TOOLKIT

LEGACY WASTE MANAGEMENT AND DUMPSITE REMEDIATION TO SUPPORT SWACHH BHARAT MISSION 2.0

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Abbreviations

C&D waste	Construction and demolition waste
CFU	Colony forming units
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CSWAP	City solid waste action plan
DM	Default method
FCO	Fertilizer Control Order
FOD	First order decay
GHG	Greenhouse gas
IARC	International Agency for Research on Cancer
LandGEM	Landfill gas emissions model
MoHUA	Ministry of Housing and Urban Affairs
MSW	Municipal solid waste
NEERI	National Environmental Engineering Research Institute
NGT	National Green Tribunal
PAH	Polyaromatic hydrocarbons
PCC	Pollution Control Committee
PCDD/F	Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans
PIL	Public interest litigation
PPM	Parts per million
RDF	Refuse-derived fuel
SBM	Swachh Bharat Mission
SCF	Scrap combustible fraction
SPCB	State Pollution Control Board
TPD	Tonne per day
ULB	Urban local body

Introduction

Chronic negligence of sustainable and scientific treatment has resulted in an ever-growing mass of municipal solid waste making its way into dumpsites in India. Many of the older dumpsites continue to stew a toxic legacy. The Ministry of Housing and Urban Affairs (MoHUA) has recognized that unlined dumpsites are causing air and water pollution and creating long-term environmental and health hazards. The operational guidelines of Swachh Bharat Mission (SBM) 2.0 have made it mandatory for cities with a population of less than 1 million to clear legacy waste sites by March 31, 2023 and cities with a population of more than 1 million to remediate their dumpsites by March 31, 2024.[1]

The Central Public Health and Environmental Engineering Organization (2020) has reported in 2020 that as much as 1,250 hectare of precious land is lost every year in India to dispose of municipal solid waste.[2] A National Green Tribunal (NGT) report puts the urban land locked up in India's legacy waste dumpsites at more than 10,000 hectares, equivalent to nearly 14,500 football grounds. Reclaiming existing dumpsites in an environmentally sound and economically viable manner is an utmost priority for city authorities across India.

In the recent past, there has been a paradigm shift in waste management policy in India that has cleared the path for remediation of legacy waste dumpsites while hollowing out the arguments and excuses against it. Swachh Bharat Mission 2.0 has earmarked a mammoth financial outlay of Rs 1,41,600 crore, with focus on source segregation, material recovery facilities, phasing out single-use plastic, construction and demolition waste processing, and remediation of all legacy dumpsites in the country. As India strives to establish a more scientific and sustainable solid waste management system, guided by the principles of decentralization and circular economy, it cannot allow the efforts to be weighed down by legacy waste.

Management of legacy waste by landfill mining or biomining may present unique challenges, but it can also create technology-based solutions for deriving revenue-generating fractions and valuable land from dumpsites. This opportunity should not be wasted.

What is legacy waste?

Although the term "legacy waste" has not been defined in any official government document in India, it typically refers to aged municipal solid waste in landfills or dumpsites. There is no information on how old waste must be in order to qualify to be called legacy waste. Legacy waste is a mix of partially or completely decomposed biodegradable waste, plastic waste, textiles, metals, glass and other components.

It is important to note that legacy waste dumpsite remediation projects in India concern themselves not only with legacy waste dumpsites but also with any unscientifically managed dumpsite that is relatively young. The agenda is to clear unscientifically designed and mismanaged dumpsites that might be causing or can cause long-term environmental and public health hazards.

Composition of legacy waste

Typically, Indian dumpsites contain a mix of legacy waste and fresh municipal solid waste. However, the composition and characteristics of legacy waste are different from that of fresh municipal solid waste. This difference significantly influences the choice of treatment technologies and end-use of recovered materials.

A dumpsite is an ecosystem in itself, where unique interactions take place between the biotic and abiotic components. These interactions make legacy waste different from fresh municipal waste. For example, biological entities such as microbes act on organic mass in waste and convert it into simpler forms. This happens in five phases, namely, an initial adjustment phase, transition phase, acid phase, methane-fermentation phase and maturation phase. Three significant reactions are involved in the process: acetogenesis, acidogenesis and methanogenesis.[3]

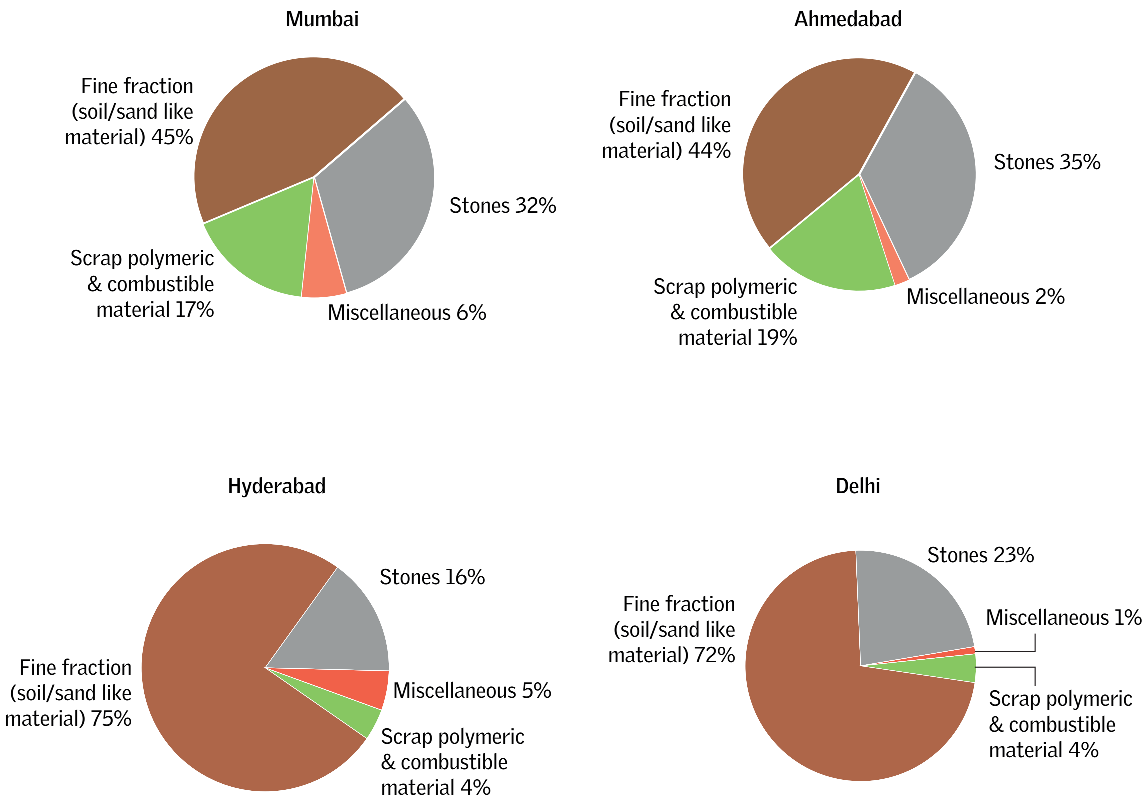
The vintage of a landfill considerably influences the composition of the legacy waste it contains. Usually, “fines” are the single-largest component of legacy waste. Fines in legacy waste are nothing but decomposed and mineralized organic waste mixed with silt, sand and fine fragments of construction and demolition (C&D) waste. The older the landfill, the more time microbial decomposition has to take place; therefore, the higher the fraction of “fines”.

Decomposition also helps in the “settlement” (mass and volume reduction) of the landfill. However, this depends on several factors such as initial compaction, characteristics of the waste, degree of decomposition, effect of air and water on the consolidation of waste, height of completed landfill, availability of moisture and routing of moisture inside the landfill.[4]

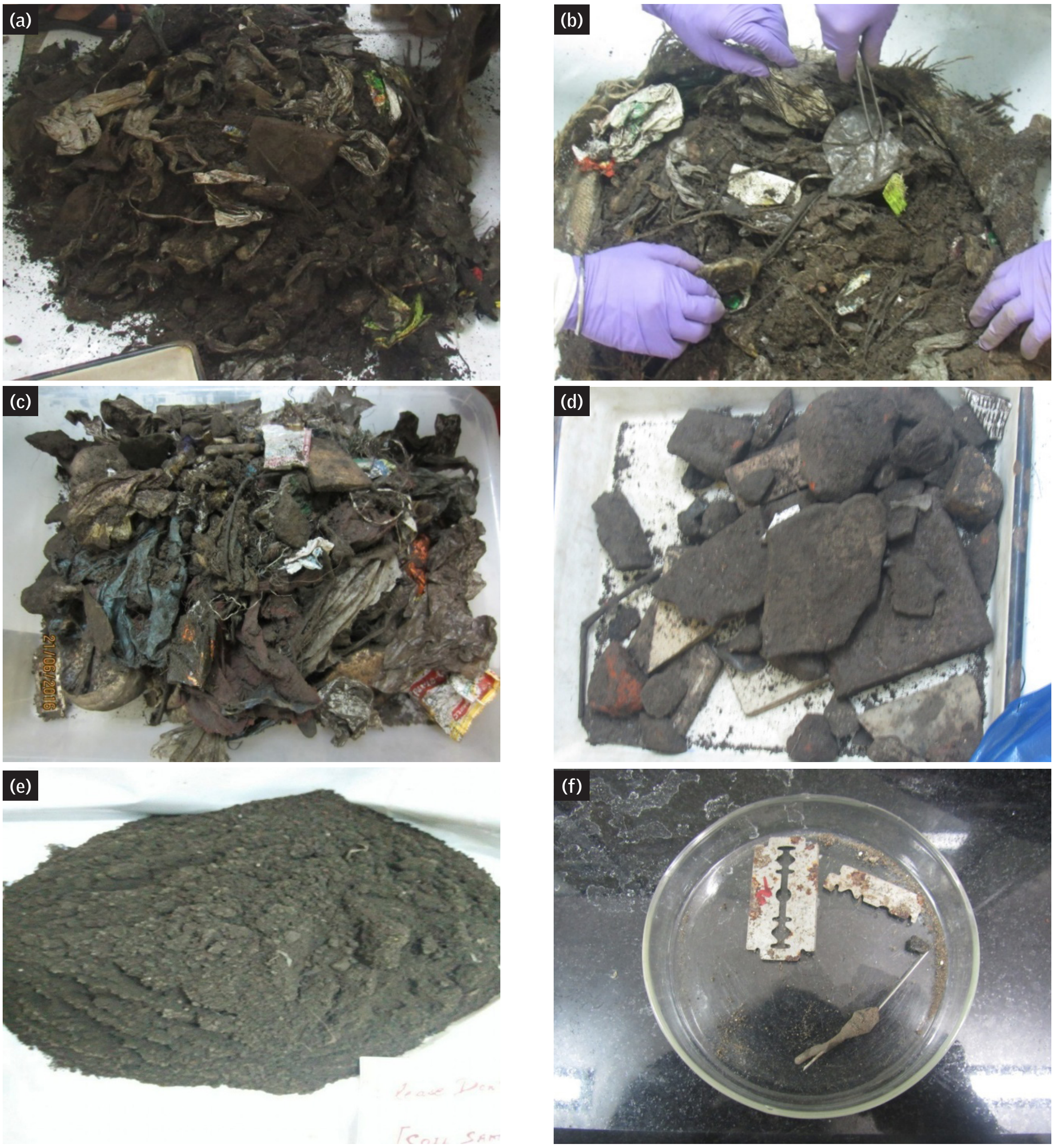
Effective decomposition and degradation of waste is also restricted by several factors. Some of them are low moisture content, poor shredding of waste disposed of in landfills, high bulk density and lack of inoculum (microbial population).[5] Nearly 90 per cent of the ultimate settlement due to decomposition of the organic fraction of waste in a landfill occurs in the initial five years.[6] The remaining decomposition depends upon the characteristics of the waste.

As already mentioned, fines constitute the biggest fraction in legacy waste. Research studies reveal that fines constitute about 40–60 per cent of legacy waste. Old dumpsites may contain a wide range of reusable or re-processable items such as broken concrete bats; bricks; boulders; fine-grained inert fractions (suitable as construction product or additive); recoverable metals such as iron, aluminium and copper; fine soil-like material (for composting, if the organic fraction is substantial), as well as combustible fractions (for energy recovery).[7,8,9] Reportedly, a quantity of 12 million tonne of inert waste is generated in India from street sweeping and as C&D waste. It constitutes nearly one-third of the total municipal solid waste deposited in landfills.[10]

Graph 1: Composition of legacy waste in different dumpsites



Source: Richa Singh, *Solidification and Stabilization of Hazardous Waste*, Department of Environmental Science and Engineering, IIT Bombay; Somani, M. et al , Elsevier, 137, pp. 82–92; and Singh, A. and Chandel, M.K., 2020, Elsevier, 134, pp. 24–35



Various fractions of legacy waste obtained after sampling and segregation of waste from the Pirana dumpsite:
(a) Mixed waste received at Pirana dumpsite in 2017; (b) Manual segregation of waste; (c) Scrap polymeric and combustible materials (d) Inert waste of size >10 mm; (e) Fine fraction of size <6 mm; (d) Miscellaneous items like razors and needles

Source: Richa Singh, *Solidification and Stabilization of Hazardous Waste*, Department of Environmental Science and Engineering, Indian Institute of Technology Bombay, Mumbai, India

Combustible materials such as plastics, paper, cardboard and textiles constitute another 15–20 per cent. Coarser materials such as broken bricks, masonry and stones constitute nearly 20 per cent. Miscellaneous fraction (broken glass, metallic fractions such as razors, needles, sanitary waste, diapers, etc.) make up the remainder (1–5 per cent; see *Graph 1: Composition of legacy waste in different dumpsites*).

The composition of legacy waste varies according to the region and age of a dumpsite. For example, the proportion of fines in Hyderabad and Delhi is nearly 75 per cent, which indicates that the dumpsites are old and organic waste has been degraded over many years. However, the proportion of fines is relatively lower in the case of Ahmedabad and Mumbai, reflecting that these dumpsites are newer. The quantity of recyclables depends on the activities of the informal sector engaged in extracting recyclables.

Methane is produced by dumpsites and landfills as a result of a biochemical process called methanogenesis. This process takes place by the action of a specific class of bacteria known as methanogens. The process is responsible for mineralization of the organic portion of municipal solid waste in a dumpsite.[11] Therefore, aged waste or legacy waste has nominal carbon content (in the range of 3–9 per cent).

