Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka

UN environment programme

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Ministry of Environment

Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka

Ministry of Environment
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Forward Message

Many major cities and emerging townships in Sri Lanka are facing with the major challenge of improving their inadequate and unsustainable waste management systems. Waste must no longer be deposited in residential areas and uncontrolled landfills or end up on illegal dumpsites and in waterways. It accumulates in the environment causing soil, water and air pollution and deteriorating quality of life of nearby communities. The pollution levels in most cities and urban centers in Sri Lanka, particularly in cities are rising. It has been well understood that social and political development lack adequate economic and technical instruments to move away from collect and dispose management structure to sustainable material recycling society. In the absence of value addition for waste resources, the environmental impacts are severe, and it includes unavailability of suitable lands for waste disposal sites. Thus, the conventional waste management approach, collect and dispose, deems unsuitable and inappropriate for present day context. A strategic change will be required of waste management system designs and service delivery models to ensure the medium and high-density urban form envisaged by the long-term country target, "waste to resources," is effectively and efficiently achieved.

I am indeed honored to send this message upon the completion of the Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka. This project was initiated in 2019 with the overall aim of developing a simple yet comprehensive guideline for rehabilitation of Municipal Solid Waste dumpsites, a timely need to educate and make aware the policy makers, administrators and public about pollution and socio-economic issues arising from haphazard disposal of waste in open dumpsites. Moreover, the guideline has presented a strategy and technical plan to shift from open dumping practice to appropriate sanitary disposal considering the technical and financial capacity of Local Authorities and other involving stakeholders. Without a proper technical guideline, the initiatives undertaken to manage Municipal Solid Waste dumpsites will not be successful and sometimes ends with tragedies including loss of lives. Therefore, I believe that, without a shadow of doubt, this guideline will be instrumental in giving technical guide and insights into the planning, management, and pollution control of dumpsites in Sri Lanka. I take this opportunity to thank IGES Centre Collaborating with UNEP on Environmental Technologies (CCET), United Nations Environmental Program and Ministry of Environment, Japan (MOEJ) for their technical and the financial support as well as all the technical experts and administrative personals for their tremendous support in completing this task.

Dr. Anil Jasinghe

Secretary
Ministry of Environment

Message from UNEP-IETC

There is no place on the earth that people do not dispose of waste. While limited numbers of countries have environmentally sound disposal of waste which do not cause adverse effect to human health and the environment, the majority of countries still face challenges in the implementation of environmentally sound management of waste. Many countries continue to rely on disposing of waste in open dumping sites or, simply, open spaces in our nature. Such practices continue to be a source of negative impact on human health and the environment.

Sri Lanka unfortunately needs to dispose of waste at open dumping sites. Sri Lanka has been making efforts to improve their waste management practices and to gradually shift from unmanaged dumping sites to landfill sites managed by local authorities. With the commitment of government and support from international organizations, there are many outcomes which have improved the situation of open dumping sites and operating properly managed landfill sites in Sri Lanka has begun.

This report on "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka" has been a close cooperation between the Ministry of Environment of Sri Lanka and UNEP through the IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) and UNEP's International Environmental Technology Centre (IETC). Collectively, we recognize that proper procedure to close open dumping sites and proper management post-dumping phase are important not only to protect human health and the environment but also avoiding unforeseen pollution in the future after open dumping sites are closed. These guidelines provide technical knowledge and expertise on how to safely close and to properly manage open dumping sites.

The case studies in this report provide useful information for other countries who face similar challenges with open dumping sites. I hope that the guidelines assist governmental officials and experts not only in Sri Lanka, but everywhere open dumping exists, to safely close and rehabilitate open dumping sites and manage the environmental consequences of open dumping in a responsible and sustainable manner without adverse impacts to human health and the environment.

Monika G MacDevette

Chief, Chemicals & Health Branch
Economy Division
UNEP

Message from IGES-CCET

The current economic growth and urbanization accompanied by the rapid increase of consumption of materials and change of their consumption patterns have brought a huge challenge for local governments of many countries in their Municipal Solid Waste (MSW) management.

It is usual for us to observe this problem as a result of a series of inadequate operations of waste management starting from generation, collection, transportation toward the final disposal at landfill sites without having an established approach for segregation and recycle as resources. Uncollected wastes get scattered around the surroundings and get into drains and rivers and finally ends up at oceans contaminating the marine environment and giving disastrous impacts on marine based lives.

Among others, the management of final disposal site is a common and serious problem for many countries, and Sri Lanka is not the exception of this. Landfilling is made as open dumps mostly and becomes the sources of ground water contamination through their leachate water. Dumpsites are the third largest anthropogenic source of methane, accounting for 11 percent of estimated global methane emissions. Fire outbreaks can happen with generation of black smokes. It also affects the health of people living around the dumpsites in addition to those relying their lives on waste pickings. How to manage these problems, how to close these landfill sites safely and how to rehabilitate those sites for possible use in future are of the common interests of many cities and countries.

In this regard, IGES Centre Collaborating with UNEP on Environmental Technologies (CCET), in coordination with the Ministry of Environment, Sri Lanka, has developed "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka" to address the issue of waste dumps by providing the necessary technical guidance to local authorities, government and other relevant stakeholders for safe closure and rehabilitation of the waste dumps.

Thanks to the strong commitment of the Ministry of Environment and kind cooperation and inputs of relevant ministries and institutions, Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka is successfully developed.

I hope this guideline is of help to local governments and relevant stakeholders in Sri Lanka for safe closure and rehabilitation of their waste dumps.

Kazunobu Onogawa

Director, CCET

Acknowledgement

At the outset, we wish to thank the Secretary, Ministry of Environment and also IGES Centre Collaborating with UNEP on Environmental Technologies (CCET), United Nations Environmental Program – International Environmental Technology Centre (UNEP-IETC) and Ministry of Environment, Japan (MOEJ) for their guidance, technical, and financial support granted to conduct this assignment in collaboration with the key stakeholders from government, private and non-governmental organizations.

We extend our sincere gratitude to the tremendous work done by reviewers in the preparation of the "Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka". The contributions made by the collaborators and the inputs received from the government, private and non-governmental organizations in the form of recommendations were of immense use in preparation of this document, are thankfully acknowledged.

We extend our special thanks to Mr. S. M. Werahera and Ms. Sujeewa Fernando from the Environmental Pollution Control & Chemical Management, Division of the Ministry for taking this important initiative by requesting IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) for development of a guideline for rehabilitation of Municipal Solid Waste (MSW) dumpsites in Sri Lanka considering the need for proper disposal and management of Municipal Solid Waste in Sri Lanka.

The guideline also contains information extracted from a number of sources including the National Solid Waste Management Support Center (NSWMSC), Ministry of Local Government and Provincial Council, Central Environmental Authority (CEA), Japan International Cooperation Agency (JICA), National Building and Research Organization (NBRO), University of Moratuwa, Waste Management Authority (WP), University of Peradeniya, and numerous publications by individuals and publishers. We wish to acknowledge these organizations and individuals for their contribution enriching the understanding in this subject.

We would like to thank all the participants of the inception workshop and consecutive stakeholder meetings for their views, suggestions, and recommendations, without which this guideline would not be successful.

Finally, we sincerely hope that the contribution made in this guideline document will inspire all policy makers, administrators, and citizens at large to pay their utmost attention and care in dealing with Municipal Solid Waste (MSW) management and disposal in Sri Lanka.

Project Team

Executive Summary

Municipal Solid Waste (MSW) management, particularly final disposal as open dumps has become a global issue. Worldwide, dumpsites are the third largest anthropogenic source of methane, accounting for 11 percent of estimated global methane emissions or 881 million tonnes of CO_2 equivalent. The 50 largest dumpsites affect the daily lives of 64 million people, 17 million of whom live in Asia, and all dumpsites affect all 17 SDGs either directly or indirectly. Similarly, dumpsites have become a serious issue in Sri Lanka, which experienced catastrophic collapse of one in Meethotamulla in 2017, causing 32 fatalities and destruction of 87 houses. The lack of proper final disposal techniques has been the major bottleneck faced by many local authorities. A common grievance voiced by many local authorities is that insufficient land resources, technical support and finances hinder the transition from open disposal to sanitary landfilling. However, it has been well recognized that open dumping practice can no longer be allowed to continue, and appropriate waste resources recovery and disposal strategies should be established at any cost. Thus, simple guideline for dumpsite closure and rehabilitation is of paramount importance for local authorities which would help reduce pollution risks on the environment and public health at the local level and climate and SDG achievements at the global level.

The term "dumpsite rehabilitation" in these guidelines refers to any work, including partial work carried out on a MSW dump site aimed at improving existing conditions to minimize the hazard risk caused by leachate contamination, gaseous emissions, waste burning, collapse due to instability, and all other associated socio-economic issues. Accordingly, these dumpsite rehabilitation guidelines aim to provide for or advise on: a) a risk assessment procedure to determine the level of pollution caused by a dump and its rehabilitation potential; b) implementable rehabilitation and closure plans; c) appropriate technical intervention to minimize leachate contamination, uncontrolled gaseous emissions, waste burning, and risk of dumpsite collapse; and d) an appropriate operation and maintenance procedure that ensures sustainability of technical improvement measures.

Chapter 1 emphasizes the need for rehabilitating existing open disposal sites to improve the health and environmental setting in the country and explains the scope and organization of the guideline.

Chapter 2 discusses the distinction in definition of the term dumpsite and landfill and introduces the engineered approach to landfilling.

Chapter 3 elaborates on the dumpsite risk assessment procedure, based on the Source-Pathway-Receptor (S-P-R) conceptual model. It presents a sequential approach to risk assessment: development of a conceptual site model identifying pollution sources, pollution migration pathways and receptors of pollutants. The risk screening process introduced describes quantitative and qualitative assessment based on a risk screening process that can be executed by experts and trainers to develop a conclusion on the level of risk posed by the dumpsite.

Chapter 4 is a brief guide to the planning requirements needed to fulfill the objectives of dumpsite rehabilitation, as well as general planning requirements.

Chapter 5 elaborates on the technical planning requirements for a typical dumpsite rehabilitation project, and discusses the aspects of technical requirements, potential areas for improvements, types of studies to be conducted and potential sources of information and technical services.

Chapter 6 presents a simple decision-making process based on risk assessment and planning objectives. The process involves use of the guidelines to choose the appropriate level of dumpsite rehabilitation from five different levels of improvement based on the risk level assessed in chapter 2. The legal and regulatory requirements to be followed during the rehabilitation process are also covered.

Chapter 7 describes the different levels of dumpsite closure and development and offers a guide to choosing the appropriate closure level based on regulatory requirements, technical feasibility, and level of risks.

Chapter 8 describes the operation and maintenance requirements to be followed to achieve the objectives set forth during the planning process. It covers the maintenance of landfill cover systems, stormwater drain systems, leachate collection and treatment systems and landfill gas management systems.

Chapter 9 briefly describes the project development, design, construction, operation, and monitoring process of two rehabilitated dumpsites in Sri Lanka namely Moon Plains and Galapitayaya, Kataragama in Sri Lanka and two dumpsite rehabilitation projects in India.

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Abbreviations

APL	Aqueous Phase Liquid
CEA	Central Environmental Authority
CSM	Conceptual Site Model
EIA	Environmental Impact Assessment
IEE	Initial Environmental Examination
JICA	Japan International Cooperation Agency
LA(s)	Local Authority/ies
MC	Municipal Council
MSW	Municipal Solid Waste
NAPL	Non-Aqueous Phase Liquids
NEMC	Nuwara Eliya Municipal Council
NSWMSC	National Solid Waste Management Support Centre
PC	Physical Closure
PCM	Post-closure Management
PRB	Permeable Reactive Barrier
ReEB	Reduction of Environmental Burden
RI	Risk Index
S-P-R	Source-Pathway-Receptor
TPD	Tonnes Per Day


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1 The need for and objectives of dumpsite rehabilitation guidelines

1.1 From open dump to landfill

Dumpsites are the most widely used method of municipal solid waste disposal (MSW) in the world. They receive about 40% of the world's waste generation and serve about 3–4 billion people (ISWA, 2016). The 50 largest dumpsites in the world affect the daily lives of 64 million people, of whom 17 million live in Asia (Waste Atlas, 2014). Moreover, dumpsites are the third largest anthropogenic source of methane (CH_4) in the world, accounting for approximately 11% of estimated global methane emissions or about 1,077 million MT of carbon dioxide equivalent ($MtCO_2e$) in 2020 (Global Methane Initiative, 2020). Estimates for GHG emissions from the waste sector show it will rise 6% percent from 2020 to 2030.

Sri Lanka is no exception, and waste generation in the country is projected to rise by 22% from 2.58 million MT in 2016 to 3.16 million MT in 2030 (World Bank, 2018). In parallel with this, the country's waste management system has largely depended on dumpsites. As shown in Table 1.1, at present, about 48% (1,835 TPD) of the collected waste is managed effectively through centralized composting (1,130 TPD), sanitary landfilling (Dompe sanitary landfill, 5 TPD) and incineration (Western Power Company (Pvt.) Ltd, 700 TPD). A remaining 52% of municipal collected waste still ends up in open dumpsites and the surrounding environment. In addition, there are some resource recovery activities (metal, paper, cardboard, plastics etc.) at different points of the waste stream (household recycling, source segregated local authority collection, private sector collectors & recyclers, scavengers, and waste collection workers) for material recycling. This figure is estimated at about 12% however it is difficult to make an accurate estimate due to lack of primary data.

Considering its potential to reduce Greenhouse Gases (GHGs), the government of Sri Lanka identified the importance of improving waste management in its Second Communication on Climate Change, submitted to UNFCCC Secretariat in 2011 (Climate Change Secretariat, Ministry of Environment, 2011). It was estimated that about 1.76 Mt CO_2e (1,765.2 $GgCO_2e$) of CH_4 emissions were generated from solid waste disposal sites in 2000, and in total the waste sector's contribution to total national GHG emissions is third highest after energy and agriculture. Based on the latest data, we estimate that all uncollected waste and final disposal of the waste generated in all seven provinces in Sri Lanka generates about 1.70 Mt CO_2e (Figure 1.1), where each province has a greater potential to reduce GHGs by closing or converting disposal sites into controlled or sanitary landfills.

