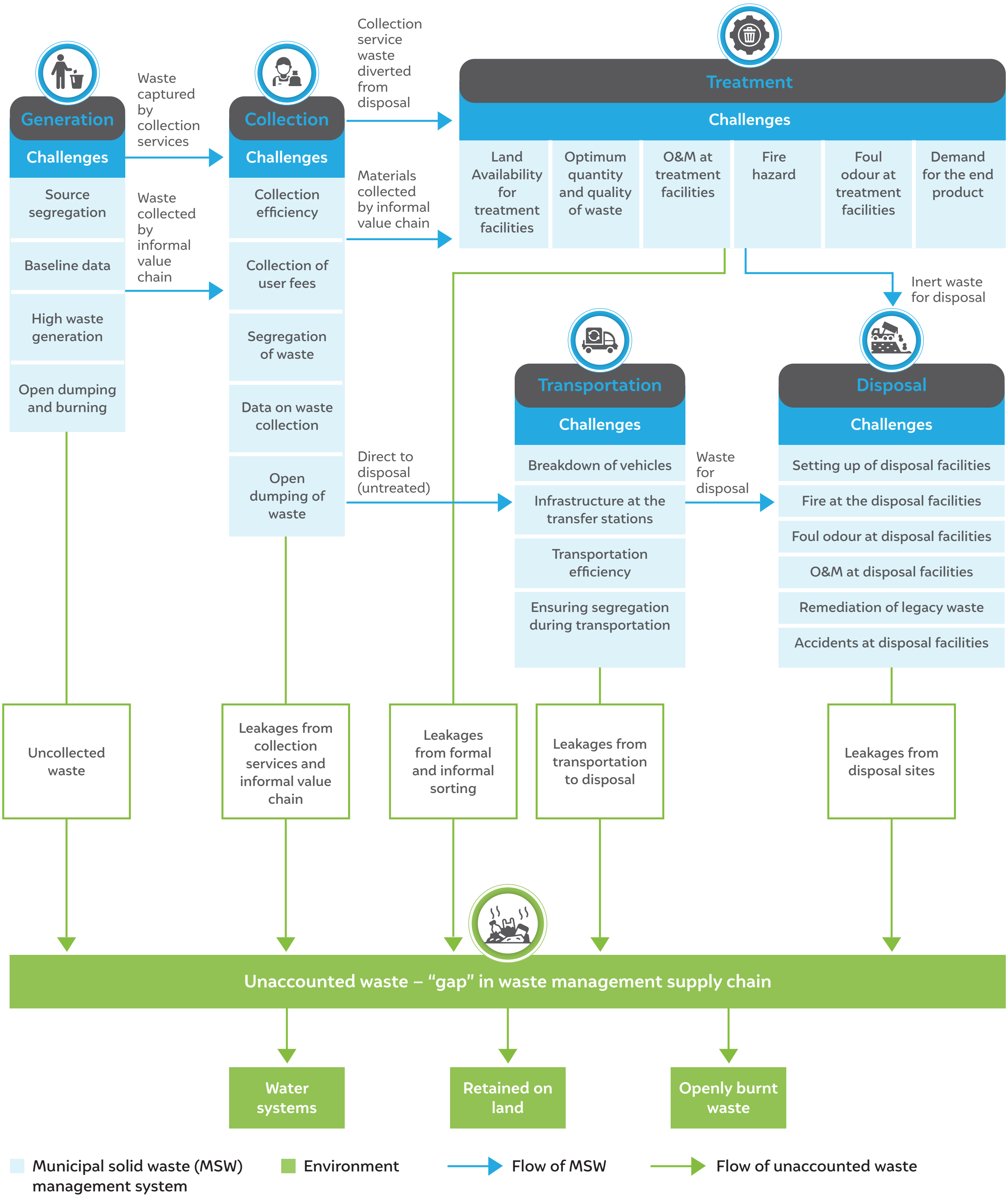
We examined eight million-plus cities – Ahmedabad, Bhopal, Indore, Navi Mumbai, Pune, Rajkot, Surat, and Visakhapatnam. These selected cities have consistently performed well according to the *Swachh Survekshan* annual survey for six years (2017–2022). We developed the CRS matrix for each level of the solid waste supply chain based on a comprehensive literature review on SWM challenges, semi-structured interviews with stakeholders, and observations and learnings from field visits.

Key insights that informed the CRS matrix

We identified 26 challenges prevalent across the SWM supply chain using secondary sources. The challenges were integrated and visualised in a waste flow diagram (WFD) system map, as shown in Figure ES1 (GIZ 2020). The WFD revealed waste leakage at various levels of the SWM supply chain due to gaps in the waste supply chain. Further, many of these challenges are deeply interlinked across the waste supply chain. For instance, improper segregation at source impacts collection and transportation efficiency and resource recovery for different types of waste.

> A tailored approach contextualised to each city's unique characteristics is required for developing waste management strategies and plans.

Figure ES1 **Waste flow diagram and system map for municipal solid waste, highlighting the identified challenges at each level of the supply chain**



Source: Authors' compilation; adapted from GIZ. 2020. Waste Flow Diagram (WFD): A Rapid Assessment Tool for Mapping Waste Flows and Quantifying Plastic Leakage. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

To close these gaps, it is crucial to identify and address the underlying root causes of the major challenges in the waste supply chain. We identified **97 root causes** for the 26 challenges, which are being addressed through **184 solutions** implemented in the selected cities in various capacities.

Over half of the identified root causes are linked to the 'attitude and awareness', 'policy- governance', and 'infrastructure' challenges.

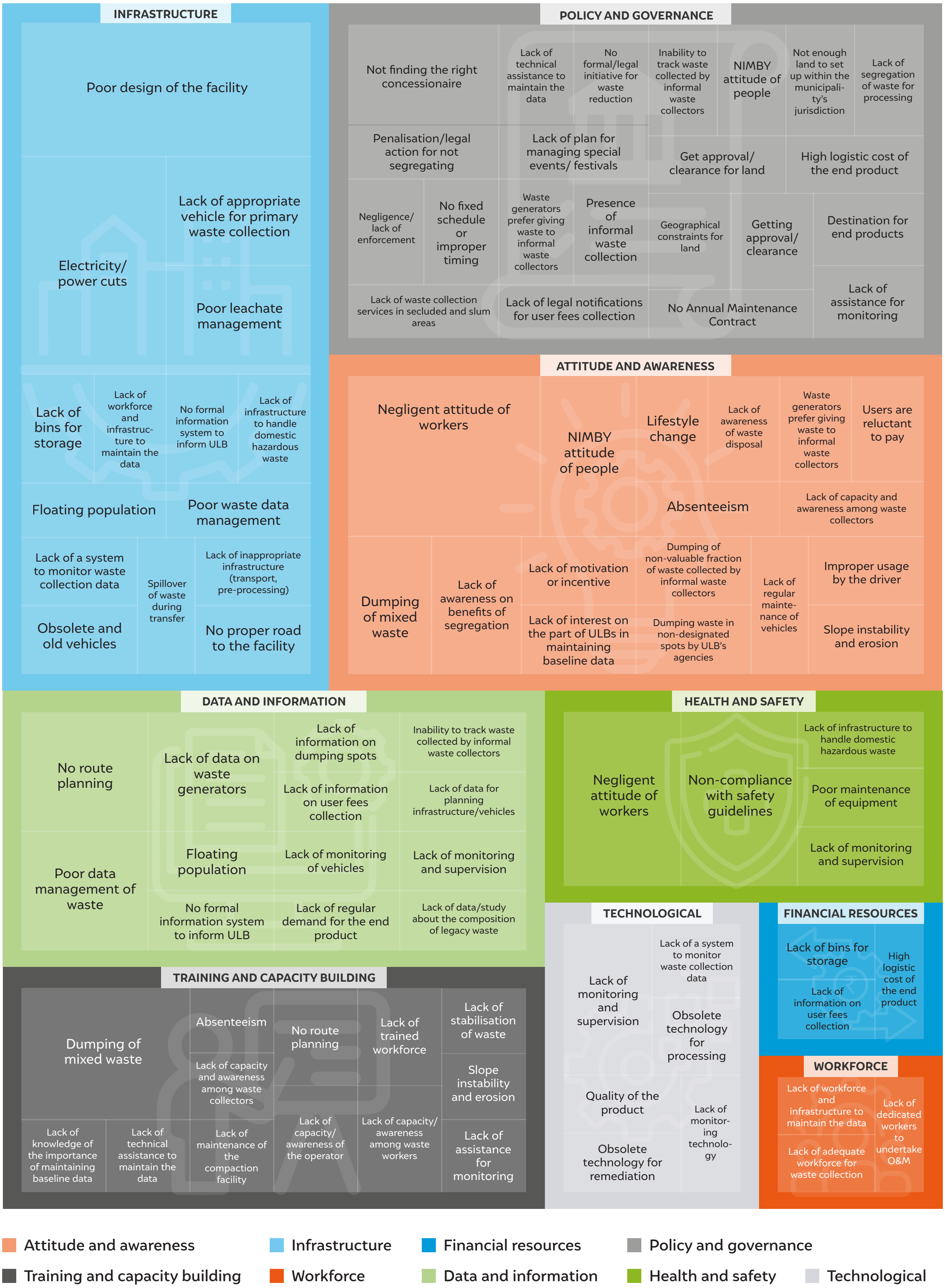
Figure ES2 provides a thematic overview of the root causes of the challenges cities face in improving SWM, as captured in the field visits. The 'infrastructure' category accounts for about 20 per cent of root causes. It includes issues such as the lack of effective management information systems, appropriate vehicles for waste collection and transportation, and waste storage areas. Unreliable power supply and poorly designed facilities further exacerbate the problem. 'Policy and governance' account for 19 per cent of root causes – this includes problems associated with getting the necessary approvals, ensuring transparency in tenders, enforcing regulations, agreement with the concessionaire, and incorporating informal waste workers into the formal SWM system.

'Attitude and awareness' and 'training and capacity-building' are the other major themes that account for another 30 per cent of the root causes, including limited awareness of segregation and open dumping, insufficient motivation or incentive for citizens and workers, suboptimal route planning and usage of vehicles, inadequate regular maintenance at waste management facilities, and general negligence among workers, among others. 'Data and information' and 'technology' also emerged as important themes that emphasise the need for accessing and managing data effectively and integrating technological solutions in the waste management system of the city.

Interestingly, 'financial resources' and 'workforce' did not emerge as prominent themes. While both these factors constitute critical components for an effective SWM system, the analysis suggests that the effective utilisation of resources is key rather than just an abundance of them. The findings also align with existing research that demonstrates that increased SWM spending does not directly translate to better outcomes (Gupta and Sachdeva 2021). The findings highlight the need for a shift in focus from resource allocation to resource optimisation.

Recognition of the Prior Learning Framework emphasises training sanitation workers to build technical knowledge and skill assets for operating advanced machinery and equipment following the prescribed safety guidelines.

Figure ES2 Root causes of the major challenges in the waste supply chain, categorised across different themes



Source: Authors' compilation

Conclusion and recommendations

The CRS matrix developed as a part of this study can be used as a strategic tool by cities to customise and implement solutions that address the underlying root causes of the challenges they face. This framework also provides cities with the opportunity to innovate and develop their own unique solutions. We recommend the following actions based on the learning and insights from the selected cities to strengthen the existing SWM system.

- **Need for a comprehensive and updated baseline inventory**. Cities rely on waste data, including on waste generation and composition, based on guesstimates, or surveys that are often decades old. Access to updated and reliable data is crucial, as it not only helps improve planning and management but also supports better estimation of air and greenhouse emissions from the waste sector.
- **Establish waste reduction targets and policies that align with *Mission LiFE*.** There are significant differences in per capita waste generation among the million-plus cities, with only a few, such as Pune, having waste reduction targets. Aligning with the 'Reduce Waste' theme of the *Mission Lifestyle for Environment (LiFE)*, cities can promote zero-waste ecosystems such as zero-waste wards, events, societies, and festivals.
- **Adopt minimum three-way segregation across the supply chain.** Segregation of domestic hazardous waste is frequently overlooked, risking contamination of the entire waste stream and jeopardising overall treatment efficiency. We recommend that cities adopt a comprehensive three-tier segregation system that covers every phase of the waste journey – from its source through collection and transportation until its final destination.
- **Prepare tailored SWM plans for vulnerable areas and high-waste generation events**. Urban areas such as slums, micro-mini industrial clusters, and crowded commercial zones often face SWM problems that require tailored strategies and plans. Additionally, during high-waste generation events such as festivals, municipalities should be equipped to respond by deploying additional workforce and resources or by optimising the existing SWM infrastructure.
- **Give an equal focus to operation and maintenance as to procuring machines and vehicles**. While procuring vehicles or machinery, municipalities should engage in meticulous planning while procuring vehicles or machinery with monitoring and oversight of the designated agency. Similarly, ULBs must consider an annual maintenance contract (AMC) for regular maintenance, repairs, and support for machinery deployed at processing or disposal sites.
- **Incorporate pre-processing infrastructure to improve the quality of waste and end products**. Numerous treatment facilities underperform due to not receiving waste of optimal quality. We recommend that municipalities or service providers need to incorporate pre-processing treatment facilities to help improve the lifespan of machinery and ensure the quality of the end products derived from waste processing.
- **Develop and enhance the capacities of workers engaged in the waste supply chain**. It is essential to enhance the skills of individuals across all levels within the SWM supply chain. ULBs should comprehensively assess training needs and analyse skill gaps to effectively promote skill development for optimal service delivery. Municipalities can leverage the e-resources available on the SBM Urban e-learning portal and iGOT to enable continuous learning and capacity building.
- **Support bioremediation with clear plans for managing inert and recovered waste**. The CPCB (2019) guidelines on legacy waste disposal stress the importance of identifying potential markets for screened waste fractions from biomining and bioremediation during the planning stage. It is important to involve stakeholders and local partners in ULBs' efforts to find economically feasible solutions for the recovered waste. Recovered waste fractions – including refuse-derived fuel, coarser particles, and fine soil-like materials – must fulfil specified standards for further use.
- **Leverage data dashboards and command centres to improve SWM operations**. Cities should utilise the integrated command and control centre (ICCC) developed under the *Smart City Mission* to improve their SWM operations. The ICCC can support multiple applications across the supply chain, such as identifying and monitoring garbage vulnerable points (GVPs), collecting user fees, tracking waste collection vehicles, and monitoring fire incidents at treatment facilities and dump sites.

1. Introduction

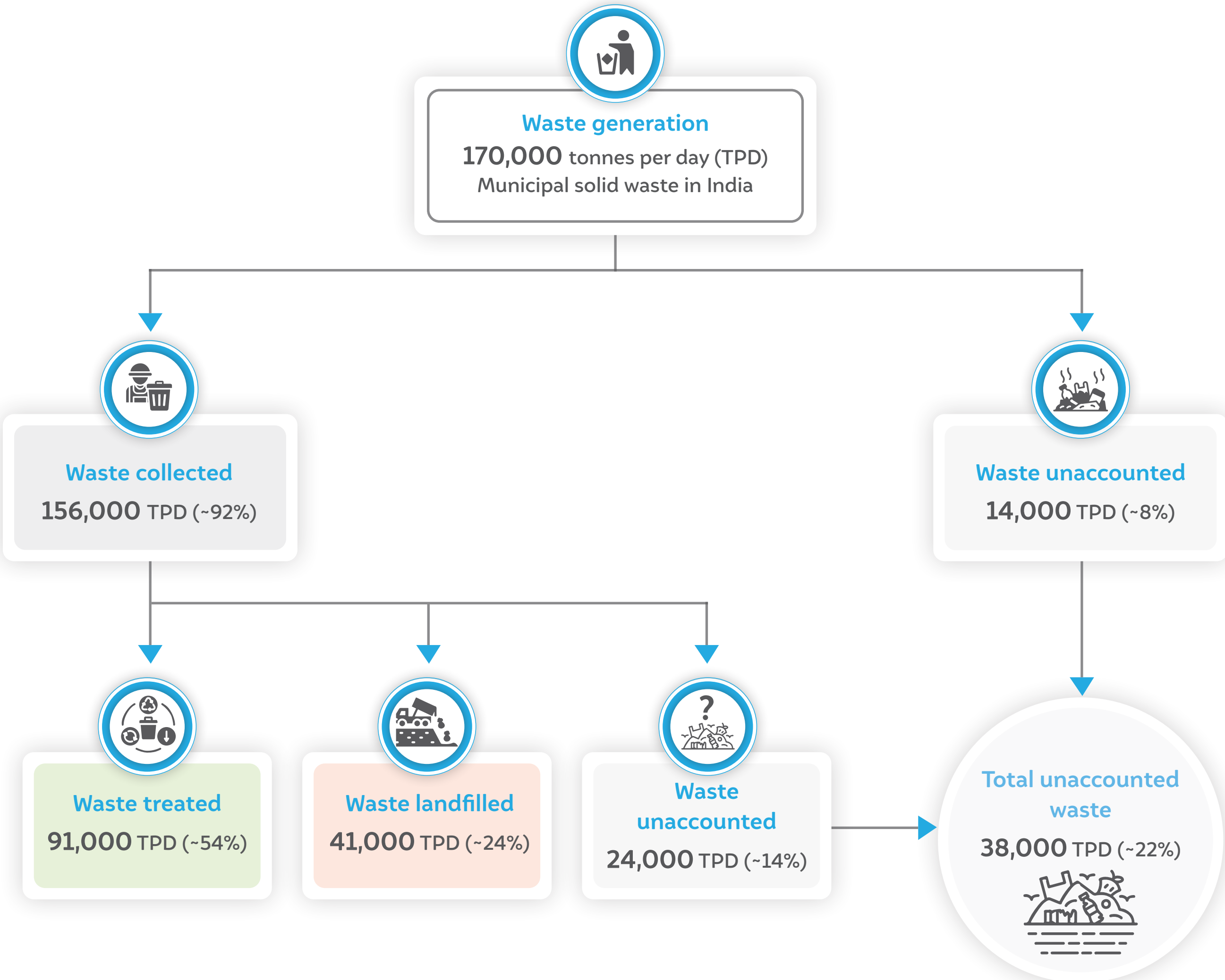
India is experiencing rapid urbanisation and population growth. According to UN estimates, India's urban population will increase to 814 million by 2050 (from 410 million in 2015); by 2030, half of the country's population will live in the cities (United Nations 2015). With more people moving to cities and changing lifestyles and consumption patterns, the amount of waste generated has increased significantly.