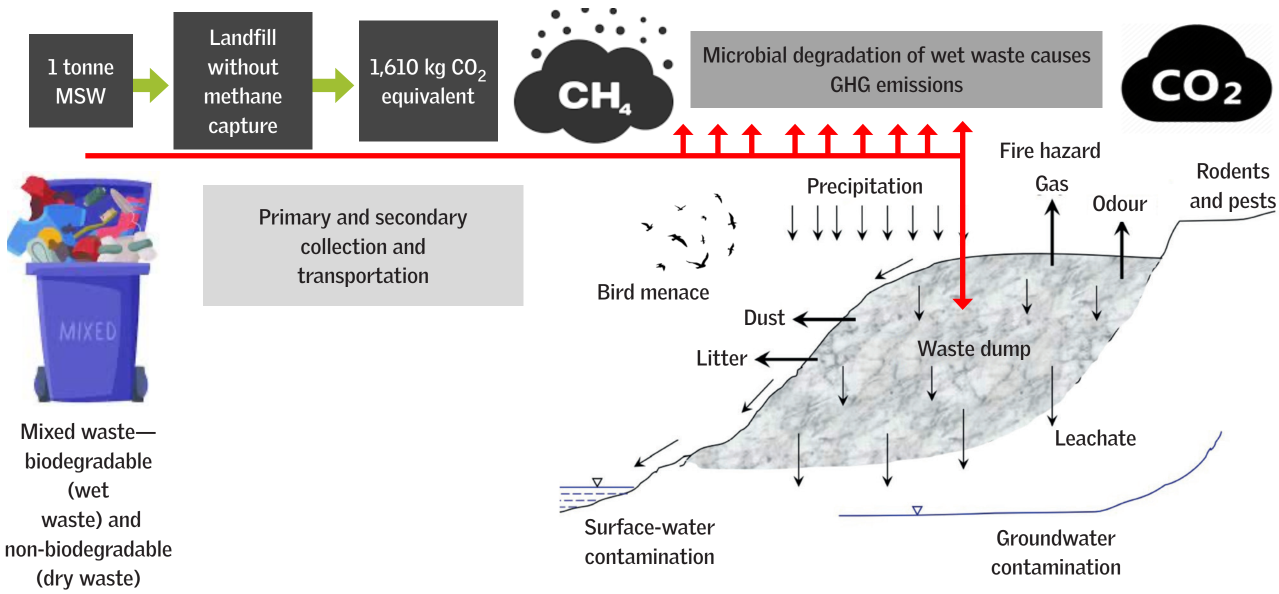
Environmental and health hazards associated with legacy waste dumpsites

Open dumpsites or unscientific landfills are deemed to be closed when the landfill reaches an unstable height and additional dumping of waste can lead to landslides.

Earlier, disposal of non-segregated waste in unscientific landfills used to be the norm. But unlined unscientific dumpsites produce toxic leachate that forms puddles in the surrounding area and seeps into the ground, polluting both surface-water and groundwater resources. Such dumpsites also release greenhouse gases like methane. They are prone to dumpsite surface fires that result in rapid emission of dangerous pollutants into the atmosphere. Unscientific dumpsites also put limitations on urban development. These and other negative effects have made disposal of waste in unscientific dumpsites an untenable practice.

On the other hand, robust promotion of better waste-management practices like source segregation and the three Rs (reduce, reuse and recycle) has created the conditions for a paradigm shift in waste management. Old landfills and their legacy waste need to be dealt with if the shift in waste management is to succeed.

Figure 1: Environmental hazards due to open dumping of waste



Source: CSE

Infamous dumpsites like Deonar in Mumbai; Bawana, Bhalswa, Ghazipur, Narela and Okhla in Delhi; Bingipura and Laksmipura in Bengaluru; and Dhapa and Garden Reach in Kolkata are a few examples of unscientific landfills in India.[12] These dumpsites are often in the news for the wrong reasons. Dumpsite fires were reported at Deonar in 2016 and again in 2018, which severely affected the air quality in the adjoining areas.[13,14] In another incident at the Ghazipur dumpsite in Delhi, two people died due to the collapse of 50 tonne of garbage that came crashing down like a 16-storey building.[15]

A study conducted on the Ghazipur landfill area of Delhi estimated that methane emissions flux was 18 mg/m^2/h (lowest, in winter) and 264 mg/m^2/h (highest, in summer).[16] Nitrous oxide emissions were estimated to be in the range of 230–1,730 microgram/square metre per hour (μg/m^2/h). Another study by researchers from the Indian Institute of Technology (IIT) Delhi and Jawaharlal Nehru University (JNU) reported the total methane emissions contributed by the three dumpsites in Delhi (Bhalswa, Ghazipur and Okhla) in 1984–2015 were 311.18, 779.32,1288.99 gigagram (Gg) per annum predicted by DM, FOD and LandGEM method respectively.[17]

Several studies have reported the release of halogenated persistent organic pollutants and polycyclic aromatic hydrocarbons during open burning of municipal solid waste. The bioavailability of dioxin furans (polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans-PCDD/Fs), polychlorinated biphenyl (PCBs)and polyaromatic hydrocarbons (PAHs) estimated in a study was 3.96–612 picogram per gram (pg/g), not detectable–182 nanogram per gram (ng/g) and 0.62–3649 ng/g, respectively in Kodungaiyur and Perungudi dumpsites of Chennai city.[18]

Open dumpsites are a potential source of bioaerosols.[19] A study conducted on a dumpsite in Dehradun reported high concentration of bioaerosols.[20] The mean concentration of fungal and bacterial aerosols was observed to be 4582.75 ± 1358.25 colony forming units per cubic metre (CFU/m^3) and 3609.53 ± 1000.28 CFU/m^3 respectively. The bioaerosol composition showed a predominance of potential pathogens, including Alternaria, Aspergillus, Cladosporium, Penicillium and gram-negative bacteria Bacillus, Coccus and Streptobacillus.

A study reports that 270,000 premature deaths occur every year globally due to pollution caused by open burning of waste.[21] Another study reports that open burning of waste contributes 5 per cent of the global GHG emissions.[22]

Old dumpsites contain many well-known toxins and carcinogens, e.g., heavy metals (see *Table 1: Concentration of toxic metals in dumpsites*). The source of these metals could be domestic hazardous waste generated from households and disposed of along with regular municipal solid waste at dumpsites. Arsenic,

Table 1: Concentration of toxic metals in dumpsites*

Heavy metal (mg/kg)	Concentration (in mg/kg)						
	Okhla, Delhi	Bhalswa, Delhi	Noida	Hyderabad	Kadapa, Chennai	Mulund, Mumbai	Indian soil limits
Chromium	188–201	168–199	273–395	169–189	179–198	149–615	
Nickel	111–130	94–146	221–268	104–120	105–124	36–197	
Copper	121–156	75–216	50–164	227–249	116–120	147–988	135–270
Zinc	118–242	147–229	157–428	209–375	128–158	271–1,984	300–600
Arsenic	13–34	9–30	68–322	36–122	52–64	NA	
Selenium	1.3–1.6	1.18–2	4–6	1.9–2.6	1.9–2.4	NA	
Cadmium	6.9–7	6.9–7.5	11–16	6.6–7	6.9–7.1	1.3–6.7	3–6
Lead	27–34	23–33	33–39	26–30	31–34	34–526	

* Complied from:
Somani, M., Datta, M., Ramana, G.V. and Sreekrishnan, T.R., 2020. Contaminants in soil-like material recovered by landfill mining from five old dumps in India. *Process Safety and Environmental Protection*, 137, pp. 82–92, Elsevier, The Netherlands.
Singh, A. and Chandel, M.K., 2020. Effect of ageing on waste characteristics excavated from an Indian dumpsite and its potential valorisation. *Process Safety and Environmental Protection*, 134, pp. 24–35, Elsevier, The Netherlands.

cadmium, chromium, lead and mercury are systemic toxicants known to induce multiple organ damage, even at lower levels of exposure. According to the United States Environmental Protection Agency (USEPA) and the International Agency for Research on Cancer (IARC), these metals are also classified as either “known” or “probable” human carcinogens based on epidemiological and experimental studies showing an association between exposure and cancer incidence in humans and animals.[23,24]

Soil samples from the Ghazipur landfill indicate the presence of organic contaminants as well as high cytotoxicity and genotoxicity.[25] Toxicity values of certain organic chemicals such as halogenated compounds, polycyclic aromatic hydrocarbons, sterols, terpene and benzene derivatives, and heavy metals were found within the cancer-risk values laid out by USEPA standards.[26]

Legacy dumpsites also cause huge financial losses. A study by the Council of Scientific and Industrial Research–National Environmental Engineering Research Institute (CSIR–NEERI) estimated that the external costs (negative externalities) of the Bhandwari dumpsite in Gurugram due to air, water and soil pollution; climatic factors (greenhouse gas emissions) and aesthetics was nearly Rs 148.46 crore.[27] Another joint study of the Central Pollution Control Board (CPCB), IIT Delhi and NEERI reported that the three dumpsites at Bhalswa, Ghazipur and Okhla in Delhi have collectively caused nearly Rs 450 crore in damage to the environment over the years.[28] Deterioration of air and water quality in a five kilometre radius of the dumpsite cannot be attributed directly to dumpsite activities through empirical data, so the interim damage cost was assessed on the basis of legacy waste and leachate to determine the environment compensation needed to be levied for violation of Solid Waste Management Rules, 2016.

The continued existence of old dumpsites also has many socioeconomic implications that have not been monetized by anyone. Scavengers and middlemen who buy and sell sorted waste material from garbage dumps typically build their precarious shanties in these areas, thereby expanding the area of extreme poverty and adding to the deterioration of the neighbourhood. One consequence is a drop in property prices, restricting the development of urban and peri-urban areas. Inadequate municipal solid waste disposal also causes deterioration of border urban ecosystems such as agricultural land, recreational areas, tourist places of interest and archaeological sites. The local flora and fauna are also severely affected.

Treatment of legacy waste and circular economy

Many national and international waste experts have spoken in support of the concept of "landfill mining" as a tool for resource recovery and for reducing environmental hazards associated with landfills and dumpsites across the globe.[29–32] However, management of waste obtained through excavation during reclamation of open and old dumpsites is one of the challenging tasks in cost-effective landfill mining.[33] It is essential to identify the potential influence of

A BRIEF HISTORY OF LEGACY WASTE LANDFILL REMEDIATION

The first landfill remediation operation was reported in Tel Aviv, Israel in 1953. Soil mined from the landfill was used as a fertilizer medium in orchards.[34]

In the late 1990s, a series of landfill mining studies was conducted to minimize groundwater contamination, promote recovery and reuse of mined materials, and extend landfill capacity in Florida and Connecticut.[35,36] The Florida study showed that a significant fraction of mined waste (60 per cent) was a soil-like material.

In Europe, Germany was the first country to experiment on mining of legacy waste,[37] followed by Italy (Sardinia landfill)[38] and Sweden (Filborna landfill).[39] The main fractions of materials mined from landfill in the West were "fines" (in the range of 55–75 per cent) and smaller quantities of energy-rich materials.[40,41] A study carried out in Belgium has reported the excavation of an old dumpsite using cactus grab cranes. As per the study, the waste was subsequently fractionated into eight distinct sets to identify waste-to-energy, material recycling and nature restoration potential.[42]

In 1989, the Deonar dumpsite in Mumbai was mined as a pilot case study for using material recovered in composting. Kurian Joseph and his research group from Anna University (2003) pioneered the study of legacy waste at Kodungaiyur and Perungudi dumpsites in Chennai. Samples were collected from a depth of 3 metre. Fine particles were found to constitute 65 per cent of the waste and their use as compost material or landfill cover material after assessing the geotechnical suitability was suggested. Heavy metals in the recovered material were found to exceed composting standards in India but were well within USEPA limits.

In 2007, bioremediation of compacted old waste using bioculture (sprayed from a tanker truck with a high-pressure pump) was tried in Mumbai (at the Gorai dumping ground), Pune and Nasik.[43] The waste was then turned into aerobic windrows. Excavators were employed to ensure proper mixing. Odour-control sanitizers were also applied at the sites. Leachate produced by the sites was found to act as good bioculture.

Recyclable fraction obtained during the operation was taken away by ragpickers hired for the purpose. The land was reclaimed.

This method of biomining found successful application in Kumbakonam dumpsite in Tamil Nadu in 2015. Inorganic materials (including plastics and tyres) were recycled, and some materials were reused. High calorific value components were acquired by cement factories for blending with coal and for use as an alternative fuel material. Many successful biomining projects have been executed in India since then.

residuals and contaminants in the mined fraction. After a proper evaluation and treatment, new value-added products can be circulated again in the consumer chain, thus complying with principles of circular economy and closing the loop.

It is clear from many examples from around the world that landfill mining reveals its true potential if principles of a circular economy guide it instead of the linear "take, make and dispose" model (see *Box: A brief history of legacy waste landfill remediation*). Urban mining of end-of-life products is efficient and lucrative. Legacy waste dumpsites, when subjected to scientific mining operations, create

LEGAL FRAMEWORK AND JUDICIAL INTERVENTIONS FOR DUMPSITE REMEDIATION IN INDIA

The Government of India has notified Solid Waste Management Rules, 2016 for proper and effective management of municipal solid waste. Rule 15 defines the duties and responsibilities of local authorities and village panchayats of census towns and urban agglomerations for dumpsite remediation. They have to investigate all open dumpsites and existing operational dumpsites for their potential of biomining and bioremediation and, if feasible, take necessary actions to biomine or bioremediate the sites. If there is no potential for biomining or bioremediating a dumpsite, the Rules direct that it shall be scientifically capped as per landfill capping norms to prevent further damage to the environment.

Schedule I of the Solid Waste Management Rules, 2016 makes specifications for the closure and rehabilitation of old dumpsites. Solid waste dumps that have reached their full capacity or those that will not receive additional waste after setting up of new and properly designed landfills should be closed and rehabilitated by examining the following options:

(i) Reduction of waste by biomining and waste processing followed by placement of residues in new landfills or capping as in (ii)

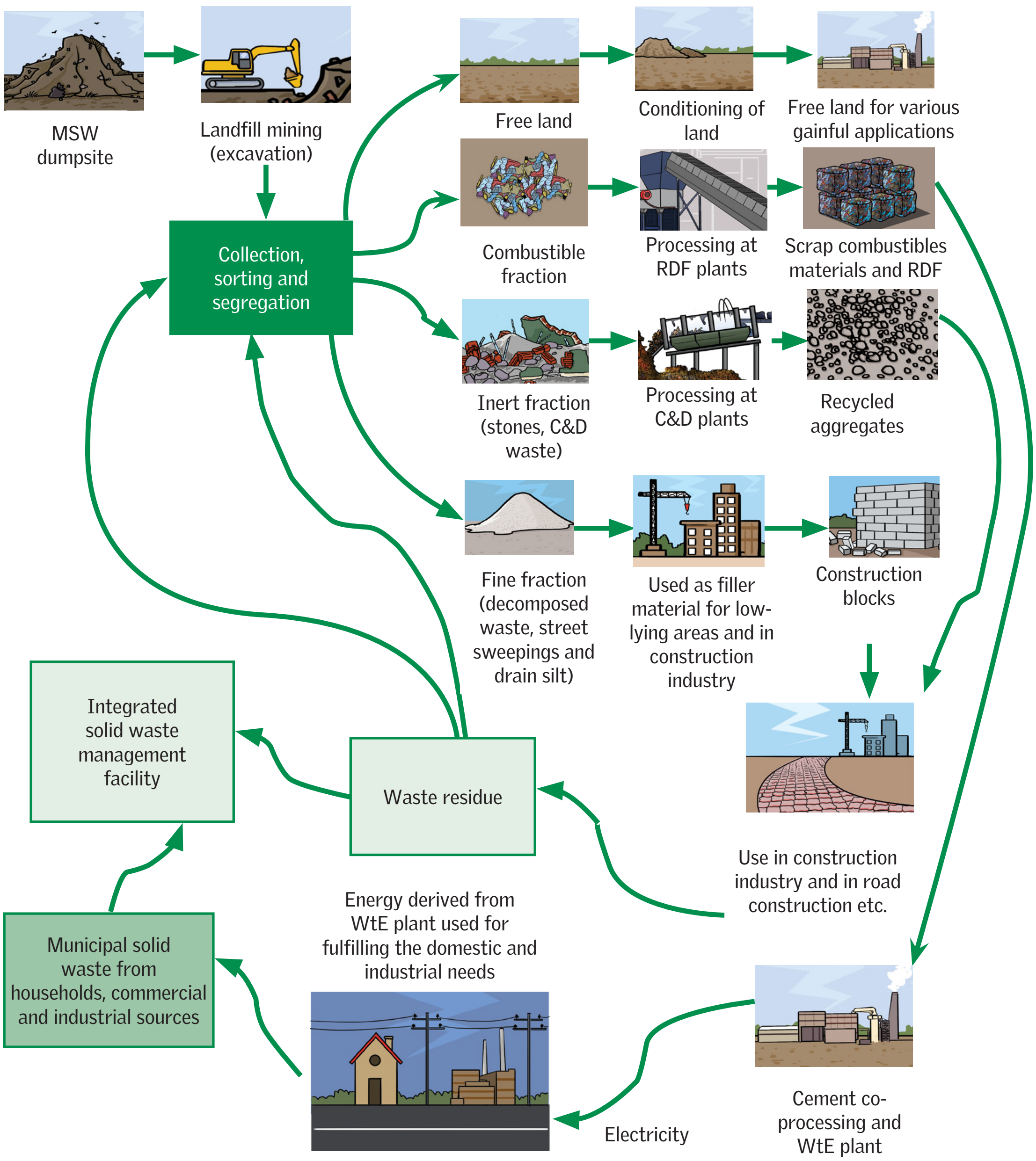
(ii) Capping with solid waste cover or solid waste cover enhanced with geomembrane to enable collection and flaring or utilization of greenhouse gases

(iii) Capping as in (ii) with additional measures (in alluvial and other coarse-grained soils) such as cut-off walls and extraction wells for pumping and treating contaminated groundwater

(iv) Any other method suitable for reducing environmental impact to an acceptable level

On July 17, 2019, the National Green Tribunal passed an order directing that capping of legacy waste would lead to huge environmental and health consequences. The tribunal suggested biomining and bioremediation as environmentally safe and the most preferable approaches to dumpsite remediation. The order also stated that there is hardly any situation where bioremediation is not possible. It directed bioremediation of all dumpsites by October 2020. It directed that action plans be prepared and implemented by all municipal corporations of Delhi. CPCB was to verify waste clearance as per norms and submit a report.