Table 1.1 Waste management in Sri Lanka

Province	Area (km²)	Population (Number)	Generation (TPD)	Collection (TPD)	Composting (TPD)	Sanitary Landfilling (TPD)	Incineration (TPD)	Open dumpsites (TPD)	Number of dumpsites
Western	3,684	5,851,130	3,368	1,952	517	5	700	730	51
Central	7,155	4,080,247	871	362	95	0	0	267	43
Southern	5,448	2,643,575	838	272	143	0	0	129	60
Eastern	8,813	1,810,422	838	431	48	0	0	383	38
North Western	7,692	2,644,284	596	235	118	0	0	117	45
Sabaragamuwa	4,925	2,045,176	525	182	72	0	0	110	29
North Central	10,409	1,424,903	409	103	68	0	0	35	35
Northern	9,123	2,250,753	374	195	15	0	0	180	16
Uva	8,298	1,362,939	323	123	54	0	0	69	22
Total	**65,547**	**24,113,429**	**8,142**	**3,855**	**1,130**	**5**	**700**	**2,020**	**339**

Source: Compiled by the authors based on JICA, (2016); Beckhanov and Mizabaev, (2018); Dharmasiri, (2019) and latest statistics by 2021

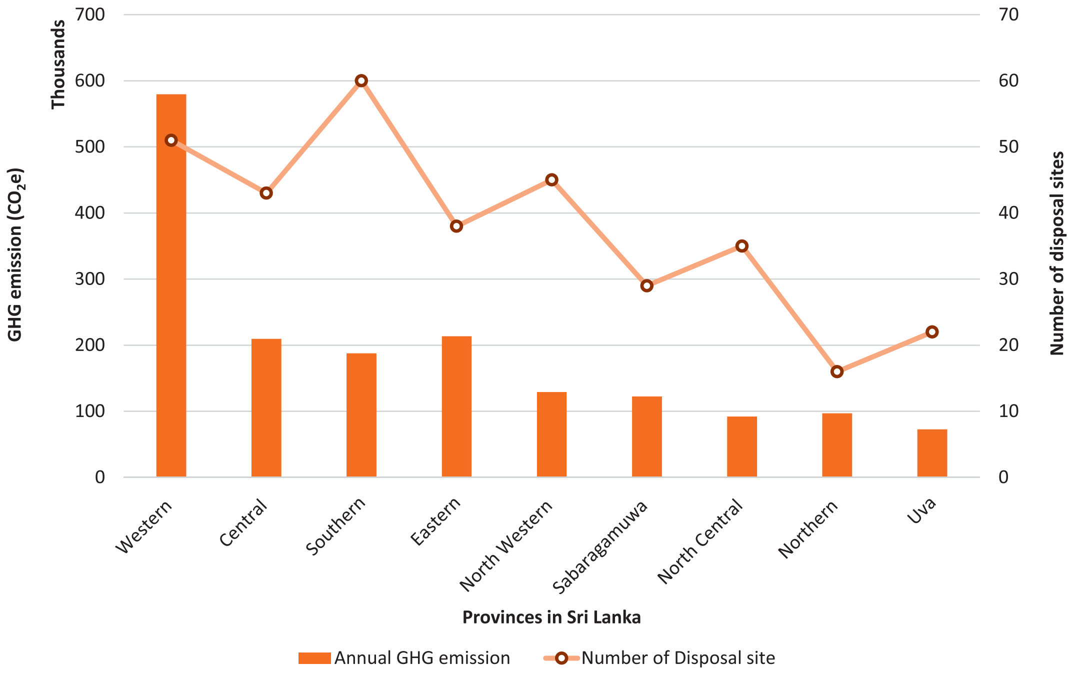

Figure 1.1 Number of disposal sites and GHG emissions from open dumps in Sri Lanka (Dharmasiri, 2019; Barton et al. 2008)

In addition to climate impacts, open dumps cause severe damage to the environment, public health and safety. For example, the landslide collapse of open dumpsite in Meethotamulla, Western Province in 2017 was one of the most serious man-made environmental disasters in Sri Lanka's recent history. The tragedy ended up killing 32 people, the destruction of 60 houses and partial destruction of 27 houses (BBC, 2017). Further, open burning of waste releases smoke, toxic particulates, and gaseous contaminants into the atmosphere around dumpsites and, when carried by wind, into the environment at great distances from the origin. The potential for the spread of infection is large and is often related to direct contact with waste by workers, scavengers, and other unauthorized persons. To protect the environment and to assure better public health and safety, open dumps need to be closed and replaced by controlled or sanitary landfills and complimented with other waste disposal technologies and methods.

Figure 1.2 Linking MSW dumpsite management with SDGs

Doing so would also bring benefits for achieving government commitments to the sustainable development goals (SDGs). Therefore, a solid waste management policy consistent with the social and economic development goals of the country as depicted in the "Vistas of Prosperity and Splendor" policy manifesto has to be implemented to uplift social environmental and economic status of the country. Moreover, the government envisages to create an eco-friendly environment where all can co-exist harmoniously. In this context, as shown in Figure 1.2, waste dump rehabilitation activities affect almost all domains of the SDGs, not limited to SDG 12 on sustainable consumption and production, SDG 3 on good health and well-being and SDG 6 on clean water and sanitation.

However, the lack of environmental literacy, awareness, and experience with the related risks and pitfalls of dumpsites means the public often negatively perceives landfilling as an inappropriate way of managing MSW. Thus, successful conversion of open dumpsites to sanitary landfill sites is one of the ways of assuring the public that landfills are an acceptable means of waste disposal. Another important aspect in this process is the selection of appropriate technologies, operational practices and monitoring programmes, to ensure environmental standards are met when upgrading dumpsites.

In the eyes of the public in Sri Lanka, successful dumpsite rehabilitation or restoration is often considered one of the more important elements because the results endure and are visible for much longer than the period in which the site is operational. Also, many of the engineered structures which are essential in preventing environmental pollution are below ground and are therefore not visible. A well rehabilitated dump site converts the land to beneficial use. Further, rehabilitation of an existing dumpsite to a landfill offers an assurance that any new landfill site in the future will also be restored to a similarly high standard, thereby promoting public confidence in the landfilling process.

1.2 Scope of the guidelines

These guidelines are set out to cover the land disposal facilities (landfill/dumpsites) that accept MSW. Such waste may include regular MSW collected by LAs, residual solid waste left after resource recovery (recycling and composting), and source segregated solid waste (non-recyclable and non-hazardous solid waste). In particular, the guidelines is aimed at assisting in developing rehabilitation plans for MSW dumpsites that are in use, but also describes the process of preliminary risk assessment to determine whether rehabilitation is needed at the outset.

The types of land disposal facilities that require rehabilitation are categorized as follows.

- All types of open dump sites
- All types of controlled dump sites
- All types of semi-engineered landfill sites
- Any landfill site that needs to be rehabilitated/ closed as per regulatory requirements or failure to meet emission standards (CEA)

However, it should be noted that as per existing government policy and regulations, all new final disposal sites should be sanitary landfills and require approval from CEA after conducting an Environmental Impact Assessment (EIA). In addition to technical expertise, it also requires an integrated waste management system to be set up with adequate planning, institutional and administrative capacity, financial resources, civic support and finally political consensus to successfully shift from open dumping of mixed solid waste to controlled disposal and sanitary landfilling of residual municipal waste in Sri Lanka.

1.3 Basic concept of the guidelines

1.3.1 Dumpsite rehabilitation

The term “dumpsite rehabilitation” in these guidelines refers to any work carried out on a MSW dump site or part of a MSW dump site aimed at improving the existing site conditions in order to minimize hazard risk caused by leachate contamination, gaseous emissions, waste burning, collapse due to instability, and all other associated socio-economic issues. Thus, the dumpsite rehabilitation plan should aim at developing the following.

- An appropriate technical intervention to minimize leachate contamination, uncontrolled gaseous emissions, waste burning, and risk of dumpsite collapse.
- An appropriate operation and maintenance procedure ensuring that technical improvement measures are sustainable.
- A monitoring and correction mechanism confirming that technical improvement measures are appropriate.
- A closure and post-closure plan to be implemented once the intended lifespan of the rehabilitated dumpsite comes to an end.

1.3.2 Dumpsite safe closure

“Dumpsite safe closure” in these guidelines refers to any work carried out on an existing or abandoned MSW dumpsite aimed at minimizing the hazard risk caused by leachate contamination, gaseous emissions, waste burning, collapse due to instability, and all other associated socio-economic issues, and restoration of the site to as natural condition as possible. Thus, the dumpsite safe closure plan should aim at developing the following.

- A properly closed dumpsite where all appropriate technical interventions have been taken to ensure safe storage of the waste and to prevent pollution of the surrounding environment.
- A post-closure monitoring and correction mechanism that confirms the technical improvement measures are appropriate.

2 Types of final disposal facilities

2.1 Dumpsite vs engineered landfill

Open dumping or land-raise sites are currently the primary disposal method for most MSW and account for around 80% of the country's waste stream. The term "landfill" is also erroneously used to refer to open dumpsites in Sri Lanka.

A common misconception is that landfills are simply holes in the ground into which waste is tipped. However, modern practices require a significant degree of engineering to contain the waste, control emissions and minimize potential environmental effects. The primary by-products of landfilling, where biodegradable materials are disposed of are landfill gas – (a combination of methane (CH_4), and carbon dioxide (CO_2), along with trace organics); and leachate (a liquid resulting from water passing through the waste mass and water generated in the process of decomposition). A significant part of landfill engineering is geared towards dealing with these substances. As such, landfills require containment lining systems and systems for both leachate and landfill gas collection and treatment. Owing to a higher degree of isolation of waste and due to control of emissions from dumpsites, a properly designed landfill is often termed a "Waste Containment Facility".

While the term 'landfill' usually relates to sub-surface waste disposal, it also generically encompasses 'land-raise', i.e., above ground disposal. Most types of waste may be disposed of via landfill; however, the landfill route is currently being discouraged to encourage more sustainable waste management practices such as minimization, re-use, recycling, and energy recovery. Nevertheless, landfilling appears set to be the norm for disposing of MSW into the foreseeable future. In terms of size, the actual sites involved can range from a few hectares (ha) to over 100 ha and can receive inert, non-hazardous (including MSW) or hazardous wastes. Similarly, waste throughputs can vary widely between sites.

The common distinction between sanitary and semi-engineered landfills is that the latter provides no treatment for methane gas collected, whereas the former does. The majority of landfills are operated by the 'phased cell' system whereby, as one cell is being filled, another is being prepared, and a further one is being completed or restored (usually for an agricultural, amenity or nature conservation use). Waste is tipped by incoming transfer/collection vehicles at a designated 'working face' on the cell where active disposal takes place and then spread out and compacted by a compactor in a series of layers, or 'lifts', to minimize void space. At the end of the workday the cell or final lift is often covered by a 'daily cover' usually consisting of soil, or another inert material, to reduce odours, the spreading of litter and to prevent access to the waste by birds and vermin.

Table 2.1 Comparison of basic features of MSW dumpsites and landfills

Open dumpsite	Semi-engineered landfill	Sanitary Landfill
1. Impermeable liner		
Absent Waste dump on ground	**Present** Installed at the bottom and sides of landfill cell. Not necessarily a synthetic liner	**Present** Properly designed impermeable liner is available
		
2. Leachate collection system		
Absent Surface/ lateral seepage diversion pipes/drains are occasionally available	**Present** Bottom, lateral and surface seepage diversion pipes/drains are present	**Present** Properly designed leachate drainage layer, collection pipes and diversion pipe network are present
		
3. Leachate treatment system		
Absent Simple nature-based treatment systems such as constructed wetlands may be available	**Present** Almost all leachate emissions are diverted to a sort of treatment system either nature-based or highly engineered treatment system	**Present** Leachate is diverted to a highly engineered treatment system (biological + chemical) followed by nature-based wastewater treatment systems for secondary/ tertiary treatment
		

Open dumpsite	Semi-engineered landfill	Sanitary Landfill
4. Gas collection system		
Absent Passive surface emission or simple vertical gas vents may be available	**Present** A network of passive vents or active gas suction pipe network is present	**Present** Properly designed gas emission pipe network is connected to centralized collection system that permits only controlled emission
		
5. Gas emission control system		
Absent Simple and uncontrollable flares may take place at passive vents	**Absent** Simple and uncontrollable flares may take place at passive vents	**Present** All gaseous emission points are diverted to centralized control flaring system or control combustion facility for energy generation
		
6. Landfill machineries		
Absent Occasionally employs general earth-moving machinery for daily operations	**Present** Often relies on general earth-moving machinery for daily operations; occasionally employs specific machines for major works	**Present** Employs a range of landfill machinery for specific planned operations
		

Open dumpsite	Semi-engineered landfill	Sanitary Landfill

7. Waste disposal practice

Open dumpsite	Semi-engineered landfill	Sanitary Landfill
Open dumping Occasionally employs earth-moving machinery to secure space and stabilize shape; occasionally applies thin layer of cover soil	**Controlled dumping** Often employs earth-moving machinery to secure space, compact waste and make stable slopes; often applies daily cover soil layer, intermediate cover and final cover layers on finished slopes	**Controlled and planned disposal** Always employs appropriate machinery to compact waste, rearrange and make stable slopes; always applies daily cover soil layer, intermediate cover layers and final cover layers on finished slopes

8. Operation & Maintenance plan

Open dumpsite	Semi-engineered landfill	Sanitary Landfill
Absent Only when the need arises, often temporary	**Present** At least a simple plan is developed during the landfill planning stage and developed into a comprehensive plan during use	**Present** A comprehensive landfill management plan is developed at the inception stage which includes operational, maintenance, closure (after-use) and emergency response plans

Open dumpsite	Semi-engineered landfill	Sanitary Landfill
9. Human resources		
Skilled workers are not available Occasionally employs unskilled workers for daily operations, with tasks limited to assisting collection vehicles	**Skilled operators are available** Regularly employs skilled workers for daily operations and general maintenance	**Skilled operators are available on-site** Always employs skilled workers for daily operation, general maintenance and planning
10. Monitoring mechanism		
Absent Occasionally conducts visual observations and emission tests as per regulatory requirements	**Present** Often conducts visual observations, regular emission tests including groundwater monitoring. Monitoring is an integral part of management plan. Complies with regulatory requirements	**Present** Often conducts visual observations, regular emission tests including groundwater monitoring. Monitoring is an integral part of management plan. Complies with regulatory requirements
11. Closure and post-closure use plan		
Plans are not available	**Present** Often limited to closure plan	**Present** The closure and post-closure plans are developed at inception and strictly followed by operators

Dumpsite on a coastal lagoon

Dumpsite on a large canal

Dumpsite on a shallow lake

Dumpsite on a beach

Dumpsite on a river bank

Dumpsite on a river bank

Dumpsite on a freshwater wetland

Dumpsite on a estuarine

Figure 2.1 Different types of MSW dumpsites located in unsuitable areas

3 Dumpsite pollution risk assessment

3.1 Objectives

The concept behind introducing Pollution Risk Assessments is to ensure LAs adopt a consistent approach to conducting environmental risk assessments, particularly those for open disposal sites, as well as to assess the environmental impact and remediation options for long-standing unregulated waste disposal sites. Such sites are generally operated illegally and do not follow any legal licensing regime, thus are not subject to any nationally affiliated monitoring scheme or legislation. This chapter provides guidance on how to assess the pollution risk of open dumpsites that likely pose a threat to the environment and public health.

In more detail, this assessment is aimed at determining the intrinsic risk posed by a certain kind of activity and does not consider any potential future remediation measures, thus is a conservative approach. It is designed to assist the responsible authority in carrying out risk prioritization, therefore allowing for a rapid response to the site in question in the advent it is determined as of highest risk. This it manages by setting out a clear methodology for conducting the risk assessment as well as any remediation measures required through a transparent decision-making process.

3.2 Basic concept behind dumpsite risk assessment

The risk assessment is designed to gauge likelihood of occurrence as well potential consequences and represents a systematic means of determining and evaluating the nature, effects and extent of exposure a vulnerable receptor may experience in relation to a particular hazard. It therefore informs processes of management and communication of risk. An environmental hazard is an event or ongoing process, which if materializes will lead to circumstances having the potential to degrade, directly or indirectly, the quality of the environment.

A pathway is a route by which a particle of water, substance or contaminant moves though the environment and meets, or otherwise affects a receptor. For a risk to exist there must be a source (or hazard or pressure), a pathway and a receptor (or target); this is the basis for the **Source-Pathway-Receptor (S-P-R)** conceptual model for environmental management.

In addition, a conceptual model also provides information useful to the scoping of any investigation as it identifies the sites that pose the greatest risk to the environment and human beings and also identifies the S-P-R linkages that have the highest risk associated with them.

The risk assessment methodology facilitates a clear decision-making process in devising a strategy to control any potential risks evident in the conceptual model. The detailed information obtained through the investigative programme will inform decisions on the extent of measures required to manage the risk, which may involve breaking the pathway or removing the source or in some cases monitoring the receptor.

3.3 A conceptual framework of risk assessment

As discussed earlier, in comparison with properly designed sanitary landfills, dumpsites are often perceived as potential hazards; however, the nature and magnitude of the threats from dumpsites are unknown and unforeseen. Understanding the dangers and risks posed by dumpsites to the surrounding environment and how the sites cause regional and global environmental pollution are the key information required to make decisions on dumpsite management. To determine whether to rehabilitate and close or to remediate, upgrade and operate a dumpsite, the environmental risks it poses must be carefully assessed. A dumpsite (or landfill) risk assessment involves technical investigations (stability, groundwater contamination, presence of hazardous waste, waste amount and volumes, landfill hydrology, etc.) and environmental impact assessments (hydrological, ecological, health, socio-economic etc.). These processes often require a great deal of technical competence and consultation with the interested and affected parties, specifically the adjacent communities.

3.4 Source-Pathway-Receptor conceptualization

Typically, the risk assessment process involves a set of logical, systemic, and well-defined activities that provide decision makers with a sound identification, measurement, quantification, and evaluation of the risk associated with certain natural phenomena or man-made actions (Kurian et al. 2005). Estimating the potential adverse impacts of the waste disposal facilities on public health and the environment is an extensive and costly process which requires use of the Source-Pathway-Receptor model. S-P-R relations can be developed once the following items have been clearly defined.