1.1 Status of India's looming waste crisis

According to the Central Pollution Control Board (CPCB), India generated approximately 170,000 tonnes of municipal solid waste daily in 2021–22 (CPCB 2024). Of this, about 156,000 tonnes were collected, 91,000 tonnes (~54 per cent) were treated, and 41,000 tonnes (~24 per cent) were landfilled. As shown in Figure 1, the remaining 22 per cent of waste was unaccounted for and untraceable in the solid waste supply chain. In the absence of effective solid waste management (SWM) services, this significant portion of unaccounted waste either gets burnt or dumped in non-designated sites (Ramadan et al. 2022).

Data from the CPCB annual report shows that only 15 states and union territories are treating more than 50 per cent of the solid waste being generated in their territory (CPCB 2022). In 4 states and union territories, over 50 per cent of waste is unaccounted for, more details are given in Annexure 1. Further, there are considerable gaps in the data on the SWM supply chain due to systemic challenges within the supply chain and inefficacious processes for treating solid waste (Jacob 2022).

Figure 1 Approximately 38,000 TPD (~22%) of municipal solid waste remains unaccounted for



Source: Authors' analysis; data from CPCB. 2024. Annual Report 2021–2022 on Implementation of Solid Waste Management Rules, 2016. Central Pollution Control Board

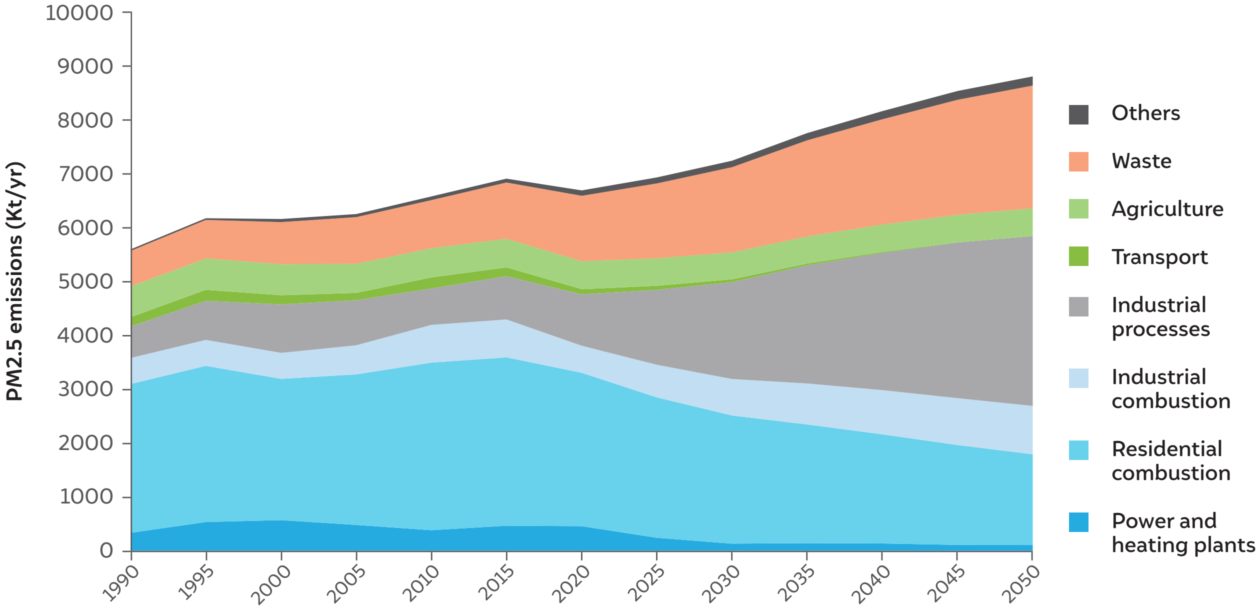
1.2 Implications of improper solid waste management for air pollution and climate change

Unaccounted waste can have severe environmental and health impacts. Improper disposal of waste can contaminate soil and water and spread diseases such as cholera, typhoid, and hepatitis (WHO 2021). Studies have shown that there is an increased risk of adverse birth and neonatal outcomes for people living near landfills, incinerators, and dump sites/open burning sites (Vinti et al. 2021). For instance, residents near the Deonar dump site in Mumbai had a higher prevalence of respiratory illnesses, eye irritation, and gastrointestinal problems (SK Singh et al. 2021).

Open waste burning is linked to increased particulate matter concentration in the air – a leading environmental health risk (Singh, Singh, and Biswal 2021). In Indian cities, 2–24 per cent of daily waste is burnt, while in rural areas, this figure could be as high as 90–100 per cent of the total waste generated (Nagpure, Ramaswami, and Russell, 2015). According to the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model, the waste sector contributed around 1200 kilo tonnes per year (Kt/yr) of PM2.5 emissions in India in 2020, which accounted for about 18 per cent of the country's total PM2.5 emissions (GAINS n.d.); this is projected to almost double by 2050 (Figure 2). According to an Indian Institute of Science Education and Research study, by 2035, open waste burning will become one of the significant contributors to air pollution in India (Sharma, Annadate, and Sinha 2022).

Waste bales at Material Recovery Facility (MRF) run by NGO Waste Warriors.

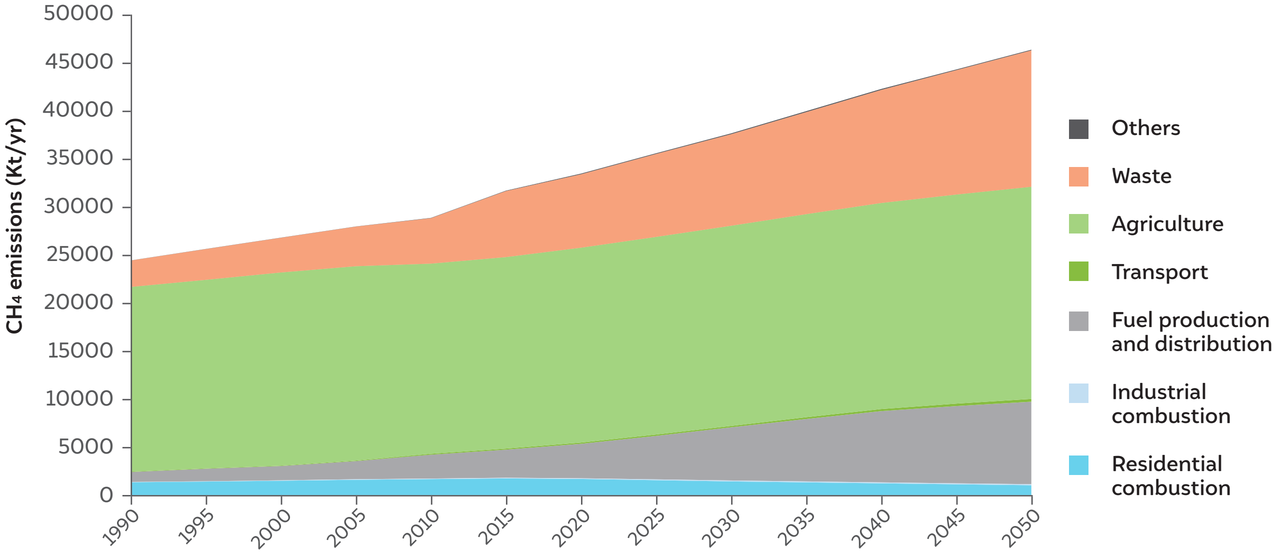
Figure 2 By 2050, the solid waste sector will be the second-largest contributor to PM2.5 emissions



Source: Authors' analysis; data from GAINS Online. n.d. GAINS Model. Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS). Accessed March 25, 2024

Improper SWM also contributes to climate change. For instance, organic waste, such as food waste, which ends up in landfills, decomposes and produces methane, a potent greenhouse gas. Methane is the second-most abundant greenhouse gas after CO2 and is responsible for 20 per cent of greenhouse gas (GHG) emissions; municipal solid waste contributes up to 11 per cent of all global methane emissions (CK Singh et al. 2018). According to the third *Biennial Update Report* submitted to the United Nations Framework Convention on Climate Change (UNFCCC), between 1994 and 2016, India's waste sector (solid waste disposal and wastewater) registered the highest increase in GHG emissions, recording a surge of 224 per cent (R Singh 2023; MoEFCC 2021). Furthermore, data from the GAINS model indicate that in 2020, the waste sector produced approximately 7700 Kt/yr of methane, which accounts for about 23 per cent of India's total methane emissions. As highlighted in Figure 3, emissions from the waste sector are projected to nearly double by 2050 and contribute up to 30 per cent of the total methane emissions.

Figure 3 In India, the waste sector will be the second-largest contributor to methane emissions by 2050

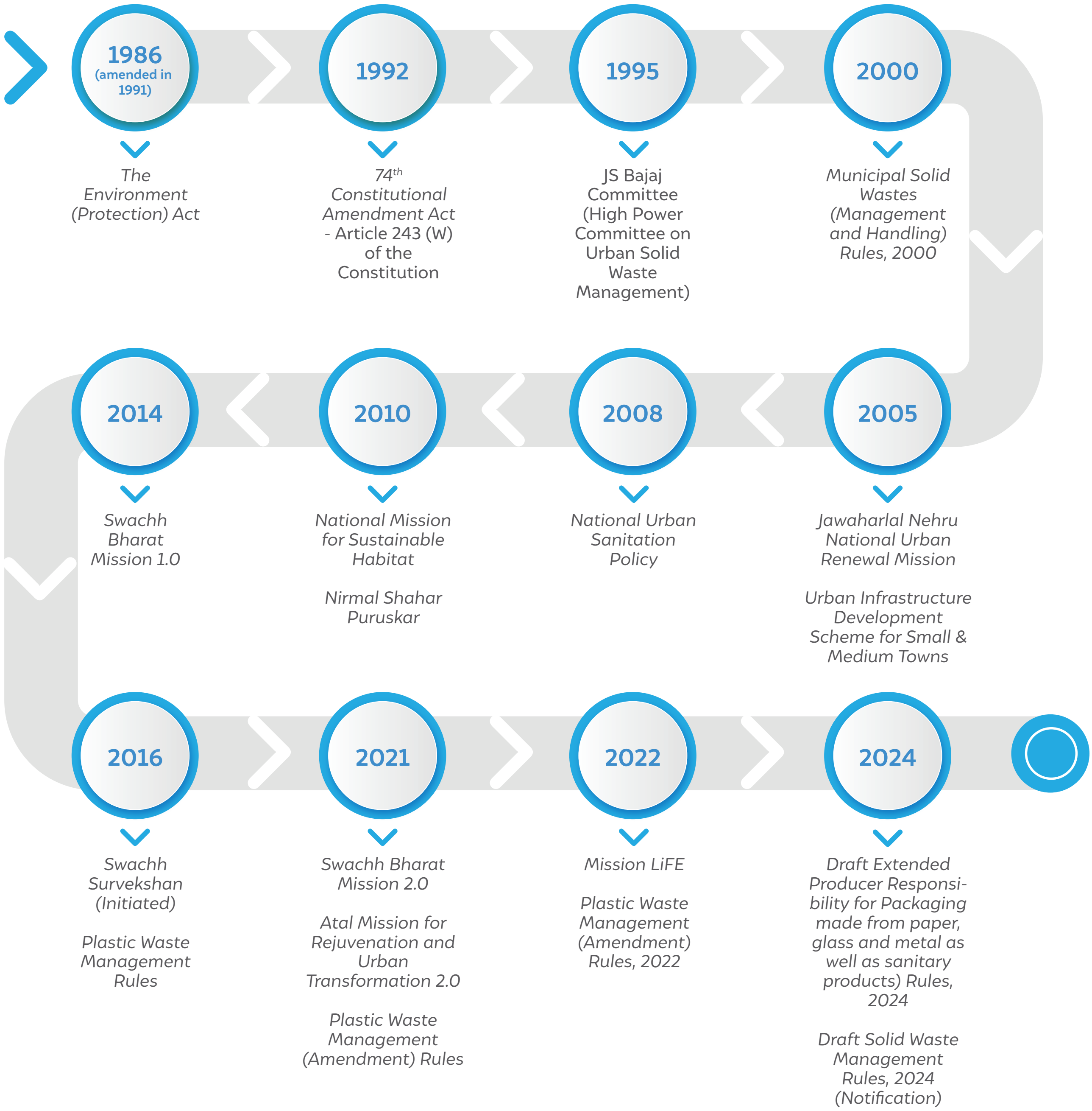


Source: Authors' analysis; data from GAINS Online. n.d. GAINS Model. Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS). Accessed March 25, 2024

1.3 Role of policy and national-level programmes in reducing the gap

Improving SWM is vital for sustainable development in India due to its association with a wide range of global issues, including health, climate change, poverty alleviation, food and resource security, and sustainable production and consumption. Sanitation, cleanliness, hygiene, and waste management are linked with the Sustainable Development Goals (SDGs) framework and are linked explicitly or implicitly with more than half of the 17 goals (UNEP 2015). India has introduced multiple initiatives and programmes targeted at SWM to achieve these goals more effectively, making it a national priority as illustrated in Figure 4.

Figure 4 **Evolution of policies and programmes on solid waste management in India**



Source: Authors' compilation

Swachh Bharat Mission (SBM) is India's flagship waste management programme launched in October 2014. Phase 1 of SBM has been instrumental in raising awareness and motivating citizens and urban local bodies (ULBs) to maintain the cleanliness and sanitation of their surroundings (Mukherjee Basu and Punjabi 2020). The SBM has increased waste treatment and reduced the amount of waste going to landfills. According to CPCB data, in 2015–16, about 20 per cent of the waste was treated; by 2021–22, this figure increased to over 50 per cent. The share of waste that gets landfilled has reduced from 37 per cent in 2015–16 to about 24 per cent in 2021–22. However, the gap or unaccounted waste has only reduced from 42 to 22 per cent. Figure 5 shows that there has not been a significant change in the share of unaccounted waste over the last three years. There was a sudden dip in the gap percentage in 2017–18, which can be attributed to fewer ULBs and towns reporting that year; for instance, in 2021–22, 4590 ULBs and 3659 towns reported their data compared to 1768 ULBs and 1828 towns in 2017–18 (CPCB 2017; CPCB 2024).

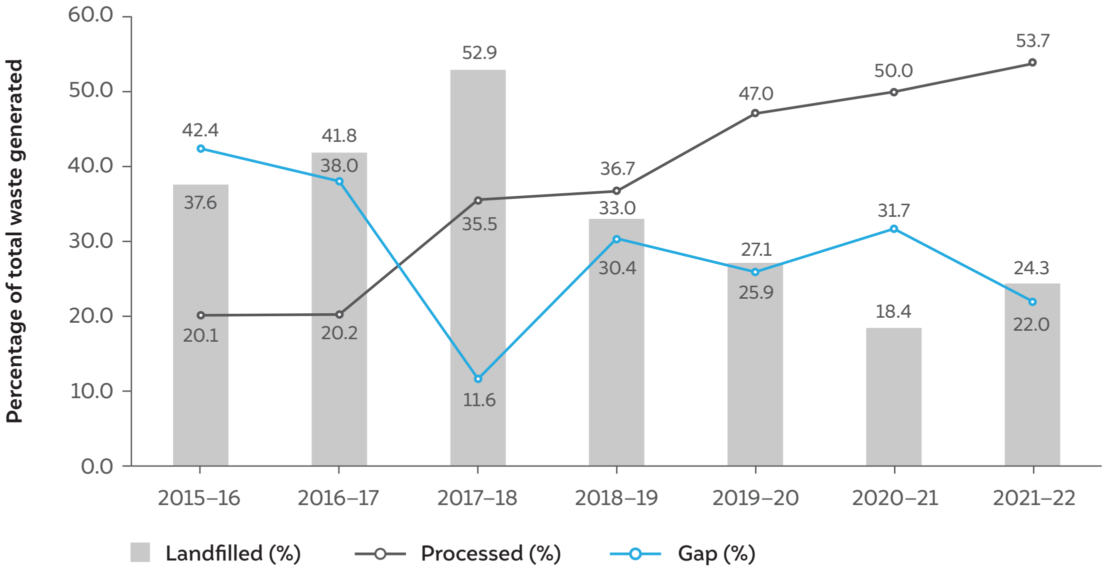
SBM has been extended for five years, from October 1, 2021, to October 1, 2026, under *Swachh Bharat Mission (Urban) 2.0*. The vision of *SBM Urban 2.0* is for Indian cities to achieve 'garbage-free' status. Cities are required to comply with certain prescribed conditions, including the scientific management of generated waste, scientific processing of 100 per cent of waste, remediation of legacy waste, implementation of efforts towards waste reduction, and maintenance of visible cleanliness (MoHUA 2022). Further, a budget of INR 1,41,600 crore has been earmarked for the next five years – 2.5 times more than the previous phase (Ministry of Road Transport & Highways 2021). For *SBM Urban 2.0* to successfully improve SWM, we must first understand why gaps exist in the operations of the waste supply chain.