Figure 2: Sustainable business model for management of legacy waste based on the principles of circular economy



Source: Richa Singh, *Solidification and Stabilization of Hazardous Waste*, Department of Environmental Science and Engineering, Indian Institute of Technology Bombay, Mumbai a sustainable business model (see *Figure 2: Sustainable business model for management of legacy waste based on the principles of circular economy*).

Mining of dumpsites may help achieve three broad objectives:

1. Extend landfill capacity or free the land under the dumpsite for other uses
2. Yield scrap combustible fraction (SCF) from scrap polymeric and combustible materials
3. Yield inert fraction that can be used in construction and geotechnical applications.

The land recovered through landfill mining can be utilized to establish waste management facilities and for construction of engineered landfills by installing suitable liner systems and leachate collection and treatment facility on a portion of the reclaimed land. The reclaimed land may also be used for other purposes as per the requirement and upon satisfaction of fit-for-use criteria for the identified application.

Polymeric waste obtained from dumpsites can be potentially utilized as refuse-derived fuel (RDF), which can be used for energy recovery. Electricity produced from RDF can be utilized by energy-intensive industries and households.

Management of legacy waste should be combined with integrated waste management facilities having adequate capacities for collecting, transporting and disposing of municipal solid waste produced on a day-to-day basis as well as legacy waste trapped in dumpsites.

Status of dumpsite remediation in India

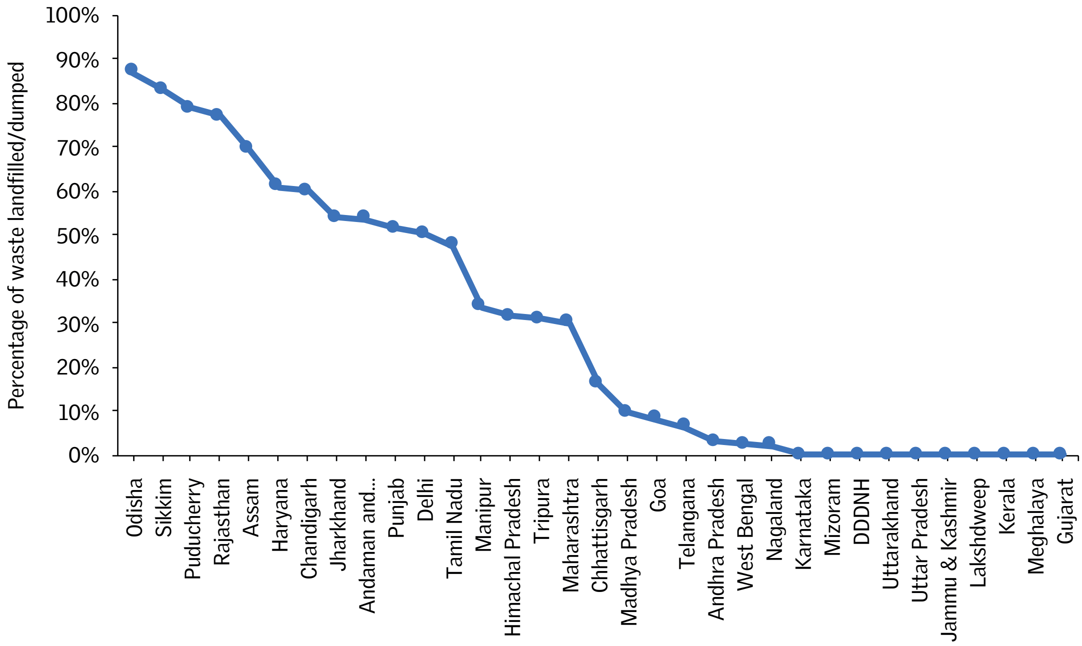
As per the 2019–20 CPCB Annual Report, India generated approximately 1.5 lakh tonne per day (TPD) of municipal solid waste, of which nearly 97 per cent was collected. About 47 per cent waste generated was treated and 27 per cent sent to landfills. Around 26 per cent waste remained unaccounted for. This translates to nearly 40,000 TPD of waste and includes waste that remains uncollected by urban local bodies (ULBs) (3 per cent of the waste generated) and unaccounted for or unattended waste (23 per cent of the waste collected by ULBs). The latter category might include recyclables picked up by informal sector workers as well as waste that finds its way into aquatic and terrestrial systems such as drains, rivers, ponds, lakes, sewer lines, empty plots of land and garbage heaps alongside roads and highways. Smaller garbage heaps alongside roads and streets are not typically identified as dumpsites but need to be cleared by adopting the appropriate process.

In 2019–20, more than half of the waste (80,000 TPD) generated in India was disposed of in dumpsites or remained unattended. Interventions under Swachh Bharat Mission have increased the quantity of waste treated every year, but a substantial fraction of waste remains unprocessed across the country (see *Graph 2: How much waste does India dump in landfills?* and *Graph 3: How much waste does India treat?*).

According to the 2019–20 CPCB Annual Report, there were 3,084 dumpsites in India in 2020. Of these, 91 were reclaimed and 14 converted into sanitary landfills. Uttar Pradesh had the highest number of dumpsites (611), followed by Madhya Pradesh (328) and Maharashtra (327) (see *Graph 4: State- and Union Territory-wise distribution of dumpsites in India*).

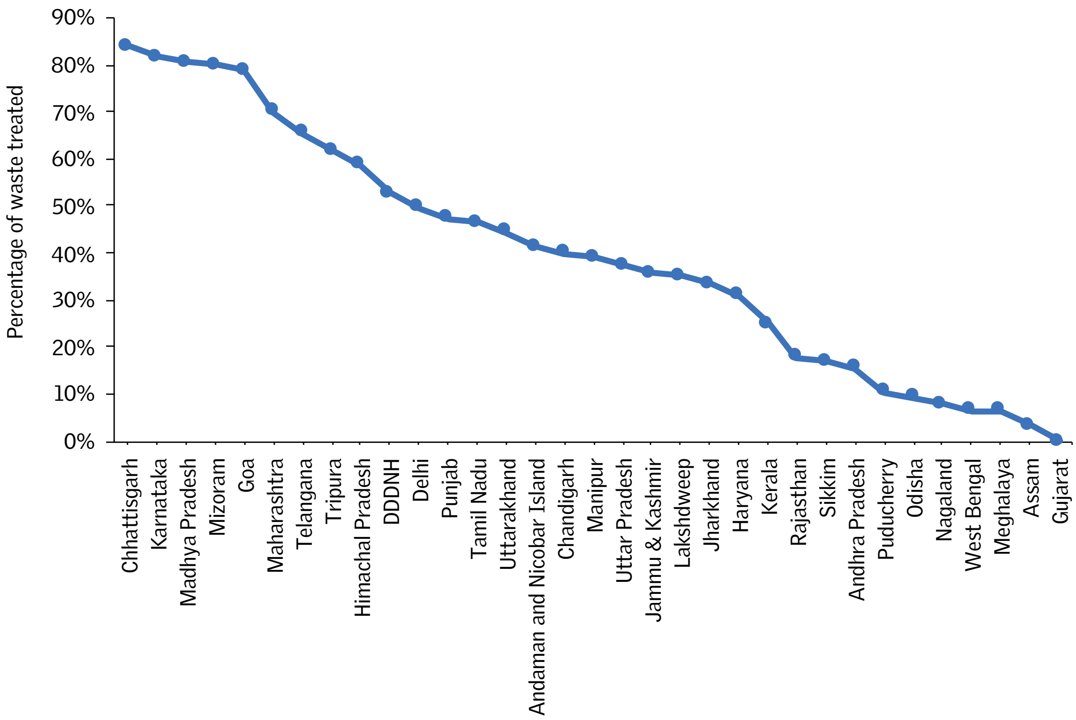
Madhya Pradesh has reclaimed the highest number of dumpsites (50), followed by Karnataka (15) and Kerala (6). Karnataka has converted six dumpsites into sanitary landfills, Andhra Pradesh has converted three, and Chandigarh, Meghalaya, Rajasthan, Sikkim and Telangana have each converted one dumpsite into a sanitary landfill (see *Graph 5: Dumpsites reclaimed, capped and converted into sanitary landfills in India*). Details regarding the quantity of waste disposed of in these dumpsites have not been provided by SPCBs and PCCs. Clearly, the overall picture of dumpsite remediation in India is far from satisfactory (see *Table 2: Status of major dumpsites in India*).

Graph 2: How much waste does India dump in landfills?



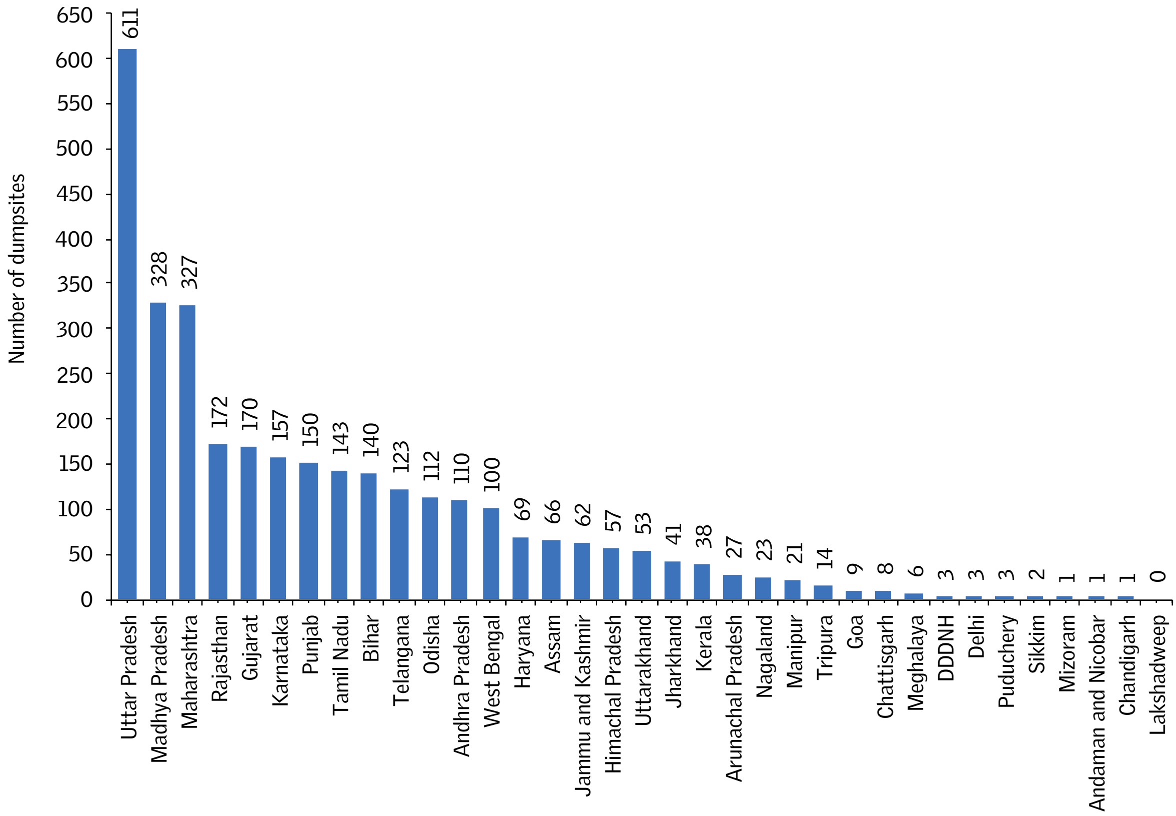
Source: CPCB Annual Report, 2019–20

Graph 3: How much waste does India treat?



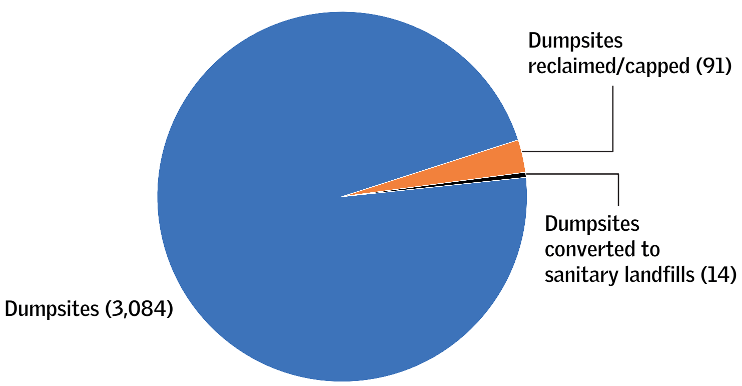
Source: CPCB Annual Report, 2019–20

Graph 4: State- and Union Territory-wise distribution of dumpsites in India



Source: CPCB Annual Report, 2019–20

Graph 5: Dumpsites reclaimed, capped and converted into sanitary landfills in India



Source: CPCB Annual Report, 2019–20

In 2021, CPCB, upon receiving directions from NGT, inspected Bhalswa, Ghazipur and Okhla, the three dumpsites in Delhi.[44] It found that though waste stabilization through bioremediation was being practised, only 5 per cent of the waste in the three dumpsites had been processed.