Source

I. Areal extent of dumpsite and total amount of solid waste disposed

II. Characteristics of the site such as the depth of solid waste and degree of compaction

III. Characteristics of the wastes accepted by the site owner/operator during past and future active life

Pathway

I. Concentration, gradient, flow direction and flow rate of pollutants through surface and groundwater, air and soil contamination

II. Persistence and transformation of the pollutants and their transformation products

III. Permeability and absorptive capacity of soil and underground geological formations

IV. Precipitation, wind patterns and mass movement of water on surface and in soil

Receptor

I. Size and extent of the impact area (soil, water, and air)

II. Number of people and especially sensitive populations that could be influenced by the release of pollutants from the site

III. Total period over which pollutant release would likely occur and duration of potential exposure

IV. Synergistic and antagonistic impacts of pollutant releases on ecosystem (biological and physicochemical environment)

V. Adverse health impact that might occur

3.5 Risk assessment methodology approach

Typically, the risk assessment methodology is a structured, transparent, and practical process that will aid decision-making, and often makes use of a phased (step-by-step) approach. A phased approach ensures that the greatest amount of effort and resources may be targeted where the most vulnerable and sensitive receptors are located or where there is significant uncertainty combined with potential for significant environmental damage to occur (Environmental Protection Agency, 2007). The phased approach is presented as three steps:

1) Development of Conceptual Site Model (qualitative),

2) Site Investigations and Testing (quantitative), and

3) Refinement of Conceptual Site Model based on qualitative and quantitative assessments.

The basic framework for risk assessment is presented in the following section.

3.5.1 Step 1: Development of a Conceptual Site Model (CSM) for Risk Screening and Prioritization

A CSM provides a comprehensive description of the release mechanisms, source, geology, hydrology and distribution of pollutants in solid, aqueous and vapor phases. It answers three fundamental questions about the site: 1) where does the contamination mostly reside? 2) where is contamination being transported? and 3) in what phases does the contamination exist?

A sample pictorial illustration of a CSM model is shown in Figure 3.1. CSM identifies possible Source-Pathway-Receptor (S-P-R) linkages, provides a preliminary or qualitative risk assessment of the site, and includes an assessment of the likelihood and magnitude of any effects of each linkage. The initial CSM assessment of a dumpsite should involve collecting and evaluating data on the dumpsite in question, as well as exposure routes and receptors. When combined, this information will facilitate detailed technical assessments in Step 2.

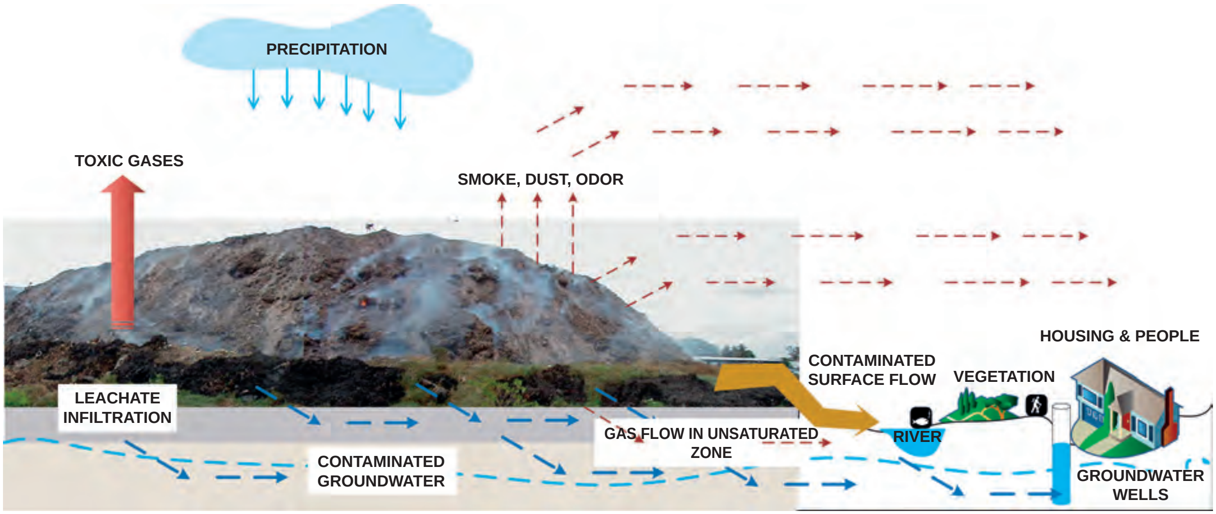

Figure 3.1 Illustration of Source-Pathway-Receptor (S-P-R) in Conceptual Site Model (CSM)

The conceptual site model is a means of understanding the way the dumpsite is likely to behave. The Environment Agency of England and Wales has defined a conceptual model as follows, 'A textual or graphical representation of the relationship(s) and receptor(s) developed on the basis of hazard identification and refined during subsequent phases of assessment' (Environment Agency, 2000). In simple terms, this means that a picture is built up progressively, on the basis of systematic investigations, through the application of a conceptual model of the relationship between the existence of a potential hazard and the linkage to the likely receptors. This programme of investigations is designed to establish the actual situation (Environmental Protection Agency, 2007). A well-defined Conceptual Site Model (CSM) should be used as a basis for all subsequent risk assessments and to identify all possible sources (S), pathways (P) and receptors (R) as well as the processes that are likely to occur along each of the S-P-R linkages and uncertainties. CSM development should be an iterative process, with the principles it applies being closely aligned with the proposed approach to risk assessment methodology, as illustrated in Figure 3.1. There are three key stages of CSM development:

1) Desk study and site inspection (including walkover survey which provides information for the initial development of a CSM)
2) Site investigation (that may be required to test and refine the initial model)
3) Environmental monitoring/modelling to validate the CSM

The objective of the initial desktop survey is to conduct a preliminary site investigation and to develop a preliminary report that enables an early decision to be taken before further investment in studies and remediation. The investigation should focus on the following main aspects;

1) Site location and proximity
2) Historical use and development of the site
3) Ecological environment
4) Geology and soil conditions
5) Climate and hydrology
6) Socio-economic situation

The risk screening process requires expert knowledge. However, a basic framework for risk assessment will be presented in the following section.

Risk screening

The following risk screening tool has been developed based on the work by Kurian et al., 2005. The screening structure consists of 27 parameters identified by academics, municipal officers, regulators, consultants, and environmentalists as the most significant preliminary screening parameters. These parameters are attributed a weightage (0 to 1,000) based on their relative importance, then the weights of attributes (W_i) are assigned using pair-wise comparison (Canter, 1996) such that the total weightage equals 1,000. Each attribute is measured in terms of a sensitivity index (S_i) on a scale of 0 to 1 to facilitate computation of cumulative scores, called the Risk Index (***RI***), which can be used for classification of dumpsites for closure or rehabilitation. According to the index, "0" indicates zero or very slight potential hazard, and "1" indicates the highest potential hazard (Saxena and Bhardwaj 2003; Kurian et al., 2005).

$$RI = \sum_{i=1}^{n} W_i S_i$$

where,

W_i - weightage of the i^{th} variable, ranging from 0–1,000

Si - sensitivity index of the i^{th} variable, ranging from 0–1

RI - Risk Index variable, ranging from 0–1,000

n -number of variables

Dumpsites with higher scores (***RI***) indicate higher risk to human health and warrant immediate remedial measures on-site, with the priority dropping accordingly. Those with the lowest scores indicate low sensitivity and insignificant environmental impacts. The following presents the proposed criteria for use in hazard evaluation based on the hazard potential index.

Table 3.1 Attribute weightage and sensitivity (adapted from Kurian et al., 2005)

No.	Attribute	Attribute Weightage	Sensitivity Index			
			0.0–0.25	0.25–0.5	0.5–0.75	0.75–1.0
	I - Site specific criteria					
1	Distance from nearest water supply source (m)	69	> 5000	2500–5000	1000–2500	< 1000
2	Depth of filling of waste (m)	64	< 3	3–10	10–20	> 20
3	Area of the dumpsite (Ha)	61	< 5	5–10	10–20	> 20
4	Groundwater depth (m)	54	> 20	10–20	3–10	< 3
5	Permeability of soil (1 x 10^{-6} cm/s)	54	< 0.1	1–0.1	1–10	> 10
6	Groundwater quality	50	Not a concern	Potable	Potable if no alternative	Non-Potable
7	Distance to critical habitats such as wetlands and reserved forest (km)	46	> 25	10–25	5–10	< 5
8	Distance to the nearest airport (km)	46	> 20	10–20	5–10	< 5
9	Distance from surface water body (m)	41	> 8000	1500–8000	500–1500	< 500
10	Type of underlying soil (% clay)	41	> 50	30–50	15–30	0–15
11	Life of the site for future use (years)	36	< 5	5–10	10–20	> 20
12	Type of waste (MSW/HW)	30	100% MSW	75% MSW + 25% HW	50% MSW + 50% HW	> 50% HW
13	Total quantity of waste at site (t)	30	< 104	104–105	105–106	> 106
14	Quantity of wastes disposed (t/day)	24	< 250	250–500	500–1000	> 1000
15	Distance to the nearest village in the predominant wind (m)	21	> 1000	600–1000	300–600	< 300
16	Flood risk (flood period in years)	16	> 100	30–100	10–30	< 10
17	Annual rainfall at site (cm/y)	11	< 25	25–125	125–250	> 250
18	Distance from the city (km)	7	> 20	10–20	5–10	< 5

No.	Attribute	Attribute Weightage	Sensitivity Index			
19	Public acceptance	7	No Public concerns	Accepts Dump Rehabilitation	Accepts Dump Closure	Accepts Dump Closure and Remediation
20	Ambient air quality - CH_4 (%)	3	< 0.01	0.05–0.01	0.05–0.1	> 0.1
	II - Related to characteristics of waste at dumpsite					
21	Hazardous contents in waste (%)	71	< 10	10–20	20–30	> 30
22	Biodegradable fraction of waste at site (%)	66	< 10	10–30	30–60	60–100
23	Age of filling (years)	58	> 30	20–30	10–20	< 10
24	Moisture of waste at site (%)	26	< 10	10–20	20–40	> 40
	III - Related to leachate quality					
25	BOD of leachate (mg/L)	36	< 30	30–60	60–100	> 100
26	COD of leachate (mg/L)	19	< 250	250–350	350–500	> 500
27	TDS of leachate (mg/L)	13	< 2100	2100–3000	3000–4000	> 4000
	Cumulative attribute weightage	1000				

Table 3.2 Criteria for hazard evaluation based on the hazard potential index (Kurian et al., 2005)

Class	Overall Score	Hazard Evaluation	Step 2	Recommended Action
1	750–1000	Very High	Should proceed to risk assessment Step 2	Securely close the dump with no more land filling in the area. Should take remedial action to mitigate the impacts.
2	600–749	High	Should proceed to risk assessment Step 2	Securely close the dump with no more land filling in the area. Remediation is optional, if economical with high-tech solutions.
3	450–599	Moderate	Should proceed to risk assessment Step 2	Immediate rehabilitation of the dumpsite into sustainable landfill by appropriate technology
4	300–449	Low	Should proceed to risk assessment Step 2	Rehabilitate the dumpsite into sustainable landfill in a phased manner by appropriate technology; close the dumpsite if no plans for extension.
5	< 300	Very Low	May proceed to risk assessment Step 2	Potential site for future sustainable landfill; close the dumpsite if no plans for extension.

3.5.2 Step 2: Site investigations and testing

Step 1 will inform the scoping of Step 2, Site Investigations and Testing, if a high risk is identified and further refining of CSM is necessary.

Site investigations should focus on providing sufficient information to determine whether a linkage exists and set out both the significance of the S-P-R linkage and the risk posed by the hazards (waste type). For example, when investigating the source (dumpsite), it may be appropriate to use the investigative techniques of trial pitting, geophysics, probing or boreholes in a phased approach. The degree of uncertainty surrounding each site and the cost of the investigations should be balanced against the level of the perceived risk. Site investigations will have to determine whether the waste body has the potential to generate landfill gas and leachate. It is critical to analyze the stability of the ground below the dumpsite as well as the stability of the waste slope as most open dumpsites are located on steep slopes or weak ground (wetlands, marshes, riverbanks, etc.).

3.5.3 Step 3: Refinement of conceptual site model and quantitative risk assessment

Based on the information gathered during the Step 2 investigations, the CSM developed in Step 1 should be refined. Where appropriate, the risk screening methodology should be re-applied to validate the risk classification of the site prior to proceeding to the quantitative risk assessment. This approach enables the sensitivity and/or degree of uncertainty for each S-P-R linkage to be identified, based on which it can be determined whether a Generic Risk Assessment or Detailed Risk Assessment needs to be carried out.

A Generic Risk Assessment may be used at less sensitive locations and/or where the information is available to suggest that the level of risk is low. It is generally a deterministic (i.e., resulting in a pre-determined outcome given particular conditions) and conservative approach, which uses generic guideline values (i.e., values which are generally applicable to an entire group, e.g., based on the proposed future land use of the site).

On the other hand, in the case of a sensitive site or insufficient information together with a potentially high level of risk to the environment, a Detailed Risk Assessment approach will be required. This type of risk assessment is probabilistic (i.e., is based on probability or likelihood) and requires a substantial amount of site-specific data, which will have to be gathered if it has not already been obtained during Step 2.

3.6 Experience and qualifications required for risk assessment

In any dumpsite risk assessment exercise, it is very important to have a robust and transparent process, as it will be the subject of close scrutiny and will determine the remediation measures to be applied and the resources required to undertake the work. Thus, it is important to have experienced persons carry out or supervise the risk assessment.

Different levels of expertise and experience are required for the different phases of the methodology.

- Step 1: Conceptual site model, risk screening and prioritization requires the least amount of specialist input but does require a conscientious mindset and good understanding of the bases and development of conceptual models and source-pathway-receptor linkages. Furthermore, the importance of the risk assessment methodology to Step 1 must never be underestimated due to its fundamental influence on the entire risk assessment, as the results of the risk prioritization provide the initial risk classification on which all subsequent actions will depend. Those conducting the Step 1 risk assessment need to have been trained in risk assessment methodology.
- The guidance provided in Steps 1 and 2 of the risk assessment methodology will assist authorities to carry out the work themselves if they possess the relevant experience and expertise. In any case a suitably qualified, trained, and experienced professional in the field should carry out the risk assessment.

Alternatively, the guidance can be used to inform the specification for consultancy services. Comprehensive lists of public organizations which can provide the required expertise are shown in tables 5.1 and 5.2.

4 Planning requirements

The requirements for rehabilitation and safe closure include physical feasibility, environmental feasibility and operation and maintenance feasibility. As discussed in previous chapters, the safe closure of dumpsites forms a major part of the rehabilitation plan – e.g., a dumpsite extending over a wide area might need to be physically rearranged as well as safely closed, with the secured land used for future landfilling. Development of a new landfill, whether located at a previous dumpsite or new site, is required to follow standard landfill design, construction, and operation procedures. The content of this document does not deal with landfill design; however, most of the techniques used in rehabilitation and safe closure were derived from landfill design principles.

1) The general technical objectives of dumpsite rehabilitation to landfill and safe closure should include the following:
   a) To prevent slope failure and collapse due to unstable slopes
   b) To prevent wastes from littering or overflowing from the open dump site
   c) To prevent emissions, fires or explosions that may be caused by landfill gases
   d) To minimize offensive odors, pathogens, and vectors being emitted from landfill site
   e) To provide storm water run-off and drainage facilities
   f) To minimize environmental pollution caused by leachate from landfill site
   g) To prevent groundwater contamination
   h) To take measures for waste stabilization

2) Once the dumpsite is rehabilitated to a landfill for future use, technical objectives should be set as follows:
   a) To make and maintain slopes preventing failure and collapse due to instability
   b) To prevent waste from littering or overflowing
   c) To enable landfill gases to be safely emitted, preventing direct emissions, fires and explosions
   d) To minimize offensive odours, pathogens, and vectors
   e) To manage storm water diversion, and drainage facilities
   f) To collect, treat and safely dispose of leachate
   g) To monitor groundwater to assure contamination prevention measures are in working order
   h) To take measures for enhanced waste stabilization
   i) To implement appropriate maintenance activities of disposal sites such as providing for application of sufficient final soil cover and providing final soil cover on closed slopes, as well as post closure maintenance of cover, drainage, and vegetation
   j) To continue environmental monitoring work on issues such as water quality including leachate generation from surface water and groundwater, disposal site gases and air quality of disposal sites
   k) To maintain the surface condition of access roads to disposal sites

3) Safely closed dumpsites and closed landfills should be managed as regards the following:
   a) To implement measures to continue final cover management including repairing of exposed soil, vegetation, and drainage system
   b) To continue use of leachate and landfill gas collection and treatment systems until such emissions are of a safe limit requiring no treatment
   c) To continue post monitoring activities ensuring the stability of slopes and fill
   d) To facilitate the smooth transition from closure plan to post-closure land use plan

In summary, the appropriate measures and activities required to achieve safe closure should be determined based on the conditions of the site, including usage level, existing facilities, the surrounding environment and post closure land use.