1.4 The need for customised waste management practices

Multiple studies have listed best practices to address often undefined broader challenges. Consequently, several solutions have been proposed for one or more than one challenge. However, selecting a suitable localised solution for a specific challenge requires a comprehensive understanding of the underlying root causes. Cities vary significantly in aspects such as waste generation, geography, climate, culture, resources, and local legislation, which can result in different root causes for similar kinds of challenges.

Replicating successful models from other cities overlooks the importance of assessing the current status of SWM in the ULB in relation to the requirements of existing regulations, policies, guidelines, and identified service level benchmarks. This lack of assessment may lead to gaps in achieving the desired level of services and will serve as the basis for preparing a plan to improve the SWM system (CPHEEO 2016b).

Figure 5 ***Swachh Bharat Mission*** **helped increase waste treatment but showed no significant reduction in the gap of unaccounted waste over the past three years**



Source: Authors' analysis; data from CPCB. 2022. Annual Report 2020–2021 on Implementation of Solid Waste Management Rules, 2016. Central Pollution Control Board

This highlights the inadequacy of the one-size-fits-all approach, as solutions that work in one context may not necessarily work in another. Hence, simply adopting waste management models without considering their local conditions is unlikely to yield sustainable results.

Through this study, we aim to understand the challenges that cities face across the waste supply chain and identify their root causes through primary field visits and stakeholder interviews. Subsequently, it also aims to map solutions and strategies that can be adopted to address these root causes. We develop a challenge–root cause–solution (CRS) matrix, which compiles a list of strategies that can be adopted to address the specific challenges ULBs face in various local contexts instead of replicating successful models from other cities.

A compost plant with a capacity of 120 metric tonnes per day at the Bhanpur trenching ground in Bhopal, Madhya Pradesh, processing organic waste through windrow composting.

2. Research methodology

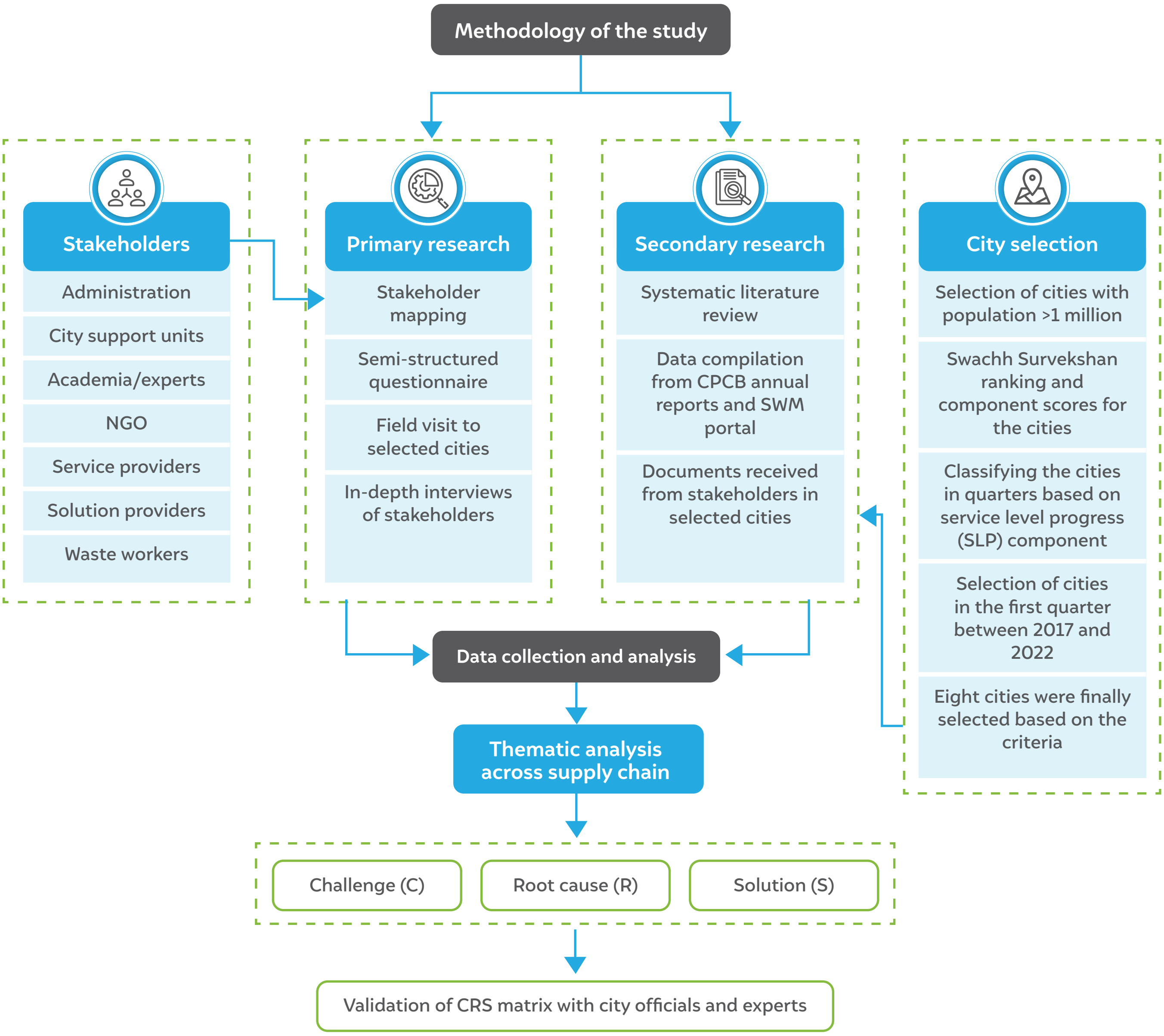
In this study, we conducted a comprehensive literature review to understand the challenges cities encounter throughout the waste supply chain. We also analysed publicly available data related to municipal solid waste, including CPCB annual reports, data from the SBM portal, and others. To understand the root causes of the challenges and explore potential solutions, we selected eight cities that have consistently performed well in the annual cleanliness survey (*Swachh Survekshan*). On-site visits and semi-structured interviews with stakeholders were conducted in these selected cities from October 2022 to July 2023.

We constructed a CRS matrix for each level of the supply chain after analysing and compiling information from the literature, secondary data, interviews, and field observations. Then, we subsequently validated the resulting matrix with city representatives and experts. Figure 6 highlights the key methodological steps involved in the study, and the following sections outline the detailed methods used in the research process.

2.1 Identification of challenges

SWM involves various stages, from waste generation to disposal, and each stage presents different sets of challenges. We conducted a targeted search on Google Scholar using the phrase 'municipal solid waste management challenges in India' to identify the challenges associated with municipal SWM in India.

Figure 6 Key methodological steps taken for this study



Source: Authors' compilation

We also reviewed policy documents, guidelines, and case studies to supplement the literature and get insights into the common challenges cities face in managing waste. Based on insights from the literature, we then categorised the challenges at each level of the supply chain. The final compilation of the challenges from the literature is presented in Annexure 2.

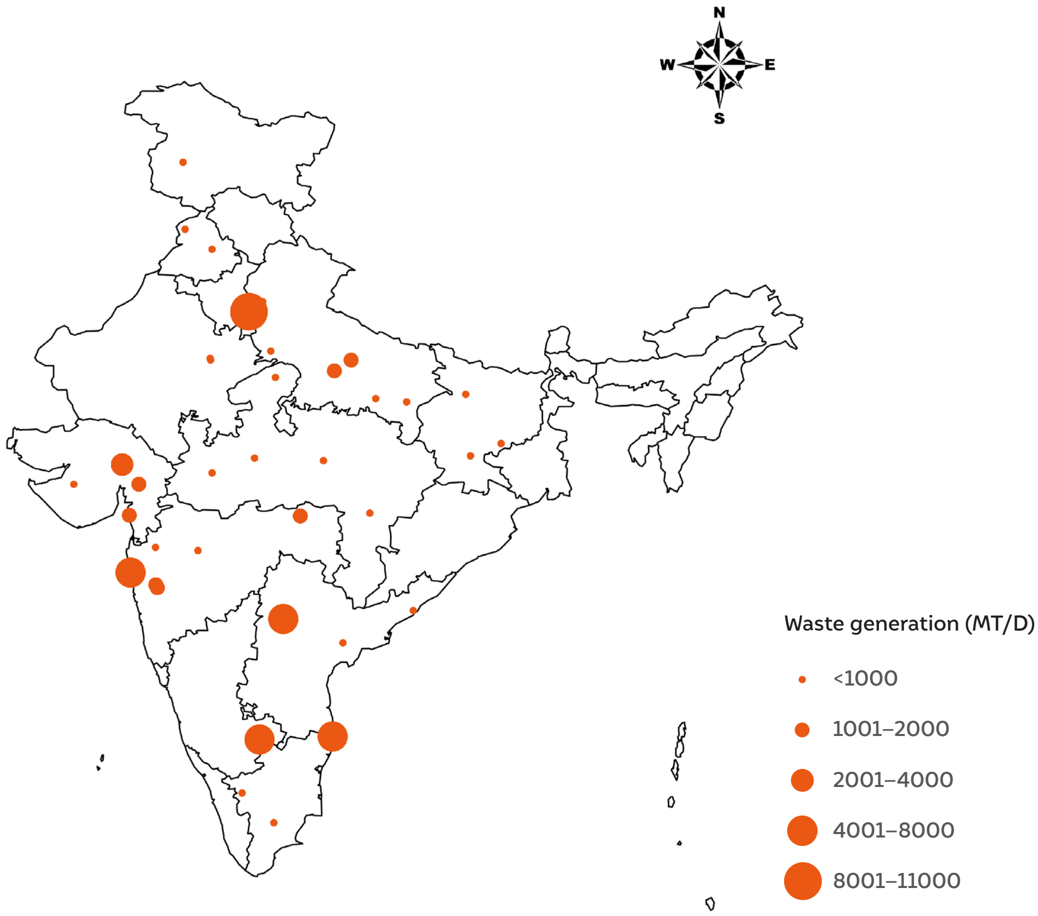
2.2 Reviewing and analysing the data on municipal solid waste

Under the *Municipal Solid Waste Management Rules, 2016*, the CPCB is mandated to prepare a consolidated annual report on SWM in the country. We digitised and analysed the data from these annual reports. *Swachh Survekshan* is an annual cleanliness survey conducted by the Government of India to evaluate and rank cities based on their cleanliness and SWM practices. The survey covers waste collection, transportation, processing, and disposal. It also offers performance evaluations and insights for improving waste management practices in cities. For this study, we analysed the performance of the selected eight cities using their annual reports and indicator-level data on the *Swachh Survekshan* dashboard (MoHUA n.d.).

The Fifteenth Finance Commission categorises urban areas into Category-I cities with a population of more than one million and Category-II cities with a population of less than a million. It has allocated INR 38,196 crore through the *Million-Plus Cities Challenge Fund* (MCF) for air pollution and waste management from 2021–22 to 2025–26. The million-plus cities are characterised by substantial solid waste generation; 45 ULBs participating in the *Swachh Survekshan* programme collectively contribute up to 45 per cent of the total waste generated (Figure 7). Further, in these cities, open waste burning, on average, contributes to about 10 per cent of the total PM2.5 emissions. Additional details on waste generation and their contributions to air pollution are provided in Annexure 3.

Monitoring and supervision of municipal solid waste collection at the ICCC, Rajkot Smart City Office, Rajkot, Gujarat.

Figure 7 45 ULBs in India contribute to about 45% of the country's total waste generation



Source: Authors' analysis; data from MoHUA. n.d. Swachh Survekshan 2022. Ministry of Housing and Urban Affairs, Government of India

2.3 Selection of cities

We aimed to identify the underlying root causes of SWM challenges in the million-plus cities and explore potential solutions and strategies for addressing them. We used the service-level progress (SLP) component in the *Swachh Survekshan* to select consistently well-performing million-plus cities. The SLP component is based on performance parameters such as segregated waste collection, processing, disposal of solid waste, and sustainable sanitation and indicates the sanitation standards maintained by ULBs. The contribution of the SLP component to the overall score has also increased with the evolution of *Swachh Survekshan's* methodology. As per the *Swachh Survekshan* 2024 toolkit, the SLP component contributes up to 60 per cent of the *Swachh Survekshan* scoring (MoHUA n.d.).

We categorised the cities[1] into four quartiles for 2017 and 2022, using the SLP component. The best-performing cities in Quartile 1 of both years were finally selected. We identified eight cities with a population exceeding one million that had consistently performed well in SWM. More information on the methodology for selecting cities for the study is given in Annexure 4. These eight cities are Ahmedabad, Bhopal, Indore, Navi Mumbai, Pune, Rajkot, Surat and Visakhapatnam. We studied these cities to investigate the primary challenges they encounter and showcase the effective practices and solutions they have adopted to address their root causes. Learnings from these cities can offer valuable insights for other cities seeking to improve their SWM system.

1. The million-plus ULBs that participated in Swachh Survekshan 2022 are Surat, Indore, Navi Mumbai, Rajkot, Visakhapatnam, Ahmedabad, Bhopal, Pune, Jabalpur, Vadodara, Greater Mumbai, Coimbatore, Vijayawada, Raipur, Gwalior, Thane, Varanasi, Greater Hyderabad, Pimpri Chinchwad, Kanpur, Faridabad, East Delhi Municipal Corporation, Madurai, Nashik, Vasai-Virar, Lucknow, Kalyan Dombivli, Nagpur, South Delhi Municipal Corporation, Amritsar, Chennai, Dhanbad, Ranchi, Ludhiana, Prayagraj (Allahabad), Ghaziabad, Meerut, Agra, Aurangabad, Srinagar, Jaipur, Bengaluru (Bruhat Bengaluru Mahanagara Palike), Patna, North Delhi Municipal Corporation, and Jaipur Heritage.

2.4 Stakeholder mapping

After selecting the cities, we undertook a comprehensive mapping of stakeholders for each city to understand the SWM landscape. This step included reviewing documents, government websites (including the *Swachh Survekshan* portal, municipalities' websites, and the *Smart Cities Mission* website) and newspaper articles. The study also utilised LinkedIn to conduct city-specific searches and employed a snowball method to identify key stakeholders. We also categorised the stakeholders based on their roles in the waste management ecosystem – administration, city support units, consultants, academia and subject experts, non-governmental organisations (NGOs), service providers, solution providers, and waste workers. We identified and engaged with over a hundred stakeholders across different categories from the selected cities. Further details on the stakeholders are provided in Annexure 5.

2.5 Questionnaire development

We used a semi-structured questionnaire to gather information from the stakeholders. We adopted this approach as it allows us to get specific information or details from structured questions and broader perspectives from open-ended questions. We used a core set of questions to get the information and steer the discussion; these questions also provided flexibility in engaging and exploring areas of particular relevance for each stakeholder group. This allowed us to gather unique insights from the stakeholders and delve into the root cause of the challenges. We also sought feedback from experienced professionals in the waste sector to improve the questionnaire. The final questionnaire used in the study is provided in Annexure 6.

2.6 Data collection through interviews and field visits

We conducted primary field visits and interviews with relevant stakeholders in the selected eight cities. The stakeholders included officials from municipal corporations, agencies providing SWM services, consultants, city support units, waste workers, NGOs, and other key actors. The interviews with these stakeholders provided on-ground information to identify and validate existing challenges and map root causes. During the field visit, we documented operations and strategies to understand the solutions these stakeholders had adopted for managing waste across the supply chain. We also requested data and relevant documents from city officials to cross-check and validate the information gathered from secondary sources, interviews, and field visits.

2.7 Compilation and thematic analysis: The CRS matrix

The city-level information collected from across the eight cities was compiled to prepare the CRS matrix, which was used to derive key insights and identify trends related to the challenges, underlying root causes, and SWM solutions. The CRS matrix was then shared with the respective city officials as part of its validation process. This process allowed to collect additional information that might have been missed in the initial literature review or during interviews and field visits.