Table 2: Status of major dumpsites in India

Dumpsite	Year when it became operational	Height (metre)	Land occupied (acre)	Approximate quantity of legacy waste (million tonne)	Quantity of fresh waste received (TPD)	Status of biomining
Ghazipur, Delhi	1984	65	70	14	2,500	As per the CPCB report, 24 trommels have been installed, but only 0.35 million tonne of legacy waste was processed and stabilized till January 2021
Okhla, Delhi	1994	60	46	5.56	1,750	As per the CPCB report, 10 trommels have been installed; 0.31 million tonne of legacy waste was processed and stabilized till January 2021
Bhalswa, Delhi	1994	62	36	8	2,000	As per the CPCB report, 19 trommels have been installed; 1.15 million tonne of legacy waste was processed and stabilized till January 2021
Deonar, Mumbai	1927	35	326	12	500	Not started yet
Mulund, Mumbai	1967	30	59	19.6	NA	According to BMC data, till March 2020, 0.11 million tonne of legacy waste was treated of the legacy waste at the dumpsite
Bhandwari, Gurugram	2009	37	27	2.7	1,900	Biomining is underway; 18 trommels have been installed for segregation. There is no plan for disposal of recovered fractions. RDF is not managed as per MoHUA guidelines. Leachate storage ponds for collection in poor condition
Kodungaiyur, Chennai		91	258	6.4	NA	Pre-feasibility study underway

NA = Information not available

Source: Data compiled on the basis of site visits and reports available in the public domain

During CSE field visits, no stabilization was observed at Ghazipur and Okhla. At Bhalswa, windrows were not being prepared properly. Stabilized waste was generating fumes, which is an indicator of poor stabilization. Due to poor stabilization, the quality of refuse-derived fuel (RDF) was found inadequate after screening of the processed legacy waste, as per the standards given by MoHUA. RDF was disposed of at waste-to-energy plants.

The plan for disposal of only screened fractions at the three disposal sites is also not implemented properly. Some quantities of waste that should have been stopped as per the screening procedure still makes its way into the dumpsites. Leachate treatment and gas collection mechanisms are conspicuously absent at the three dumpsites.

As in other cities, the practice of dumping fresh waste into the dumpsites not only increases the quantity of waste to be remediated but also complicates the ancillary problems discussed in this section. Three major dumpsite fires broke out because of dumping of fresh waste at Bhalswa, Ghazipur and Okhla dumpsites.[45]

Approaches to dumpsite remediation

There are two approaches to dumpsite remediation: biocapping and biomining.

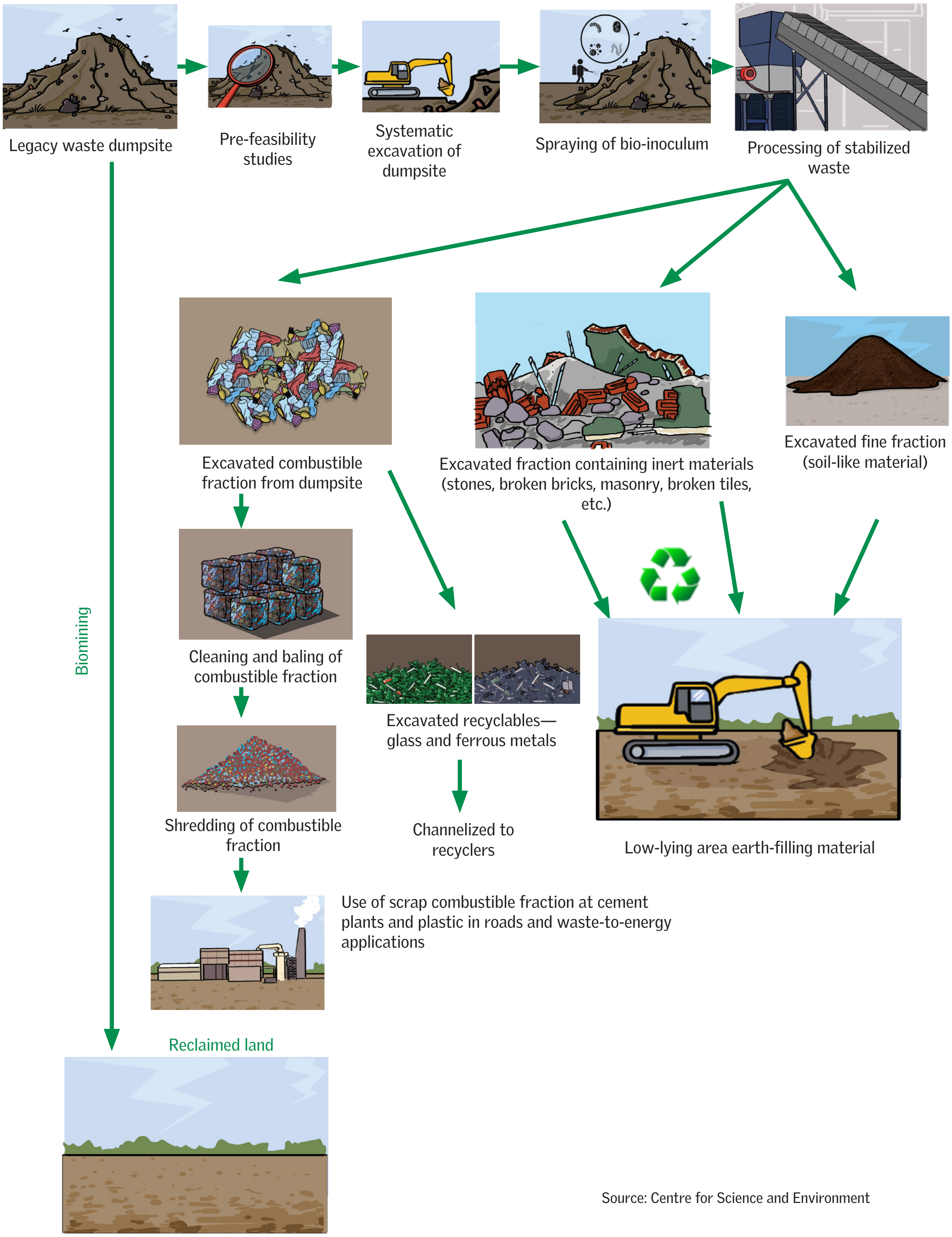
Biocapping is a scientific process of covering a dumpsite with barrier layers consisting of high density polyethylene (HDPE) liner, clay liner and a vegetative cover to minimize the percolation of rainwater into the legacy waste underneath. Mechanisms are installed for collection and treatment of leachate and landfill gases. However, 100 per cent recovery of landfill gases and leachate from an unscientific landfill is not practically feasible. Capping might appear to be a convenient and time-effective method for dumpsite remediation, but it does not reclaim the land or ensure scientific treatment of legacy waste. So it leaves behind lingering environmental and health hazards.

For these reasons, the Solid Waste Management Rules, 2016 and several National Green Tribunal (NGT) directives have mandated that urban local bodies opt for biomining over biocapping.

However, biocapping could be a solution for the closure of scientifically designed landfills or dumpsites built in eco-sensitive zones where biomining is not possible because of steep, inaccessible ravines and narrow valleys. Biocapping of dumpsites requires at least 15 years of post-closure maintenance to monitor pollution levels in groundwater and surface-water sources and air (especially methane emissions). Biocapped landfills also need to be inspected periodically for settlement due to physical, chemical and biological transformation, leachate generation, erosion and naturally occurring invasion by deep-rooted vegetation.

In contrast, dumpsite remediation through biomining ensures long-term sustainability and environmentally sound treatment of legacy waste. Biomining operations also present lucrative revenue-generating opportunities (see *Figure 3: Schematic representation of the biomining process and revenue-generating fractions*).

Figure 3: Schematic representation of the biomining process and revenue-generating fractions



Source: Centre for Science and Environment

Steps for biomining of legacy waste

Dumpsite remediation through biomining has six broad steps, including:

1. Pre-feasibility assessment, including thorough site investigation studies, surveys and waste characterization;
2. Systematic excavation of legacy waste;
3. Stabilization by the spraying of bioculture to reduce the volume and mass of the waste;
4. Processing of the excavated fraction;
5. Utilization of extracted waste fractions in various gainful applications; and
6. Clearing and conditioning of recovered land

Pre-feasibility assessment

A pre-feasibility assessment is the critical first step in biomining operations. It deliberates the relevant factors of a biomining operation, including economic, technical and legal factors, and timeline considerations. A thorough pre-feasibility assessment helps ascertain whether a biomining project can be completed successfully within the stipulated timeline. It also helps in executing the operations in a technically sound and economically viable manner.

A detailed pre-feasibility study consists of an in-depth analysis of the historical background of a dumpsite, including but not limited to accounting statements, operation and management, market share and policies, financial data and legal requirements related to the dumpsite.

- **Technical and operational feasibility:** Concessionaires have customized machinery (mobile and stationary) to carry out excavation and advanced machinery to conduct segregation and processing. However, if an urban local body (ULB) conducts the biomining operation itself, it has to assess the capacity in terms of availability of machinery, trommels, etc. for executing the process and resources must be allocated accordingly. In the latter case, the cost of the project is reduced on account of the ULB being able to utilize resources that are already available to it. It can rent other equipment, if needed. Municipal workers might need skill upgrades for a successful biomining operation.

- **Economic feasibility**: This assessment typically includes a cost–benefit analysis of the biomining project, especially with regard to land.

- **Legal feasibility**: This includes understanding the legal requirements in terms of permissions and clearances needed from State Pollution Control Boards and other relevant authorities.

- **Timeline feasibility:** Under this, the ULB estimates how long a biomining project will take to complete and prepares an operational schedule with tasks and timelines accordingly.

Key considerations for a pre-feasibility assessment

The following information should be collected and assessed in a pre-feasibility study of a biomining project:

- Preliminary data about the area of the dumpsite; its height and age; whether disposal of waste has happened above or below the ground; whether the dumpsite is active or non-operational; visible surface fires, if any; information on accidents related to fire and subsidence, etc.

- The contours of the dumpsite and its hydro-geological, geological and ecosystem type; baseline study of heavy metals in the surface and subsurface soils and water; and rainfall, soil type, surface hydrology, topography, wind direction, etc.

- Quantity of waste (legacy and fresh) to be remediated. Typically, a contour survey helps in estimating the quantity of waste a dumpsite contains. The density of legacy waste can be considered as 1 tonne per cubic metre as per the rule of thumb provided by the Central Public Health and Environmental Engineering Organization (CPHEEO). However, it is recommended to use other appropriate methods to find the precise density of waste in a dumpsite.

- The composition of waste (percentage of various fractions and characterization [moisture, organic and heavy metals content, and the calorific value of combustible materials]) also needs to be gauged.

Sampling methods for assessing legacy waste composition

Stratified random sampling (based on component) can be chosen as the sampling design to analyse the legacy waste composition in a dumpsite. A similar approach has been adopted for efficient estimation of solid waste generation and composition in several studies.[46]

For sampling, a dumpsite should be divided into at least three strata: stratum 1—the lower surface (where old waste is located); stratum 2 (the middle layer); and stratum 3 (the upper surface of the dumpsite where fresh waste is dumped). Sampling locations can be chosen randomly from areas in the periphery and the middle of the dumpsite, if accessible. Samples are collected with the help of an excavator. Since the excavator can only reach up to a depth of 5 metre, waste is collected by digging horizontal trenches or pits (on flat surfaces) and lateral trenches or pits (on the peripheries).

The excavated waste should be dried and various components should be carefully weighed. Samples should be screened using sieves into fractions of size >20 mm, 4–20 mm and <4 mm.

Sample collection locations within a dumpsite should be chosen so that representation of all major components of waste in the samples is ensured (see *photos: Typical sampling of legacy waste using a JCB—Pirana dumpsite*). A minimum quantity of 100 kg of legacy waste should be collected from each sampling point. Chemical analysis of the waste sample follows the physical constituent analysis and should be performed in a laboratory accredited by the Ministry of Environment, Forest and Climate Change (MoEF&CC) and National Accreditation Board for Testing and Calibration Laboratories (NABL).

Requirements of the planning phase

First and foremost, an alternative plan for treatment and scientific disposal of fresh waste generated by the city is a must. It is practically impossible to remediate a legacy waste dumpsite if the city keeps adding fresh waste to the site. For example, East Delhi Municipal Corporation (EDMC) treats nearly 1,000 tonne of legacy waste per day at Ghazipur. Simultaneously, about 2,500 tonne of waste is dumped at the site daily. Cases like this, when a dumpsite receives more fresh waste every day than the quantity of legacy waste it treats, lead to systemic failure of the remediation work.

It is also imperative to conduct risk assessment and emergency planning prior to the commencement of dumpsite bioremediation and biomining. The steep slope at a dumpsite and arrival of fresh waste can create safety issues for workers, operators and managers of bioremediation and biomining operations.

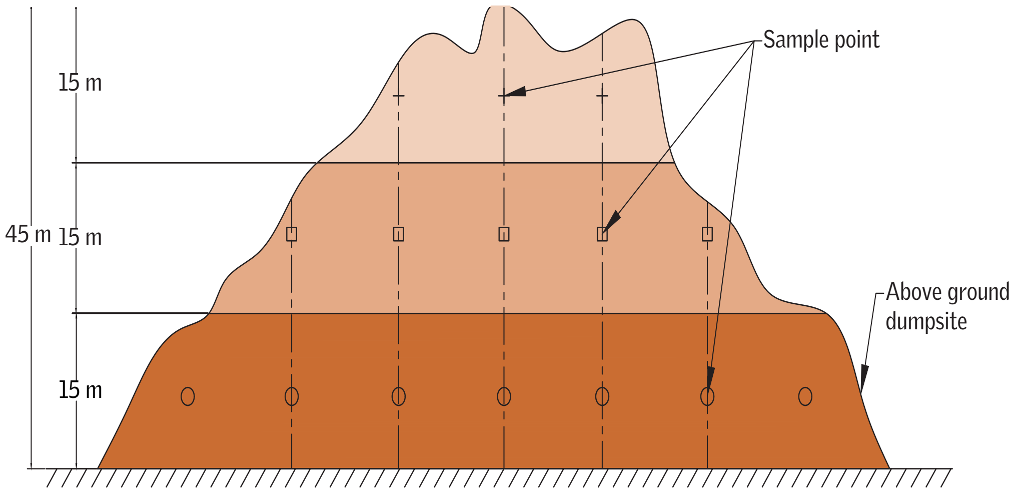
Additionally, the following pointers should be considered in the planning phase:

- Training and capacity building of the manpower involved;
- Low-lying areas in the city and surrounding areas to be identified to ensure end-use of fine fractions;
- Tie-ups and collaborations with nearby cement plants or energy-intensive

Typical sampling of legacy waste using a JCB—Pirana dumpsite
Left (top and bottom): Front-hoe loaders used for legacy waste sample collection from the surface of the dumpsite Right (top and bottom): Legacy waste sample pit

Source: Richa Singh, Solidification and Stabilization of Hazardous Waste, Department of Environmental Science and Engineering, Indian Institute of Technology Bombay, Mumbai

Figure 4: Sampling plan for a dumpsite



Source: CSE

industries should be made during the planning phase in order to ensure end-use of combustibles recovered from legacy wastes;

- Potential recyclers to be explored;
- Other recyclables like glass and metals recovered from the waste during screening to be sorted out and pre-treated (air-dried) before sending them to recycling industries; and
- Availability of sufficient water and power supply to be ascertained.