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5 Collection of technical information for planning

The technical feasibility of rehabilitating a dumpsite to a landfill depends on many factors; however, the decision depends on the actual site. Once the risk assessment and Conceptual Site Model (CSM) have been developed, the operator/owner of the dumpsite should conduct a technical feasibility assessment to determine the best possible scenario. To carry this out, all the relevant technical information needs to be gathered, thus represents the key to the process.

5.1 Collection of general technical information

First, the following key information should be collected from the dumpsite location. This information may be collected if it relates to the whole landmass or relevant areas, depending on the type of information and practicality of collecting it. The types of information are:

1) Climate: Rainfall intensity and distribution, evapotranspiration, wind patterns, temperature, and humidity
2) Topography & Ground: Geology, soil, and spatial variation of ground condition
3) Hydrology: Presence of surface water, groundwater, and flow patterns
4) Ecology: Occurrence and distribution of flora and fauna
5) Background environment quality: Air, water, and soil quality in and around the site
6) Land use: Land use plan, urban development plan, zones, etc.

The above information is generally available as secondary data (e.g., climate, geology, surface hydrology, ecology, and environment quality), but if not readily available, a brief guide to information sourcing and technical surveys is shown in Table 5.1 below.

Table 5.1 Types and sourcing of general information required for rehabilitation planning

Type	Description	Secondary data sources	Surveys
Climate	Daily rainfall, evapotranspiration, wind pattern, temperature, and humidity data for minimum 10 years	• Department of Meteorology • Natural Resource Management Centre- Department of Agriculture • Disaster Management Centre-Ministry of Disaster Management	Not applicable
Topography	Land extent, topography, land use maps (1: 10,000) covering dumpsite and minimum 1 km radius from dumpsite	• Survey Department of Sri Lanka	Topographic survey (land survey or arial survey)
Hydrology	Surface water bodies and drainage patterns, occurrence, and distribution of groundwater	• Department of Irrigation • Mahaweli Authority • Sri Lanka Land Reclamation & Development Corporation • Natural Resource Management Centre- Department of Agriculture • Disaster Management Centre-Ministry of Disaster Management	Hydrological survey Groundwater monitoring using boreholes or electromagnetic surveys (e.g., Ground Penetration Radar- GPR, Resistivity)
Ecology	Occurrence and distribution of flora and fauna	• Department of Forestry • Department of Wildlife • Central Environmental Authority	Site-specific ecological survey
Background environment quality	Quality of air, water, and soil	• Central Environmental Authority • Natural Resource Management Centre- Department of Agriculture	Air, water and soil quality testing
Land use	Existing land use and future plans	• Urban Development Authority • District Secretariat • Department of Forestry • Department of Wildlife • Central Environmental Authority • Natural Resource Management Centre- Department of Agriculture • Disaster Management Centre-Ministry of Disaster Management • Mahaweli Authority, Sri Lanka • Sri Lanka Land Reclamation & Development Corporation • Survey Department of Sri Lanka • Provincial Council • Local Authority	Not applicable

5.2 Site-specific technical information

Site-specific technical information should be thoroughly evaluated based on the site survey/investigation. The items in Table 5.2 will be required to evaluate the dump site and to provide the proper measures for rehabilitation and safe closure.

Table 5.2 Types and sourcing of site-specific technical information for rehabilitation planning

Item	Proposed surveys/ information	Agencies
Topographic and Geological survey	The topographic and geological data of the sites should be collected, and further surveys should be carried out where necessary.	• National Building Research Organization • Survey Department of Sri Lanka • Universities • Registered consultancy firms
Structures and facilities of dump site	The details of existing dumpsite facilities, proposed landfill facilities and records of dumpsite operations should be collected. All facilities that are to be established in future should be clearly identified and indicated on the plan.	• National Building Research Organization • Universities • Registered consultancy firms
Shape and stability of filled waste	The shape of the site should be clarified to evaluate the stability of the landfill site.	• National Building Research Organization • Universities • Registered consultancy firms
Total amount of disposed waste	The total amount of the filled waste should be estimated based on the operation record and topographic profile of the site.	• Operator • National Building Research Organization • Universities • Registered consultancy firms
Quantity and quality of leachate	Estimations should be made of the quantity and quality of leachate generated from the dumpsite. On-site quantitative and qualitative measurements and mathematical modeling/ calculations are required.	• National Building Research Organization • Universities • Registered consultancy firms
Quantity and quality of landfill gas	Estimations should be made of the quantity and quality of landfill gas generated from the dumpsite. On-site quantitative and qualitative measurements and mathematical modeling/ calculations are required.	• National Building Research Organization • Universities • Registered consultancy firms
Degradation of the filled waste	Information and data regarding the following should be collected and/or measured: • The physical composition of the waste • Mechanical properties of dumped and remolded waste	• Operator • National Building Research Organization • Universities • Registered consultancy firms

In addition to general and site-specific information and data, rehabilitation and safe-closure tasks may require potential sites for sourcing cover soils, temporally storage of excavated waste, alternative access roads to be identified, as well as facilities necessary during construction (site office, stores, machine workshops, etc.) to be established.

If any existing physical infrastructure facility, dwelling or residential units are to be relocated, the developer should formulate a separate relocation and resettlement plan. The physical and infrastructure plan for resettlement is often separate from the dumpsite rehabilitation or safe closure plans.

5.3 Identification of potential sites for upgrading

Identification of the type of dumpsite that can be upgraded to a landfill for ongoing use as a final disposal facility is one of the most challenging tasks for an LA, as the type of dumpsite depends on the characteristics of the site in question. However, general types of dumpsite that can potentially be upgraded to a proper landfill through rehabilitation process are as follows:

i. Above ground dumpsites
ii. Below ground dumpsites
iii. Above & below ground dumpsites
iv. Slope dumpsites
v. Valley dumpsites

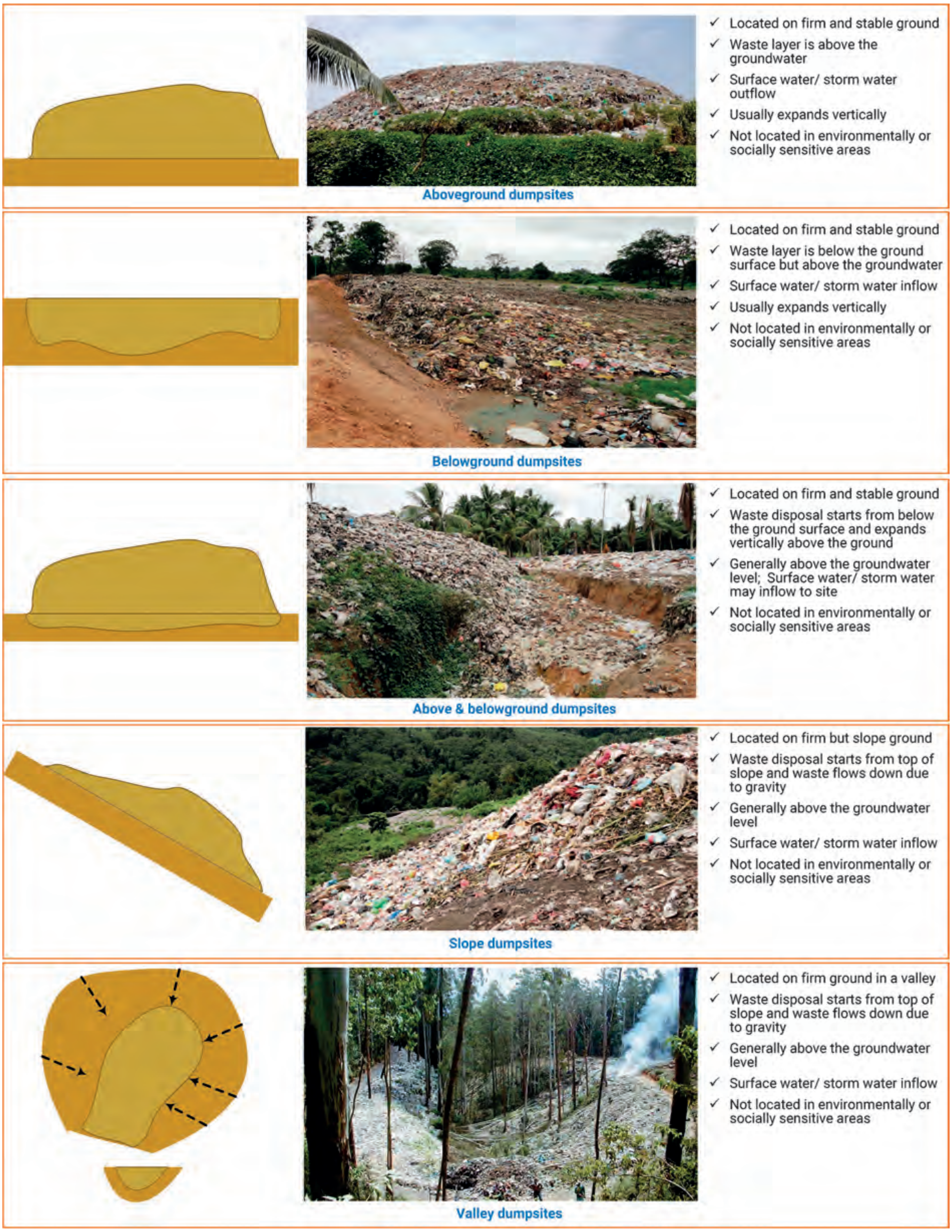


Figure 5.1 Types of dumpsites having potential for upgrading

6 Decision-making approaches

If the decision taken is to upgrade a dumpsite to a proper landfill facility, the developer should ensure that all necessary requirements to contain waste in-situ are met. However, from a practical point of view such dumpsites rarely exist, thus the best practice is to develop a safe closure plan for the existing dumpsite and start a new engineered/sanitary landfill for future use.

6.1 Preceding and precautionary approach

If operation of a dumpsite is to cease and the site is to be closed, it is necessary to formulate a safe closure plan, which comprises the actual Physical Closure (PC) and the Post-Closure Management (PCM). This also applies to abandoned sites.

6.2 Prioritization of dumpsites

The priority of rehabilitation of a dumpsite depends on the level of risk it poses for the environment and society. These risks (see section 3.5 for description) are classified into five levels (as given on Table 3.2).

Technically, the priority is established based on two evaluation criteria:

i. Potential to use the dumping area (or available lands around dumpsite) for establishing/ upgrading a landfill for future use

ii. Level of intervention needed to contain waste on-site or off-site

In addition, the land use potential of the dumpsite is an important socio-economic criterion to be considered and is crucial for developing a post-closure land use plan. The developer should analyze the specifics of the intended utilization of the land the closed dumpsite is on, such as for housing, as well as any planned development in the surrounding areas in the future for both closed as well as currently operating sites. For residential land use at closed sites, it is necessary to implement a strict safe closure that takes sufficient consideration of public health and safety. As development progresses surrounding a closed dumpsite it becomes a social requirement to effectively use the land formerly occupied by the closed dump site. Furthermore, in addition to environmental risks, closed dumpsites create problems related to depreciation in surrounding land values and difficulties in land transactions.

Accordingly, Figure 6.1 illustrates a brief guide for decision making. Further, the five classes of dumpsites can be further described as follows.

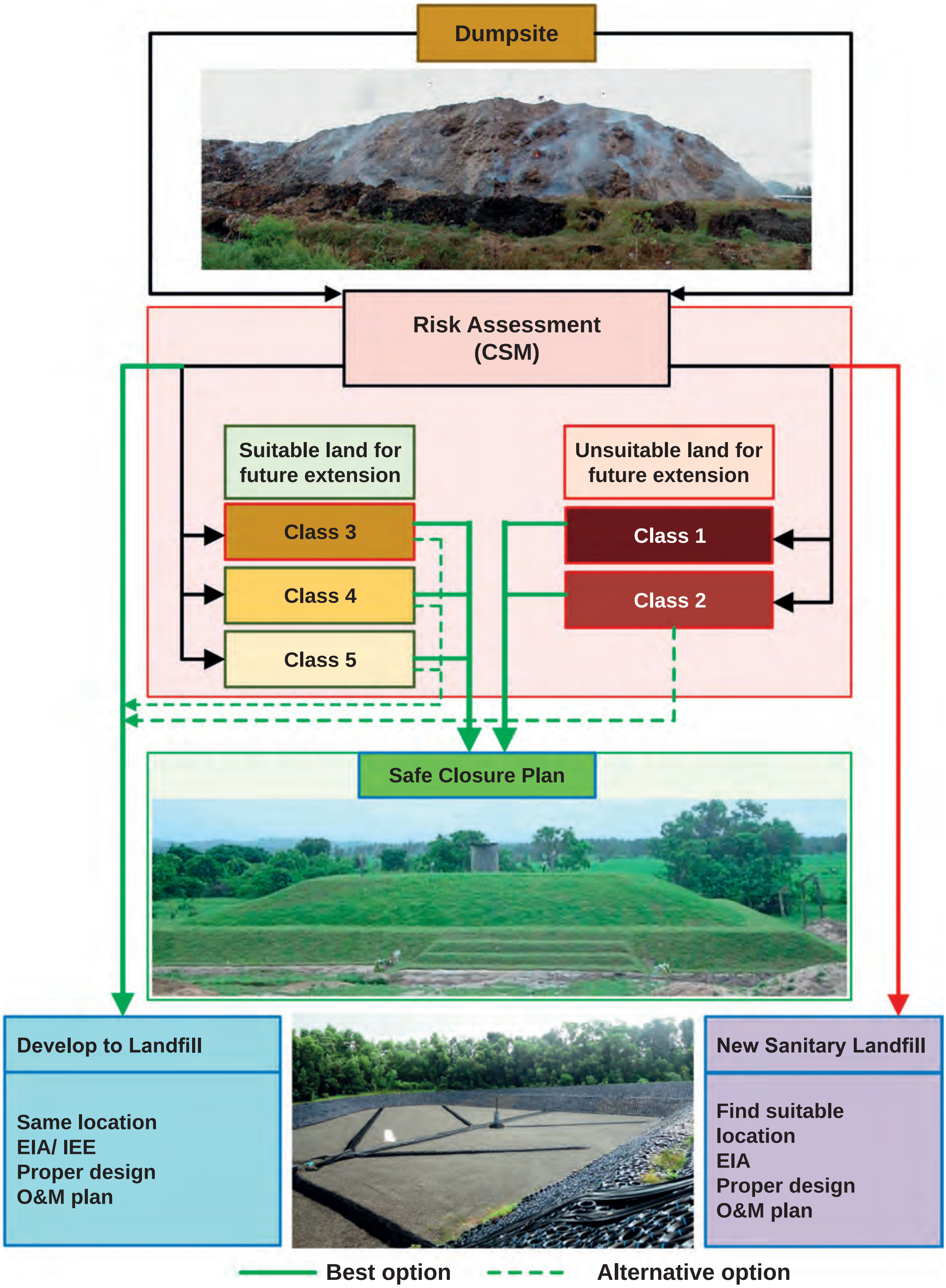


Figure 6.1 Hazard risk potential-based decision-making guide for safe closure or rehabilitation of dumpsite

6.2.1 Class 1 dumpsites

Class 1 dumpsites are sites with a hazard risk potential/ score of more than 750 – the highest hazard potential – and consequently are set as highest priority sites for immediate rehabilitation. These sites have a high environmental impact risk in their current condition as well as after closure and rehabilitation.

Examples of Class 1 landfills are sites close to water supply sources located downstream of a river system and where the groundwater is a source of drinking water. Such sites require advanced safe closure measures for leachate treatment and groundwater protection.