Adopting a deductive approach, we thematically categorised the various root causes for easier understanding and explanation. Based on the literature review, we finalised the following nine themes, namely: (1) infrastructure, (2) training and capacity building, (3) data and information, (4) attitude and awareness, (5) policy and governance, (6) technological, (7) health and safety, (8) financial resources, and (9) workforce. We assigned these themes to each of the root causes for thematic analysis. A brief explanation of the thematic component of the root cause analysis of the SWM supply chain is given in Annexure 7.

2.8 Limitations of the study

This study offers insights into the challenges, root causes, and solutions employed by eight consistently best-performing million-plus cities in SWM. In this context, it is crucial to acknowledge certain limitations, which are integral to understanding the scope and applicability of the study's findings.

> **The Fifteenth Finance Commission has allocated INR 38,196 crore through the *Million-Plus Cities Challenge Fund* (MCF) for air pollution and waste management from 2021–22 to 2025–26.**

Firstly, this study primarily focuses on urban areas with large populations; this implies that the challenges specific to smaller municipalities and rural regions may not be comprehensively addressed. Secondly, the rationale for selecting these cities is based on their performance in the *Swachh Survekshan* assessment over the last six years (2017–2022). Therefore, this choice excludes certain million-plus cities that did not participate in the assessment (such as those from Kerala and West Bengal). Thirdly, this study intends to cover the overall SWM system in each of the eight cities.

Still, due to some exceptional circumstances and entry restrictions, we could not meet with a few stakeholders and gather information from specific treatment facilities and disposal sites.

Additionally, this study solely focuses on municipal solid waste, excluding other waste streams such as hazardous, construction and demolition, biomedical, or e-waste. Finally, to ensure relevance and feasibility, we refrain from exploring the challenges faced by different waste generators, such as households or industries; we primarily focus on challenges at the ULB level.

Solid waste management is a dynamic process, and new challenges and root causes may emerge over time, extending beyond the scope of this research. Overall, these limitations frame the study while acknowledging the multifaceted nature of SWM in India's urban landscapes.

RRR ('Reduce, Reuse, and Recycle') campaign by SWM officials in the wards to raise awareness among citizens in Visakhapatnam.

3. Results and discussion

SWM supply chain broadly consists of five functional elements, which include generation, collection, transportation, treatment and disposal. These different components of the supply chain are also deeply interlinked. In this study, we developed a Challenge-Root cause-Solution (CRS) matrix for each level of the supply chain, and case studies are provided on how specific cities manage their solid waste. The analysis and findings discussed in the following sections focus on the different levels of the supply chain.

3.1 Waste generation

Solid waste generation is the starting point of the SWM supply chain. It is influenced by various factors such as population, economic activity, climate, and consumption patterns. Understanding the trends in the quantity and composition of waste is a crucial step in devising SWM strategies (USEPA n.d.). It also serves as a critical input parameter for designing appropriate waste management infrastructure, including the number of vehicles, workforce, and size and type of technology required (Chaudhary et al. 2021).

In this study, we identified four major challenges in waste generation that are linked to 16 root causes. Field visits and interviews revealed 35 types of solutions being implemented in various capacities across the cities to address these root causes (see Figure 9). Determining the source of waste generation, such as household and non-household entities, including commercial establishments, institutions, and public spaces, is imperative to identify potential gaps or leakages in the SWM system.

One of the significant challenges cities confront is the high and escalating rate of waste generation. Currently, Indian cities generate approximately 55 million tonnes of municipal solid waste annually, projected to surge to 165 million tonnes by 2030 and a staggering 436 million tonnes by 2050 (MoHUA 2021). This trend is particularly noticeable in million-plus cities, where current waste generation has doubled since 2004, indicating a 100 per cent increase. Additional details on waste generation in the million-plus cities are available in Annexure 3. Interviews with stakeholders revealed that the root causes for high waste generation include changing lifestyles, limited waste reduction policies and initiatives, a floating population, and a lack of comprehensive plans for managing waste during events such as weddings and festivals.

CEEW researchers at the decentralized waste management site for leaf litter in a park in Indore.

BOX 1 Waste reduction plan and source segregation through the SWaCH cooperative – a case study of Pune

SWaCH cooperative, wholly owned by self-employed waste pickers, who collect waste from households and commercial establishments in Pune.

The Pune Municipal Corporation signed an agreement with the SWaCH cooperative, one of India's first unions of waste pickers that handles about 70 per cent of waste collection in Pune. It integrates waste pickers into formal systems while driving waste reduction and source segregation.

Root causes addressed for source segregation and high waste generation

Root causes	Solutions
Lack of awareness among the citizens to segregate the waste into three categories (wet, dry, and domestic hazardous)	Door to door (D2D) awareness and specialised campaigns, such as the Red Dot Campaign for domestic hazardous waste with the help of SWaCH workers. Dedicated recycling points or *pinjras* have been established in locations where SWaCH workers store the dry waste and subsequently sell it to scrap shops.
Lack of motivation/ incentives among waste generators for segregation	The municipality incentivises sustainable waste management practices by offering a 5-10 per cent property tax rebate to societies that effectively manage their organic waste through composting.
No penalisation or legal action against littering	Fine imposed by the municipality on the generators for not segregating the wet and dry waste.
No formal/legal initiative for waste reduction	Pune Plan G25, a waste reduction initiative, aims to achieve a 25 per cent reduction in waste generation by 2025, taking the base year as 2017. SWaCH has taken up zero waste projects for bulk waste generators (BWGs) through in-situ composting and consistent awareness activities.

Source: Authors' analysis

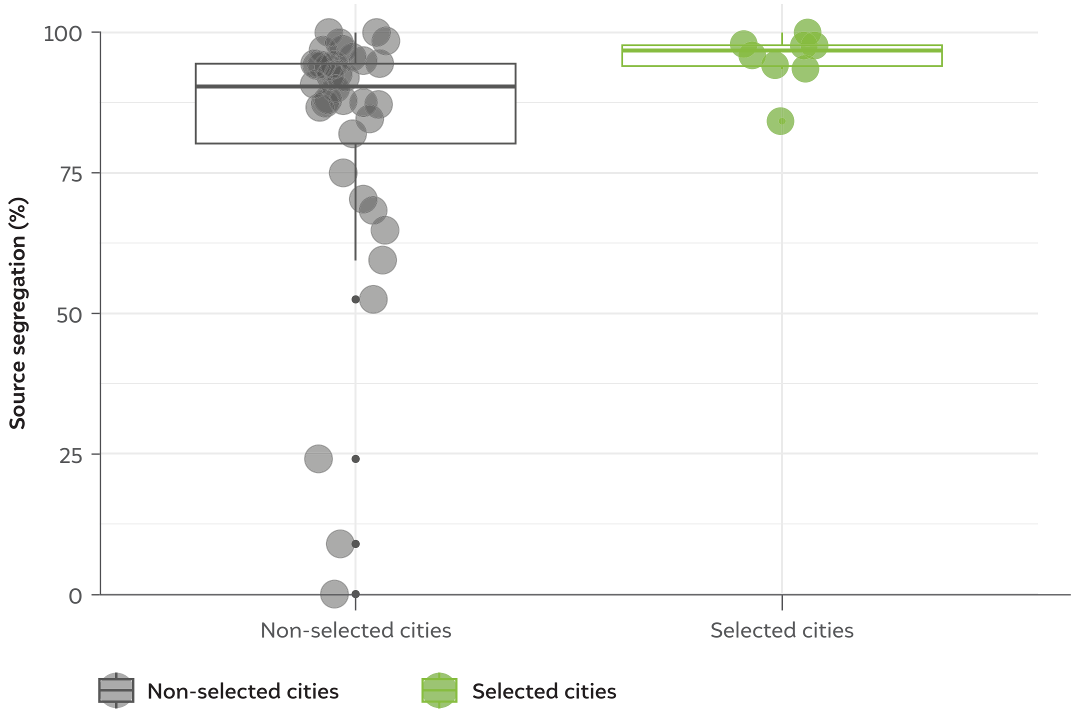
Segregating waste at the source is one of the most critical challenges at the generation level. *The Solid Waste Management Rules, 2016*, highlight the essential role of waste generators by mandating segregation at source. According to a NITI Aayog report, source segregation benefits subsequent stages of the waste supply chain through waste minimisation, reduced cost, optimised infrastructure operations, and efficient utilisation of municipal machinery and workforce (NITI 2021). Data from the *Swachh Survekshan* portal indicates that source segregation in India's million-plus cities is about 84 per cent (Figure 8). The average segregation rate in the eight selected cities is 95 per cent. We found that the selected cities have tackled challenges in waste segregation by addressing root causes such as inadequate awareness, insufficient motivation and incentives for segregation, the lack of resources for storage such as dustbins, and the lack of enforcement and penalties.

> "We have conducted various awareness campaigns and activities that helped in improving the segregation levels over the years, and we have achieved **100 per cent source segregation**. But continuously maintaining it is still a daily challenge for our city."
>
> \- Environmental engineer interviewed in a selected city

Lack of access to updated and accurate baseline data is another problem in the SWM ecosystem. For instance, Hujare and Telsang (2020) flag challenges related to the variability and lack of reliability of waste data in Indian cities. This inconsistency can potentially lead to inaccurate estimations of the infrastructure required for effective SWM. Reliable and updated baseline data can empower policymakers, authorities, and key stakeholders to develop data-driven strategies and make informed decisions. We found that some of the reasons why cities do not have a comprehensive baseline include the absence of a dedicated agency or department for data tracking, the lack of administrative awareness of the need for a baseline, inadequate technical assistance, and insufficient infrastructure for accurately recording and monitoring waste generation and composition data.

The open dumping of waste needs attention as it creates GVPs that become hotspots of contamination. Additionally, open burning adversely impacts the environment and human health (Singh et al. 2021). We found that the root causes for open dumping of waste include lack of awareness among waste generators, inefficient waste collection in the area, lack of information on dumping points, and limited monitoring and enforcement of regulations. Therefore, generating public awareness, enhancing community ownership, and strengthening enforcement is vital to developing effective waste management strategies.

Figure 8 84% of waste is segregated at source in the million-plus cities



Source: Authors' analysis; data from MoHUA. n.d. Swachh Survekshan 2022. Ministry of Housing and Urban Affairs, Government of India

BOX 2 A zero-waste model – a case study of Navi Mumbai

Stree Mukti Sangathan, an NGO that works towards the empowerment of women waste pickers, has worked on the Zero Waste Slum Model in Navi Mumbai.

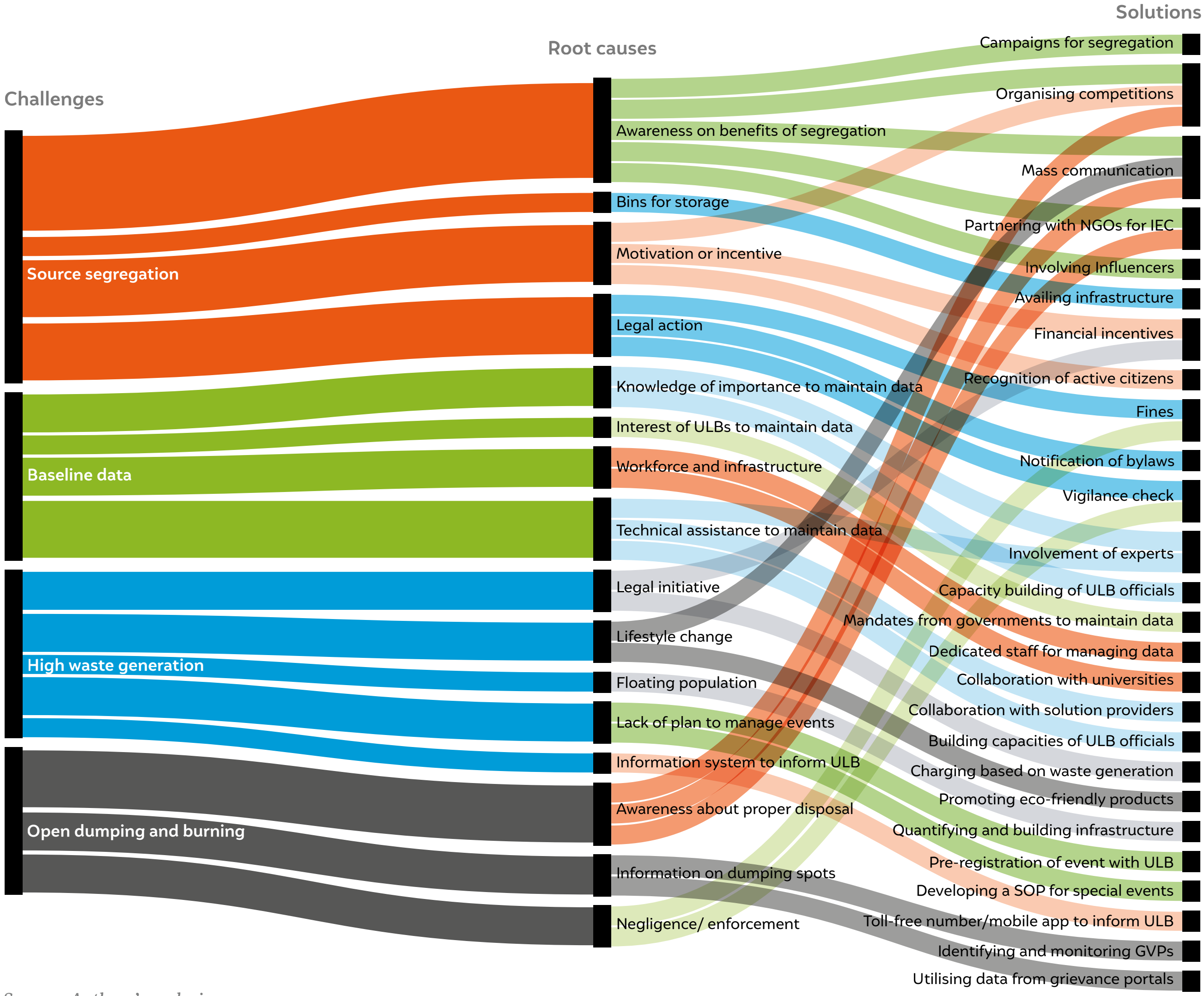
As a part of its SWM, the Navi Mumbai Municipal Corporation has taken several initiatives to increase awareness and behaviour change in the city. To tackle the issue of SWM in the slums, it came up with the 'zero-waste model'.

Root causes addressed for open dumping

Root causes	Solutions
Lack of community awareness on open dumping	The Navi Mumbai Municipal Corporation (NMMC) partnered with transgender communities, National Service Scheme (NSS) volunteers, and local NGOs to conduct awareness campaigns on cleanliness and the importance of waste segregation. NMMC collaborated with NGOs such as Stree Mukti Sangathan and launched the 'zero waste model' as a collaborative effort to provide employment opportunities for women waste workers and proper disposal to prevent open dumping.
Lack of information by the ULB on dumping spots	NMMC identified garbage vulnerable points and converted them into green zones by installing potted plants, sculptures made from recycled materials, and murals.
Negligence/lack of enforcement	Levying penalties on housing societies and commercial establishments for not segregating waste and littering public places. Nuisance detection squads to scan for litter violators and illegal dumping of waste. Technology driven initiatives such as the WhatsApp helpline allow citizens to report littering and dumping.