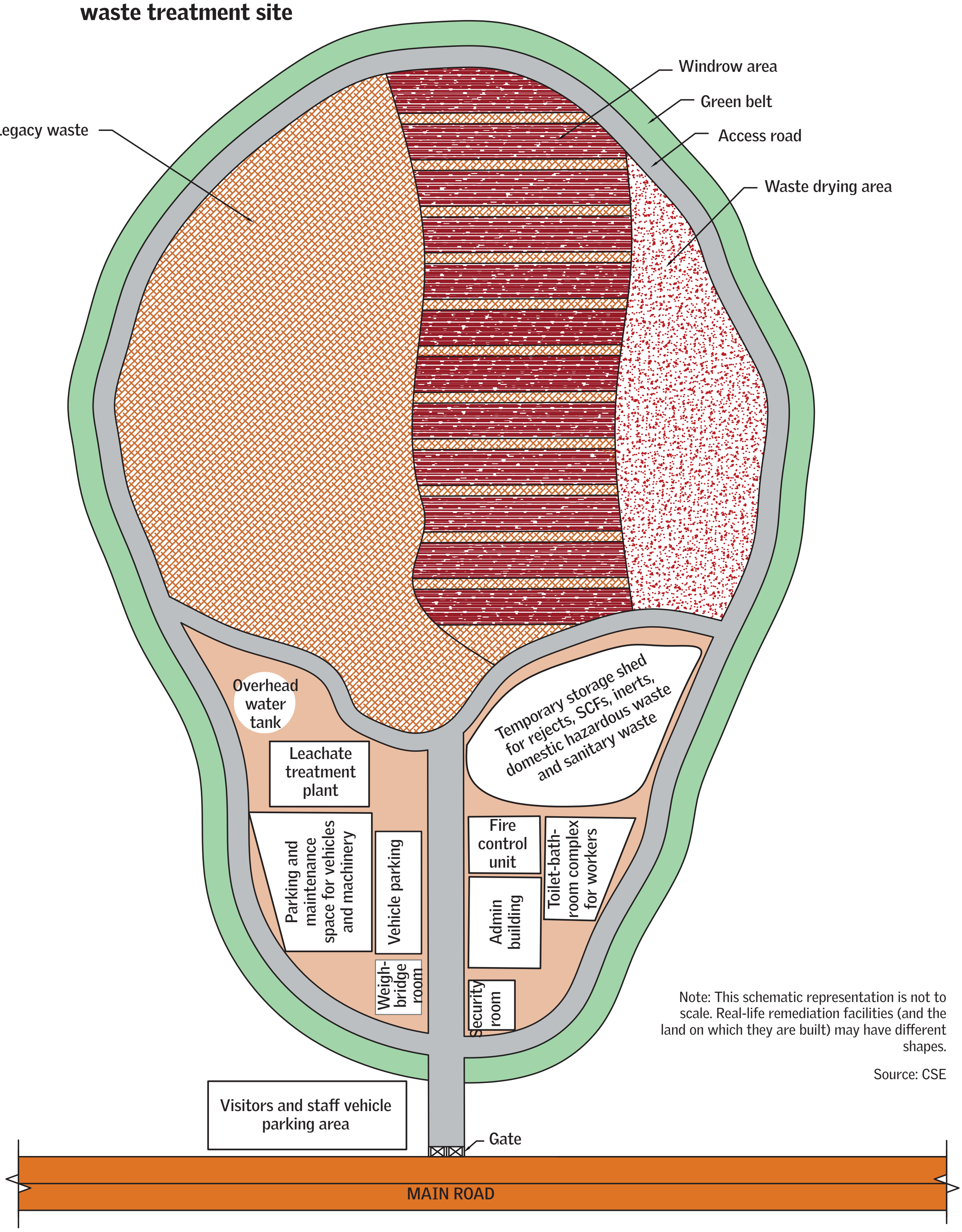
The following are the infrastructural facilities required for setting up of machineries and equipment in biomining of a dumpsite:

- Secure entrance gate
- Security and reception office
- Weighing bridge
- Records room
- Laboratory
- Medical room
- Workers' area
- Parking for vehicles (heavy earth equipment, trucks, etc.) with tyre washing facility
- Administrative building
- Temporary storage area for rejects, domestic hazardous waste and sanitary waste
- Material storage area
- Environmental monitoring unit
- Leachate collection and treatment unit
- Fire control unit
- Waste drying and windrow area
- Toilet–bath complex, with personnel protection equipment (PPE) storage room)
- Overhead water tank

Systematic excavation of legacy waste

Loaders and excavators are used to excavate legacy waste. Dumpsites typically contain puddles of leachate in different layers and many odorous gases. Before starting the process of excavation, it is necessary to vent out these gases and drain out the leachate. An excavator or front-end loader may be used to dig up and transport excavated material. Leachate should be collected and treated in the leachate treatment plant as and when needed during operations.

Figure 5: Layout and ground plan of a typical dumpsite remediation and legacy waste treatment site



Note: This schematic representation is not to scale. Real-life remediation facilities (and the land on which they are built) may have different shapes.

Source: CSE

Considerations during legacy waste excavation and material handling

Preparation of a detailed operation plan: Based on the estimated time it will take for each process—including legal permissions, stabilization, processing, segregation and disposal of inert materials and segregated compostable fraction (SCF)—a detailed operational plan with work process flow and timelines must be prepared.

Availability of PPE: Safety of workers must be ensured through procurement of necessary personal protective equipment (PPE).

Provisions for fire control: Fires are a common phenomenon at large landfills. It is challenging to initiate biomining on a smouldering dumpsite. It is thus important to have fire identification and control systems in place. Subsurface landfill fires can be controlled by such techniques as excavation of the fire source (burning balls of textile, oily rags or plastics) from the mixed garbage, smothering the fire or extinguishing it with injections of water or inert gases. Earthmover drivers must be trained to undertake such fire control operations. Wet soil should be kept handy to immediately plug excavated holes. Fire points must be tackled patiently and systematically—i.e. one by one—till the dump is smoke-free (see *Annexure 4: Fire control at dumpsites*).

Depth of excavation: If a dumpsite is below the ground level, the lowest level must be reached to assess the stability, slope, nature of strata and degree of contamination.

Procurement of machinery and equipment: Appropriate number of excavators, backhoe loaders and other heavy earth equipment required for the excavation activity must be purchased.

Trained manpower: Drivers and operators of heavy earth equipment should be trained to handle the quantities, types and variability of material they are likely to encounter, major environmental concerns for the waste to be handled, occupational health and safety concerns for the waste to be handled, and emergency management procedures.

Odour and dust management: Odour and dust from a dumpsite cause problems for workers as well as nearby residents. They must be controlled by stabilizing the waste and regularly spraying bioculture solution and deodorizers on waste heaps. Dust from dumpsites can become airborne due to the movement of heavy earth equipment and other vehicles. In order to control dust generation, suppression methods such as surface wetting should be employed.

Record keeping: Proper records must be maintained about the quantity of waste excavated and diverted on a daily, weekly and monthly basis. In addition, a site manual containing information regarding the excavation should be prepared. These documents are necessary to keep track of things as the remediation process may have to be modified during the operational phase.

Regular monitoring: The authority entrusted with dumpsite remediation is required to develop monitoring criteria, establish institutional mechanisms and have processes in place to report performance data transparently on a disclosure platform. Doing so may require adequate funding, equipment and skilled manpower to achieve these goals, especially when regulatory agencies may not have spare personnel to undertake such tasks.

Environmental monitoring: Monitoring of stipulated parameters of air and water quality and noise levels in and around the site should be performed during biomining (see *Annexure 1: Environmental parameters*).

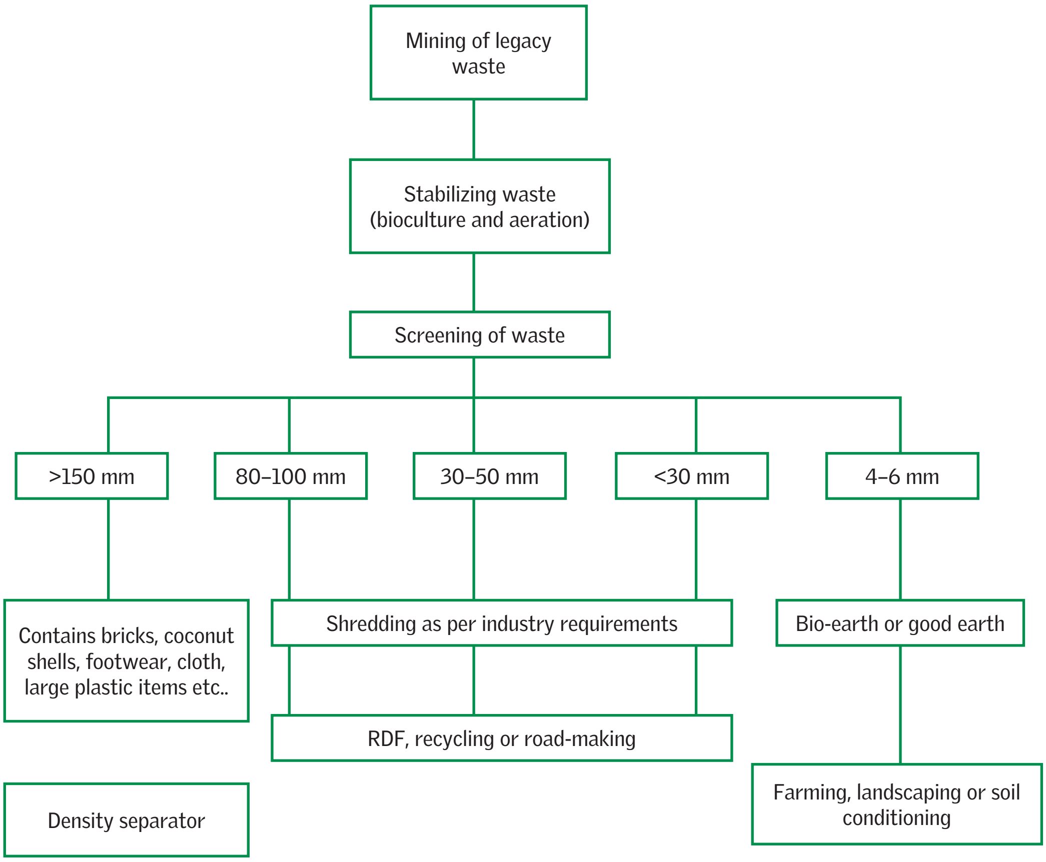
Stabilization with bioculture spray to reduce volume and mass of waste

Microbe-mediated stabilization decomposes the biodegradable fraction in legacy waste, thereby reducing its mass and volume. During stabilization, the landfill is converted into windrows of equal size in a planned manner, frequently raked and sprayed with bioculture to reduce the number of flies, eliminate pathogenic activity, reduce moisture and complete the biodegradation process. Stabilization helps in facilitating further sorting and segregation of waste into soil, stones and combustibles with utmost accuracy, thus ensuring good quality of recovered materials.

Biocultures can be procured commercially from the market or prepared on-site. For example, in Ambikapur, a mixture of cow dung, milk, urine, jaggery and water were used as bioculture.

Leachate generated during the stabilization process should be collected by using suction pumps and treated efficiently. It should be tested for various parameters as mentioned in Solid Waste Management Rules, 2016 (see *Annexure 2: Standards for treated leachates*).

Figure 6: CPCB guidelines on the processes of biomining and bioremediation



Source: Guidelines for Disposal of Legacy Waste, CPCB (2019)

Processing of excavated fraction

Excavated waste is subject to shredding, screening, air classification and ferrous separation (see *Figure 6: CPCB guidelines on the processes of biomining and bioremediation*). Commonly used screen sizes, as per the CPCB guidelines, are: 150 mm, 80–100 mm, 24–50 mm, 12–16 mm and 4–6 mm. Density separation helps recover combustibles (usually composing 5–10 per cent of the waste) that can be used as fuel replacement in cement kilns and waste-to-energy plants.

Air classification separates lighter materials from heavier ones by making use of an air stream of sufficient velocity. A cyclone separator may be used in conjunction with the air classifier to remove lighter separated fraction from the air stream after it exits the classifiers throat. Cyclone separators use centrifugal action, which causes material to move up the walls of the separator as per their density, the lighter the material, the higher up it goes (see *photographs on page 38*). Ballistic separators (to separate stones, soil and humus) and magnetic separators (to separate ferrous metals) are also used.

Considerations during legacy waste processing and material handling

Space for waste stabilization and processing: It is imperative to identify and allocate necessary space for pre-processing of excavated waste. Space is also required for stabilizing the waste after excavation. If machinery and equipment related to processing of legacy waste cannot be housed on-site due to unavailability of space, waste needs to be transported to another location for treatment, increasing the cost of processing.

In addition, the following are the key considerations for legacy waste processing and material handling:

- Procurement of equipment/machineries for sorting and processing of legacy waste fractions;
- Quantities, types and variability of material to be handled;
- Material flows and mass flow, quantification of residual waste;
- Number and types of vehicles or other transport means required for segregation, separation and dewatering (procurement of equipment and machinery such as trommel, vibrating screen, disc/star handling equipment, loaders, conveyers and fork lifts);
- A record of quantity of waste treated and diverted should be prepared on a daily, weekly and monthly basis. A site manual giving all site investigation, design and construction details should also be prepared in case the remediation process is modified during the operational phase.

Utilization of extracted waste fractions for gainful application

Excavated waste is divided into many fractions based on size. The finest fraction is mainly composed of soil and sand, and may be rich in organic material. It can be used to improve soil fertility. The coarsest fraction contains bricks, stones, coconut sheets, footwear, cloth and larger plastics. The lighter mid-fractions are mostly plastics and can be shredded as per industry requirement for use in bitumen hot mix plants to make plastic roads or as RDF for co-processing in cement kilns. The fraction with particles less than 50 mm in size does not require shredding for use as RDF.

Ballistic separators used in legacy waste sorting

Trommel screens used in legacy waste size segregation

Conveyors at a legacy waste treatment site

Source: CSE

Figure 7: Steps involved in dumpsite remediation

Excavation of legacy waste from the top of a dumpsite using a JCB

Conversion of a dumpsite into parallel windrows

The waste is turned over once a week with equipment

Spraying of bio-inoculum for biodegradation of partially degraded and non-degraded waste

Sorting of waste after six weeks (once full stabilization has been confirmed) into different fractions based on size of the particles

Source: CSE

The heavier mid-fractions are mostly stony and inert and can be used in the lowest layers of road-making or plinth-filling in low-lying areas, but should not contain more than 3–5 per cent plastics by weight.

Less than 10 per cent of the original waste consists of unusable residual rejects and may continue to remain on-site, either in a small heap or spread evenly to raise the ground level by a couple of metres.

The following three factors are critical in assessing the potential of the scrap combustible fraction (SCF) used in cement plants:

i) the calorific value of the waste should be greater than or equal to 2,500 kCal/kg;
ii) the ash content should be less than 20 per cent; and
iii) the moisture content should be less than 30 per cent.

However, most urban local bodies struggle to find takers for their SCF. Cement plants are reluctant to install separate pre-processing systems needed to make SCF ready for use as an alternative fuel or raw material.

Typically, SCF recovered from legacy waste sites that are contaminated with toxic components such as pesticides should be fed to the main burner of the kiln to ensure its complete combustion at high temperatures. For this, plastics may need to be shredded to less than 20 mm size. Non-recyclable plastic waste that is not contaminated with toxic components can be fed at the other feed points such as calciner, kiln inlet or mid-kiln depending upon its size.

Typically, in this case, the conversion of SCF into refuse-derived fuel (RDF) is carried out by the cement plant on-site. This involves setting up of a pre-processing facility with storage, shredding and blending capabilities as well as a co-processing facility. Therefore, cement plants must make a reasonable profit to pay off these investments.