These sites are also generally unsuitable as locations for sanitary landfills, thus the only rehabilitation option is to safely close the dumpsite using all feasible techniques to mitigate any risks.

The owners and operators of Class 1 dumpsites should immediately develop safe closure strategies and plans for establishing a sanitary landfill in a suitable new location or adopt alternative waste disposal methods.

6.2.2 Class 2 dumpsites

Class 2 dumpsites are sites with a hazard risk potential/ score of between 600 and 749. They have the second highest hazard potential and consequently are set as high priority sites for immediate rehabilitation. These sites also involve a high risk of environmental impact in their current condition, but this can be minimized by applying appropriate techniques.

Examples of Class 2 landfill sites are those close to water bodies and upstream of a river system and where the surface and groundwater in downstream areas are sources of drinking water. Such sites require advanced safe closure measures for leachate treatment and groundwater protection.

These sites are generally unsuitable as locations for sanitary landfills; therefore, advanced technical interventions may be required if a decision is made to upgrade a dumpsite to a sanitary landfill. Such advanced techniques are often site-specific. Consequently, the most economically feasible option is to safely close the dumpsite by applying appropriate techniques to mitigate the risk. In the safe closure plan, it is necessary to incorporate measures to minimize the leachate generated from rainwater infiltration into the dumpsite and washout of waste to the surrounding areas.

The owners and operators of Class 2 dumpsites should develop safe closure strategies and plans for establishing a sanitary landfill in a suitable new location or alternative waste disposal methods.

6.2.3 Class 3 dumpsites

Class 3 dumpsites are those with a hazard risk potential/ score of between 450 and 599 and have a moderate hazard risk, therefore can potentially be upgraded to landfills at their current location. However, as the waste at these dumpsites continues to pose a risk, safe closure is a priority. Any risks of environmental impact of a site in its current condition can be minimized through use of appropriate techniques.

Examples of Class 3 landfill sites are those in the upstream parts of river systems and where the surface and groundwater in downstream areas are sources of drinking water. Hence, advanced safe closure measures are needed for leachate treatment and groundwater protection.

These sites are generally suitable for locating a sanitary landfill; therefore, common technical interventions can be used if the decision is made to upgrade a dumpsite to a sanitary landfill. The techniques used are often general in nature; however, owing to the risk posed by the existing waste dumpsite, the preferred option is to safely close the dumpsite by applying appropriate techniques to mitigate the risk. In the safe closure plan, it is necessary to incorporate measures to minimize leachate generated from rainwater infiltration into the dumpsite and washout of waste to the surrounding areas.

Further, as the hazard risk is moderate the site has potential to be upgraded to a sanitary landfill. Therefore, Class 3 dumpsites should be developed into sanitary landfills if the owner wishes to continue disposing of waste at the same location.

6.2.4 Class 4 dumpsites

Class 4 dumpsites are those with a hazard risk potential/ score of between 300 and 449, which is a low hazard risk, therefore can potentially be upgraded landfills at their current location. However, the waste at the dumpsite continues to pose a risk if not handled carefully. In these sites, the environmental impact risk of the current condition can be minimized through appropriate methods.

Examples of Class 4 landfill sites are those located in remote areas where the likelihood of downstream and groundwater contamination is low. Hence, moderate safe closure measures for rainwater infiltration and groundwater protection are required.

These sites are often suitable for locating a sanitary landfill; therefore, common technical interventions can be used if the decision is made to upgrade a dumpsite to a sanitary landfill. The technics are often general. However, owing to risks posed by the existing waste dump, the preferred option is to shift or enclose the existing waste in the dumpsite through use of appropriate methods. If the dumpsite is to be closed, measures to minimize leachate generated from rainwater infiltration into the dumpsite and washout of waste to the surrounding areas are required.

As the hazard risk is low the site has potential to be upgraded to a sanitary landfill. Therefore, Class 4 dumpsites should be developed into sanitary landfills if the owner wishes to continue disposing of waste at the same location.

6.2.5 Class 5 dumpsites

Class 5 dumpsites are those with a hazard risk potential/ score of below 300, the lowest hazard risk, therefore have high potential for upgrading into landfills at their current location. However, waste at these dumpsites continues to pose a risk if not handled carefully. Any environmental impact risk of a site in its current condition can be minimized through use of appropriate techniques.

Examples of Class 5 landfills are those in remote areas where the likelihood of downstream and groundwater contamination is very low due to low rainfall intrusion and the absence of a permanent groundwater table below the dumpsite. Such sites only require a moderate level of safe closure measures for control of rainwater infiltration to the dumpsite and groundwater protection.

These sites are appropriate as locations for sanitary landfills, therefore common technical interventions can be used if the decision is made to upgrade a dumpsite to a sanitary landfill. The techniques used to do this are often general, however, owing to the risk posed by the existing dumpsite, the appropriate option is to shift or enclose existing waste at the dumpsite applying appropriate techniques. If the decision is made to close the dumpsite, it is necessary to incorporate measures to minimize leachate generated from rainwater infiltration into the dumpsite and washout of waste to the surrounding area.

As the hazard risk is very low the site has the potential to be upgraded to a sanitary landfill. Therefore, class 5 dumpsites should be developed into sanitary landfills if owners wish to continue disposing of waste at the same location.

6.3 Different types of dumpsites suitable for upgrading to landfill

When a dumpsite is being upgraded or closed, appropriate measures should be undertaken to prevent environmental pollution caused by leachate or methane gas which results from decomposition and degradation of the waste. As shown in Figure 6.1, developers should take the decision as to whether the existing dumpsite is suitable for upgrading to a proper landfill or requires immediate closure based on the risk assessment criteria discussed above.

6.3.1 Closure levels

The extent of the closure programme may vary depending on the current conditions of the dumpsite. In general, irrespective of future expansion to a sanitary landfill or safe closure, safe closure plans should be developed for the entire dumpsite or existing/abandoned portion of the dumpsite. In developing the safe closure plan, the site conditions, amount of waste disposed, types of waste dumped, as well as other factors need to be considered through use of pre-closure assessment.

6.3.2 Site-specific approach

To determine the safe closure requirements, the conditions of the dump site should first be investigated. The conditions on-site will also determine the risks related to environmental pollution/hazards as well as potential for post-closure land use. Nonetheless, even after a dumpsite has been closed, proper maintenance or post-closure management should be carried out continuously to monitor the environmental conditions within and throughout the surroundings of the dumpsite. Subsequently, when the potential hazards of the dumpsite no longer pose a threat, the applicable post closure land-use plan can then be implemented.

6.3.3 Dumpsite mining

MSW dumpsite/landfill mining, also known as dumpsite/ landfill reclamation, refers to the process of excavating previously disposed of materials from a dumpsite/landfill to recover directly recyclable resources (metal, glass, plastic, etc.), combustibles (plastics, paper etc.), and soil-like fractions (soil, sand, gravel, rock etc.). The purpose of mining may also be to extend the usable volume of a dumpsite/landfill. Landfill mining may be required in unison with site remediation techniques such as bioremediation and biomining to detoxify contaminated land and excavated waste.

Figure 6.2 Assessing the potential of dumpsite mining by trial excavations

Assessment of technical, environmental, and economic feasibility is the first and foremost factor to be considered before deciding to move forward with dumpsite/landfill mining activity. In practice, an important part of the work involves trial excavation and analysis of the composition and resource recovery potential of mined waste (Figure 6.2).

Though the potential of dumpsite mining has been discussed widely, dumpsite/landfill mining has only been practiced to a limited extent at several locations in the word. The feasibility of dumpsite mining depends on many factors, such as potential of resource recovery, cost of mining, disposal of mined materials and stability of dumpsite/landfill. Therefore, it has generally been municipal authorities that perform dumpsite/landfill mining operations, which directs learning processes towards solving dumpsite/landfill problems rather than resource recovery. Dumpsite/landfill mining is not, however, necessarily to be perceived as just a recycling activity. It could also be understood as a remediation or mining activity (Krook et al., 2012). Thus, applied research such as demonstration projects, reviews of experiences from previously conducted projects and interviews with societal actors (e.g., legislators and authorities) is essential for understanding the capacity of technology and conditions for realization of dumpsite/landfill mining – for example, as regards how much of the deposited resources can actually be transformed into marketable recyclables, and how current environmental legislation, taxes and subsidies will be applied to landfilling.

Thus, there is a need to develop standardized frameworks in order to evaluate critical factors for economic and environmental performance – frameworks necessary for decreasing the uncertainties that currently prohibit implementation of dumpsite/landfill mining.

6.4 Legal process of dumpsite rehabilitation and safe closure

Dumpsite rehabilitation, safe closure or any other development of/alteration to existing dumpsites should follow the proper process that ensures legal clearances and public acceptance. Below lists the basic processes that should be followed:

1) The operator/owner (e.g., Local Authority) of a dumpsite assesses the dumpsite to clarify the environmental pollution potential (risk assessment 3.2) and land use potential.

2) Based on the risk assessment, the operator/owner sets the closure level of the landfill site (Figure 6.1).

3) The operator/owner of the dumpsite prepares a “Safe Closure/Rehabilitation Plan” for submission to the Provincial/State government and Central Environmental Authority for approval. Generally, the review process takes at least 12 months, thus this plan needs to be submitted at least one year before the intended date of commissioning the work. The approval agencies may request an Environmental Impact Assessment (EIA) , an Initial Environmental Examination (IEE) or preliminary appraisal (Environmental Protection Licensing/ Environmental Appraisal) be conducted based on the scale and nature of rehabilitation/safe closure plan.

4) It is the decision of project approving agencies to examine the rehabilitation/safe closure plan and approve it if it meets the requirements. As part of the approval process, project approving agencies will carry out monitoring work during the physical work as well as following the safe closure of the site.

5) After gaining approval, the operator/owner of a landfill site implements physical closure work and post closure management activities. These activities should be periodically reported to the Central Environmental Authority (CEA) or/and any other organization identified at the project approval stage.

6) Once the dumpsite is closed or rehabilitated, the owner develops a "post-closure land use plan" and submits it to the relevant authorities, such as the Provincial Council, Divisional Secretariat, Divisional Secretariat, Waste management Authority (Western Province), National Solid Waste Management Support Centre, Urban Development Authority, Sri Lanka Land Development Cooperation (SLLDC), Marine Environment Protection Authority (MEPA), Department of Wildlife Conservation, Forest Department, National Water Supply & Drainage Board (NWS&DB), Natural Resources Management Centre (NRMC), and Disaster Management Centre (Ministry of Defense) or any other organization identified during the approval process.

7) Upon approval being granted, the owner then carries out the plan for post-closure land use.

6.5 Health and safety precautions

The health and safety concerns of waste dumpsite/landfill rehabilitation are related to the excavation of dumpsite/landfills, i.e. leaching of hazardous substances, slope stability issues and risks for formation of explosive and poisonous gases (Kurian et al., 2005).

The general perspective on dumpsite rehabilitation is that the risks for occupational health impacts are generally low, although gaseous emissions may be significant, especially at the bottom layers of the dumpsite/landfill. Thus, it is imperative that authorities will in most cases plausibly require an approved health and safety plan involving procedures for management of hazardous waste, systematic monitoring of air quality, and trained and well-equipped workers.

Therefore, it is a prerequisite to prepare and obtain necessary approval for an Emergency Response Plan (Contingency plan) for emergency situations such as health hazard for workers, accidents, and fires/explosions. In addition, a comprehensive Environmental Monitoring Plan (EMP) should be developed to avoid or minimize the adverse impacts to the physical, biological, and social environments during rehabilitation projects.

7 Dumpsite rehabilitation and closure levels

Dumpsite rehabilitation and closure levels depend on many technical and socio-environmental factors. However, this section provides a brief guide for decision makers to identify different levels of improvements that have been conceptualized based on technical feasibility and risk potential. In this guide, the dumpsite closure levels are classified into four categories, C1 to C4, based on previous work related to rehabilitation manuals, such as the National Solid Waste Management Commission (NSWMC), (2010) and Japan International Cooperation Agency, (2004).

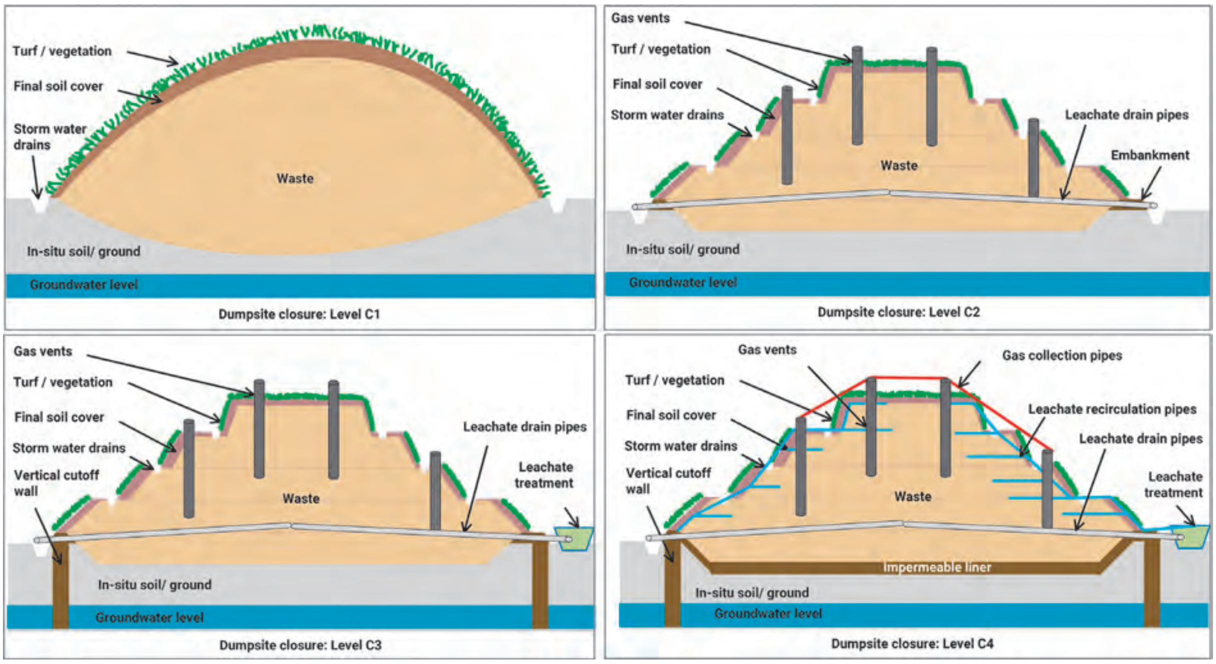


Figure 7.1 Schematic comparison of dumpsite rehabilitation and closure levels

7.1 Consideration on setting the safe closure level

The level of safe closure for each group can basically be set according to the priorities shown in Table 7.1. However, to estimate the scale of budget required, as well as other items, it is necessary to estimate which closure level from C1–C4 should be applied to each dump site.

The safe closure level, which should be decided based on the results of landfill surveys for each dump site, depends on the degree of environmental impact at each site; therefore, the closure level is set based on the items of the environmental risk potential, which were discussed in earlier chapters.

First, it is necessary to classify each item of the environmental risk potential into four groups relating to the safe closure levels C1–C4. Following this, the necessity of each closure level is judged from the total score of each item which was calculated when setting the priorities for environmental risk potential.

The relationships between the safe closure levels C1–C4 and environmental risk potential items are shown in Table 7.1.

In closure level C1, where final cover is assessed with the aim of maintaining good sanitary conditions, the indices for the environmental improvement are “waste cover”, “vegetation condition”, “vector and wild animals”, and “odour, landfill gas and smoke”.

In closure level C2, where an assessment is made of the storage structure, reformation and protection of slopes, storm water drainage facilities, gas vents, etc. with the aims of preventing outflow of waste and early stabilization of the landfill site, the indices for the environmental improvement are "landslide", "soil subsidence", "odour, landfill gas and smoke", and "leachate quantity".

In closure level C3, assessment is made of the leachate collection system and leachate re-circulation with the aim of preventing environmental impact from the leachate, and the indices for the environmental improvement are "leachate quantity", and "location of water intake".

In closure level C4, assessment is made of leachate treatment and seepage control work with the aim of ensuring groundwater protection, and the indices for the environmental improvement are "location of drinking water well", and "geological condition".