Source: Authors' analysis

Figure 9 Challenges, root causes, and solutions in waste generation



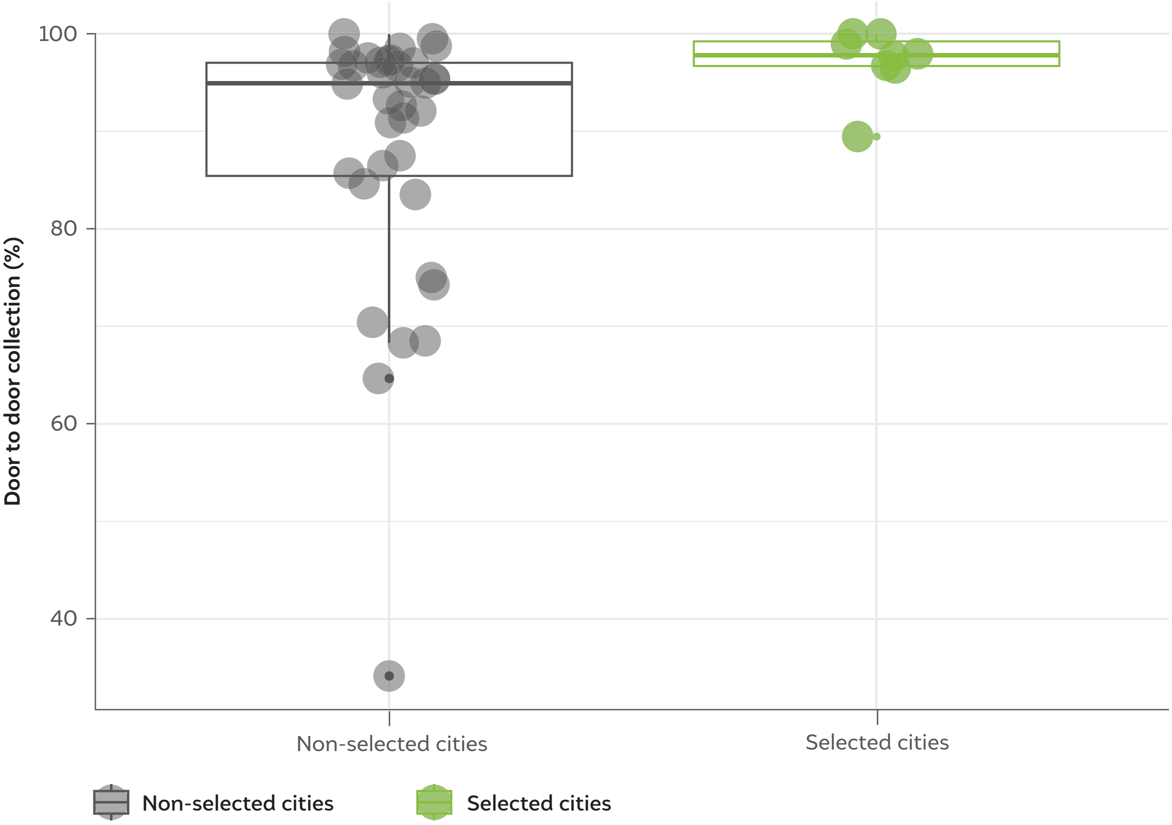
Source: Authors' analysis

3.2 Waste collection

As waste progresses along the SWM supply chain, it becomes crucial to manage solid waste properly for sustainable urban development. Waste collection is at the forefront of effective SWM. Based on the availability and feasibility of ULB services, the waste collection system can be categorised into community bins, block collection, kerbside collection, and door-to-door (D2D) collection (Coffey and Coad 2010). Inefficiencies in the waste collection services provided by ULBs can result in instances of open dumping and uncontrolled burning of solid waste, leading to adverse repercussions. For instance, the unrestricted dumping of waste into drains and water bodies can lead to blockages and affect the chemical composition of the water, negatively impacting aquatic ecosystems (Abubakar et al. 2022). We identified five major challenges in this supply chain that are linked to 21 underlying root causes. Field visits and interviews revealed 38 kinds of solutions currently being implemented to address these root causes in various capacities across cities. The details are listed in Figure 11.

To tackle inefficiencies in the waste collection system, ULBs have introduced D2D waste collection services, replacing community bins, identified as a common cause for GVPs. The data from the *Swachh Survekshan* portal shows that about 90 per cent of waste is collected D2D in the million-plus cities; among the eight cities selected for the study, the average D2D collection is 97 per cent (Figure 10). Our findings from the field highlight key areas for enhancing the efficiency of the waste collection system. Addressing issues such as the improper timing of primary waste collection services, lack of appropriate waste collection vehicles, insufficient workforce, worker absenteeism, informal waste collection systems, insufficient data on the types of waste generators, and inadequate waste collection services in areas such as slums will significantly improve the overall effectiveness of the system.

Figure 10 **90% of waste is collected door-to-door in the million-plus cities**



Source: Authors' analysis; data from MoHUA. n.d. Swachh Survekshan 2022. Ministry of Housing and Urban Affairs, Government of India

The collection of segregated waste is another key aspect of an efficient waste collection system and sustainable waste management. It promotes recycling and minimises waste, reducing the amount of waste reaching landfills (NITI 2021). During the field visit in the eight cities, it became apparent that maintaining segregation during waste collection requires addressing the lack of appropriate vehicles for primary collection, the lack of a system to handle domestic hazardous waste, and the need to improve capacity and awareness among the waste collectors.

Waste collection service provided by the Amdavad Municipal Corporation, Ahmedabad, Gujarat.

BOX 3 Using the ICCC for efficient waste collection – a case study of Indore

Monitoring of waste collection vehicles at ICCC, Indore.

Waste collection from commercial establishments in the evening in Indore.

Indore has consistently been recognised as the cleanest city in India due to its administrative support, capacity building of *safai mitra* (sanitation workers), citizen-led engagement, and awareness activities.

Root causes addressed for inefficient waste collection and lack of segregation

Root causes	Solutions
No fixed time schedule/ improper timing	Monitoring the collection vehicles at the ICCC keeps the waste collection system aligned with better waste management. Vehicle monitoring aids in overseeing points of interference, vehicle speed, stoppage timings, and route deviations.
Lack of appropriate vehicle for primary collection	Primary waste collection vehicles have separate compartments for collecting solid waste that has been segregated into six categories wet, dry, plastic, sanitary, domestic hazardous, and e–waste.
No route planning	The route plan is developed based on the city level baseline assessment. Primary waste collection vehicles are monitored by the ICCC using technologies such as GPS (global positioning system) and RFID (radio frequency identification) for deviations. Alerts are sent to the driver when a deviation or delay is noticed. The driver must respond to the alert with a valid justification, failing which the driver faces disciplinary action.
Lack of collection services from secluded and slum areas	Customised hand carts are deployed to collect waste in narrow lanes. Volunteers from NGO volunteers provide oversight to prevent open dumping in slum areas.
Lack of data on waste generator	A city level baseline assessment is undertaken to map different waste generators in the city and estimate the type and number of vehicles required for waste collection.
Generators prefer giving waste to informal workers	The jagirdari system (informal waste collection) was phased out by the Indore Municipal Corporation, and the informal waste workers were integrated into the formal waste collection system.
Lack of capacity and awareness among waste collectors	Waste collectors are accompanied by an NGO volunteer (from Feedback Foundation, Basix Municipal Waste Venture, Divine Waste Management). The role of NGO Worker is to supervise the waste collectors. Waste collectors have clear instructions from the authorities not to collect the waste if it is not segregated at the source.

Source: Authors' analysis

The ULBs levy user fees to effectively recover costs linked to civic infrastructure services, including sanitation and SWM, ensuring both service quality and availability (Nallathiga 2009). However, they often face challenges in collecting these user fees. We found that the challenges ULBs faced in relation to the collection of user fees and the lack of updated waste collection data had some common root causes. These were the presence of informal waste collection systems, the lack of information on user fees for waste collection services, and no established system to monitor SWM data.

Waste collectors (formal and informal) play an essential role in SWM by providing uninterrupted and invaluable civic services. Yet, the presence of informal waste collection systems is a root cause for various challenges in mainstream waste collection. These challenges subsequently lead to the open dumping of waste.

Integrating informal waste workers into formal waste management systems at various levels of the SWM supply chain is critical.

Another significant challenge in waste collection relates to the lack of adequate protective gear for waste collectors working in unhygienic conditions. Waste collectors are exposed to hazardous working environments while handling waste, making them vulnerable to transmittable diseases.

The findings from the study suggest that ensuring waste segregation at each level requires waste workers to be both aware of its importance and motivated to sustain it. Sanitation and waste collectors should be recognised as frontline workers and be given access to regular training and capacity-building workshops.

A waste collector using a hand cart for residential waste collection in Visakhapatnam, Andhra Pradesh.

BOX 4 Employee motivation is the key to building capacity in solid waste management – a case study of Visakhapatnam

RFID tagging of houses after waste collection by Secretariat volunteers.

Since 2019, the Greater Visakhapatnam Municipal Corporation has followed a decentralised governance system in Andhra Pradesh, known as the *Sachivalayam* System or secretariat system. A sanitary inspector and volunteers are assigned to the sanitation department to supervise and implement SWM activities in the assigned ward secretariat.

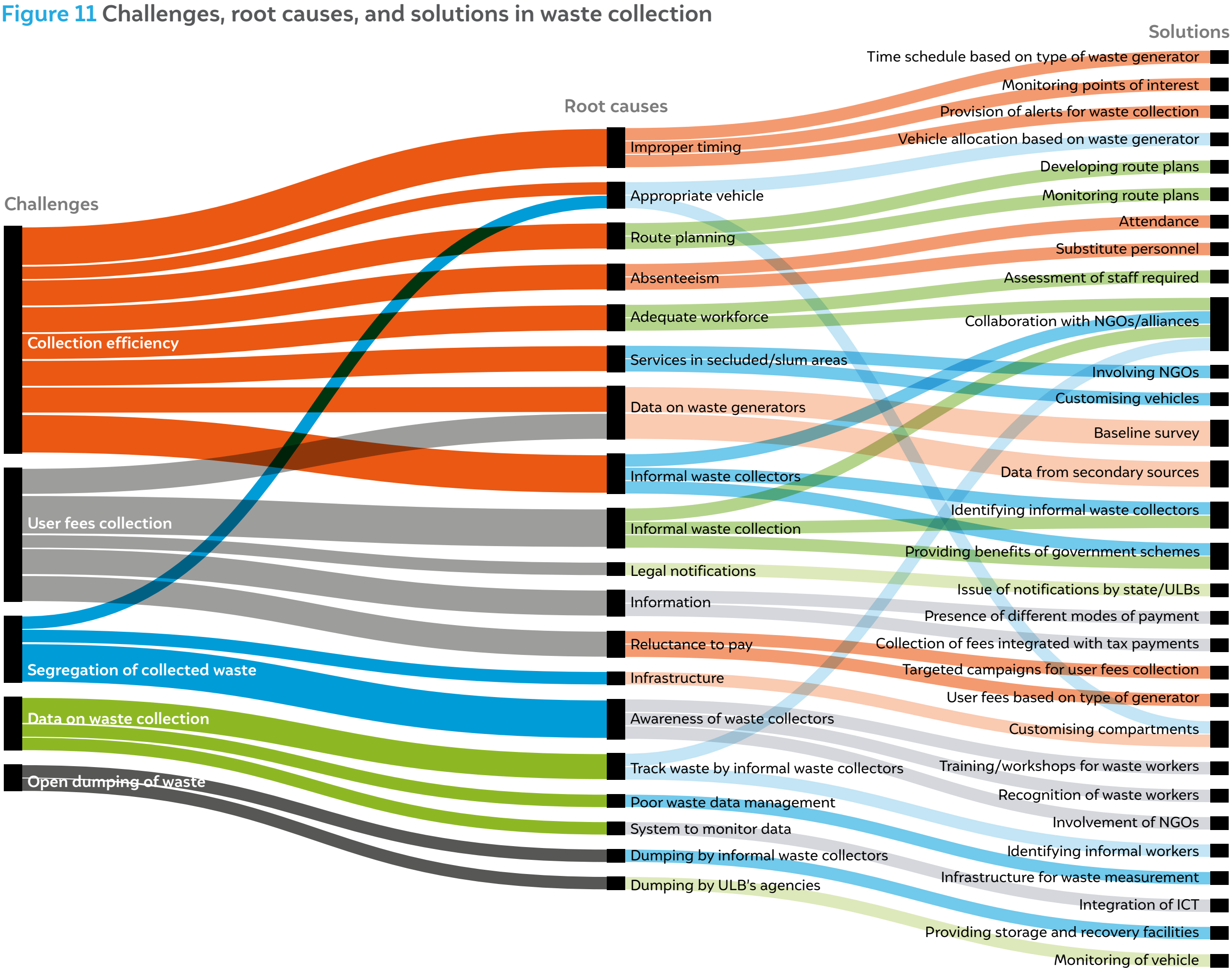
GVMC 'Employee of the Month' recognition.

Root causes of user fee collection issues and lack of waste collection data addressed

Root causes	Solutions
Lack of data on waste generators	The *Sachivalayam* has enabled the mapping of the households and types of generators in every ward.
Lack of information on user fee collection	Under the *Sachivalayam* system, citizens have the option to pay their user fees by visiting the *Sachivalayam* and using the QR code, or by having volunteers visit their houses to collect the fees.
Lack of a system to monitor waste collection data	A sanitary inspector uses a mobile application integrated with RFID at household gates to monitor solid waste collection. Monitoring of the primary collection vehicles at the ICCC.
Absenteeism	Every morning, a sanitation inspector at the ward office oversees the biometric attendance of the *safai mitra*. The inspector also meticulously maintains a detailed daily log of tasks assigned to each worker. These tasks are subject to inspection and subsequent approval upon completion.
Lack of awareness among the waste collectors	The Greater Visakhapatnam Municipal Corporation recognises one *safai mitra* as 'Best Employee of the Month.' It also acknowledges the secretaries for their outstanding work, which is displayed on the corporation's notice board.

Source: Authors' analysis

Figure 11 Challenges, root causes, and solutions in waste collection



Source: Authors' analysis

3.3 Waste transportation

Transportation of waste is a functional element of the waste supply chain that must be regular and systematic to ensure regular movement of waste. Once waste is collected from households and commercial establishments, it must be transported to suitable treatment or disposal facilities. If it is not done effectively, it can lead to a backlog of waste, potentially leading to open dumping or littering in water bodies. In this study, we identified 4 significant challenges during waste transportation that are linked to 12 potential underlying root causes. From the field visits, we documented 22 different solutions that are being implemented in different capacities across cities to address these challenges, which are showcased in Figure 12.

With the expansion of cities, the distance between waste collection points and treatment facilities has grown. As a result, cities have established transfer stations to allow ULBs and SWM agencies to prioritise local waste collection over long-distance transport (USEPA 2002). These transfer stations potentially reduce fuel costs and traffic congestion caused by the movement of waste vehicles (Yadav et al. 2015). Additionally, integrating material recovery facilities (MRFs) at transfer stations can lead to improvements in the recovery of recyclable waste. However, the primary challenge in many cities is the lack of adequate infrastructure and maintenance at these transfer stations. An additional challenge is maintaining waste segregation during transportation and at transfer stations. Common root causes for these challenges include improper vehicle design, poor facility design, no regular maintenance of the equipment in the facility, lack of data for planning, and the limited capacity of operators. Tackling these root causes is essential for optimising the functionality of transfer stations in the urban SWM landscape.

BOX 5 Proper transfer station infrastructure for effective operations – a case study of Surat

Transfer station in Surat, equipped with a weighbridge, fire emergency plan, and an integrated MRF.

Surat was one of the first cities in the country to introduce a D2D collection system and have a transfer station. There are five agencies working in eight zones, and each zone has one transfer station. We visited the Pal transfer station, which is about 20 years old and covers the west zone.

Root causes addressed for ensuring segregation and proper infrastructure at transfer station

Root causes	Solutions
Lack of data for planning infrastructure/vehicles	The municipality has mapped the flow of waste from each ward to its corresponding transfer station. The vehicle is weighed at the transfer station, and using RFID the system issues a receipt containing details such as quantity and type of waste, vehicle registration, source transfer station, and the vehicle's timing.
Design of transfer station hampering segregation	The transfer station is designed in such a way that wet and dry waste are emptied at different locations to avoid mixing waste. The hopper for the wet waste compactor is located on the first floor, and a designated material recovery facility is on the ground floor.
Lack of maintenance of facility	Regular cleaning of the compactors is done using a high pressure jet pump.
Electricity/power insufficiency	Whenever a power outage occurs, the concerned person notifies the relevant officials and the electricity operator through a dedicated WhatsApp group.

Source: Authors' analysis

Frequent breakdown of vehicles is a major problem during waste transportation, causing disruptions in waste collection schedules and impacting overall operations. We identified some of the major factors for these breakdowns during our interviews. These include inadequate vehicle maintenance, improper use by drivers, poor road conditions in the city, and a reliance on old and unfit vehicles. Studies show that implementing predictive maintenance can result in a 25 to 30 per cent reduction in maintenance costs and a 20 to 25 per cent increase in the availability of vehicles (Arena et al. 2022). Additionally, proper route planning, real-time monitoring of vehicles, and training of drivers can improve overall transportation efficiency and reduce waste leakages in the supply chain.

BOX 6 Operation and maintenance of vehicles at the transfer station – a case study of Bhopal

O&M and repair of vehicles at the transfer station with an integrated decentralised MRF, Bhopal.