At the cement plant level, the income streams are tipping fee and savings due to reduction in use of coal; expenditures are cost of RDF handling and management, cost of co-processing, cost due to production loss and pre-processing cost. Transportation cost is considered at Rs 3 per tonne, with full charge for returning an empty load. (As per the 2017 *Guidelines for Co-processing of Plastic Waste in Cement Kilns*, the distance between a processing plant and cement plant should be less than 100 km).[47]

The per capita monthly burden on account of the additional tipping fee towards SCF disposal as RDF in cement kilns along with its transportation over a distance of 100 km works out to about Rs 2 per month and would increase to about Rs 8 capita for a distance of 600 km.[48]

Considerations for gainful application of recovered legacy waste:

The following are key considerations for gainful application of recovered material:

- Fractions recovered from the mining of legacy waste should be tested, especially for the presence of toxic metals and organic contaminants.

Table 3: Components of legacy waste, potential applications and associated environmental and health hazards

Components of legacy waste	Potential applications	Environmental and health hazards
Fine soil-like material	As earth-filling and road-making material, and as substitute for clay in the construction industry	Presence of leachable heavy metals and organics
Coarser inert material	In filling up low-lying areas and as aggregate in C&D waste processing industry	Presence of leachable heavy metals and organics
Scrap polymeric combustible material	RDF and road-making	Contamination with inerts, and high ash and sulphur content
Hazardous material	Disposed of in a scientific landfill	Can lead to many environmental hazards if not disposed of properly

Source: CSE

- Leaching tests (toxicity characteristics leaching procedure [TCLP]) of the fine fraction (soil-like material) should be conducted before using it as earth-filling material.

- Fine fraction (soil-like material) to be used as so-called "soil enricher" or bio-soils should be tested for various parameters, especially toxic metals as per the FCO 2009 and 2013 compost standards (see *Annexure 3: Compost quality standards*).

- Fine fraction can also be used for refilling the ground on the same site for greenery provided it conforms to soil standards for toxic metal concentration.

- Sanitary and household hazardous waste such as diapers, sanitary pads, sharps and injections should be disposed of in a scientific landfill.

- Coarser particles (such as broken bricks, masonry and stones) recovered as construction and demolition waste should be sent to a C&D waste processing facility for producing building materials and the rejects of the waste should be sent to a scientific landfill.

Clearing and conditioning of recovered land

Once legacy waste has been treated on-site, the cleared and reclaimed land can be used for various purposes. Before that, it should be ensured that the land is free from contamination. For that, a thorough investigation of the subsurface layer should be performed to assess the presence of heavy metals and other pollutants.

Case studies*

Ajith Singh Nagar Dumpsite Reclamation Project: Vijayawada Municipal Corporation

Table 4: Vijayawada municipal solid waste management—an overview

City	Vijayawada
Dumpsite	Ajith Singh Nagar
Age of the dumpsite	More than 20 years
Total dumpsite area	65 acre
Accumulated waste quantity	3.05 lakh tonne
Percentage of land reclaimed	100 per cent
Value of recovered land	Rs 650 crore**
Waste utilization	100 per cent
Leachate treatment plant (for capped area as per the CPHEEO manual and Solid Waste Management regulations)	NA
Total project cost	Rs 25.7 crore
Legacy waste treatment and disposal cost	Rs 842 per tonne

** https://www.thehansindia.com/news/cities/vijayawada/vijayawada-ajit-singh-nagar-free-from-dumping-yard-menace-653714

Source: CSE

Vijayawada, spread over an area of 61.88 sq. km, is the second largest city in Andhra Pradesh. It is the third most densely populated urban built-up area in the world and has experienced phenomenal population growth—from 1.04 million in 2011 (as per Census 2011) to an estimated 1.19 million in 2021. The city is divided into three zones and 64 sanitary divisions and municipal wards, and generates approximately 400 metric tonne of municipal solid waste per day.

Prior to 2019, a 65-acre plot in Ajith Singh Nagar was used for dumping waste. Originally, this land had been allocated to two private agencies for setting up a waste-to-energy plant using incineration technology and a waste-to-compost facility. By 2010, both agencies had shut down their operations. This resulted in unsegregated waste being dumped on the land without processing, and eventually accumulating as a stock to approximately 3.05 lakh tonne of legacy waste. Leachate from the dumpsite started affecting groundwater quality. Frequent fire-related incidents and foul odour severely affected the health of the residents living in the vicinity of the dumpsite, which was at the centre of the city.

* Case studies have been prepared on the basis of field visits and analysis of data obtained from city corporations and concessionaires responsible for biomining projects..

BEFORE AFTER

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Images of Ajith Singh Nagar dumpsite before and after completion of the remediation project

Vijayawada Municipal Corporation (VMC) had to find a solution to the accumulated waste and reclaim the land. In 2017, Zigma Global Environ Solutions Private Limited was entrusted with the responsibility of implementing a biomining project at the dumpsite. In July 2019, the project was completed and the land was reclaimed.

It is the largest dumpsite land reclamation using biomining project in India. More than 47,200 tonne of SCF was mined and sent to nearby cement plants for co-processing. In addition, a little over 171,500 tonne of fines was recovered and used as earth-filling material in low-lying areas and 276 tonne of recyclables was channelized to the recycling industry. All in all, 87 per cent of the waste was gainfully utilized. Of the reclaimed land, a plot of two acre was converted into a waste-to-compost facility, another plot of the same size was converted into a plastic waste management facility, a four acre plot was converted into a construction and demolition waste plant, and there is a proposal to convert a five acre plot into a farmers' market.

With the clearing of the dumpsite, VMC was able to abate more than 211,000 tonne of CO_2 emissions every year. The RDF generated from the process and co-processed in cement kilns has saved 7,931 tonne of CO_2 emissions.*

* As per the estimates of Zigma Global Environ Solutions Private Limited

Low-cost housing societies to rehabilitate slum dwellers had been built in the vicinity of the dumpsite by the state government but uptake was almost zero. Once the dumpsite was reclaimed, people from the economically weaker sections moved in. There is also a proposal to convert a portion of the reclaimed land into a park for these residents.

The city generates 497 tonne of waste per day. It has a robust waste management system with 100 per cent source segregation and efficient treatment of 92 per cent waste generated. Only inerts and residual solid waste are disposed of in the sanitary landfill.

Atladara Dumpsite Reclamation Project: Vadodara Municipal Corporation

Table 5: Vadodara municipal solid waste management—an overview

City	Vadodara
Dumpsites	Altadara
Age of dumpsite	More than 40 years[55]
Total dumpsite area	17 acre
Accumulated waste quantity	4.21 lakh tonne
Percentage of land reclaimed	100 per cent
Waste utilization	96 per cent
Leachate treatment plant (for capped area as per CPHEEO manual and Solid Waste Management regulations)	NA
Total project cost	Rs 33.26 crore*
Legacy waste treatment and disposal cost	Rs 887 per tonne

* Project cost provided by the contractors

Source: CSE

Vadodara is the third largest city in Gujarat, with a population of approximately 2.5 million. It generates approximately 600 tonne of waste every day.

An abandoned dumpsite in the city on the banks of the river Vishwamitri severely affected the lives of the people living around it. As the bottom of the dumpsite was not lined, leachate polluted the underground water table. Frequent fires caused air pollution in the area.

The river Vishwamitri is home to the mugger or marsh crocodiles (*Crocodylus palustris*), a threatened reptile species in India and legally protected under Schedule I of the Indian Wildlife (Protection) Act, 1972. A Public Interest Litigation (PIL) was filed by residents of Atladara as the leachate generated by the dumpsite flowed into the river without treatment.

BEFORE AFTER

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Images of Atladara dumpsite before and after completion of the remediation project

The NGT directed the Vadodara Municipal Corporation to remediate the dumpsite, spread across 14 acre (5.66 hectare) of land and containing 0.42 million tonne of waste. Under Swachh Bharat Mission, the project was awarded to Zigma Global Environ Solutions. The remediation project commenced in July 2018 and was completed in December 2019.

During the operations, about 80,000 tonne of SCF was co-processed in nearby cement and waste-to-energy plants. About 324,000 tonne of inert material from the site was used in filling up and reclaiming low-lying areas. About 118 tonne of recyclables were channelized to recyclers. The project ensured reduction of about 292,000 tonne in CO_2e emissions every year. Moreover, carbon savings of 13,500 tonne CO_2e were achieved through the use of alternative fuels by the cement industry.

The remediated land is now being used for setting up a construction and demolition waste facility and a plastic waste processing facility. A sizeable piece of reclaimed land is to be utilized by the Vadodara Municipal Corporation for gainful applications after getting clearances from the state pollution control board.

Sector 54 Dumpsite Reclamation Project, Noida

Table 6: Noida municipal solid waste management—an overview

City	Noida
Dumpsite	Sector 54, Noida
Age of dumpsite	Five years
Total dumpsite area	Four acre
Accumulated waste quantity	1 lakh tonne
Percentage of land reclaimed	100 per cent
Waste utilization	92 per cent
Leachate treatment plant (for capped area as per CPHEEO manual and Solid Waste Management regulations)	NA
Total project cost	Rs 11.93 crore*
Legacy waste treatment and disposal cost	Rs 1,193 per tonne

* Project cost provided by the contractors

Source: CSE

Noida (short for New Okhla Industrial Development Authority) is a satellite city of Delhi and part of India's National Capital Region. It is spread over an area of 203 sq. km. As per provisional reports of Census of India, the population of Noida stood at 642,381 in 2011. The city generates about 600 tonne of municipal solid waste per day.

Since Noida did not have any secured landfill site as prescribed under the Solid Waste Management Act, 2016, unsegregated waste was disposed of in an unscientific manner in Sector 54. On May 29, 2018, the National Green Tribunal (NGT), heeding to a plea by the residents, issued a stay order against dumping of garbage and municipal waste at the site. Subsequently, the tribunal ordered the civic body to start landfill mining to clear the 1 lakh tonne of accumulated waste. Zigma Global Environ Solutions Private Limited was awarded the contract to biomine and reclaim 4 acre (1.61 hectare) of land at the dumpsite.

Work on the project started in December 2018 and was completed in December 2019. The project was dubbed Wasteland to Wetland. Under it, the entire reclaimed area was converted into a wetland. It was declared the fastest project

Good quality soil sent to the horticulture department

Refuse-derived fuel sent to cement manufacturing units

Rocks and inerts to fill up low-lying areas

Various fractions recovered from the legacy waste dumpsite

Source: Swachh Bharat Mission, Urban

BEFORE AFTER

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Images of Noida dumpsite before and after completion of the remediation project

of land reclamation in India so far and was the recipient of the 2019 Smart City Award for Best Urban Development Project—Greenfield Development awarded by the Union Ministry of Housing and Urban Affairs(MoHUA).

During the biomining operations, more than 20,000 tonne of refuse-derived fuel (RDF) was sent to nearby cement plants for co-processing. Additionally, 72,000 tonne of fine soil-like material was earth-filled in low-lying areas. With the clearing of the dumpsite, Noida was able to abate more than 69,000 tonne of CO_2emissions every year and the RDF generated from the process and co-processed in the cement kilns saved 3,376 tonne of CO_2 emissions.

Dumpsite remediation at Bhanpur Khanti: Bhopal Municipal Corporation

Table 7: Bhopal municipal solid waste management—an overview

City	Bhopal
Dumpsite	Bhanpur Khanti
Age of dumpsite	47
Total dumpsite area	37 acre
Accumulated waste quantity	11 lakh m^3
Capped area	16 acre
Percentage of land reclaimed	57 per cent
Value of recovered land	Rs 180 crore
Waste utilization	30 per cent
Leachate treatment plant (for capped area as per solid waste management regulations)	50 kilolitre per day
Total project cost	Rs 42 crore*
Legacy waste treatment and disposal cost	Rs 382 per tonne

* Project cost provided by the contractors

Source: CSE

Bhopal, capital of Madhya Pradesh, covers an area of 413 sq. km and is divided into 85 wards. As per Census 2011, the city of 1,938,251 residents and generates nearly 1,000 tonne of municipal solid waste every day.

For 47 years, the city dumped waste at an unscientific dumping site at Bhanpur, close to residential areas and agricultural land. An estimated 5 million tonne of waste accumulated at the dumpsite and it received around 800 tonne of fresh waste every day. The dumpsite was a major health hazard to the city's population.

The dumpsite caused many problems. Leachate from it contaminated surrounding surface water and groundwater resources. The dumpsite also emitted methane and carbon dioxide.

The flagship Swachh Bharat Mission motivated and helped Bhopal Municipal Corporation (BMC) to adopt sustainable waste management. For remediation of the Bhanpur dumpsite, the city adopted a hybrid model (i.e., a combination of biocapping and biomining methods).

Saurashtra Enviro Projects Private Limited was contracted by BMC in 2018 to conduct dumpsite remediation. The process of bioremediation and scientific closure took nearly three years. The total quantity of legacy waste stabilized, processed and segregated was 242,000 m^3 (159,720 tonne). A 16 acre (6.47 hectare) plot of land was biocapped as per the capping standards prescribed under the Solid Waste Management Rules, 2016 and the Central Public Health and Environmental Engineering Organisation (CPHEEO) manual. A proper gas collection system was put in place along with a leachate treatment plant with a

BEFORE

AFTER

Images of Bhanpur dumpsite in Bhopal before and after completion of the remediation project

Source: Bhopal Municipal Corporation, CSE capacity of 50 kilolitre per day (KLD). The capital cost of biomining and scientific closure of the dumpsite was around Rs 42 crore. The cost of operation and maintenance for five years after the closure is Rs 10 crore. However, BMC officials will have to conduct post-closure monitoring for the next 15 years (as per the Solid Waste Management Rules, 2016). As per BMC officials, the estimated value of 21 acre (8.49 hectare) of reclaimed land is Rs 180 crore.

The remediation of the Bhanpur dumpsite helped the city government earn the confidence of citizens. The city successfully implemented 100 per cent four-way segregation—into wet, dry, sanitary and domestic hazardous—waste. Waste fractions are diverted to appropriate facilities and recycled products are utilized gainfully. For disposal of rejects and inerts (street sweepings and drain silt), the city has identified a suitable site for constructing a sanitary landfill.

Indore Municipal Corporation: Dumpsite turned into city forest

Table 8: Indore municipal solid waste management—an overview

City	Indore
Dumpsite	Devguradiya dumpsite
Age of the dumpsite	More than 50 years
Total dumpsite area	100 acre
Accumulated waste quantity	15 lakh tonne
Percentage of land reclaimed	100 acre
Waste utilization	80 per cent
Leachate treatment plant (for capped area as per the CPHEEO manual and Solid Waste Management regulations)	NA
Total project cost	Rs 54 crore*
Legacy waste treatment and disposal cost	Rs 360 per tonne

* Project cost provided by the contractors

Source: CSE

Indore, situated on the Malwa plateau, is the commercial and industrial centre of Madhya Pradesh. Spread over 276 sq. km and divided into 19 zones and 85 wards, it is the largest and most densely populated city in central India. The current population estimated to be approximately 2.6 million.

Indore generates about 1,029 tonne of waste on a daily basis. Devgurdiya, a 100-acre (40.46 hectare) dumpsite located in the city that had accumulated approximately 1.5 million tonne of legacy waste, was reclaimed through bioremediation in 2018. The city's legacy waste included plastic, metal, cloth and wood and other recyclable and combustible materials. It would catch fire from time to time, polluting the air and turning into a hazard for the environment and people living in the vicinity.

In 2016, Indore started a dumpsite remediation project. Indore Municipal Corporation (IMC) deployed its own equipment and machinery—including dumpers, tractors, water tankers, JCBs, forklifts and chain-mounted excavators—for the biomining operations for treating the 1.5 million tonne of accumulated waste. Trommels were rented from a third party at a cost of Rs 10 crore. The overall treatment and disposal cost of legacy waste was estimated to be approximately Rs 360 per tonne. The entire process of remediation and processing of legacy waste took 24 months.