Table 7.1 Requirements for dumpsite rehabilitation and closure levels

	Closure level	Requirements
C1	Minimum closure level	• Waste dump is covered with cover soil • Vegetative cover is established on cover soil to protect from erosion; also for scenic beauty • Drains are established around the closed dumpsite to divert stormwater away from dump
C2	Basic closure level	• Waste dump is reshaped and restructured to ensure stability (geometry) in order to avoid slope failure • If required, embankments are constructed to protect from sliding in hilly landscapes • Make stable slopes (1 vertical: 3 horizontals; maximum 5 m vertical expansion) and setback terraces (3–5 m width) • Slopes and terraces (optional) are covered with soil • Vegetative cover is established on cover soil to protect from erosion; also for scenic beauty • Drains are established on terraces, slopes and around the closed dumpsite to divert stormwater away from dump • Leachate drain pipes are installed on slopes and bottom (if feasible) to allow leachate to drain from dump • Vertical gas vents are installed to reasonable depth on the dump
C3	Moderate closure level	• Waste dump is reshaped and restructured to be stable (geometry) to avoid slope failure • If required, embankments are made to protect from sliding in hilly landscapes • Make stable slopes (1 vertical: 3 horizontals; maximum 5 m vertical expansion) and setback terraces (3-5 m width) • Slopes and terraces (optional) are covered with soil • Vegetative cover is established on cover soil to protect from erosion; also for scenic beauty • Drains are established on terraces, slopes and around the closed dumpsite to divert stormwater away from dump • Leachate collection pipes are installed in each lift, on slopes and bottom (if feasible) to collect leachate to centralized collection point • Leachate treatment system is installed • Vertical gas vents are installed to a reasonable depth on the dump • Groundwater monitoring wells are installed

	Closure level	Requirements
C4	Advance closure level	• Waste dump is reshaped and restructured to be stable (geometry) to avoid slope failure • If required, embankments are made to protect against sliding in hilly landscapes • Make stable slopes (1 vertical: 3 horizontals; maximum 5 m vertical expansion) and setback terraces (3-5 m width) • Impermeable liner is installed at the bottom of the dumpsite to prevent leachate percolation • Slopes and terraces (optional) are covered with cover soil • Vegetative cover is established on cover soil to protect from erosion; also for scenic beauty • Drains are established on terraces, slopes and around the closed dumpsite to divert stormwater away from dump • Leachate collection pipes are installed in each lift, on slopes and bottom (if feasible) to collect leachate to centralized collection point • Leachate treatment system is installed • Vertical gas vents are installed to a reasonable depth on the dump • Groundwater monitoring wells are installed • Landfill gas collection system connecting all gas wells is installed • Landfill gas is flared for emission control or sent to landfill gas combustion system for energy recovery

8 Maintenance of rehabilitated or closed facilities

8.1 Covers and dykes

Maintenance of the top cover and dykes is needed to avoid damage to the top cover or storage structure, thus preventing the following problems:

- Scattering or outflow of waste
- Occurrence of offensive odours or vectors
- Disaster which has direct impact on human life and property, such as collapse of the landfilled waste
- Obstruction of post-closure land use caused by ground erosion
- Destruction of the landscape
- Increased quantity of leachate due to increased soaking of rainwater into landfilled layer

To inspect the top cover, surface drains and dykes, a visual inspection of the parts on the ground should be performed in accordance with the following items. The frequency of regular inspection should be decided in view of the condition of these facilities. In addition, a further inspection should be performed after heavy rain. Areas where stress is concentrated due to structural reasons should be designated in advance as areas requiring inspection. The following items should be checked:

- Leakage from dykes
- Cracks in the top cover and dykes
- Subsidence of the cover and dykes
- Erosion of the top cover and dykes
- Swelling of the slope
- Collapse or slippage of slope
- Disappearance of vegetation on the cover and dykes.

If damage has been confirmed, repairs should be performed. If cracks and corrosion remain, such corrosion will be accelerated by rainfall and repairs will become difficult. Therefore, frequent, prompt checks and timely repairs work are vital.

8.2 Surface stormwater drainage on the top cover

Surface drainage is impended by subsidence of the landfill site due to instability or decomposition of the landfilled waste. Obstruction of surface drainage causes damage to the top cover and retaining structure by rainwater and causes an increase in leachate due to rainwater soaking into the landfilled layer.

To inspect the state of surface stormwater drainage, a visual inspection should be performed in line with the following items:

- Damage to surface stormwater drainage
- Existence of differential subsidence
- Deposition of waste, earth, and sand
- Existence of overflow points or stagnant water points

The frequency of regular inspection should be decided in view of the condition of surface drainage. In addition, an extra inspection should be carried out following heavy rain.

8.3 Cut-off drainage around the site

If a fault occurs to the function of the cut-off drainage due to obstruction from discharged earth, sand and so on, this increases the quantity of leachate due to rainwater soaking into the landfilled layer.

To inspect the cut-off drainage, a visual inspection should be performed in line with the following items:

- Damage to cut-off drainage
- Deposition of waste, earth and sand
- Existence of overflow points or stagnant water points
- Situation of inflowing rainwater as well as earth or sand from the surrounding area

The frequency of regular inspection should be decided in view of the condition of the cut-off drainage. In addition, an extra inspection should be performed after heavy rain.

Management roads should be built and assessed to improve access to other sites of cut-off drainage as required so that maintenance work, such as removal of earth and sand that may have accumulated at the site can be performed promptly.

8.4 Gas ventilation pipes

Gas ventilation pipes are often damaged by the subsidence of a landfill site, which is caused by destabilized or decomposition of the landfilled waste. Pipes also become clogged with discharged earth and sand. If there is damage or clogging of gas ventilation pipes, proper venting of the landfill gas becomes difficult and this affects the stability of the landfill site.

For gas ventilation pipes exposed on the landfill surface, the following item should be checked by visual inspection:

- Transformation and damage of gas ventilation pipes exposed on the landfill surface

For gas ventilation pipes located below the landfill surface, since it is difficult to carry out visual inspection, these should be judged based on the following items:

- Change in the amount of gas generated and concentration of landfill gas from gas ventilation pipes
- Gushing of gas from the landfill surface not originating from the gas ventilation pipes
- Change in leachate quality

8.5 Leachate collection pipes

If damage or clogging of leachate collection/drainage pipes occurs, it becomes difficult to manage and treat the leachate properly. Moreover, since the groundwater level inside the landfill will rise, there is a higher risk of leachate infiltrating underground. This will raise the water pressure above the designated level and put pressure on the retaining facilities.

For leachate collection/drainage pipes exposed on the ground, the following items should be checked by visual inspection:

- Cracks and holes in pipes
- Scale deposits inside pipes
- Leakage from the joints in pipes
- Clogging of the pipes (check inside the pipe from end of pipe)

Since most leachate collection/drainage pipes are buried underground, this should be estimated based on the following items:

- Leachate quantity at the end of leachate collection/drainage pipes
- Groundwater level inside the landfill
- Cracks and subsidence of the landfill surface
- Clogging of the pipes (check inside the pipe from end of pipe)

8.6 Leachate treatment facility

If the leachate treatment facilities are not functioning properly, it is difficult to perform stable treatment of the leachate meeting the desired treated water quality. This can cause water pollution downstream.

Inspection of the leachate treatment facility should be carried out based on the following items:

- Quantity and quality of raw leachate
- Quantity and quality of treated water
- Water level of leachate control facility
- Setting of operating conditions and adjustments based on water quality and operation data (PH, DO, ORP, MLSS, etc.)
- Moisture content of dehydrated cake, SS of squeezed water, operating conditions of equipment (if sludge treatment facility is installed)
- Check of chemicals, lubricants and fuel
- Check, adjustment and repair of individual equipment and machinery

8.7 Dumpsite and landfill site phytoremediation

Phytoremediation, the use of plant and vegetation to remediate contaminated land and water, has demonstrated its usefulness in waste management. Working from this standpoint, Nagendran et al., (2006) elaborates on the different mechanisms of phytoremediation by vegetation and its target pollutants (Table 8.2). Generally, phytoremediation coupled with irrigation provides a relatively inexpensive means of moving impaired water to a planted area or forest for treatment, greatly expanding the ways in which phytoremediation can be used. However, understanding of the dynamics of phytoremediation requires a multi-disciplinary approach involving the biology, biochemistry, and engineering of remediating systems. Even with such advances in processes however, the actual phytoremediation required must be adapted to dumpsite/landfill conditions. Thus, tremendous scope exists for investigating di erent aspects of this technology and its applications for MSW landfills and dumpsites.

Phytoremediation, as a means of detoxification or remediation of contaminated sites, has its own weaknesses and drawbacks, however. Physical and chemical remediation (excavation, extraction, stabilization, thermal conversion) may take weeks to months to accomplish whereas phytoextraction or degradation may need several years. Therefore, for sites that pose acute risks for human and other ecological receptors, phytoremediation may not be the sole technique of choice (Nagendran et al., 2006). Also, root contact is a primary limitation in phytoremediation applicability. Remediation with plants requires that contaminants be in contact with the root zone of plants, either through the growth of plant roots or by moving the contaminated media to the rootzone of plants, which may not be applicable in all situations. Moreover, high concentrations of contaminants and/or toxicants may inhibit plant growth and thus limit application on some sites or parts of sites. Plant biomass also decays and decomposes and spreads to other areas by harvesting and propagation. Consequently, to avoid recontamination and spreading of contaminants, a mechanism to extract and safely dispose of contaminated plants should be established in phytoremediation.

Table 8.1 Potential application of pytoremediation (modified from Nagendran et al., 2006)

Application	Description	Contaminants	Types of plants
Soils			
Phytotransformation	Sorption, uptake, and transformation of contaminants	Organics, including nitroaromatics and chlorinated aliphatics	Trees and grasses
Rhizosphere biodegradation	Microbial biodegradation in the rhizosphere stimulated by plants	Organics, e.g., PAHs, petroleum hydrocarbons, TNT, pesticides	Grasses, alfalfa, many other species including trees
Phytostabilization	Stabilization of contaminants by binding, holding soils, and/or decreased leaching	Metals, inorganics	Various plants with deep or fibrous root systems
Phytoextraction	Uptake of contaminants from soil into roots or harvestable shoots	Metals, inorganics, radionuclides	Various natural and selected hyperaccumulators, e.g., Thalaspi, Alyssum, Brassica
Water/ groundwater			
Rhizofiltration	Sorption of contaminants from aqueous solutions onto or into roots	Metals, radionuclides, hydrophobic organics	Aquatic plants (e.g., duckweed, pennywort), also Brassica, sunflower
Hydraulic control plume capture/ phytotrans	Removal of large volumes of water from aquifers by trees	Inorganics, nutrients, chlorinated solvents	Poplar, willow trees
Phytovolatilization	Uptake and volatilization from soil water and groundwater; conversion of Se and Hg to volatile chemical species	Volatile organic compounds, Se, Hg	Trees for VOCs in groundwater; Brassica, grasses, wetlands plants for Se, Hg in soil/sediments
Vegetative Caps	Use of plants to retard leaching of hazardous compounds from landfills	Organics, inorganics, wastewater, landfill leachate	Trees such as poplar, plants (e.g., alfalfa) and grasses
Constructed wetlands	Use of plants as part of a constructed ecosystem to remediate contaminants from aqueous waste streams	Metals, acid mine drainage, industrial and municipal wastewater	Free-floating, emergent, or submergent vegetation; reeds, cattails, bamboo

8.8 Vegetative buffer zones

Vegetative buffer zones, or "Green Belts" refers to areas that are kept in reserve within the allotted land of the rehabilitated dumpsite facility, around the core of the site, for the purpose of plantation and landscaping to reduce the adverse effects from pollutants like windblown litter, fugitive emissions (dust, gaseous emissions), noise, as well as to control soil erosion and so on. It also acts as a natural shield to protect people around the facility from these pollutants. However, currently no scientific basis is available for making provisions for vegetative buffer zones around waste landfill facilities In Sri Lanka.

The important factors to be considered in developing a vegetative buffer zone during dumpsite rehabilitation are:

- The plant species should be fast growing
- It should create a thick canopy cover
- It should be perennial and evergreen
- It should have a high carbon/CO_2 sink potential
- It should be effective in absorbing pollutants without growth being significantly affected

Accordingly, the following Table 8.2 provides to selecting vegetation for establishing vegetative buffer zones in dumpsite rehabilitation:

Table 8.2 Suggested species for vegetative buffer zone

Climate	Surface/ groundwater	Type of vegetation	Suggested species
Dry zone	No groundwater or perennial surface water	Drought tolerant perennial shrubs and trees	• *Ricinus communis (Castor oil/ Thel-Endaru)* • *Bauhinia racemose (Maila)* • *Samanea saman (Pare-Mara)* • *Gliricidia sepium (Wata-Mara)* • *Leucaena leucocephala (Ipil-Ipil)* • *Jatropha curcas (Wata-Endaru)* • *Azadirachta indica (Neem/ Kohomba)*
Dry zone	Shallow groundwater or seasonal surface water	Vegetation that can tolerate waterlogged conditions	• *Ricinus communis (Castor oil/ Thel-Endaru)* • *Samanea saman (Pare-Mara)* • *Terminalia arjuna (Kumbuk)* • *Filicium decipiens (Pihibhiya)* • *Jatropha curcas (Wata-Endaru)*
Wet/ Intermediate zone	No groundwater or perennial surface water	Perennial shrubs and trees	• *Ricinus communis (Castor oil/Thel-Endaru)* • *Samanea saman (Pare-Mara)* • *Gliricidia sepium (Wata-Mara)* • *Leucaena leucocephala (Ipil-Ipil)* • *Jatropha curcas (Wata-Endaru)* • *Macaranga peltate (Kanda)* • *Trema orientalis (Gaduma)* • *Hibiscus tiliaceus (Belipatta)*
Wet/ Intermediate zone	Shallow groundwater or permanent surface water	Vegetation that can tolerate waterlogged/ saline conditions	• *Annona glabra (Wel-Atha)* • *Arundo donax (Bata)* • *Bambusa vulgaris (Kaha-Una)* • *Hibiscus tiliaceus (Belipatta)* • *Dillenia suffruticosa (Diyapara)*

8.9 Landfill machinery and equipment

In active landfill operations, waste handling and compaction machines are involved in spreading and compaction of waste on site. Tracked tractors, tracked loaders, and steel-wheeled compactors are the primary machines for these applications. However, many factors must be considered before selecting the right equipment, chief of which is daily tonnage. Steel-wheeled compactors are recommended only for large-scale filling activities usually exceeding 500 tonnes/day. Versatility is also important in selecting machinery for small landfills; machines that can handle several tasks obviate the need for other equipment. Small landfills use as little equipment as possible; excavating, spreading, compacting and covering can often be accomplished with one machine. Waste handling machines should also be in perfect working order since backups cannot be kept in small landfills. The following Table 8.3 shows several types of machinery and equipment that can be used in operations of active and closed landfills.

Table 8.3 Types and specifications of machinery and equipment

Machine	Specifications	Activities
Tracked tractor (waste handling bulldozer)	• Weight of 20/30 T • At least 40 kNm^{-2} ground pressure • At least 10 m^2 blade capacity • At least 3 m machine width	• Waste spreading • Waste compaction • Waste grading • Cover soil application and compaction • Slope construction
Track loader/tracked mini excavator	• 1 m^3 bucket capacity • At least 4 m bucket lift ability	• Cover soil loading • Cover soil spreading • Compaction on slopes • Waste handling if bulldozer unavailable
4W Tractor & trailer	• Around 2.5 m^3 capacity • Off-road drive	• Cover soil transport within the site • Equipment & material transport
2W Tractor & trailer	• Min. 8 kW power • Roofed trailer	• Transport of minor equipment • Transport of materials • Multipurpose
Grass cutter	• Single cylinder gasoline, air cooled • Straight metal blade	• Weed control

8.10 Groundwater remediation

Dumpsites pose a serious threat to the surrounding groundwater environment, particularly in the high rainfall region when combined with a shallow groundwater level. Ammonia, chloride, heavy metal ions and other organic compounds found in leachate are released into the environment, and their toxicity causes potential hazards to the environment. Low-lying landfills form pools where waste remains immersed for long periods, which raises the leaching rate of pollutants, and heavy seasonal rains and subsequent water flows cause surrounding surface water and soil environment pollution.