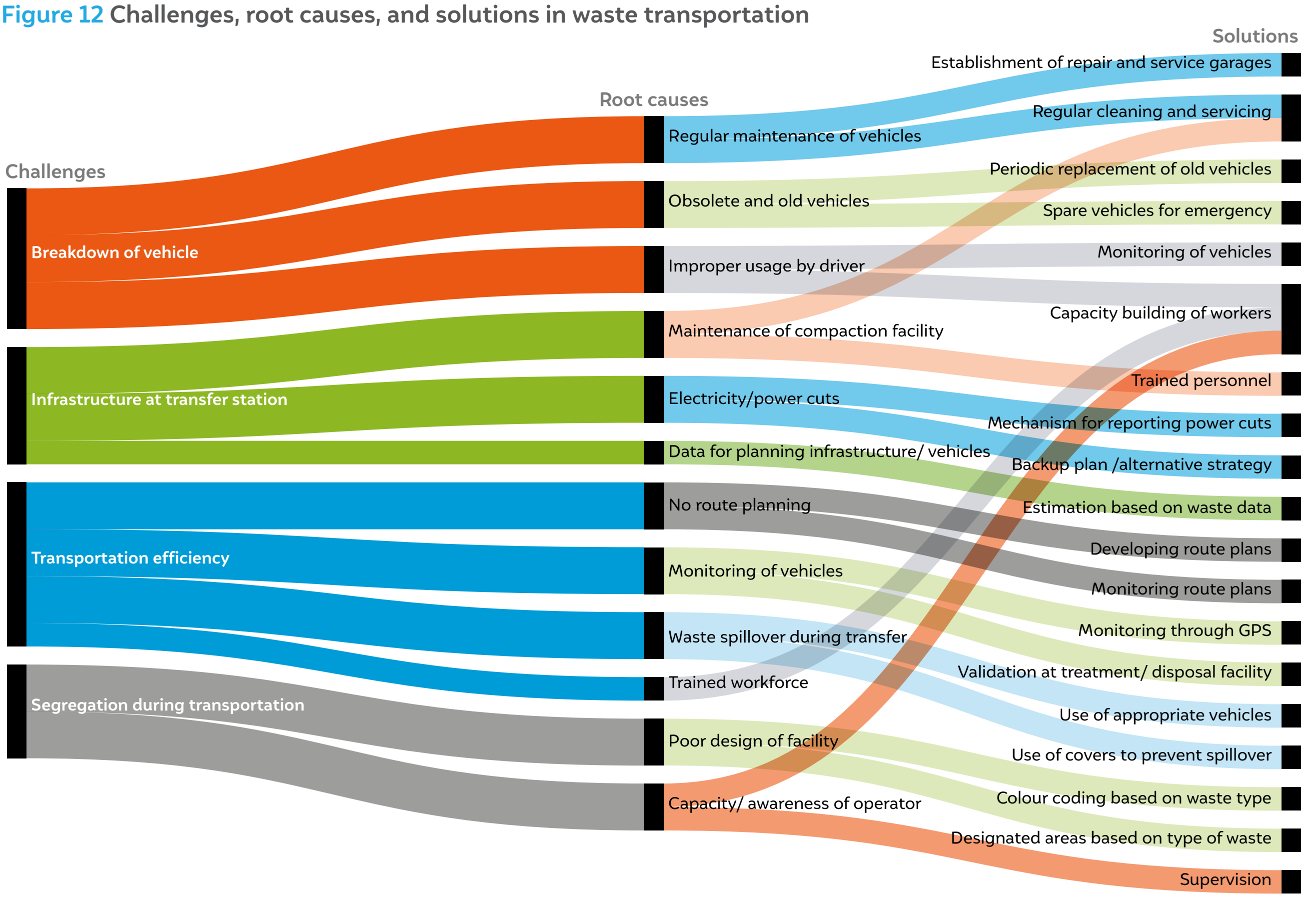
The transfer station at Transport Nagar, Bhopal, is one of the 12 transfer stations in the city, receiving waste from 5 wards in 2 zones. The transfer station is well equipped with a weighbridge, green and blue capsules with hook loaders and a fuel pump. An MRF run by an NGO recycles the dry waste reaching the transfer station.

Root causes addressed for the breakdown of vehicles and ensuring segregation

Root causes	Solutions
Lack of regular maintenance	The transfer station is equipped with waste compactors, facilities for vehicle repair and maintenance, and a refuelling station. The plant operator ensures the cleanliness of primary collection vehicles, intervenes if a dirty vehicle arrives, and directs the driver to have it cleaned at the transfer station.
Lack of trained manpower	The plant operator trains and supervises the new staff on the operations of the equipment and machinery at the transfer station.
Design of the facility to ensure segregation	Sarthak, an NGO running a material recovery facility, is present at the transfer station and ensures resource recovery for recycling various categories of dry waste.

Source: Authors' analysis

Figure 12 Challenges, root causes, and solutions in waste transportation



Source: Authors' analysis

3.4 Waste treatment

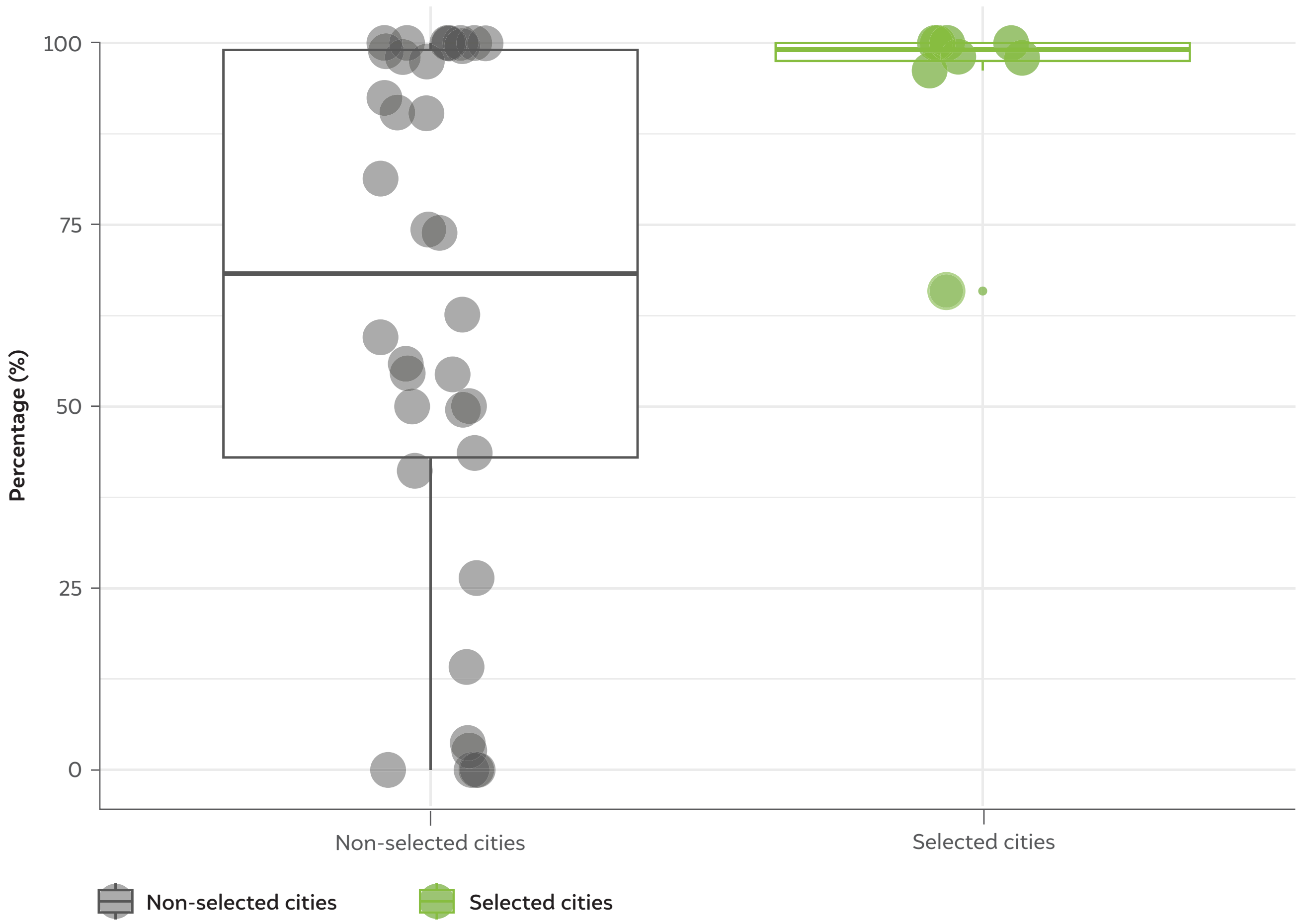
"There is no such thing as waste – just material in the wrong place"

- Michael Thompson, author of *Rubbish Theory*

Following the collection and transportation stages, waste treatment is vital in the solid waste supply chain. It is a key step in advancing the principles of a circular economy, where materials and products never become waste. The circular economy approach focuses on converting waste into resources while maintaining the quality and integrity of the process; it is an essential strategy for achieving multiple SDGs (Kruchten and Eijk 2020). Furthermore, processing waste effectively contributes to the sustainable use of natural resources and reduces gaps and emissions in the supply chain (Khan, Su, and Khurshid 2022). Waste can be processed by adopting various methods depending on the type of waste, such as composting and biomethanation for wet waste and material recovery for dry waste. According to the Ministry of Housing and Urban Affairs, compost and bio-CNG from wet waste could generate revenues of approximately INR 365 crore and INR 1,679 crore annually, respectively, while recycling of dry waste has the potential to yield about INR 11,836 crore per year (MoHUA 2021).

Although there is a strong economic case for waste treatment, significant challenges hinder the implementation of these practices. According to the CPCB annual report (2021), only half of the country's waste is currently processed; about 69 per cent gets processed in million-plus cities, as per the *Swachh Survekshan* portal (Figure 13). We identified six major challenges in waste treatment that are linked to 21 root causes. Through field visits to processing facilities and stakeholder interviews, we documented 46 solutions being implemented in the selected cities to address these challenges. The challenges, their root causes, solutions, and the potential for customisation in improving waste treatment are shown in Figure 14.

Figure 13 On average, about 69% of waste is treated in the million-plus cities



Source: Authors' analysis; data from MoHUA. n.d. Swachh Survekshan 2022. Ministry of Housing and Urban Affairs, Government of India

One of the first barriers to waste processing is unavailability of suitable land for establishing treatment facilities. The requirement for land can fluctuate significantly based on the scale and type of waste processing involved. We found that issues over land availability include the 'not in my backyard' (NIMBY) sentiment among residents, not enough land within municipal jurisdictions, and complexities associated with obtaining approvals and clearances. These factors result in insufficient waste treatment capacity in cities, given the amount of waste generated. Therefore, to address these root causes, designated areas must be allocated within ULB jurisdictions for treatment facilities in city plans. Given limited land availability, ULBs must explore decentralising waste treatment to reduce transportation costs and facilitate localised treatment of waste. We found that establishing treatment facilities, whether centralised or decentralised, demands building trust and awareness among different stakeholders, including municipalities, resident welfare associations (RWAs), ward leaders, and experts. This can be achieved by engaging in collective decision-making, conducting inclusive stakeholder consultations, and fostering transparency.

After establishing the treatment facility, a key challenge for its operation is not receiving the right quality and quantity of waste. The feedstock at the facility directly impacts resource recovery and the financial viability of processing facilities. For instance, when waste received at the facility is not properly segregated, extra resources and workforce are required for separation and sorting. To improve the quality of waste, facilities have adopted pre-processing infrastructure for dust removal, cleaning, shredding, drying, and bailing. We found that establishing a clearly defined agreement between the concessionaires and ULB, with regular coordination, improved segregation levels of waste at the facility. We also found that having a proper inventory of waste data and utilising the analytics can help in planning, storage and sorting of the waste effectively.

BOX 7 Decentralised compost plants located near a vegetable market and transfer station – a case study of Rajkot

Final compost (product) made from organic waste from the nearby vegetable mandi at the 5 TPD compost plant in Rajkot.

Rajkot has two decentralised 5 tonnes per day (TPD) capacity organic waste-to-compost plants, which are operated and maintained by Excel Industries. The organic waste is received from the nearby *mandi* (vegetable market) and fed into the organic waste converter. The compost is ready in ten days and sold to farmers at fixed rates.

Root causes related to land availability and receiving sub-optimal quality and quantity of waste addressed

Root causes	Solutions
Getting approval and clearance	A public-private partnership model has been established where the municipality supplies the land, and a third party oversees operations. Additionally, to speed up the clearance process, the facility can handle a capacity of 5 tonnes per day.
'Not in my backyard' (NIMBY) attitude of people	The facility is strategically positioned adjacent to the vegetable market and the transfer station. The curing system, enhanced with specialised inoculum, effectively eliminates any potential odour-related concerns associated with waste treatment.
Lack of segregated waste	The organic waste is received from the *mandi* (vegetable market) and is fed into the organic waste converter.
Lack of capacity/awareness among workers	The facility employs previously trained informal workers to manage the operations.

Source: Authors' analysis

A key issue in waste processing is the operation and maintenance (O&M) of these facilities. Regular maintenance ensures the efficient functioning of these facilities, prolongs their lifespan and improves the quality of the treated waste. We identified multiple challenges to regular O&M, including a shortage of personnel, outdated technology, a lack of planned schedules for maintenance, and worker negligence. Many of these challenges can be easily addressed by regularly inspecting equipment and conducting training for both technical and non-technical staff. Additionally, customising the machinery to suit the facility's needs can enhance adaptability and improve overall maintenance practices.

"The machine we brought into our facility did not perform as per the incoming waste, which resulted in frequent breakdowns. Then, we upgraded and customised it with the vendor based on the quality of our waste. This helped in improving the lifetime of a machine."

- Plastic waste management unit owner in one of the selected cities

The demand for the final product significantly influences the economic viability of processing facilities (Ahluwalia and Patel 2018). We found that this could be due to product quality derived from waste, high logistical costs, and lack of uptake and demand in the local market. To address these concerns, some facilities build consumer trust through various strategies, including product labelling, obtaining legal quality certifications, and social media marketing. These facilities also forge partnerships with local stakeholders and secure commitments from ULBs to ensure consistent uptake of their end products.

BOX 8 BioCNG plant located near a vegetable market – a case study of Surat

Bottled BioCNG (product) at the 50 TPD biogas plant in APMC market, Surat, Gujarat.

Surat established a 50 TPD biomethanation plant near the Agriculture Produce and Livestock Market Committee (APMC) through a public–private partnership (PPP) model. There are three digesters and one gas collector at the facility. Overall, it takes about 45 days to complete the biomethanation process. The plant's initial investment got break-even in four years, and it is currently profitable, making it a highly economically viable initiative.

Root causes relating to O&M of the facility and demand for the end product addressed

Root causes	Solutions
Obsolete technology	Two staged thermophilic biomethanation for ensuring high efficiency in converting waste to syngas. The plant has a multi fed digestor that can treat multiple types of wet waste.
Negligent attitude of workers in the facility	The workers undergo regular training at the facility. CCTVs across the facility help monitor (and deter) negligence.
Quality of the product	A gas analyser tests the gas and ensures the final component gas is 97% pure.
High logistic cost	Final biogas is bottled in cylinders and sent to different end users. The facility has partnerships with local industries and Indraprastha Gas Limited for uninterrupted distribution.
Lack of regular demand	The facility has regular demand from the local industries for biogas. Additionally, the slurry is also converted into solid and liquid manure and sold in the market. The facility has developed promotional content through brochures, social media, references, and websites to boost visibility and drive demand for the product.

Source: Authors' analysis

Environmental challenges, such as fire hazards and noxious odours, frequently result in the closure of processing plants (Kumar et al. 2017). These issues are typically associated with poor facility design, insufficient monitoring practices, non-compliance with safety regulations, and a lack of diligence among the workers. A few facilities have addressed these root causes by implementing comprehensive layout plans for their treatment facilities, ensuring strict adherence to fire safety guidelines, and installing advanced ventilation systems. The enforcement of occupational health and safety (OHS) or environment, health and safety (EHS) standards further prioritises the well-being of both the workforce and the environment. We found that adopting new technologies such as IoT-enabled (Internet of Things-enabled) cameras, smog detectors, and sensors can facilitate data-driven decisions for monitoring and managing fires.

BOX 9 Plastic waste recycling plant at Kapulupadda dumping yard – a case study of Visakhapatnam

CEEW researchers at a plastic recycling facility in Visakhapatnam, Andhra Pradesh.

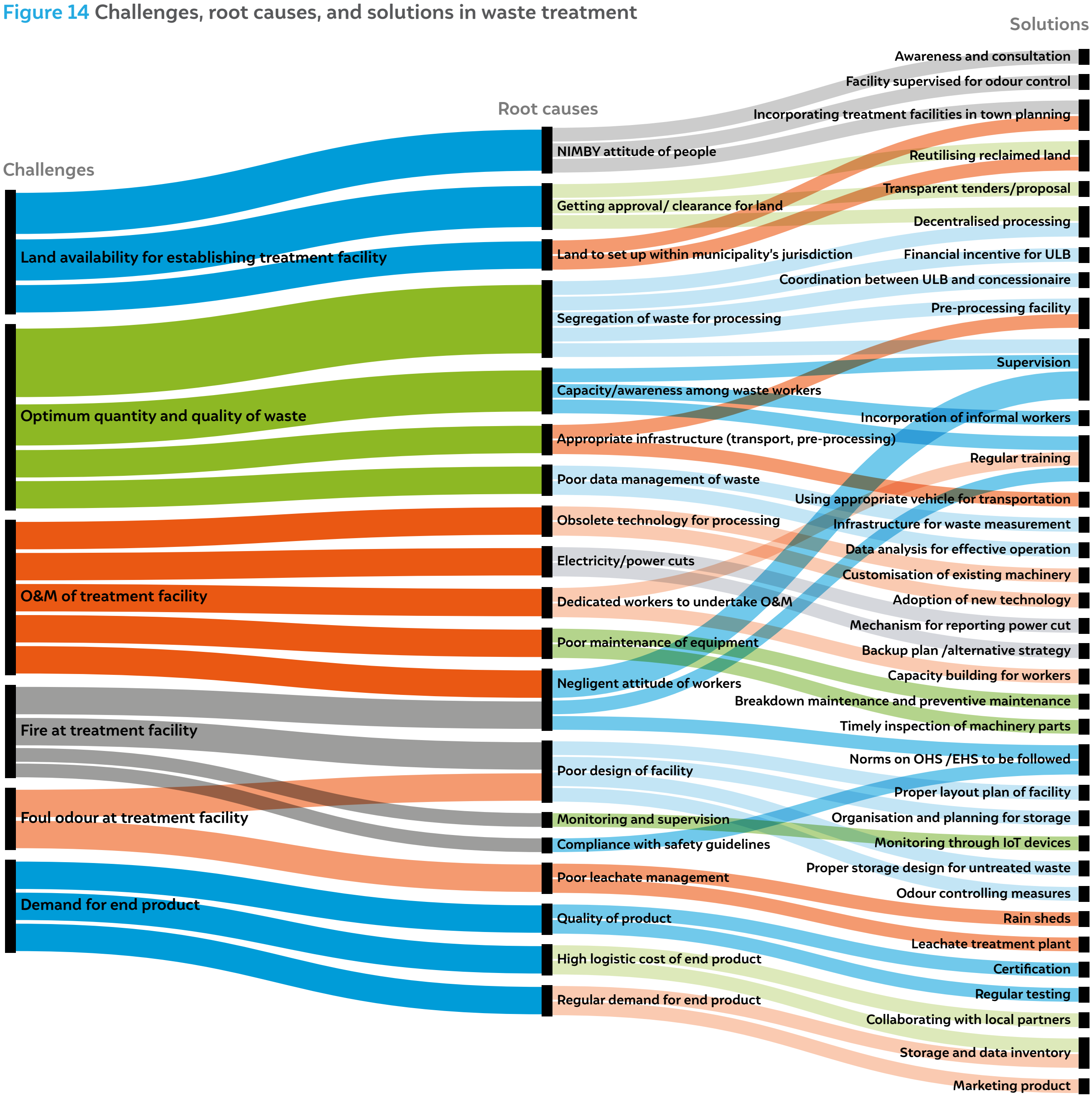
By collaborating with local NGOs and foundations, Visakhapatnam established a plastic waste recycling unit at the Kapuluppada dumping yard.