The city was able to recover 8–10 per cent recyclables from the legacy waste. The scrap combustible fraction (SCF) was sent to cement plants and for road-making. Fine soil-like material recovered was used to fill and level the site. Recovered C&D waste was sent to a processing material to produce building material. The leftover (about 15 per cent) waste was sent to a secured landfill.

A city forest was developed over the 100 acre (40.46 hectare) of reclaimed land.

BEFORE AFTER

Images of Devguradia dumpsite in Indore before and after completion of the remediation project

Source: https://www.thebetterindia.com/169584/ias-hero-indore-garbage-management-recycling/, CSE

Indore Municipal Corporation (IMC) planted more than 2 lakh saplings of different varieties, including pras peepal (*Thespesia populnea)*, teak (*Tectona grandis*) and some varieties of ornamental plants. A 67 acre (27.11 hectare) plot of land adjacent to the dumpsite has been earmarked for construction of a sanitary landfill for disposal of inerts and rejects (on 12.5 acre [5.05 hectare]), a bio-CNG plant (on 55 acre [22.25 hectare]) with a capacity of 550 tonne per day [TPD]), and 400 TPD material recovery facilities.

Madhya Pradesh Pollution Control Board (MPPCB) and the Central Pollution Control Board (CPCB) are currently conducting periodic checks and inspections to analyse environmental parameters at the remediated site, including those related to air, groundwater, surface water and soil. The soil is also tested periodically for the presence of arsenic, barium, benzene, cadmium, chromium, carbon tetrachloride, chlordane, chlorobenzene, chloroform and other substances. Initially, the monitoring was conducted on a monthly basis, but now it is being conducted on a quarterly basis.

The city has been practising six-way segregation and efficient treatment of municipal solid waste. A meagre quantity of waste (6–8 per cent) ends up in the scientifically constructed and operated sanitary landfill.

Kuberpur Dumpsite Reclamation Project: Agra Municipal Corporation

Table 9: Kuberpur dumpsite remediation—an overview

City	Agra
Dumpsite	Kuberpur
Age of dumpsite	10–11 years
Total dumpsite area	42 acre
Accumulated waste quantity	9.4 lakh tonne
Percentage of land reclaimed	100 per cent
Waste utilization	60–70 per cent
Leachate treatment plant (for capped area as per CPHEEO manual and Solid Waste Management regulations)	NA
Total project cost	Rs 30.45 crore
Legacy waste treatment and disposal cost	Rs 324 per tonne

Source: CSE

Agra is situated on the banks of the Yamuna river in Uttar Pradesh, about 210 km south of the national capital New Delhi. According to Census 2011, the population of Agra was 1,585,704.

The city generates about 850 tonne of municipal solid waste every day. Before 2019, Agra did not have any waste recycling facilities or scientifically designed functional sanitary landfill site as prescribed under Solid Waste Management Rule, 2016. Unsegregated waste was disposed of indiscriminately in an unscientific manner at the Kuberpur dumpsite.

In October 2019, the Agra Municipal Corporation (AMC) started a biomining project to clear the 9.4 lakh tonne of accumulated legacy waste at the Kuberpur site. The project was completed in March 2022.

The fine fraction obtained was used for filling up low-lying areas and levelling another parcel of land in the existing site after confirming its physico-chemical characteristics. C&D waste from the project was utilized within the site in the construction of a temporary road, a green park and fencing. The remaining C&D waste is being processed at the 5 TPD C&D waste processing plant that has been constructed on a 3 acre (1.21 hectare) plot of the recovered land. AMC plans to establish a waste-to-energy plant as well as the rehabilitation of the sanitary landfill facility within the site premises. The recovered scrap combustible fraction

Figure 8: Remediation plan for the Agra dumpsite

VIVEK OJHA–SPAAK SUPER INFRA INDIA PVT LTD, AGRA

VIVEK OJHA–SPAAK SUPER INFRA INDIA PVT LTD, AGRA

Spraying of bio-inoculum during stabilization of legacy waste

BEFORE AFTER

Images of the Kuberpur dumpsite in Agra before and after completion of the remediation project

Source: CSE

(SCF) is stored safely in a storage shed and will be utilized in the waste-to-energy plant as feedstock. Ferrous materials were separated through magnetic separators and other valuable materials were sold to local recyclers.

Nearly 42 acre (16.99 hectare) of land at dumpsite has been reclaimed. The land is inspected at regular intervals by AMC officials for the presence of toxic pollutants like heavy metals.

Currently, the city is processing biodegradable waste at centralized and decentralized composting facilities and recyclables are channelized to a material recovery facility (MRF). Considerable efforts are however needed to enforce source-segregation of waste in the city.

DUMPSITE REMEDIATION IN HILLY REGIONS

Why it is a matter of concern

Many hilly regions, including Arunachal Pradesh, Assam, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and Uttarakhand, are known for their scenic beauty and fragile ecosystems. Solid waste management in these regions has not been given adequate attention in the past. Waste gets accumulated in rivers, lakes, ponds and wetlands, causing irreversible damage to the entire ecosystem. This sad state of affairs is quite noticeable in major cities and towns in the Northeast and other mountainous regions.

In particular, cities in these regions still follow a linear waste management model based on collection, transportation and disposal in dumpsites. As much as 80–90 per cent of waste is indiscriminately dumped in dumpsites in these states and a significant fraction of generated waste remains uncollected by city officials.

Planning biomining of old dumpsites in hilly regions is quite arduous, given the complexities of the ecosystem, topography and climatic conditions. From quantification to disposal, legacy waste needs to be handled with great caution and expertise. The cost incurred in treatment and disposal of legacy waste fractions in hilly regions is expected to be high because of several operational and technical challenges. Since the transportation cost of the mined fractions—largely scrap combustible fraction (SCF)—is high due to unavailability and inaccessibility of processing facilities, the transportation of machinery, deployment of skilled manpower etc., are critical requirements.

A legacy waste dumpsite in Kashmir

Source: CSE

Legacy waste remediation project in Leh, Ladakh

Table 10: Details of the legacy waste remediation project in Leh

Parameter	Details
Dumpsite name	Bombgarh
Land ownership	Mostly owned by the municipal committee, with a private sector stake as well
Quantity of waste	132,000 m^3 Estimated tonnage 70,000–100,000
Area	28.4 acre (11.49 hectare) of undulating land
Waste profile	Fine fraction: 42 per cent Plastic, paper and cloth: 52 per cent Metals, stones and others: 6 per cent
Project duration	18 months (February 2022–August 2023)
Technology deployed	Biomining of waste fractions: • **Recovery of recyclables** • **Land levelling with soils and fines** • **Scientific disposal of the remaining fraction**
Agencies involved	Executing agency: Municipal Committee, Leh, under the Directorate of Urban Local bodies, Ladakh Service provider: PH Jadhav (sole proprietor) Technical support agencies: Ladakh Ecological Development Group; BORDA, South Asia; Smart City PMU; PricewaterhouseCoopers, India (PwC)

Source: Municipal Committee, Leh

LADDAKH ECOLOGICAL DEVELOPMENT GROUP

Bombgarh dumpsite in Leh

LADDAKH ECOLOGICAL DEVELOPMENT GROUP

Biomining of legacy waste at the Bombgarh dumpsite

Project update: As of August 1, 2022, about 35,000 tonne of waste have been cleared out from the upper, higher end of the dumpsite. Waste clearing is scheduled to be completed by the end of December 2022.

Major lessons for legacy waste treatment in hilly regions

Higher service delivery cost: Due to the high cost of transport of machinery and higher power and water tariffs in the hard-to-reach mountainous area, the cost of service delivery is substantially higher than that prescribed in national guidelines. Adhering strictly to those limits might result in sub-standard service delivery. The increased costs need to be factored in when designing contracts for similar challenging geographies.

Local use of recovered material: Substantial quantities of the recovered material can be locally reused in:

- Plastics: For road construction, recycling, etc.
- Soils and fines: For levelling of undulating land and as construction fillers
- Rocks and stones: For construction locally (cost of construction in the mountainous regions is very high, using local material might drive down costs)

Local use of recovered fractions can help raise funds for cash-strapped small urban local bodies.

Extended project timelines: Due to harsh climatic conditions and non-availability of labour, projects in hilly regions might take longer to complete. For example, in Leh, remediation is almost impossible to do in winter months when temperature goes down to –20°C. This aspect needs to be factored into remediation contracts.

Need for specialized policy for mountainous regions: Standardized national-level policies often lack the nuance to deal with specific challenges in hilly regions. Urban local bodies in hilly regions need to be given the policy space to tailor costs, treatment technologies and timelines as per local requirements.

Outsourcing of services: Legacy waste remediation is a machinery-heavy operation. Small mountain urban local bodies (ULBs) tackling the issue in-house often face a challenge of availability of skilled resources to repair and maintain trommels, sieves, etc. which leads to delays and further accumulation of waste. Outsourcing of these projects to service providers might be a possible solution to the issue.

Comprehensive scoping: Comprehensive scoping is needed to ensure that biomining, transportation and final disposal of residual waste, incineration of the remaining fraction and land reclamation, etc. are duly incorporated into a single service contract. A split in the scoping exercise may affect seamless sequencing and lack of resource optimization.

Cluster-based approach

It is advisable to first identify all dumpsites where biomining is required. Then governments should prepare a comprehensive action plan at the state level. It is critical to select the appropriate contractor by a tendering process based on their technical and financial competence in the domain of legacy waste treatment and disposal. The cluster-based approach is the best way forward to encourage successful agencies in this field. For example, the Directorate of Urban Local Bodies, Kashmir follows a cluster-based approach, wherein six dumpsites (with a cumulative quantity of nearly 80,000 tonne of waste) have been identified by the state for remediation of legacy waste. A tender has been prepared and uploaded for the selection of a competent agency to execute the work. It is yet to be finalized.

Waste quantification

The exact quantification of legacy waste in hilly regions is challenging because of uneven land patterns. Dumping waste after trenching the ground is a common practice which leads to difficulty in finding the exact ground level or original ground level. A topographical survey can give us the exact top profile only whereas to get the ground level profile, a bore pit can be used as a proximate method. This can be done by dividing the land in a grid pattern to get the exact quantity of legacy waste based on top profile as well as below the ground level profile.

Project tenure

Since the weather in hilly regions is uncertain, it is difficult to complete biomining projects within a stipulated timeline. While preparing the detailed project report of bioremediation of legacy waste in a hilly region, the project completion time should be estimated after analyzing the overall climatic condition of the terrain. Prolonged monsoon period is one of the challenges faced by cities located in the mountainous regions in the Northeast.

Waste processing

While adopting the approach and methodology for processing of legacy waste, the following points should be taken in consideration:

- Waste stabilizing process should be carried out under a "shed" to minimize the impact of climatic conditions;
- The right machinery and equipment must be selected;
- SCF should be stored in covered spaces to minimize the impact of the climatic conditions and timely transportation should be ensured to avoid bulk accumulation of waste; and
- Leachate treatment is necessary as and when required because of excess leachate production.

Disposal
For the disposal of domestic hazardous waste, sanitary waste and other types of waste mined from a legacy waste dumpsite that cannot be reused or recycled in any way, a regional sanitary landfill facility should be constructed as per availability of land in the lower reaches of the hills.

Financial
For the successful completion of a bioremediation or biomining project in hilly terrain, it should be financially viable. The project cost of biomining of legacy waste in a hilly region cannot be the same as that in normal terrain. The higher cost in hilly terrain is due to the following factors:

- Unavailability of cement factories and waste-to-energy plants for disposal of refuse-derived fuel, inerts and rejects leading to high transportation cost of mined fractions;
- Higher transportation cost of machinery and equipment;
- Deployment of skilled manpower;
- Establishment of under-the-shed processing facilities; and
- Arrangement of basic amenities like electricity and water.

Challenges in dumpsite remediation through biomining

Gaps in data and preliminary planning

Gaps in preliminary planning hamper biomining projects. They can be in the form of the following:

- Lack of an alternative plan for management of fresh waste. Many cities continue to dump fresh waste in legacy waste dumpsites while they are being biomined, making the process of biomining a Sisyphean task.
- Lack of detailed project reports and proper tenders covering all aspects of dumpsite remediation, including the appropriate methods of treatment like stabilization by bio-inoculum and size segregation. It is critical to cover important terms and conditions as well as the scope of work in the tenders.
- Lack of standard protocols for sampling of legacy waste. As a result, there is lack of data on the composition of legacy waste, which makes it difficult for ULBs to prepare waste disposal plans (based on the compositional study) and arrive at an approximate costing.
- Inappropriate environmental monitoring parameters in post-mining. Most ULBs that have conducted remediation are not clear about post-mining monitoring.
- No clear standards for post-mining activities.
- Lack of data on quantification, bore hole testing, and leachate and gas generation from dumpsite.
- Lack of availability of sanitary landfill sites for scientific disposal of inerts (street sweepings and drain silt) as well as rejects.
- Lack of protocols to ensure safety of personnel involved in biomining.

Statutory compliance

There is lack of a uniform government policy or protocol to obtain permissions and clearances for biomining. There is ambiguity in the "clearances" issued by the State Pollution Control Board; every state has a different mechanism to obtain which makes the process time-consuming.

Lack of disposal plans for recovered materials

Many urban local bodies struggle to find economically viable options for disposal of recovered material. There may not be any takers for scrap combustible fraction (SCF) in the vicinity of a legacy waste dumpsite. Even if there is potential for utilization, it may require additional infrastructure. For example, many cement factories do not have a pre-processing unit, which is critical for co-processing of SCF recovered from biomining. Similarly, the management of inerts is challenging for many metropolitan cities due to lack of sufficient low-lying areas.

End use of reclaimed land

Despite the mandate of Swachh Bharat Mission 2.0—the largest flagship sanitation programme in independent India in terms of financial allocation—to clean up decades-old garbage mountains in cities, a comprehensive policy direction for reuse of reclaimed land after biomining has been completed is still missing. Even the 2016 Solid Waste Management Rules make no mention of potential utilization options.

According to the CPCB guidelines for disposal of legacy waste (old municipal solid waste) in 2019, cleared dumps are not permitted for habitation for at least 15 years. After that time, human settlements may be established on them after ensuring that gaseous emissions and leachate quality analysis complies with the specified standards and the soil has been stabilized. The guidelines do not differentiate between biocapped and biomined landfills or dumpsites. However, the requirement of compliance with gaseous emissions and leachate standards and soil stabilization might not be relevant for bioremediated dumpsites where waste has been excavated, stabilized and segregated, and the land has been reclaimed completely.

According to CPCB guidelines, permissible options fifteen years after the closure of landfills include reuse for setting up waste processing facilities, open stadia, sports grounds, parks and gardens, parking lots, container yards, warehouses of non-flammables and similar facilities where people are not living or working all day and night.

The absence of clear and separate provisions for end use of land reclaimed after biomining leaves a lot to the imagination of urban local bodies (ULBs). As a result, ULBs are even considering reuse of reclaimed land for large housing projects. While this may appear to be a good option that could fetch substantial revenue for city governments, scientific evidence to prove that reclaimed land and the groundwater beneath reclaimed land is free of toxic contamination is lacking.

Lack of a scientific disposal plan for non-recyclable and non-usable material

Non-recyclables such as hazardous and sanitary waste obtained from biomining are supposed to be disposed of scientifically in sanitary landfills or incinerated. Residual solid waste or rejects from fresh municipal solid waste processing are also supposed to be disposed of in sanitary landfills. Currently, however, there is a dearth of sanitary landfills in the country. As per the CPCB annual report of 2019, there are over 379 operational sanitary landfills in India. Karnataka has the highest number of sanitary landfills (191), followed by Uttar Pradesh (83) and Rajasthan (36). Fifteen states and Union Territories do not have any sanitary landfill facilities.