Remediation of soils and groundwater in a MSW landfill site or rehabilitated dumpsite has thus emerged as a challenge. Unlike contaminants in an industrial or agricultural site, contaminants from MSW landfills are diverse. Those chiefly found in soil are: 1) organic chemicals (Aqueous Phase Liquid (APL) and Non-Aqueous Phase Liquids (NAPL)), 2) inorganic chemicals (e.g., heavy metals and radioisotopes), 3) mixed wastes, and 4) pathogenic agents such as bacteria and viruses. Knowledge of the physical, chemical and biological properties of the contaminants of interest is important in determining contaminant fate and transport within soil and groundwater. It also influences the selection of remediation technologies and strategies.

There are three basic types of technology for dealing with groundwater remediation: 1) destruction or transformation of pollutants to innocuous or more easily addressed compounds, 2) separation of the compounds from the soil-water matrix with subsequent treatment, and 3) containment or stabilization to keep the contaminants in place and prevent them reaching receptors (such as people who obtain drinking water from a well). One or more of these technology categories is potentially capable of reducing the volume, mobility and/or toxicity of contaminants, and the most appropriate technique for a given site must be based on presumed attainment of these general goals as well as other more site-specific cleanup targets.

Conventional remediation technologies – those for which cost and performance parameters are comparatively well known – include extraction and off-site disposal or treatment. Other techniques include stabilization and containment techniques, such as capping or the use of groundwater pump-and-treat for hydraulic containment.

All remediation techniques can be categorized as either in-situ technologies (implementable without water or soil extraction) or ex-situ technologies (water or soil must first be extracted or excavated). Although in-situ technologies do not rely on excavation of the polluted site itself, they often utilize extraction and above-ground treatment of waterborne pollutants from the groundwater. Ex-situ technologies can be characterized as either on-site or off-site depending on whether they are implementable at the waste site itself or if the excavated soil or extracted groundwater is transported elsewhere for final treatment. Often, a complete site-specific remediation strategy will involve elements of in-situ, on-site and off-site technologies.

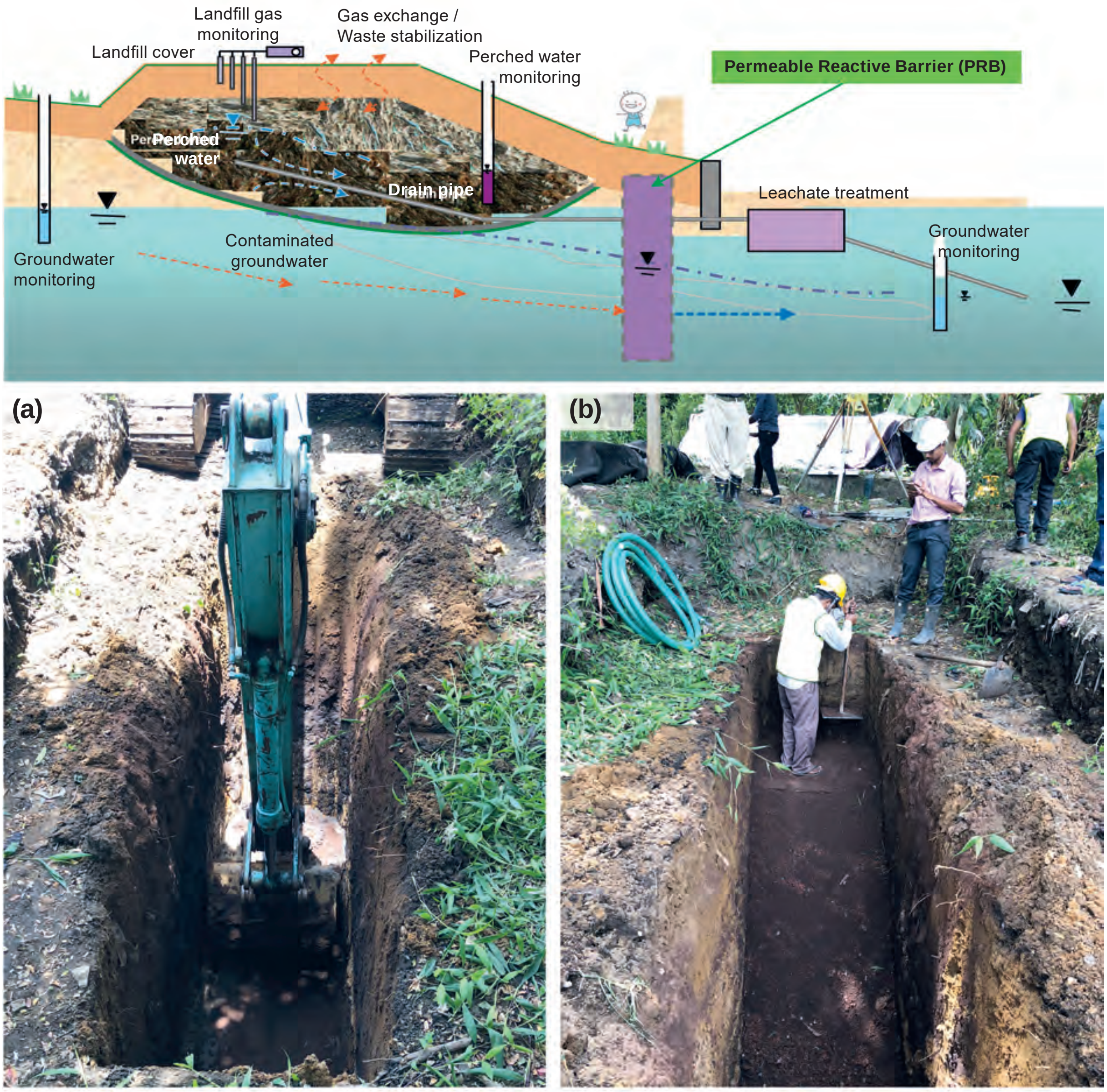
Innovative remediation methods encompass a range of technologies that have recently emerged or have yet to be fully been implemented at sufficient sites to fully understand their advantages and limitations. The following Table 8.4 provides an overview of the various remediation technologies currently available.

Table 8.4 Groundwater remediation technologies for contaminated MSW sites

Remediation Technology	Examples
Ex-situ technologies Contaminated groundwater is extracted from the subsurface and treated above ground to remove contaminants. After treatment, the water can be discharged to a nearby sewage system, surface waters or reinjected into the subsurface.	• Pump and treat (groundwater) • Excavation and treat (soil)
In-situ technologies Contaminated groundwater is treated on-site. After treatment, the treated groundwater flows downstream and connects to natural groundwater.	• Permeable Reactive Barrier (PRB) • Electrokinetic (EK) remediation • Microbial remediation • In-situ injection treatment • Nano zero-valent iron purification; micro / nanobubble phytoremediation

PRB is one of the emerging in-situ technologies for treating contaminated groundwater. PRB involves the emplacement of reactive media in the sub-surface and is designed to intercept a contaminated plume, provide a flow path through the reactive media and transform the contaminant(s) into environmentally acceptable forms to attain remediation concentration goals at the down-gradient of the barrier. The core substance of a PRB is a reactive material, which is placed across the plume of contaminated groundwater. Several kinds of reactive materials have been used in PRB systems according to the target contaminants to be treated.

Figure 8.1 shows a PRB system installed at the Sundarapola dumpsite in Kurunegala to remediate contaminated groundwater flowing downstream. A mixture of specially designed yet locally available PRB materials were packed into a trench 1 m wide, 5 m deep and 60 m long excavated across the groundwater flow (JICA, 2019).



a) Trench excavation across the groundwater flow paths to install PRB materials (1 m wide, 5 m deep and 60 m long) at Sundarapola dumpsite, Kurunegala, Sri Lanka

b) Trench filling by PRB materials (Biochar+ clay brick particles + dense clay) and compaction to finish the installation

Figure 8.1 Installation of PRB for groundwater remediation at Sundarapola dumpsite, Kurunegala (JICA, 2019)

In the advent of damage to or failure of groundwater monitoring wells or other monitoring facilities it becomes impossible to determine conditions inside the landfill or the resulting potential impact on the surrounding environment with any certainty. This tends to influence decisions concerning the maintenance of landfill sites.

Inspection of groundwater monitoring wells should therefore be carried out based on following items:

- Existence of damage or failure
- The inflow situation of the rainwater from the opening mouth of the groundwater monitoring well

For inspection of the monitoring facilities, the following items should be confirmed:

- Existence of damage or failure of equipment
- Calibration of equipment
- Existence of damage or failure of sensing elements
- Replacement of sensing elements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9 Case studies on dumpsite rehabilitation

9.1 Rehabilitation of Moon Plains dumpsite to semi-engineered landfill

The first dumpsite rehabilitation project to take place in Sri Lanka transformed the open waste disposal site on Moon Plains, Nuwara Eliya to a semi-engineered landfill commenced in 2003, with technical and financial assistance from Japan International Cooperation Agency (JICA). Prior to 2003, Nuwara Eliya Municipal Council (NEMC) disposed of 20–25 metric tonnes of mixed garbage and 5–10 m^3 of sewage to a forest near Moon Plains village every day. The open dumping of waste resulted in serious degradation of the 2.5-hectare forest environment, and the leachate, sewage and part of the waste eventually washed out to Bomburuella reservoir, 1.5 km downstream. In 2002, JICA developed a dumpsite rehabilitation feasibility project, including a detailed design and financial plan to assist the municipality in obtaining the requisite permissions from the authorities. After successfully negotiating with the Department of Forest as well as successful completion of an Initial Environmental Examination study, Nuwara Eliya MC was able to commence the rehabilitation works in 2003, which it completed within the same year.

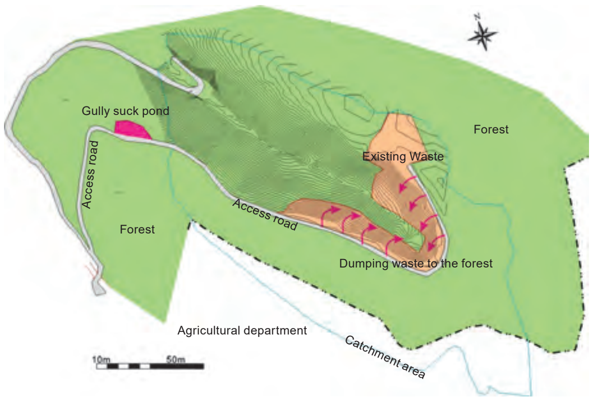
The rehabilitated Moon Plains semi-engineered landfill was the first pilot-scale rehabilitation work to comprise several facilities for managing different types of waste (the 'MSW' classification was not used at the time) disposed of by generators and collected by Local Authorities. The site introduced several auxiliary facilities, such as a low-cost sewage and leachate treatment system using coconut coir fiber attached growth media, a medical waste disposal pit, and a training and education facility.

BOX 1

1. **Risk assessment**

   July-September 2002 (3 months)

   1) Conducted a comprehensive study on quantity and composition of waste generated and disposed at dumpsite.
   2) Topographic survey of the dumpsite and the surrounding area to estimate disposed waste amount and to determine catchment area around the dumpsite.
   3) Measured the water flow rate of the small stream and analyzed stream water and leachate samples to identify key pollutants.
   4) An ecological survey was done in and around the dumpsite to gather information on types and occurrence of flora and fauna.



2. Obtaining stakeholder concession

September 2002 (1 months)

5) Conducted a public opinion survey among the residence in nearby villages.

6) Established an environmental monitoring committee comprises of CEA, Government officers, village leaders and neighboring community to monitor and witness rehabilitation project progress.

3. Engineering surveys

July-October 2002 (4 months)

7) Geological survey was conducted by drilling 8 deep boreholes (5-10 m) to determine underground soil condition, bedrock formation and groundwater conditions.

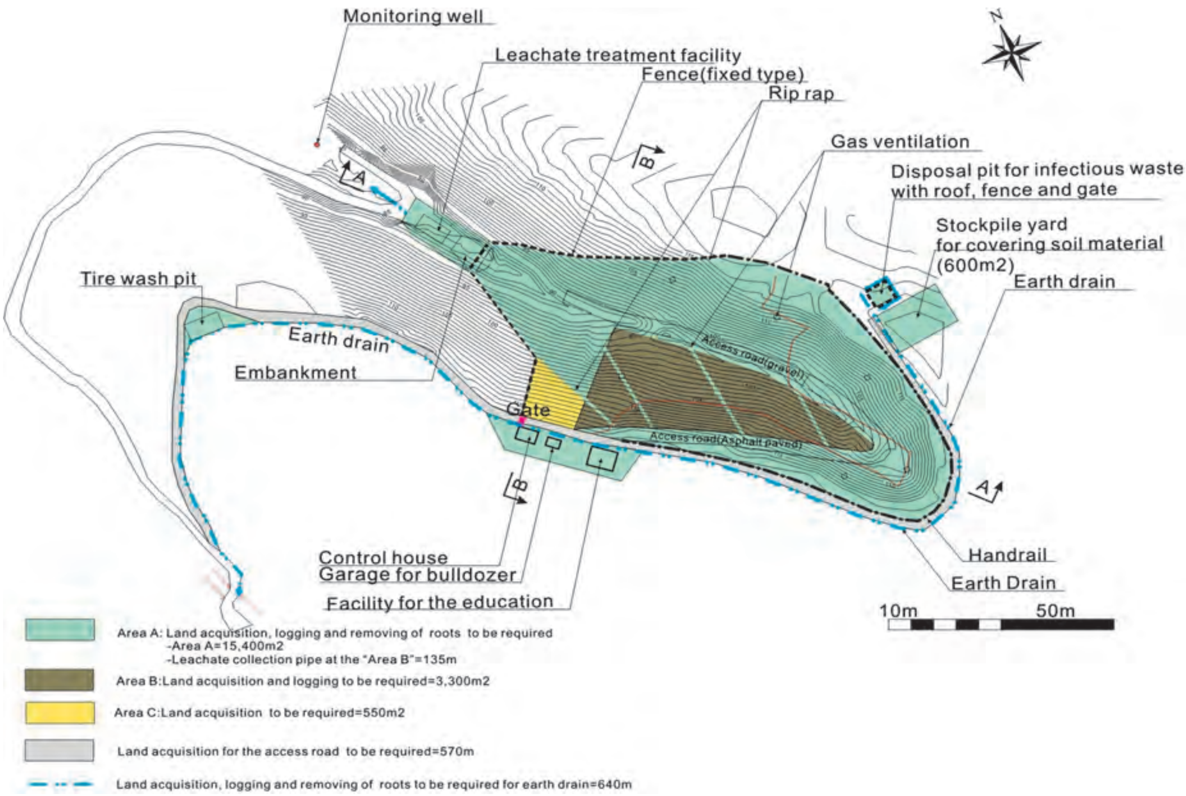
8) Stability of the dump site and water flow characteristics were analyzed by JICA team experts.

9) Assessed the road infrastructure, construction service and expertise for the intended rehabilitation work.

4. Site design

September-October 2002 (2 months)

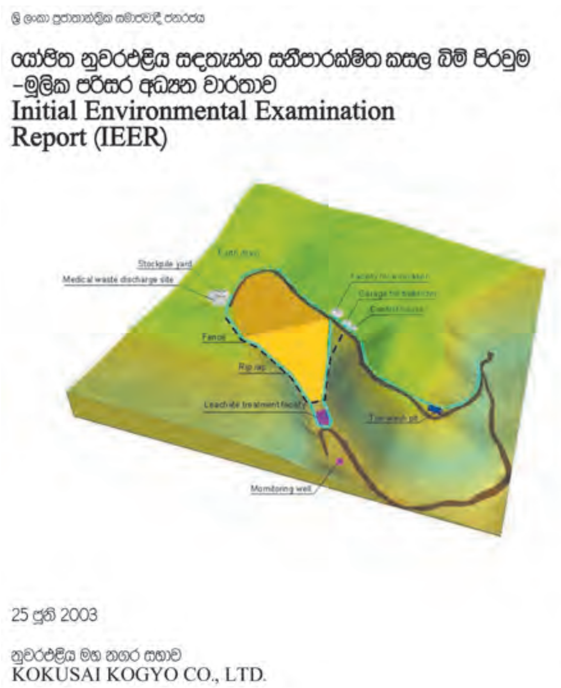
10) Team of JICA experts and local experts developed the rehabilitation project feasibility which included technical feasibility, preliminary engineering designs, cost estimations and future operation plan.