Root causes relating to land availability, operations, and environmental challenges addressed

Root causes	Solutions
Not enough land in the municipality	The recycling and material recycling facilities were established on the remediated area of the Kapuluppada dumping ground.
Segregation of waste	The plant receives plastic from the municipality and from clean up drives across the city.
Lack of appropriate infrastructure	Preprocessing infrastructure, including a conveyor belt, wrapper removal, and a washer for cleaning dirt, has been installed.
Capacity/awareness of workers	The facility operates in collaboration with a local NGO, which assists in managing the facility's regular operations.
Poor designing of the facility	The layout plan included fire safety guidelines and designated storage areas for different types of waste. Clear instructions for operating the machines are attached to the machines for workers to follow.
Lack of regular demand for recycled/processed products	Plastic waste is processed into different types of pellets, which are sent to buyers and converted into different recycled products such as toothpaste tubes, combs, and bags

Source: Authors' analysis

Figure 14 Challenges, root causes, and solutions in waste treatment



Source: Authors' analysis

3.5 Waste disposal

In India, the criteria for establishing sanitary landfills are listed in the *Solid Waste Management Rules, 2016*, which has detailed regulations that govern its siting, design, and operation (MoEFCC 2016). The disposal sites must comply with the *Solid Waste Management Rules, 2016*, and the technical guidelines mentioned in the Central Public Health and Environmental Engineering Organisation (CPHEEO) manual (CPHEEO 2016a, 2016b). Notwithstanding these guidelines, even according to the CPHEEO manual, waste disposal should be the least preferred option in the integrated SWM hierarchy (CPHEEO 2016a, 2016b).

Waste disposal sites can be broadly classified into the following categories: scientific landfill sites, controlled dump sites, and open dump sites (Swati et al. 2018). Scientific landfills are engineered facilities that receive only inert materials from processed waste. Dump sites are areas where unprocessed mixed waste is directly disposed of (CSE 2020). The current status of landfills in India is that they are operated either as open dump sites or controlled landfills. We identified 7 major challenges associated with waste disposal linked to 27 underlying root causes. Field visits and interviews revealed 43 types of solutions currently being implemented to address these root causes in various capacities across cities.

Figure 15 offers an overview of these challenges, root causes, and solutions.

Following the 'out of sight, out of mind' approach, disposal is often misunderstood as the final step in managing municipal solid waste when the waste has been removed far from the source. However, with the constant expansion of the areas under municipal jurisdictions, dump sites that were once on the periphery have been enveloped, resulting in these dump sites now becoming an integral part of the city. Besides, the current rate of unscientific garbage disposal in landfills has led to them swelling beyond their capacities; consequently, 1,240 hectares of land will likely be used as landfills each year (Mor and Ravindra 2023). During our field visit, we found that NIMBY, geographical constraints, and problems associated with getting approval or clearances are some of the root causes that impede setting up disposal facilities.

Over the years, inefficiencies in SWM – such as the uncontrolled dumping of mixed waste, the absence of scientific landfills for waste disposal, and scant regard for successive policies – have resulted in the emergence of more than 3,000 dump sites across India that accumulate legacy waste while posing severe environmental risks (CPCB 2022). As per the data reported on the *Swachh Bharat Mission – Urban* portal, there are 76 dump sites in the million-plus cities across 19 states of India, with accumulated legacy waste of about 1281.45 lakh tonnes. Of these, 523.89 lakh tonnes (~41 per cent) have been remediated, leading to the reclaiming of 1077.11 acres (~33 per cent) of land (Swachh Bharat Mission n.d.).

Schedule I of the *Solid Waste Management Rules, 2016*, has specific guidelines for closing and rehabilitating dump sites with a legacy of improper management. Remediation of legacy waste sites is essential to close unscientifically designed and mismanaged dump sites that can cause long-term environmental and public health hazards (Singh 2022). Numerous issues are associated with the legacy waste remediation process, including finding concessionaires for delivering output, using suitable technologies/techniques for remediation, securing sufficient power supply, and mitigating the risk of landfill fires. A pre-feasibility study is a crucial initial step to start the remediation process, paving the way for future biomining activities (Singh 2022).

Bioremediation using a trommel at the legacy waste dumpsite in Ahmedabad, Gujarat.

BOX 10 Bioremediation of legacy waste – a case study of the Pirana dump site in Ahmedabad

Trommel machine for biomining of legacy waste at Pirana dumpsite, with the combustible fraction from the bioremediation sent to the nearby RDF processing plant, Ahmedabad.

Covering 84 acres in Ahmedabad, the Pirana dump site has accumulated over 1.3 lakh metric tonnes of legacy waste over the past four decades. The massive waste heap at the dumpsite is as high as 75 feet, primarily consist of unsegregated municipal solid waste that includes biodegradable materials, plastics, inert debris, and hazardous substances without any prior treatment.

Root causes addressed for bioremediation of legacy waste at dump site

Root causes	Solutions
Not finding the right concessionnaire	The Amdavad Municipal Corporation invited multiple tenders for biomining of the Pirana dump site.
Irregular electricity/ power supply	Use of diesel-powered trommels for segregating the mixed legacy waste.
Mixed waste	The site processes 30,000 TPD of legacy waste, utilising various types of equipment, including 60 trommel machines (each capable of segregating 300 tonnes of waste daily). 11 automated segregation machines with a capacity of 1,000 tonnes per day, 63 excavators, and 267 Hyva trucks. To eliminate the odour, the legacy waste is treated with bioculture and regularly churned.
Destination for the end product	The legacy waste is segregated into inert materials, refuse-derived fuel (RDF), and construction and demolition waste. RDF is sent to the waste-derived fuel preparation for further processing. Inert materials are used to fill the low-lying areas.

Source: Authors' analysis

Lack of monitoring and mismanagement at dump sites can lead to site-related accidents, such as landslides, which may be life-threatening (Wang, Zhang, and Lin, 2022). Unsegregated municipal solid waste contaminated with other types of hazardous waste leads to the accumulation of toxic waste in landfills (Swati et al., 2018). Moreover, landfills that are poorly constructed and lack scientific management, liners, and gas collection systems can lead to significant environmental issues. These include groundwater contamination, leachate pollution, persistent GHG emissions, and potential surface fires. The insights from the field visits and interviews with stakeholders reaffirmed that fires and accidents pose a serious challenge and stem from poorly designed landfill sites, the dumping of mixed waste, and a lack of monitoring and supervision.

To mitigate these risks, it is imperative to undertake appropriate planning and design and to adopt effective prevention and control strategies along with operational protocols at landfill sites. This will ensure compliance with safety guidelines and obligatory environmental monitoring practices.

BOX 11 Setting up of treatment facility on remediated land – a case study of Indore

The centralised treatment facilities are established on the remediated legacy waste disposal site, known as the trenching ground, in Indore.

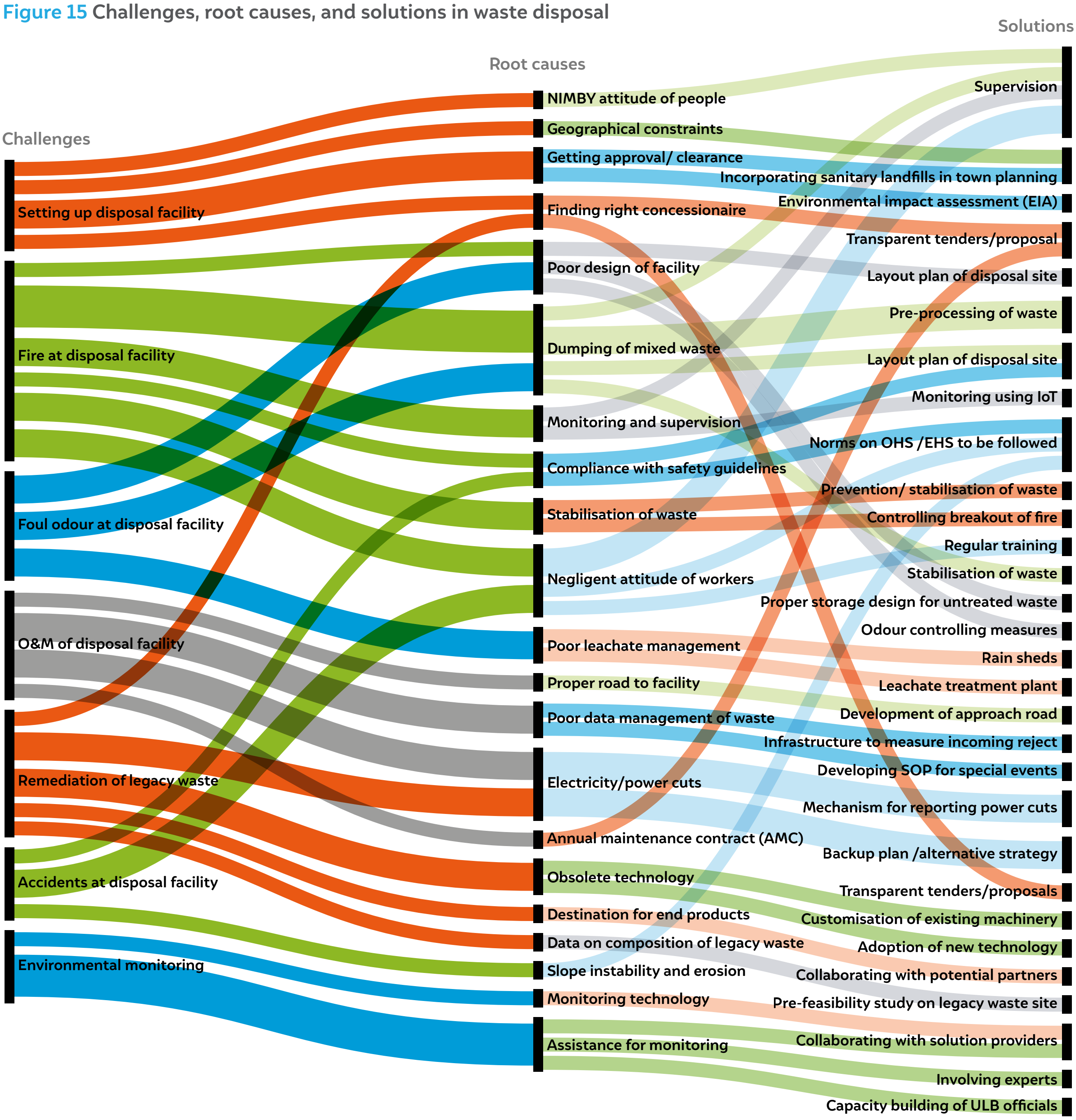
The Indore Municipal Corporation has eliminated landfills as part of its initiatives to improve the SWM supply chain. Since 2016, careful planning, effective implementation, and continuous monitoring have allowed Indore to reclaim 40 acres of land by bioremediating approximately 1.5 million metric tonnes of legacy waste in the Deoguradia trenching ground.

Root causes hindering setting up of treatment facility on remediated legacy waste site addressed

Root causes	Solutions
NIMBY (not in my backyard) attitude	The recovered land has been utilised to establish a centralised 550 TPD biomethanation plant operated by EverEnviro and a centralised dry waste processing facility operated by Nepra.
Not finding the right concessionaire	EverEnviro (bioCNG plant) manages the city's wet waste. It has a contract with the Indore Municipal Corporation (IMC) that requires it to give 50 per cent of the bioCNG produced for city buses at INR 5 per kg less than the market rate of compressed natural gas (CNG). In return, IMC supplies 90 per cent of segregated waste to the plant, for which the company pays an annual royalty of INR 2.5 crore.
Dumping of mixed waste	Waste is segregated at the source, and the segregation is maintained at every level of the waste supply chain. The dry waste processing facility uses technologies such as optical pneumatic sorting to further sort and segregate waste at scale.
Poor design of the facility	The city has well designed wet and dry waste processing facilities that follow the occupational health and safety guidelines and other norms at the facility.

Source: Authors' analysis

Figure 15 Challenges, root causes, and solutions in waste disposal

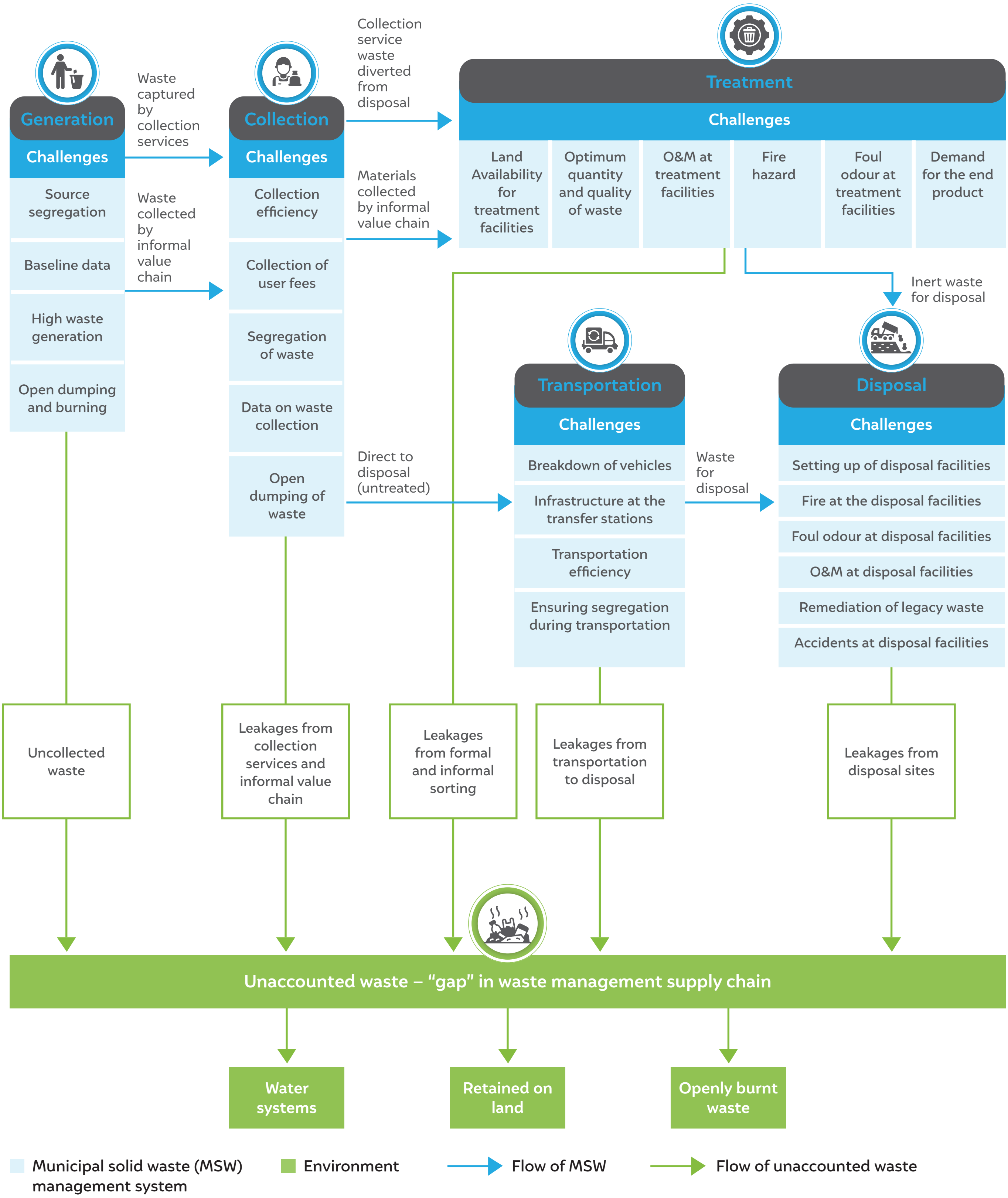


Source: Authors' analysis

3.6 Interlinked challenges across the supply chain

We identified 26 major challenges across the SWM supply chain, which are integrated and presented in the waste flow diagram (WFD) system map (Figure 16) (GIZ 2020). The WFD illustrates the leakage of waste at various levels of the SWM supply chain. Waste can leak at the source, due to practices such as dumping and burning of waste, including by households and commercial establishments. Further, if the waste is not collected throughout the city and transported regularly by formal and informal collection services, it can also result in leakage in the form of open dumping. If the collected waste is not treated due to a lack of treatment capacity or operational issues, it can also result in leakage from different processing facilities. Finally, at the disposal stage, waste is susceptible to unauthorised dumping and burning at dump sites or other locations. Therefore, to address the gaps effectively, ULBs need to identify the challenges specific to their region and map the root causes for the respective challenges.