The way forward

Developing a sustainable solid waste management plan: For successful dumpsite remediation, it is crucial to develop an efficient city-wise solid-waste management plan based on the principles of resource recovery and circular economy while ensuring that the least quantity of waste ends up in landfills as rejects or inerts. It is not possible to complete land reclamation if fresh waste keeps being dumped at the same site. Source segregation is non-negotiable, and restricting the dumping of organics and recyclables in dumpsites or landfills is extremely important to reduce the burden on landfills.

Ensuring maximum utilization of recovered fractions: The quality and marketability of scrap combustible fraction (SCF) can be enhanced through proper stabilization and treatment of legacy waste prior to segregation. Mere trommelling is not going to serve the purpose and will negatively affect the quality of recovered materials, including SCF. Proper stabilization of legacy waste using bio-inoculum is critical to improve the quality of recovered materials. The inert fraction can be utilized in the following applications:

- Reclamation of low-lying areas;
- Reclamation of mining overburden;
- Top layer of fines can be used in afforestation efforts; and
- Road construction (after evaluating civil engineering parameters)

Reclaimed land: Considering the scale of biomining operations planned in India, it is critical to have a comprehensive policy in place backed by science and research-based learning for urban local bodies on reuse of reclaimed land. Such a policy must also be backed by a protocol encompassing mandatory environmental and social safeguards and monitoring—something in line with the Environmental Impact Assessment (EIA).

Developing standards for gainful utilization of recovered fractions: Recovered fractions, especially fine-soil like materials, coarser particles and scrap combustible fractions (SCFs), should be tested appropriately for the presence of toxic contaminants (such as heavy metals) and organic contaminants before use in various gainful applications. Specific standards and test protocols for environmental safeguard should be prepared and implemented rigorously.

Incentives for proper management of recovered materials: The cost incurred in recovery and utilization of SCF and fine soil-like material from a dumpsite must compete favourably with the cost of virgin materials that are available in the market. The use of recycled materials and products will have to be made mandatory for government procurement. There is a clear and urgent need for collaboration between industry and policymakers in order to develop a sustainable business model for legacy waste businesses based on the principles of circular economy.

Capacity building of ULBs, SPCBs and state urban development departments: The capacities of urban local bodies (ULBs) and state government officials and pollution control authorities need to be enhanced with respect to the understanding and assessment of all aspects of biomining.

Construction and sustainable operation of sanitary landfills: Sanitary landfills should be built to dispose of non-recyclable and non-treatable waste recovered from biomining. These landfills should be designed and constructed scientifically as per the norms. For ensuring sustainable operations, the sites should be operated in a phased manner. Regular compaction and daily covering by soil or C&D debris must be followed meticulously.

Annexures

Annexure 1: Environmental parameters

For dumpsite remediation and legacy waste treatment, environmental monitoring data can be used to assess if the operations of excavation and waste processing are affecting the local environment in any way. Environmental monitoring is the systematic measurement of key environmental indicators over time within a particular geographic area.

Baseline monitoring: A survey should be conducted on basic environmental parameters in the area surrounding the proposed dumpsite remediation project before construction begins (see *Table: Recommended environmental components for collecting baseline data as per Indian guidelines*).

Impact monitoring: The biophysical and socio-economic (including public health) parameters within the proposed project area must be measured during the operational phases in order to detect environmental changes that may have occurred as a result of project implementation.

Compliance monitoring: This form of monitoring employs a periodic sampling method, or continuous recording of specific environmental quality indicators or pollution levels to ensure project compliance with recommended environmental protection standards.

Recommended environmental components for collecting baseline data as per Indian guidelines

Environmental component	Monitoring data baseline
Ambient air quality	Date of sampling, temperature, wind speed and direction, monitoring results for standard air quality parameters to be enclosed (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, Pb, Ni, As, benzo(a)pyrene and benzene).
Soil quality (vary in depths)	Date of sampling, depth of sampling and the soil characteristics for standard soil parameters including heavy metals to be enclosed (soil depth, particle size distribution, texture, organic matter, pH, electrical conductivity, exchangeable cations and cations exchange location, alkali metals, sodium, absorption ratio of soils, heavy metals in soil viz. Cd, Cr, Pb, Ni, Cu, Zn and Mn, infiltration rate in mm/hour, water holding capacity, porosity, NPK content, etc.)
Characteristics of surface water and groundwater	Date of sampling, depth of groundwater table and direction of flow or depth of surface water at which samples are taken, characteristics for drinking water parameter to be indicated (physico-chemical and biological characteristics as per IS:10500 (for groundwater sample) and IS: 2296 (for surface water samples)
Noise level (in decibels)	Date of sampling, and parameters to be monitored and indicated as per the norms

Source: CSE

Annexure 2: Standards for treated leachates

S. no	Parameter	Standards (mode of disposal)		
		Inland surface water	Public sewers	Land disposal
1.	Suspended solids mg/l, maximum	100	600	200
2.	Dissolved solids (inorganic) mg/l, maximum	2,100	2,100	2,100
3	pH value	5.5–9.0	5.5–9.0	5.5–9.0
4	Ammoniacal nitrogen (as N), mg/l, maximum	50	50	-
5	Total Kjeldahl nitrogen (as N), mg/l, maximum	100	-	-
6	Biochemical oxygen demand (mg/l) (three days at 27^0C), maximum	30	350	100
7	Chemical oxygen demand, mg/l, maximum	250	-	-
8	Arsenic, mg/l, maximum	0.2	0.2	0.2
9	Mercury, mg/l, maximum	0.01	0.01	-
10	Lead, mg/l, maximum	0.1	1.0	-
11	Cadmium, mg/l, maximum	2.0	1.0	-

Note: The fine fractions should also be tested for the presence of organic contaminants such as phenols, chlorinated phenols, endocrine disrupting chemicals, azo-dyes, polyaromatic hydrocarbons, polychlorinated biphenyls and pesticides

Source: Solid Waste Management Rules, 2016

Annexure 3: Compost quality standards

S. no.	Parameter	Organic compost (FCO, 2009)	Phosphate rich organic manure FCO (PROM), 2013
1	Arsenic (mg/kg)	10.001	10
2	Cadmium (mg/kg)	5	5
3	Chromium (mg/kg)	50	50
4	Copper (mg/kg)	300	300
5	Lead (mg/kg)	100	100
6	Mercury (mg/kg)	0.15	0.15
7	Nickel (mg/kg)	50	50
8	Zinc (mg/kg)	1,000	1,000
9	C/N ratio	< 20	Less than 20:1
10	pH	6.5–7.5	(1:5 solution) maximum 6.7
11	Moisture, per cent by weight, maximum	15.0–25.0	25.0
12	Bulk density (g/cm^3)	<1.0	Less than 1.6
13	Total organic carbon, per cent by weight, minimum	12.0	7.9
14	Total nitrogen (N), per cent by weight, minimum	0.8	0.4
15	Total phosphate (P_2O_5), per cent by weight, minimum	0.4	10.4
16	Total potassium (K_2O), per cent by weight, minimum	0.4	–
17	Colour	Dark brown to black	–
18	Odour	Absence of foul odour	–
19	Particle size	Minimum 90 per cent material should pass through 4.0 mm IS sieve	Minimum 90 per cent material should pass through 4.0 mm IS sieve
20.	Conductivity (as dsm-1), not more than	4.0	8.2

Note: Tolerance limits as per FCO for compost: The sum of nitrogen, phosphorus and potassium nutrients shall not be less than 1.5 per cent in the compost. For PROM: No such directive

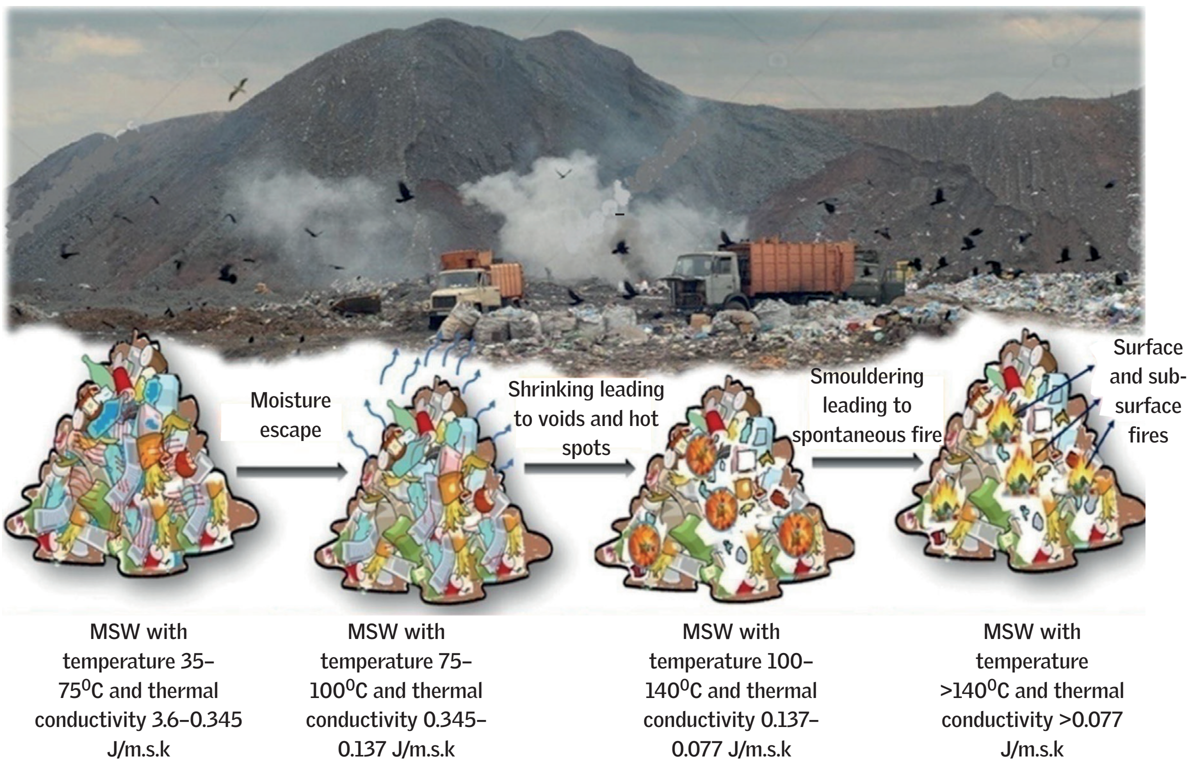
Source: Fertilizer Control Order (FCO), 2009

Annexure 4: Fire control at dumpsites

In unregulated dumpsites, heat is generated by various physical, chemical and microbiological processes. Exothermic reactions in landfills produce a lot of heat, which is not dissipated properly. Moreover, anaerobic decomposition releases methane gas that is explosive when its proportion in the air is in the range of 5.3–13.9 per cent.[56]

Surface fires are caused by "hot loads", equipment, people smoking on-site and by waste recyclers. Hot loads in this context refers to waste that catches fire, smoulders, or spontaneously combusts, and could include leaves, construction debris, fuel, tires or chemicals that could react and cause a fire. Causes of equipment-related fires include debris trapped under machines, heat from equipment (exhaust pipes) and welding. Fires are also started by recyclers to clear the waste so that they can reclaim metals. Subsurface fires result from air filtration into the waste mass. Both the waste in place and methane generated in the landfill are fuel sources, heat is generated by microbial activity in the decomposing waste. When the fire

Mechanism of dumpsite fires in India



Source: Manjunatha et al. (2020)

is below the surface, it is difficult to detect, gauge its extent, and take measures to extinguish it. Some of the visual indications of subsurface fires include sudden subsidence and depressions in the dumpsite, fissures and cracks, venting holes and rills, and smoke.

Delhi fire station (DFS) reported that Bhalswa, Okhla and Ghazipur had 69, 35, 27 major landfill fire incidents per year respectively.[57] The causes of fire include chemical reactions, reactive materials, failure of landfill gas systems, smoking or sparks, landfill equipment, lightning strikes and hot load. Extracting heat from landfills and avoiding hot loads at any given point help prevent landfill fires. Thermal conductivity and specific heat are the two important thermal properties that need to be analysed for understanding heat distribution within a landfill.

Checklist for dumpsite fire control action plan during biomining

- A separate team of fire control officials should be trained to take appropriate action to control fire incidents during biomining or just before biomining commences.
- Separate machinery—Poclains, bulldozers, water tankers and dumpers.
- Smouldering areas should be inspected visually and hot loads should be removed from the area.
- More access roads should be created to reach the location of a fire.
- Area under fire or smoke should be separated from the rest of the waste by trenching.
- Trenches should be covered up with soil or inerts obtained from biomining or with C&D debris.
- Fire tankers or water tankers should always be available on-site to douse fires. However, excess water can disturb the slope stability and increase the amount of leachate.
- Illegal entry should be stopped, rag-pickers should be allowed to work but under proper supervision.

Annexure 5: Characteristics of RDF extracted from legacy waste samples

Test parameters	RDF recovered from legacy waste	Input material for waste-to-energy plant or RDF pre-processing facility	Unit
Proximate analyses			
Moisture content	14.72	< 35	Per cent
Ash content	27.37	< 20	Per cent
Volatile matter	34.68		Per cent
Fixed carbon	23.23		Per cent
Ultimate analyses			
Carbon content	39.1		Per cent
Hydrogen	3.68		Per cent
Sulphur	0.49	<1.5	Per cent
Oxygen	14.37		Per cent
Nitrogen	0.27		Per cent
Other parameters			
Total solids	85.28		Per cent by mass
Loss of ignition	57.34		Per cent by mass
Selenium (as Se)	0.29		mg/kg
Potassium (as K_2O)	0.16		Per cent by mass
Sodium (as Na_2O)	0.12		Per cent by mass
Chloride (as Cl)	0.01	<1.0	Per cent by mass
Calcium oxide (as CaO)	2.62		Per cent by mass
Magnesium (as Mg)	0.29		Per cent by mass
Silica content (SiO_2)	114.61		mg/kg
Sulphate (as SO_4)	0.14		Per cent by mass
Iron (as Fe)	1.3		Per cent by mass
Copper (as Cu)	96.4		mg/kg
Cadmium (as Cd)	BDL (DL=3)		mg/kg

Test parameters	RDF recovered from legacy waste	Input material for waste-to-energy plant or RDF pre-processing facility	Unit
Zinc (as Zn)	15.38		mg/kg
Nickel (as Ni)	13.63		mg/kg
Mercury	BDL (DL=3)		mg/kg
Organic carbon	29.14		Per cent by mass
Phosphate (as P)	119.24		mg/kg
Bulk density	0.21		gm/cc
C/N ratio	144.81		_
Lead (as Pb)	17.09		mg/kg
Chromium (as Cr)	63.21		mg/kg
Arsenic (as As)	BDL (DL=3)		mg/kg
Titanium (as TiO_2)	168.6		mg/kg
Gross calorific value (as air dry basis)	2,614.6		Cal/gm
Net calorific value (as air dry basis)	2,279.1	>1,500	Cal/gm

Source: Central Public Health and Environmental Engineering Organisation (CPHEEO), 2018

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Legacy waste is a burden of the past we cannot ignore. In recent years, efforts to bioremediate and biomine legacy waste dumpsites has gained traction.

This toolkit is designed to be a hands-on guide for practitioners, officials of urban local bodies and other stakeholders involved in legacy waste management.

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