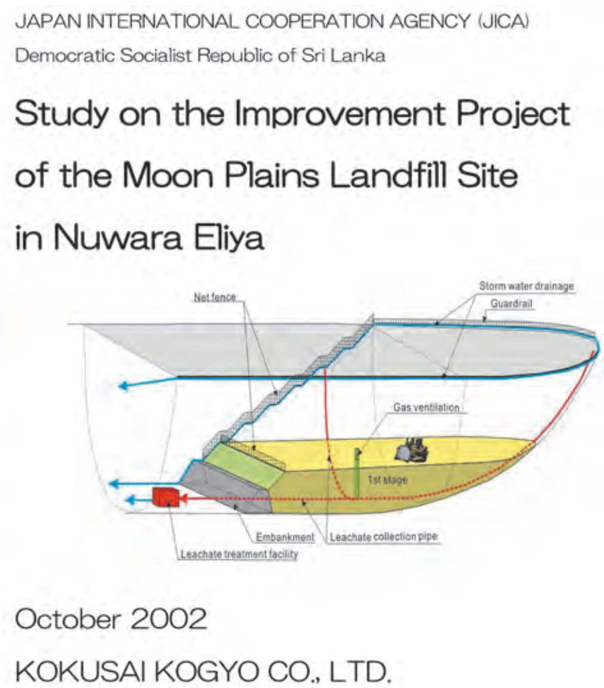


5. Project approval

October 2002 – May 2003 (8 months)

11) NEMC made a formal request from Department of Forest to transfer the ownership of the 2.5 hectares of dumpsite land to Nuwara Eliya Municipal Council. The Forest Department formally agreed to release the land after harvesting all forest timber within the site (2.5 hectares) that required a formal EIA/IEE approval.
12) NEMC then made a formal request from Central Environmental Authority to examine the project feasibility study. CEA recommended NEMC to conduct an IEE study and obtain formal approval for the project.
13) NEMC received the technical and consultancy support from JICA team of experts to prepare the IEE report and the IEE report was formally submitted to CEA. Subsequently, IEE was approved.





6. Project financing

April – June 2003 (4 months)

14) NEMC requested budget from JICA for construction and procumbent of Bulldozer for landfill operation. JICA expert team prepared the detail project budget and facilitate NEMC to secure finances from JICA.
15) JICA agreed to fund for the entire project development works.

Total construction cost = LKR 14,665,726 (JPY 18,012,000 = US$ 153,922) in 2003
Bulldozer (D4 caterpillar) = LKR 6,562,230 (US$ 68,873.11) in 2003

7. Site preparation and construction

June – September 2003 (4 months)

16) The construction was done by a Japanese construction company under the supervision of JICA expert team and NEMC engineer.
17) The project design consultants and experts closely monitored the construction works because dumpsite rehabilitation was considered a special construction project.
18) JICA expert team and NEMC engineer/technicians jointly prepared the landfill operation and maintenance manual.




8. Commissioning and operation

September 2003

19) The rehabilitation works were officially completed in November 2003 and NEMC started to operate the semi-engineered landfill from December, 2003.

Moonplain Dumpsite before rehabilitation (2003)

Moonplain semi-engineered landfill after rehabilitation (2004)

9. Monitoring visits, reporting and meetings

September 2003- September 2004 (every month); from 2004 to date, annually

20) Environmental monitoring committee continues to monitor operation, maintenance, and improvement activities of the semi-engineered landfill up to date.
21) NEMC annually submits reports on environment quality (water, air etc.) to Central Environment Authority and to the monitoring committee.

9.2 Rehabilitation of Galapitagalayaya dumpsite at Kataragama to an engineered landfill

The Galapitayaya open dump site had been used by Kataragama Pradeshiya Sabha to dispose of MSW (5–10 tonnes/day) collected from Kataragama town and peripheral areas. The site is located within crown land owned by the Department of Forest and Government Agent of Monaragala. Records show that use of the dumpsite started in the early 1990s and that the site has shifted several times within the forest. The dumpsite is scattered over two major areas, each occupying approximately 2 hectares. Since the dumpsite is in a forest reserve, scavenging of waste by wild elephants posed the major threat to wildlife in the forest, among many other environmental problems associated with the site.

The site was identified as in urgent need of rehabilitation through a project, "Pollution Control and Reduction of Environmental Burden in Solid Waste Management (ReEB Waste)", funded through Central Environmental Authority and JICA. As Kataragama Pradeshiya Sabha lacked the technical and financial capacity to undertake the rehabilitation, technical and financial assistance was provided through the project (JICA, 2016 and JICA 2019). As part of the ReEB project's recommendations, it cited the need for proper implementation of an integrated waste management system within Kataragama Pradeshiya Sabha as a prerequisite to realizing rehabilitation and sustainable operation of the landfill. Consequently, Kataragama Pradeshiya Sabha established an integrated waste management system leading to the dumpsite being rehabilitated to a landfill exclusively for residual waste disposal – once such waste had been processed to recover resources through composting and recycling. The following shows the sequence of project development.

BOX 2

1. **Preliminary assessment**
   July-September 2015 (3 months)
   1) Conducted a comprehensive study on quantity and composition of waste generated and disposed at dumpsites (JICA, 2019). Identified the environmental issues at dumpsites.

2. Risk Assessment

July-December 2017 (6 months)

2) Conducted surface water quality, air quality and noise and vibration surveys at the Galapitayaya site.
3) Conducted a topographic survey of dumpsite and surrounding area to estimate disposed waste amount and to determine catchment area around the dumpsite.
4) An ecological survey was conducted in and around the dumpsite to gather information on types and occurrence of flora and fauna.

3. Obtaining stakeholder concession and establishment of the integrated waste management system

July-December 2017 (6 months)

5) Kataragama Pradeshiya Sabha negotiated with Department of Forest and Wildlife Conservation to obtain to ownership of the land.
6) Kataragama Pradeshiya Sabha implemented an integrated waste management system.

4. Construction of electric fence around the site

November 2017 (1 month)

7) Constructed an electric fence around the site to prevent entry of elephant to the site.

5. Engineering surveys

October 2017 (1 month)

8) Geological survey was conducted by drilling boreholes (2-5 m depth) to determine underground soil conditions and groundwater conditions.
9) JICA expert team analyzed the stability of the site and water flow characteristics.
10) Assessed the road infrastructure, construction service and expertise for the intended rehabilitation work.

6. Site design

July-December 2017 (6 months)

11) JICA offered the landfill design consultancy contract to a Sri Lankan design firm that made the designs based on low-cost alternative technologies.

7. Project financing

July-December 2017 (6 months)

12) JICA funded for the entire project including site surveys, design consultancies and construction.
13) Estimated construction cost = LKR 40,000,000 (US$ 224,719) in 2019

8. Site preparation and construction

December 2017 – March 2018 (4 months)

14) The construction was offered to a local Contractor who worked under the supervision of JICA expert team and ReEB project officers.
15) The project design consultants and experts closely monitored the construction works because dumpsite rehabilitation was considered a special construction project.
16) JICA expert team and ReEB officers jointly prepared the landfill operation and maintenance manual.

Site excavation

Bottom liver installation

Bottom liver compaction

Bottom liver smooth finishing

Leachate pipe installation

Leachate pipe with geotextile

Leachate treatment system construction

Access road construction

Weighing bridge construction

Source: Japan International Cooperation Agency -JICA, (2019), ReEB Waste final report.

9. Commissioning and operation

September 2018

17) The project was officially completed in September 2018 and Kataragama Pradeshiya Sabha started to operate the engineered landfill from October 2019.

10. Monitoring visits, reporting and meetings

September 2018 to date, annually

18) Environmental monitoring committee continues to monitor operation, maintenance, and improvement activities of the semi-engineered landfill up to date.

9.3 Rehabilitation of dumpsites in India

Analyses of the economics of rehabilitation of waste dumps and revenue from dumpsite mining represent important information for the stakeholders concerned in making decisions and plans related to implementing rehabilitation work. Further, the concept of rehabilitation itself is gaining traction in India's cities of late. Major factors influencing the cost of waste dump rehabilitation are the volume and topography of dumpsites, equipment parameters, climate, labor rates, regulatory approval processes, excavation and screening costs, sampling and characterization, development costs, contractor's fees, hazardous wastes disposal as well as revenue from the sale of commodities, i.e., compost and recyclables.

Biomining is also gaining popularity in India. Projects are often judged in terms of quantities of waste excavated and processed, and operational expenditures of biomining and bioremediation depend on the size of the dumpsite. Based on CPCB's Guidelines for Disposal of Legacy Waste, costs in India are estimated at Indian Rs 400–700 (about USD 5-9) per cubic meter, irrespective of capital cost. Currently, companies generally operate biomining sites via use of mobile equipment, which is mainly based on programmable logic array (PLA)-based systems to regulate flows of stabilized waste from one trammel to another. Capital costs of such mobile equipment with capacity of 700 MTD are estimated at around Indian Rs 10 crore (USD 1.4 million) per day. The average cost of processing one MT of legacy waste is Indian Rs 750–900 (about USD 10-12), depending on dumpsite age.

9.3.1 Hyderabad

The Greater Hyderabad Municipal Corporation (GHMC) has an area of 625 sq. km and population of 6.8 million according to the 2011 census. The city generates 5,300 MT of waste daily, the biodegradable fraction of which is estimated at 54%. About 16% of generated waste is sent to sanitary landfill as inert material.

GHMC used to dump mixed waste at Jawaharnagar dumpsite, which has an area of 135 acres and of 60 m height. Initially, the dumpsite was excavated to create a slope, and a layer of impermeable soil cover was spread over the surface area of dumpsite. A leachate collection pound was then constructed to collect and process the leachate. A geotextile layer was then developed, and vegetation was planted to prevent soil erosion. The total cost of capping the dumpsite was 14.1 Million Indian Rupees (USD 19.1 million).

Figure 9.1 Capping of 135-acre Jawaharnagar dumpsite in Hyderabad (CSE, 2020)

9.3.2 Vijayawada

Vijayawada city has an area of 61.88 sq. km and population of 1.5 million, which is estimated to reach 2.5 million by 2025. The city generates 550 tonnes of waste daily, of which the biodegradable fraction is estimated at 57%.

The city used to dump mixed waste at the 45-acre Ajit Singh Nagar dumpsite. The amount of waste dumped until in the dumpsite was estimated to be 0.35 million tonnes until 2018, when bioremediation of the legacy dumpsite started. Costs for clearing the waste are estimated at around Indian Rs 18 crore (USD 2.44 million), through which 30 acres of land were to be reclaimed.

Figure 9.2 Stabilization of legacy waste in the dumpsite; (right) reclaimed land after completion of biomining process (CSE, 2020)

Additional Readings

Prospective uses and readers of this document should note that the present guidelines are based on various previous research works, international and national publications, expert knowledge sharing, and the references below. Those who are interested in reading more and accessing the sources of information for dumpsite rehabilitation, dumpsite mining, landfill design, operation and management will find additional information from the following publications.

A Guide for the Management of Closing and Closed Landfills in New Zealand. Published in May 2001 by Ministry for the Environment, PO Box 10-362, Wellington, New Zealand. ISBN 0-478-24021-X. *This document is available on the Ministry for the Environment's Web site: http://www.mfe.govt.nz. (accessed on 08/12/2020)*.

Dumpsite Rehabilitation Manual by Kurian Joseph, R. Nagendran, K. Thanasekaran, C. Visvanathan, William Hogland. Published by Centre for Environmental Studies, Anna University - Chennai, Chennai-600 025, India. *This document is available at https://www.elaw.org/system/files/Dumpsite%20Rehabilitation%20Manual.pdf (accessed on 08/12/2020)*.

Guide for Sustainable Planning, Management, and Pollution Control of Waste Landfills in Sri Lanka by SATREPS Project, JST-JICA Science and Technology Research Partnership for Sustainable Development, University of Peradeniya (May 2018).

Guidelines for Disposal of Legacy Waste (Old Municipal Solid Waste) by CENTRAL POLLUTION CONTROL BOARD (Ministry of Environment, Forest and Climate Change, Government of India) 'Parivesh Bhawan' C.B.D. Cum-Office Complex, East Arjun Nagar, Shahdara, Delhi-110032. *This document is available at http://kspcb.gov.in/MSW%20LEGACY%20WASTE_19-3-2019.pdf (accessed on 08/12/2020).*

The Study on The Safe Closure and Rehabilitation of Landfill Sites in Malaysia- Final Report (Volume 6): User Manual for LACMIS (Landfill Closure Management Information System) by Yachiyo Engineering Co., Ltd. & EX Corporation, Report No. GE-JR-04-25. The Study on the Safe Closure and Rehabilitation of Landfill Sites in Malaysia. *This document is available at* https://openjicareport.jica.go.jp/618/618/618_113_11772662.html. *(accessed on 08/12/2020).*

CLEAN IT RIGHT –DUMPSITE MANAGEMENT IN INDIA, School of Circular Economy Anil Agarwal Environment Training Institute (AAETI), CSE. Published by Centre for School and Environment, 41, Tughlakabad Institutional Area, New Delhi 110 062. This document is available at file:///C:/Users/singh/Downloads/http___cdn.cseindia.org_attachments_0.75728500_1606740511_clean-it-right--dumpsite-management-in-india%20(2).pdf (accessed on 18/01/2021).

A Roadmap for closing Waste Dumpsites –The World's most Polluted Places by ISWA's Scientific and Technical Committee Work-Program 2015-2016. Auerspergstrasse 15, Top 41 1080 VIENNA-AUSTRIA. This document is available at https://www.iswa.org/fileadmin/galleries/About%20ISWA/ISWA_Roadmap_Report.pdf (accessed on 18/01/2021).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List of Workshop Participants

List of Participants Attended the Consultative Meetings "Developing Guidelines for Safe Closure and Rehabilitation of Municipal Solid Waste Dumpsites in Sri Lanka" on 18th September 2019 and 23rd July 2020 at the Auditorium of Ministry of Environment.

No	Name	Designation	Organization
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28	Eng. (Mr) Chandima Kularathne		National Physical Planning Department (NPPD)
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30	Mr Dulan Perera	Engineer	National Building Research Organization (NBRO)
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42	Mr. Maussawa	Chief Public Health Inspector in charge SWM	Nuwara Eliya Municipal Council
43	Mr. H. A.U.K. Gunaratne	Chief Public Health Inspector	Negambo Municipal Council
44	Mr.D.M.A.R. Dissanayake	Chief Public Health Inspector in charge SWM	Bandarawela Municipal Council
45	Dr. Priyantha	Medical office of Health (MOH) in charge of SWM	Kurunegala Municipal Council
46	Ms Dammika Konara	Officer in MSW	Kurunegala Municipal Council
47	Mr. R. D. D. Rajapakse	Public Health Inspector	Kurunegala Municipal Council
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50	Mr. E. Chandrasiri	Secretary	Katharagama Pradeshiya Sabha
51	Mr. R.K. Mahinda	Development Officer	Katharagama Pradeshiya Sabha
52	Mr. Y.V.A.R. Priyankara	Chief Public Health Inspector	Badulla Municipal Council
53	Mr. Y.M. Keerthi Bandara	Technical Officer	Badulla Municipal Council
54	Mr. A.M.C.L. Andadola	Chief Public Health Inspector	Balangoda Municipal Council
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58	Mr. Sameera Dinesh		Seethawakapura Municipal Council
59	Mr. M.T. Fasal Wafee	Technical Officer	Ampara Urban Council
60	Mr. S.R. Weerakoon	Technical Officer Galle Municipal Council	Galle Municipal Council
61	Dr. R.M.S. Ratnayake		
62	Dr. Praneeth Wickramarachchi	Senior Engineer	Access Engineering PLC
63	Mr. Yasantha Gunaratne	General manager (Technical)	Sisili Hanaro Encare Pvt Ltd
64	Mr. Janaka Wijesekara	Head of Environment Management	Cleantech Ltd (Abans Group)
65	Mr. Dileepa Senevirathne	Manager	Biocarbon Pvt Ltd
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68	Mr. R. Lalith K Ranthilake	Environmental Officer	Kundasale Pradeshiya Sabha

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