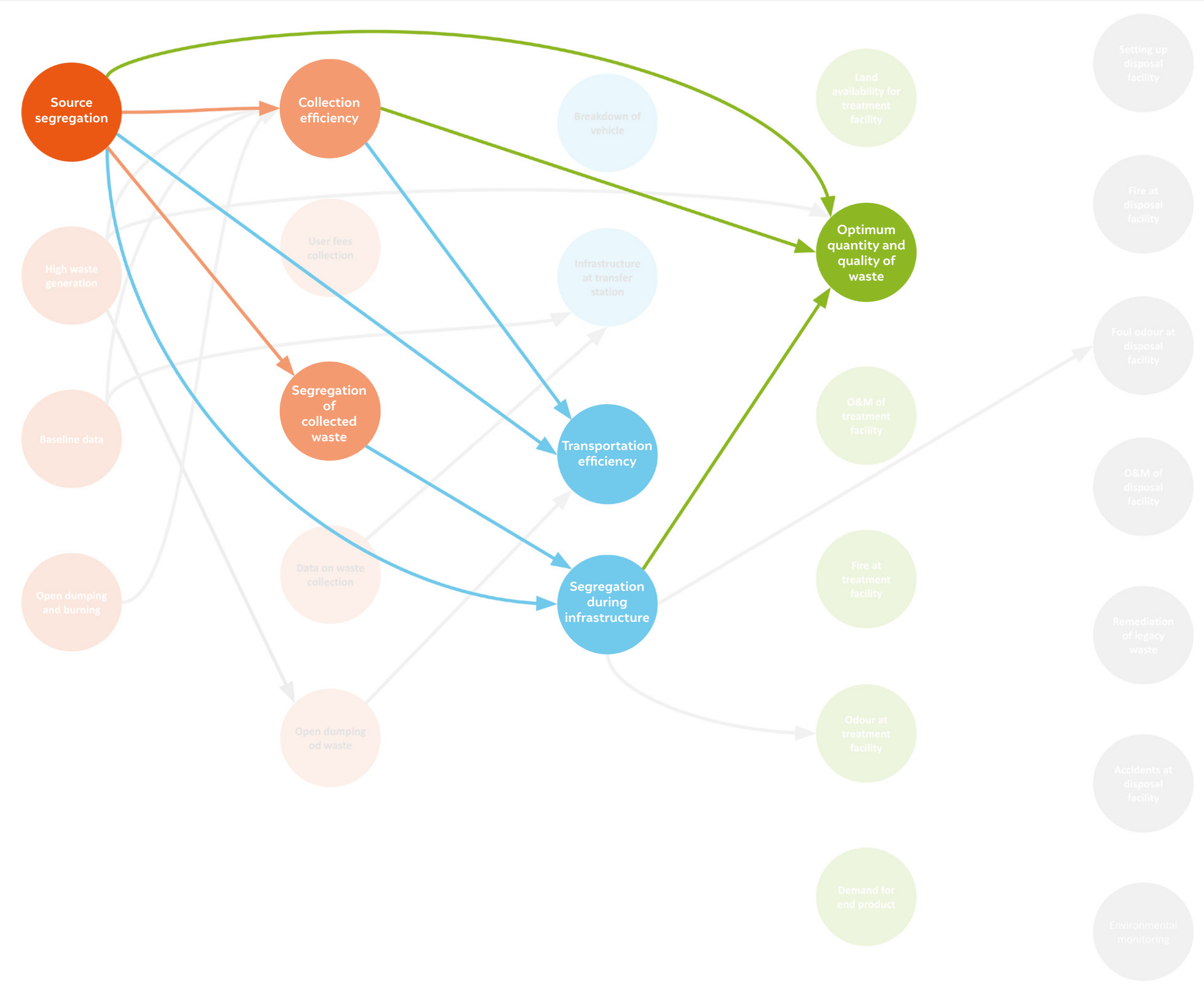
Figure 16 **Waste flow diagram and system map for municipal solid waste, highlighting the identified challenges at each level of the supply chain**



Source: Authors' Compilation; Adopted from GIZ. 2020. Waste Flow Diagram (WFD): A Rapid Assessment Tool for Mapping Waste Flows and Quantifying Plastic Leakage. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

The challenges across the waste supply chain are also deeply interlinked. Box 12 highlights how segregation influences different aspects of the waste management system.

BOX 12 Waste segregation linked with different levels of the supply chain



Generation Collection Transportation Treatment Disposal

Source: Authors' analysis

Segregating waste at the source into at least three categories – biodegradable, non-biodegradable, and domestic hazardous waste – by different types of waste generators is the first step in effectively managing solid waste. Waste segregation at the source also helps reduce the volume of unsegregated waste to be handled by ULBs (NITI Aayog 2021). As a result, ULBs can improve their collection and transportation coverage, allowing them to cover more households or reduce the number of trips required for collection.

Once segregated waste is collected, it must remain separated during primary and secondary transportation to maintain its utility. If waste collectors do not segregate the waste, then it can disincentivise source segregation efforts by generators (Kumar and Rana 2024).

The quality and quantity of waste reaching treatment facilities, such as composting plants or material recovery centres, are influenced by how well segregation is maintained throughout the supply chain (Priti and Mandal 2019). For instance, if biodegradable waste arrives mixed with domestic hazardous waste, it can contaminate the overall waste. Further, the facility may need to acquire additional workforce and machinery to sort the waste, increasing operational costs and time. Hence, a well-segregated waste which is maintained across the supply chain can minimise leakages and improve resource recovery.

4. Conclusions and recommendations

The challenges we observed in SWM are similar across the eight cities we selected but their underlying causes differ significantly. Therefore, addressing these challenges requires tailored approaches that consider these unique characteristics, including its geographical features, financial resources, workforce capacity, and local legislative framework. For an effective SWM system, ULBs must prioritise the thorough assessment and identification of the root causes of the challenges encountered at each stage of the solid waste supply chain. This step is crucial for developing city-specific strategies to overcome these hurdles.

The CRS matrix, developed for this study, is a valuable tool that assists in mapping the factors contributing to challenges and their interconnections across different stages of the SWM supply chain in urban areas. The matrix is also a practical reference guide to identify effective solutions to address these root causes. For instance, if a city encounters difficulty in segregating waste at different levels of the supply chain, it can utilise the CRS matrix to identify potential root causes linked with this challenge and brainstorm appropriate solutions. Subsequently, the city can also explore the solutions successfully implemented by the eight cities mentioned in the study and customise them to suit their unique circumstances based on feasibility and applicability. Significantly, this framework does not limit the ability of cities to innovate and develop their own unique solutions.

Based on the insights and learnings from the selected cities, we recommend the following set of actions that can help strengthen existing SWM systems across India's major cities.

Need for a comprehensive and updated baseline data inventory

The lack of reliable and comparable waste generation data constrains cities from effectively addressing many issues across the waste supply chain. Going beyond quantifying waste, it is imperative to have disaggregated data on the characteristics of the waste generated based on various factors such as climate, economic activities, or lifestyle. Many cities often rely on decades-old guestimates (Sambyal 2023), such as employing a 60:40 ratio of wet to dry waste or 500 grams per capita for waste generation (CPHEEO 2016a, 2016b). Consequently, such generalised approaches lead to inaccurate assessments, resulting in overestimating or underestimating the required infrastructure. Due to

Women employed at the MRF run by Saahas Zero Waste (SZW) sort non-biodegradable waste into 30 different categories.

the limited number of national surveys, many studies and emission estimates depend on the 2005 CPCB and National Environmental Engineering Research Institute (NEERI) report on 59 cities (Hujare and Telsang 2020). Generating more up-to-date data necessitates maintaining a detailed national-level database that is updated at regular intervals. This data inventory will also aid in accurately estimating air pollution and GHG emissions from the waste sector. Overall, this can create an ecosystem that allows for data-driven decisions on SWM and helps identify effective solutions for municipal SWM.

Establish waste reduction targets and policies that align with *Mission LiFE*

To effectively address the burgeoning issue of municipal solid waste, cities across India must emphasise reducing waste at its source. The CPCB annual report for 2021–22 reveals a stark contrast in per capita waste generation across India – from a mere 21 grams per day in Meghalaya to an alarming 526 grams per day in Delhi. Even between the million-plus cities, the differences are pronounced, with Surat's daily per capita waste generation standing at 240 grams per day, compared to Greater Hyderabad's 910 grams per day. Encouragingly, some cities, such as Pune, are aiming to reduce waste generation by 25 per cent. Cities must embrace the vision and objectives of *Mission LiFE* in their SWM efforts, adopting a holistic approach that focuses on the principles of reduction and reuse beyond just recycling. One proactive measure cities can adopt is the promotion of zero-waste initiatives in mega-events, institutions, residential societies, and festivals. Such initiatives foster community involvement and will be pivotal in ushering in behavioural change towards better SWM practices.

Adopt at least three-categories waste segregation

Despite the establishment of clear guidelines on waste segregation in the *Solid Waste Management Rules, 2016*, many cities currently overlook a critical component of SWM – the segregation of domestic hazardous waste. Failing to segregate this third category of waste and mixing it with organic or inorganic waste spoils these categories, resulting in lost resources and more waste ending up in landfills. Mixing domestic hazardous waste with dry or wet waste makes the subsequent sorting process unhygienic and injurious at times. Cities must make the three-way segregation process mandatory throughout the supply chain, starting from the source, to collection and transportation, and until it reaches its final destination. Source segregation will require capacity-building efforts not only among waste generators but also among waste-handling personnel. It must be noted that *Swachh Survekshan* recommends a four-way segregation, where sanitary waste is the fourth category.

Prepare area-specific and event-specific SWM plans for vulnerable areas and high waste–generating events

In the development and execution of SWM systems, slum dwellings, micro-mini industrial clusters, and crowded commercial zones often face unique problems. Therefore, municipalities should prepare tailored SWM strategies for these frequently overlooked areas, ensuring that they do not transform into epicentres for open waste dumping and burning. ULBs should partner with the informal sector and NGOs to enhance awareness and facilitate robust SWM practices in these areas. To address significant increases in waste generation during special occasions such as festivals, events, and peak tourism seasons, cities must mobilise additional workforce or optimise their existing infrastructure. Integrating these aspects into the city's master plan will ensure that SWM becomes an integral part of the city's holistic development strategy.

Prioritise operations and maintenance as much as the procurement of new machinery

To guarantee smooth functioning at different tiers of the SWM supply chain and maximise the use of existing infrastructure, ULBS should allocate resources towards O&M costs and efforts (whether through outsourcing or in-house management), not just capital allocation. Scheduled O&M intervals, overseen by a responsible agency, must be planned for when acquiring vehicles or machinery. Additionally, the procurement strategy must include provisions to obtain backup vehicles or spare parts for machinery in the event of breakdowns. For efficient collection and transportation of solid waste, strategies such as route optimisation, regular servicing, and proper usage are critical. Similarly, for machinery deployed at processing or disposal sites, ULBs must consider procuring AMCs that cover regular maintenance, repairs, and support.

Invest in pre-processing infrastructure to improve the quality of waste

While solid waste treatment and processing are crucial components in the supply chain, they often receive inadequate investment from ULBs. Despite ULBs taking proactive measures to establish processing facilities, operational challenges persist for various reasons.

Many treatment facilities are hindered by various inefficiencies, primarily stemming from suboptimal waste quality, which can be attributed to the non-segregation of waste at the source or the subsequent mixing of segregated waste during transportation. Integrating a pre-processing facility to clean and sort waste will improve the efficiency and lifespan of machinery and equipment while also enhancing the quality of the end products derived from waste treatment.

Develop and enhance individual capacities in the waste supply chain

Enhancing the skills, performance, knowledge, and experience of staff and stakeholders across all levels of the solid waste supply chain requires capacity building and training. It should be undertaken at the individual level to enhance the ability (creativity, knowledge, skills) and motivation (values/beliefs, confidence, efficacy, satisfaction) of SWM personnel (Morrison 2001).

As a first step, ULBs should map the stakeholders involved at various levels of SWM who require training and development. A training needs assessment (TNA) for capacity building and skills gap analysis for staff skill development should be undertaken as a next step. The training should follow a holistic approach, according to the evolving needs of the sector. It should leverage existing e-resources on learning and development, such as the SBM-U e-learning portal and integrated government online training (iGOT) platform (MoHUA n.d.).

Stakeholders with updated and advanced technical, operational, and management skills can contribute to the provision of effective, efficient, and self-sufficient SWM services (MoHUA 2022; United Nations Development Group 2017). The *Recognition of Prior Learning Framework*, a unique feature of the *National Skills Qualifications Framework*, recognises and provides a comprehensive certification of individual competence. It emphasises training sanitation workers to build technical knowledge and skill assets for operating advanced machinery and equipment following the prescribed safety guidelines. As part of knowledge management, it is essential to create appropriate material, such as training modules, videos, and plans in regional languages for effective knowledge dissemination. Additionally, ULBs should finalise a customised training calendar that includes scheduled training sessions covering machinery operations and troubleshooting techniques.

Offer financial and policy support to handle bioremediation outputs

According to the CPCB (2019), the guideline document outlines the use of recovered screened fractions from legacy waste dump sites after biomining and bioremediation. The guidelines suggest that the market for the final screened fractions should be identified at the planning stage of the biomining and bioremediation projects. Yet, many ULBs face challenges in finding economically viable solutions for recovered waste, emphasising the need to identify stakeholders and local partners to uptake recovered waste in the planning stages. ULBs also need to test recovered fractions, especially fine soil-like materials, coarser particles, and refuse-derived fuel, to check if they meet standard requirements for further applications. They should also remember to include the associated cost of transporting the recovered waste offsite. Likewise, ULBs should be able to identify potential markets for the final disposal of inert waste that can be utilised for reclaiming low-lying areas, restoring mining overburdens, and constructing roads. They can also explore the use of fine soil-like materials in revegetation initiatives. Being mindful of the specific uses of the recovered fractions and the requirements to make them marketable can render biomining and bioremediation activities economically viable.

Leverage data dashboards and command centres for improving SWM

Under the *Smart City Mission*, all 100 cities have an operational ICCC that serves as a decision support system for addressing various urban challenges and improving quality of life (Ministry of Road Transport & Highways 2023). This infrastructure also presents an invaluable opportunity for smart waste management across multiple use cases. For instance, camera feeds and citizen-generated data on digital platforms and grievance applications can help identify and monitor GVPs. Additionally, integrating GPS and RFID technology into vehicles and GIS can help optimise collection routes, reducing fuel consumption and enhancing efficiency in D2D waste collection. Technologies such as pan-tilt-zoom cameras and sensors can support the monitoring of environmental hazards such as fires at treatment and disposal sites. To utilise this infrastructure effectively, a strong emphasis must be placed on training programmes and knowledge sharing among stakeholders.

Acronyms

AMC	annual maintenance contract
BWGs	bulk waste generators
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CRS	Challenge–root cause–solution
D2D	door-to-door
EHS	environment, health, and safety
EIA	environmental impact assessment
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GHGs	greenhouse gases
GPS	global positioning system
GVP	garbage vulnerable point
ICAR	Indian Council of Agricultural Research
ICCC	Integrated Command and Control Centre
ID	identification
IEC	information, education, communication
iGOT	integrated government online training
IoT	Internet of Things
MoHUA	Ministry of Housing and Urban Affairs
MoUD	Ministry of Urban Development
MRF	material recovery facility
NGO	non-governmental organisation
NUSP	*National Urban Sanitation Policy*
OHS	occupational health and safety
O&M	operation & maintenance
PM	particulate matter
QR	quick response
RFID	radio frequency identification
RWA	resident welfare association
SBM	*Swachh Bharat Mission*
SDGs	Sustainable Development Goals
SLP	service level progress
SOP	special operating procedure
SWM	solid waste management
TPD	tonnes per day
ULB	urban local body
WFD	waste Flow Diagram

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Effective solid waste management requires tailored approaches that consider geographical features, financial resources, workforce capacity, and local legislation, with ULBs prioritising root cause analysis at each stage of the waste supply chain.

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